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YUNIBESITHI YA PRETORIA

THE DEVELOPMENT OF A DESIGN PROTOCOL FOR PRODUCTION OF HIGH SPEED COINING DIES.

by

BURGER ADRIAAN KOTZE

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DISSERTATION SUMMARY

THE DEVELOPMENT OF A DESIGN PROTOCOL FOR PRODUCTION OF HIGH SPEED COINING DIES.

B.A. KOTZE

Supervisor: **N.D.L. Burger** **Pr.Eng MEng(Mech),GCC(Mech)**

Department: **Mechanical and Aeronautical Engineering**

UNIVERSITY OF PRETORIA

In the production process of coining dies various obstacles are encountered. Due to the complexity of the process and the system, many of the underlying problems remain unidentified just to repeat themselves at a later stage.

The project was done to provide the client with a better understanding of the major factors that influence the development process. If the source of a problem can be identified and is understood a course of action can be determined that will prevent the problem from reoccurring.

The project focus was on the behaviour of the die and coin material during the deformation and heat treatment processes. The behaviour of the material was explained from a theoretical point of view and methods to control this behaviour were discussed.

A design protocol was established, which will enable the developer to achieve improved results during the development process. The main objective of the protocol is to improve consistency in the results that are obtained during the development process.

ABSTRACT

Title: THE DEVELOPMENT OF A DESIGN PROTOCOL FOR PRODUCTION OF HIGH SPEED COINING DIES.

Author: B.A. Kotze

Supervisor: N.D.L. Burger Pr.Eng MEng(Mech),GCC(Mech)

Department: Mechanical and Aeronautical Engineering

UNIVERSITY OF PRETORIA

Degree: M.Eng (Mech)

The degree of success with which coining dies are manufactured greatly influences the total development time and therefore the total success of a project. In the production process of the coining dies, various obstacles are often encountered. These obstacles retard the project and adversely affect the profit margin of the company.

There are no scientific models in place by which these dies can be developed. Consequently the development and production process is done on a trial and error basis. Due to the complexity of the process and the system many of the underlying problems remain unidentified just to repeat themselves at a later stage.

The major factors determining the success of a project, from the perspective of the development department, is the total project time, the quality of the product (i.e. the dies and the final coins) and die life.

The purpose of the project was to analyse the development process in detail and to develop a design protocol, which will guide the developer during development. The design protocol will suggest a procedure to follow when developing dies. The design protocol will assist the die developer in locating the source of certain problems systematically.

The project was done to provide the client with a better understanding of the major factors that influence the development process. If the source of a problem can be identified and is

understood the proper action could be determined and employed to prevent the problem from reoccurring. This project will serve as the basis for further development efforts in this field.

During the course of the study emphasis was put on the development and production of the high speed coining dies. The major factors that influence the development process were identified and development tests were done to establish the influence of each of these factors. The development process was broken down into components and each component was evaluated separately.

The test focus was on the behaviour of the die and coin material during the deformation and heat treatment processes. For each test a significant amount of test data was collected. The results of the tests were analysed and evaluated. The behaviour of the material was explained from a theoretical point of view and methods to control this behaviour were discussed. The test results were generalized to apply to all development projects.

The source of many of the problems that are encountered during the development and production process were identified and quantified with the test results. On the basis of these results the design protocol was established. Many of the problems encountered are process control related. Solutions to improve the process control are discussed in the report.

The design protocol will enable the developer to achieve improved results during the development process. The design protocol can also be used as a tool to establish the cause and recourse for certain development and production problems. The main objective of the protocol is to improve consistency in the results that are obtained during the development process.

The design protocol will enable the developer to implement a faster and more efficient development process, while avoiding problem areas, thereby reducing the total project time and increasing product quality and profit margins.

ACKNOWLEDGEMENTS

I would like to thank God for giving me the strength and ability.

> **"I would rather walk with God in the dark than go alone in the light."**
>
> Mary Gardiner Brainard

I would like to thank the following people and institutions for their contributions and support for making this project possible.

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- My fiancé, Elanie, for her emotional support.

LIST OF SYMBOLS AND ABBREVIATIONS

HR_b	Rockwell B Hardness
HR_c	Rockwell C Hardness
σ_y	Yield Strength
ε	Strain
H_v	Vickers Hardness

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PROLOGUE

A successful development effort and a short project time are crucial if the S.A Mint is to succeed in the competitive international industry of coin manufacturing. Scientific knowledge in the process will be an asset to the company and will guide the company in deciding where further development efforts are necessary.

The degree of success with which coining dies are made, greatly influences the total development time and therefore the total success of a project. In the production process of the coining dies various obstacles are often encountered. These obstacles retard the project and adversely affect the profit margin of the company.

There are no scientific models in place by which these dies can be developed. Consequently the development and production process is done on a trial and error basis. Due to the complexity of the process and the system, many of the underlying problems remain unidentified just to repeat themselves at a later stage.

A detailed functional analysis was done on the entire development and production process. This was necessary to identify the problem areas, to get an overall picture of the process, and to determine all the factors that play a role in each process. The inter-relationship of the different activities was also established. A report was compiled and delivered to the Mint. The report indicated certain problem areas, which need to receive attention. The functional analysis report will not be included in this report.

The purpose of the project was to analyse the development process in detail and to develop a design protocol, which will guide the developer during development. The design protocol will suggest a procedure to follow when developing dies. The design protocol will assist the die developer in locating the source of certain problems systematically.

The project was done to provide the client with a better understanding of the major factors that influence the development process. If the source of a problem can be identified and is understood the course of action can be determined that will prevent the problem from reoccurring. This project will serve as the basis for further development efforts in this field. The test focus was on the behaviour of the die and coin material during deformation and heat treatment processes.

In Chapter 1 the material that was used for the project will be analysed. Chapter 2 and 3 will deal with the design of the coin and the production of the blanks. All the development tests that were done on the production of the master punch are discussed in Chapter 4. Chapter 5 contains the results of the coining tests and the design protocol that was developed is discussed in Chapter 6.

A project overview is included in Figure 1 to show what was done during the project and to show how the structure of the report was compiled.

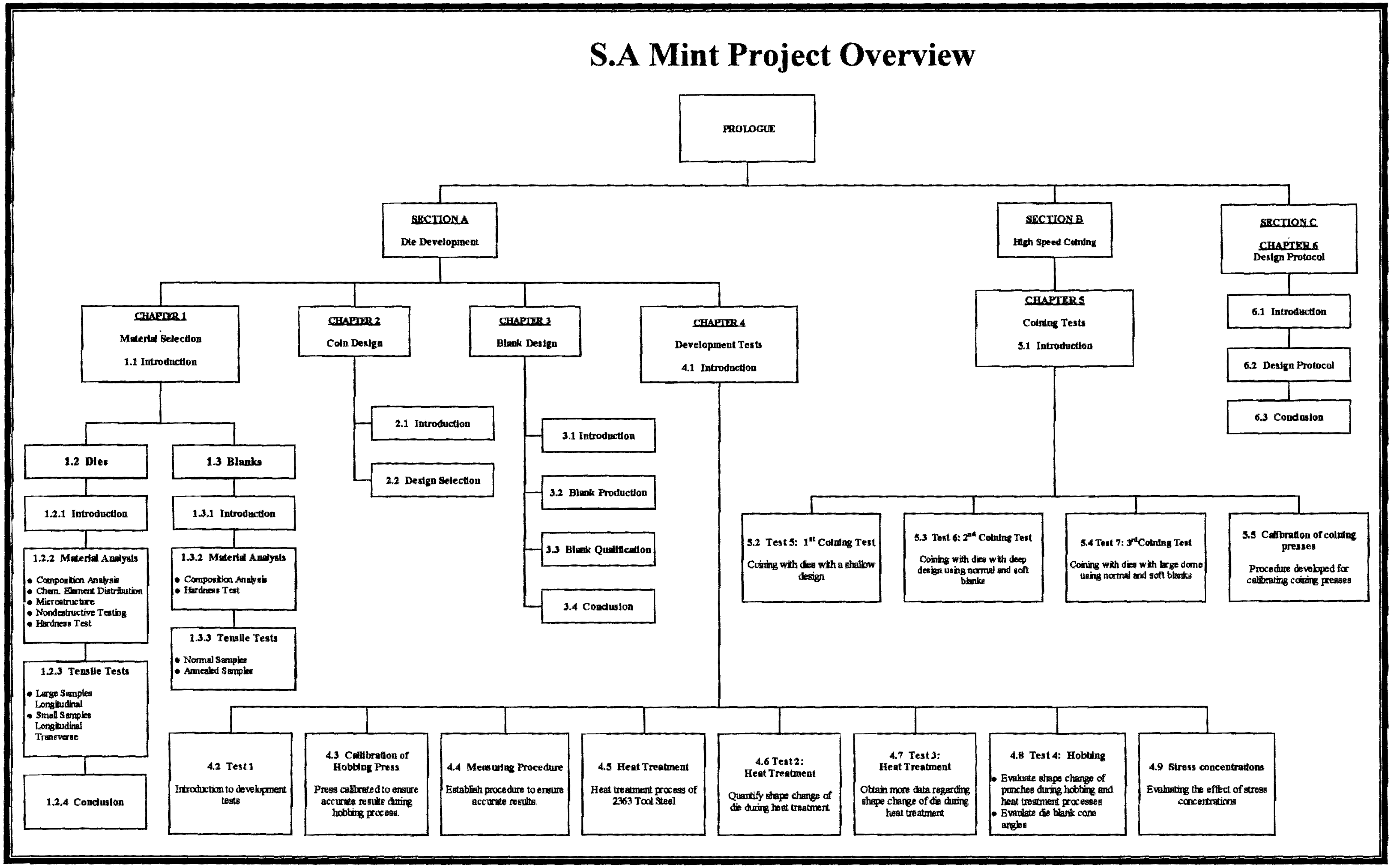


FIGURE 1 **Project Overview**

SECTION A

DIE DEVELOPMENT

INTRODUCTION

This section will provide an overview of the die development process. The details of the die development process will be discussed in the relevant sections of the report.

The procedure for the development and production of the coining dies can differ vastly from project to project. If a new coin must be produced the development process will follow all the possible steps in producing a coining die, from the design of the artwork right through to the manufacturing of the coining dies.

Certain clients will provide the master punch to ensure that the quality of the coins is the same as their current coins. The coining dies are then made from the master punch that was provided. Other clients will only provide samples of the coin. When a picture or sample of the coin is provided, for the contract, all the development steps must be followed. The different phases of the development process will now be discussed.

1. The first step is to obtain the desired design from the client. The design may be in the form of a sample coin, a drawing or a picture. The design is discussed with the client to establish the client's requirements. These requirements include aspects like the depth of the design, the level of detail of the design and the size of the design.

2. If the design requirements have been established an enlarged three-dimensional clay model is made by one of the artists. The diameter of the model is about 200 mm. An example of this clay model is shown in Figure 1.

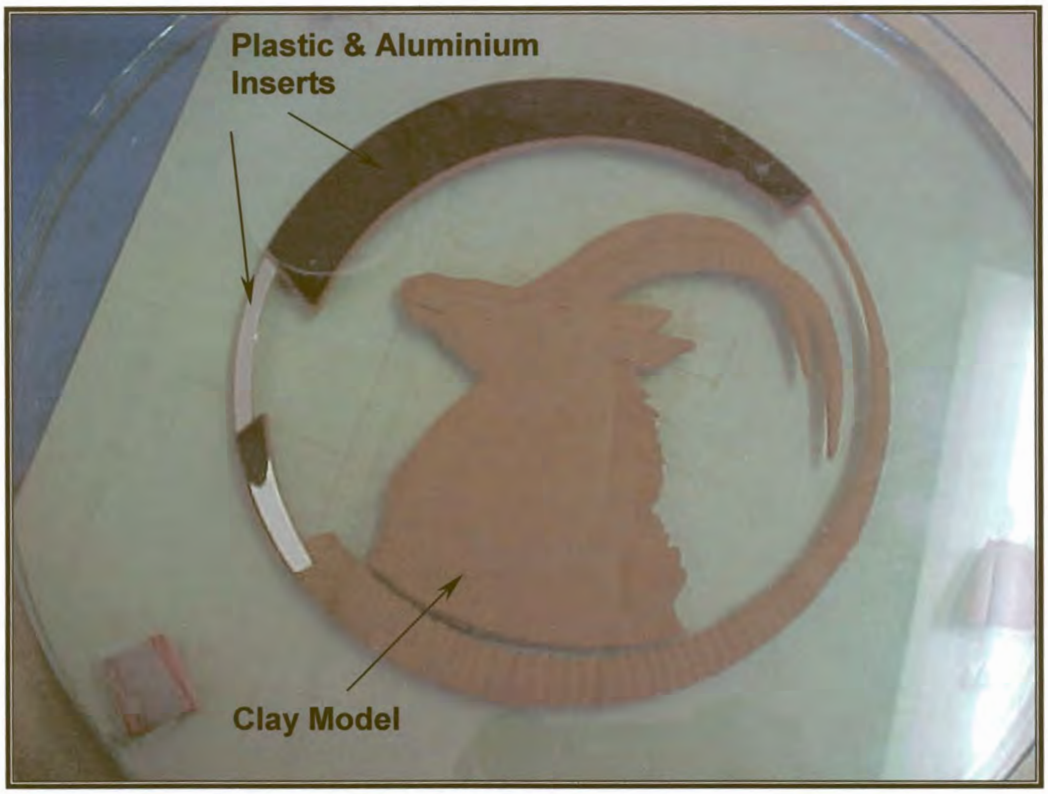


FIGURE 1 Clay model of selected design

The clay model is sometimes made up from different components of different materials as can be seen from Figure 1. For this design, plastic and aluminium inserts were used to model part of the outer edge of the design. This is done if there are straight curves and little detail on a certain section of the design. The head of the sable and the horn that forms part of the outer edge of the design were modeled in clay due to the high amount of detail and complexity of the design.

3. From the clay model in Figure 1 a negative plaster mould is cast. This negative plaster mould is shown in Figure 2. Detail can now be added to the design since it is easier to model and preserve fine detail on the plaster mould than on the clay, for example the texture of the sable's skin. The embossed text on the coin is engraved on the negative plaster mould with a CNC engraver.

FIGURE 2 Negative plaster mould

4. A positive plaster mould is cast from the negative plaster mould. On this mould the final detail is added and any necessary alterations are made. The positive plaster mould will look like the final coin, therefore the engraved text on the coin is engraved on the positive plaster mould with a CNC engraver. The positive plaster mould is shown in Figure 3. No further alterations can be made to the design from here on. Therefore the design is carefully checked to ensure that it complies with the design requirements.

FIGURE 3 Positive plaster mould.

5. From the positive plaster mould a negative silicon rubber mould is cast. The rubber mould is used to create the final mould, often referred to as the ureol (polyurethane mould). There are certain advantages in making this mould from rubber. The rubber mould is flexible and the ureol can therefore be easily removed from the rubber mould. The rubber mould cannot chip or damage easily. If this mould was made from plaster the mould could break or damage and it would then be impossible to create an exact replica of the ureol if it was damaged in some way.

The polyurethane mould is very hard and has a smooth surface finish. The ureol will be used on the reduction machine to create a machine punch.

6. The ureol is mounted on the reduction machine and a reduction ratio is calculated depending on the desired size of the final design. The reduction machine is shown in Figure 4(a). The reduction machine transfers all the detail from the ureol to the machine punch. The reduction machine takes about one week to reduce a design from a large polyurethane mould to a machine punch.

   After the machine punch is engraved on the reduction machine a relief is cut around the design to improve the hobbing quality and to reduce the hobbing force needed to transfer all the detail to the matrix. The shape of the relief is shown in Figure 4(b). Finally the machine punch is heat-treated and is now ready to be used in the hobbing process.

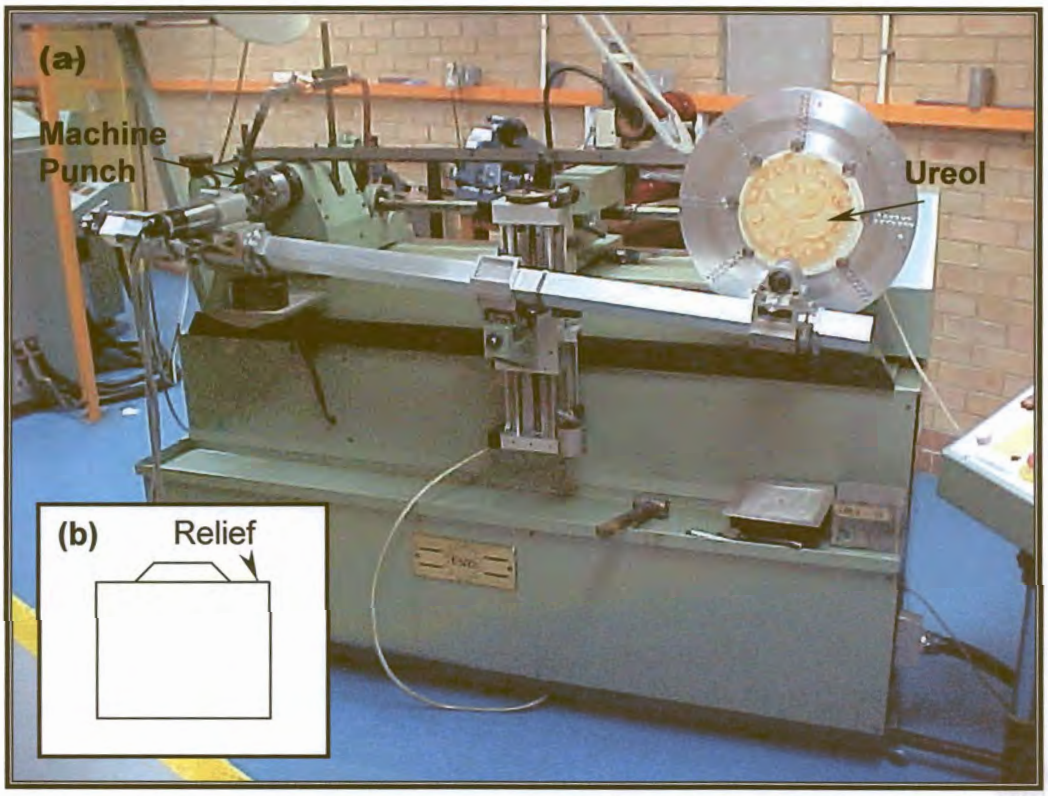


FIGURE 4 (a) Reduction machine (b) Relief cut into Machine Punch

Before the subsequent steps are discussed brief attention will be given to the shape of the die blanks that are used during the hobbing process. The punch is driven into the die blank during the hobbing process. Experiments have shown that the ideal shape of the die blank is a round billet with one end turned into the shape of a cone. This shape produces the best detail transfer with the lowest applied force. An example of such a die blank is shown in Figure 5. These die blanks are often referred to as "cones". The shape and optimum angle for these cones will be discussed in detail at a later stage but first it is necessary to proceed with the development steps.

FIGURE 5 Die blanks

7. The machine punch has been made and hardened. It is now placed in a hydraulic press and the punch is pressed on a die blank at low speed to produce the matrix (negative). The matrix is then hardened. This is a cold working process because cold working produces a smoother surface finish. However the punch is pre-heated to about 40°C to prevent cold cracking.

8. The matrix is used to hob the master punch from another die blank. The master punch has a positive image. After the hobbing process the master punch is cut to drawing specifications. Finally the master punch is sent for heat treatment. The master punch will be used to produce the coining dies (negative).

The master punch is the deliverable product that is the responsibility of the development department. Since this project concentrates on the development process most of the project time will be devoted to the process discussed above.

In the Tool room the master punch is then used to hob the coining dies. The same hobbing procedure, as described, is used. The coining dies are used to coin the blanks. The pressing procedure is summarized in Figure 6.

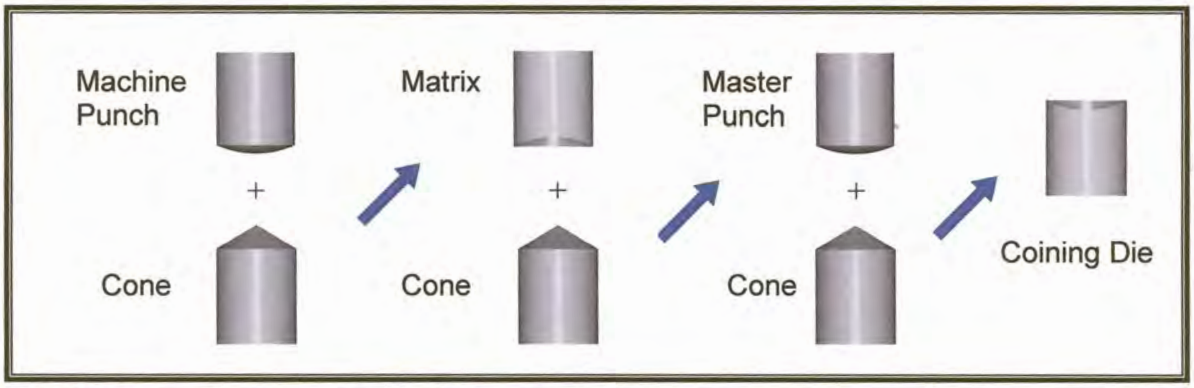


FIGURE 6 The pressing procedure

The development process involves various complicated deformation processes. There are many factors influencing the behaviour of the material during these processes. These factors will be discussed and dealt with in due course. A diagram of the development process is shown in Figure 7.

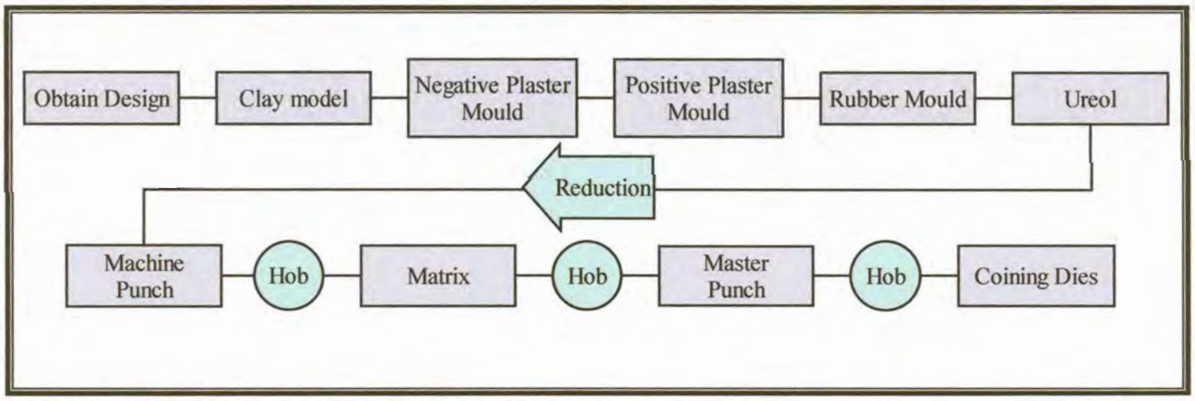


FIGURE 7 Flow diagram of development process

CHAPTER 1

MATERIAL SELECTION

1.1 Introduction

Due to the complexity of the die development process it was decided from the onset of the project to eliminate as many variables as possible, for each test. This will make it easier to control the remaining variables and to correctly identify the mechanisms that control the behaviour of the material. The type of material that is used for the dies and the blanks is the first variable to be eliminated.

It was decided to use one specific material for all the dies (i.e. the matrix, the master punch and the coining dies), and one material for the blanks. Once the design protocol has been established, the Mint can according to this protocol also test other materials and evaluate the performance of each material individually.

The selection and material analysis of the tool steel that will be used for the dies will be discussed first. After which the selection and material analysis of the blank material will be discussed.

1.2 Dies

1.2.1 INTRODUCTION

Once the decision was made to use only one material for all the dies it was necessary to select the material. There are many variables within a material but these variables will be controlled where possible during the development tests.

The material currently used by the S.A Mint for most of the dies is Thyrodur 2363 Tool Steel (Commonly referred to as Two-Three-Six-Three). The manufacturer is Thyssen. The material specifications are given in Appendix A. This is an AISI A2 (DIN 1.2363) type tool steel. The properties of this cold work tool steel include high dimensional stability during heat treatment; good wear resistance, high compressive strength and medium machinability. The machinability of the material is about 85% if compared to the baseline W group of tool steels, which are, rated at 100%.

It was decided that it would be beneficial to the Mint if the same material was used for the development project as was for their dies. A thorough material analysis was done on the 2363 Tool Steel to establish if this material was suitable for the specific application. Once the material has been characterized by means of the material analysis a conclusion can be reached on the suitability of the material for the specific application. A decision will then be made whether to use the material for the project or to select another material.

1.2.2 MATERIAL ANALYSIS (2363)

The purpose of the material analysis was to:

- Check the specifications of the manufacturer.
- Determine the composition of the material
- Check the distribution of the elements in the material.
- Check for internal defects in the material.
- Check the microstructure of the material
- Check the hardness of the material
- Check the dynamic response of the material during deformation.
- Determine whether the quality of the steel is high enough for the application.

The material analysis forms a very important part of the project. The results of the material analysis will help to explain the behaviour of the material during the die development and production processes.

A batch of the Thyrodur 2363 Tool Steel was acquired and held in bond exclusively for the project. The decision was taken that only material from this batch would be used for the project if the material was approved. By using material from one batch the material composition and property variables are reduced. The material specification lies within a certain bandwidth but there may be small differences in the composition of the material between batches. The properties of the material can also change due to differences in the cooling rate of the material during solidification or due to small changes in the annealing process. It is therefore advantageous to use material from the same batch throughout the project.

The material obtained for the project consisted of 40 mm and 50 mm diameter billets. The 50 mm billets are used for the manufacturing of the matrix and the master punch, whereas the 40 mm billets are used for the manufacturing of the coining dies. The S.A Mint did a material analysis on the material where they checked the composition of the material, the element distribution and the microstructure. Non-destructive testing was done on the material by an outside firm. Additional tests were also done on the material as will be discussed shortly.

1.2.2.1 Composition Analysis

The composition analysis was done to verify the specifications given by the manufacturer and to ensure that the material is a 2363 type Tool Steel. Three methods were used in testing the composition of the material. The results from each test can be seen in Table 1.1

Element	2363 (XRF)	2363 (LECO)	2363 (OES)	Typical 2363
Cr	4.98 ± 0.13 %		4.90 ± 0.06 %	4.80 - 5.50 %
Mn	0.44 ± 0.09 %		0.43 ± 0.03 %	0.40 – 0.70 %
Mo	0.94 ± 0.07 %		0.95 ± 0.06 %	0.90 – 1.20 %
Ni	0.20 ± 0.07 %		0.20 ± 0.03 %	
Si	0.35 ± 0.05 %		0.33 ± 0.03 %	0.20 – 0.40 %
V	0.16 ± 0.10 %		0.14 ± 0.03 %	0.10 – 0.30 %
W	0.01 ± 0.09 %		0.01 ± 0.03 %	
C		0.94 %	0.89 ± 0.03 %	0.90 – 1.05 %
S		0.001 %	<0.01 ±0.01 %	≤ 0.035 %

TABLE 1.1 Composition of 2363 Tool Steel

The first method that was used is the XRF or X-Ray Fluorescence method. The second method was a combustion process where only the Carbon and Sulphur content were determined (LECO). The third method is the OES method. This is an Emission Spectroscopy method used to test for all the main elements. Trace elements were not tested for.

It can be seen from the results of Table 1.1 that the composition of the material is within the typical values of 2363 Tool Steels. The results agree with the specifications given by the manufacturer (See Appendix A).

1.2.2.2 Chemical Element Distribution

The chemical element distribution was tested through the width of the material. This was done to determine the distribution of the major chemical elements in the material. It is important that the distribution be even through the width of the material. This analysis reveals important information about the homogeneity of the material. If for example there has been diffusion of carbon to the outer part of the material it will be revealed by this test.

The distribution of the elements is a factor, which influences the response of the material to deformation. The results of the test are shown in Table 1.2. The distance column refers to the location of the sample point from the side of the billet. The results of Table 1.2 are presented graphically in Figures 1.1 to 1.13. A graph was plotted for each element that was tested for in Table 1.2.

Thyrodur 2363 Tool Steel Chemical Element Distribution

Distance (mm)	Element (%)						
	C	Si	Mn	P	S	Cr	Mo
10	0.908	0.328	0.436	0.0251	0.0266	4.91	0.963
20	0.883	0.325	0.433	0.0252	0.0266	4.91	0.939
30	0.881	0.326	0.433	0.0251	0.0266	4.89	0.944
40	0.885	0.328	0.433	0.0252	0.0266	4.90	0.940
50	0.892	0.326	0.435	0.0251	0.0266	4.91	0.951
Average	0.890	0.327	0.434	0.0251	0.0266	4.90	0.947

Distance (mm)	Element (%)					
	Ni	Al	Co	Cu	V	W
10	0.200	0.0160	0.0273	0.0588	0.141	0.0100
20	0.199	0.0159	0.0271	0.0594	0.139	0.0100
30	0.200	0.0160	0.0273	0.0607	0.139	0.0100
40	0.201	0.0160	0.0274	0.0597	0.139	0.0100
50	0.199	0.0158	0.0271	0.0571	0.140	0.0100
Average	0.200	0.0159	0.0272	0.0591	0.140	0.0100

TABLE 1.2 Distribution of elements through 2363 Tool Steel

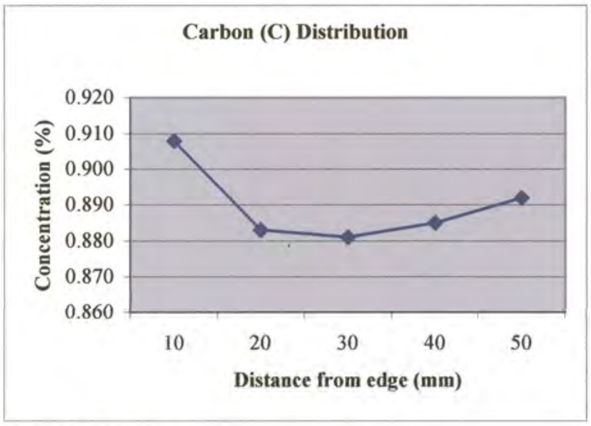


FIGURE 1.1

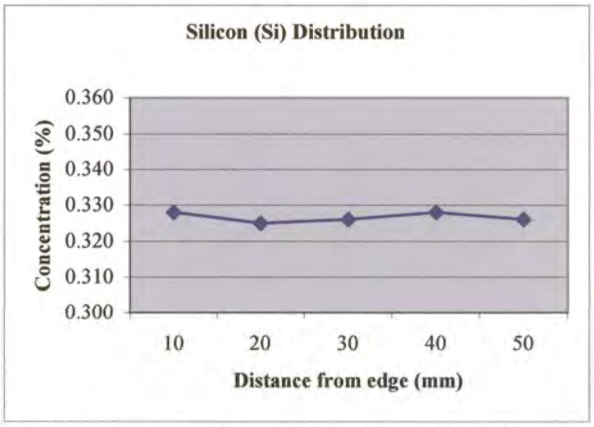


FIGURE 1.2

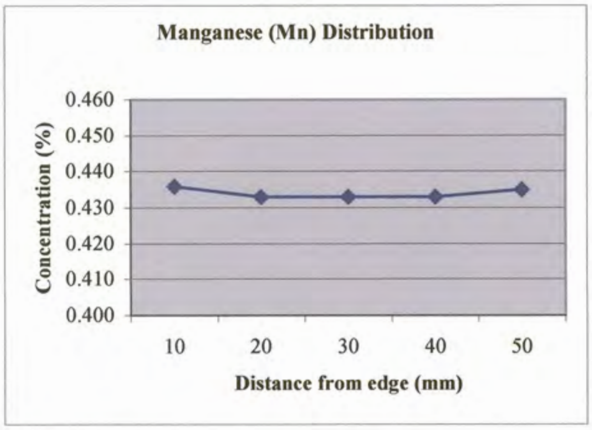


FIGURE 1.3

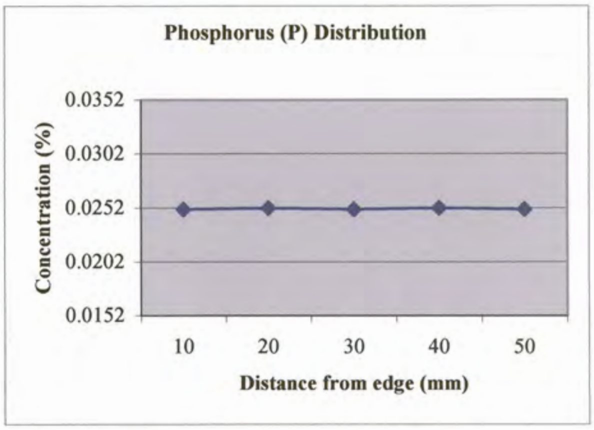


FIGURE 1.4

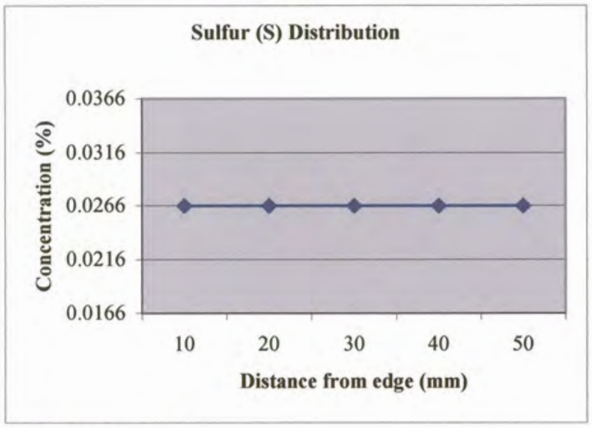


FIGURE 1.5

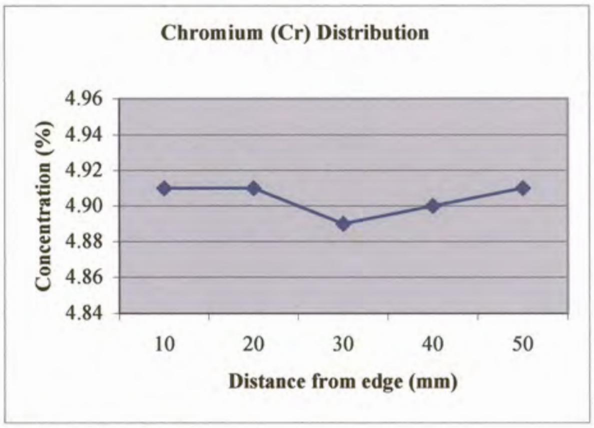


FIGURE 1.6

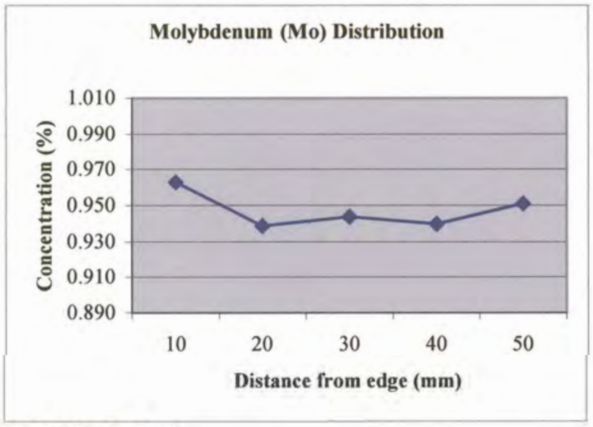


FIGURE 1.7

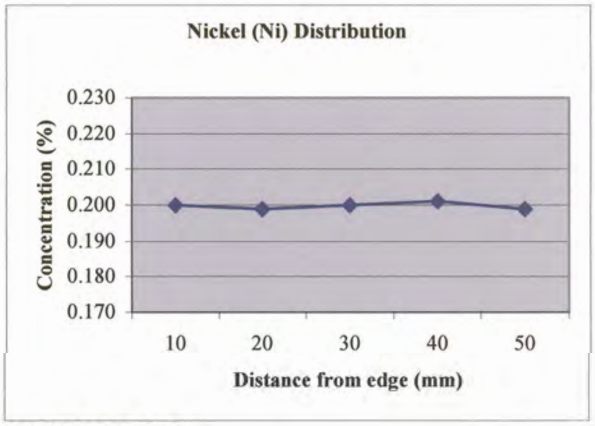


FIGURE 1.8

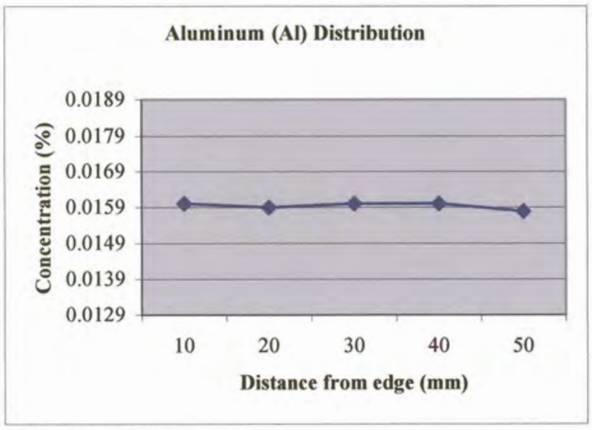


FIGURE 1.9

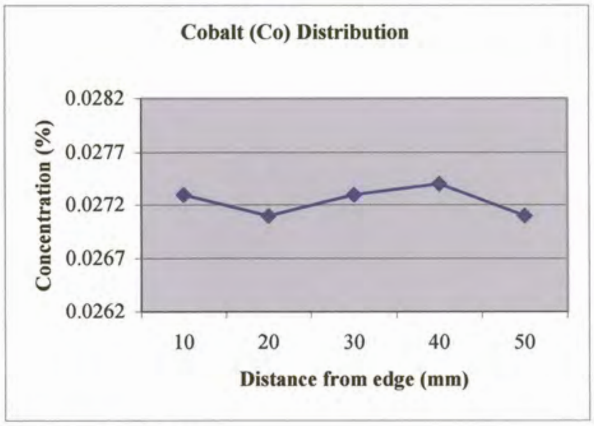


FIGURE 1.10

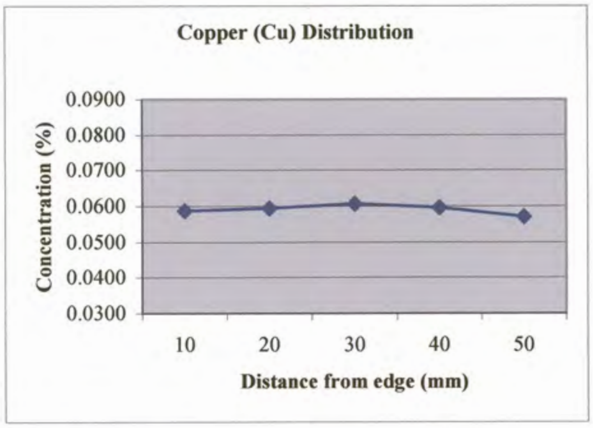


FIGURE 1.11

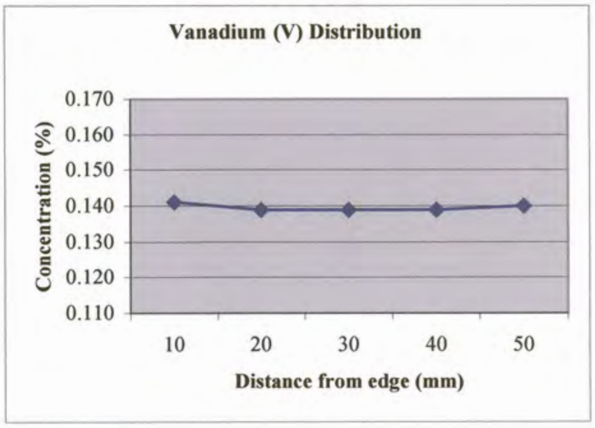


FIGURE 1.12

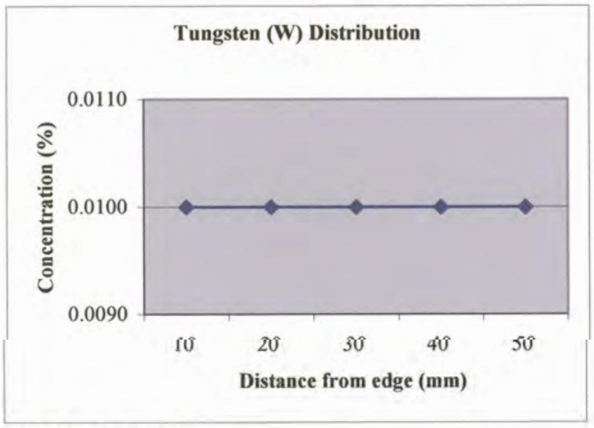


FIGURE 1.13

From the results of the test it is evident that a homogeneous distribution of elements exists in the material. The results lie within the specifications for typical 2363 Tool Steel (See Table 1.1). At this point no further analysis of the element distribution is necessary because the desired result was obtained.

1.2.2.3 Microstructure

A sample was prepared from the tool steel in the longitudinal and transverse direction. The microstructure was checked under 150x magnification (See Figure 1.14 and 1.15). The inspection revealed large carbide areas and small spherodised cementite in a ferrite matrix. Slight banding was visible in the longitudinal sectioned sample. The microstructure revealed no significant defects.

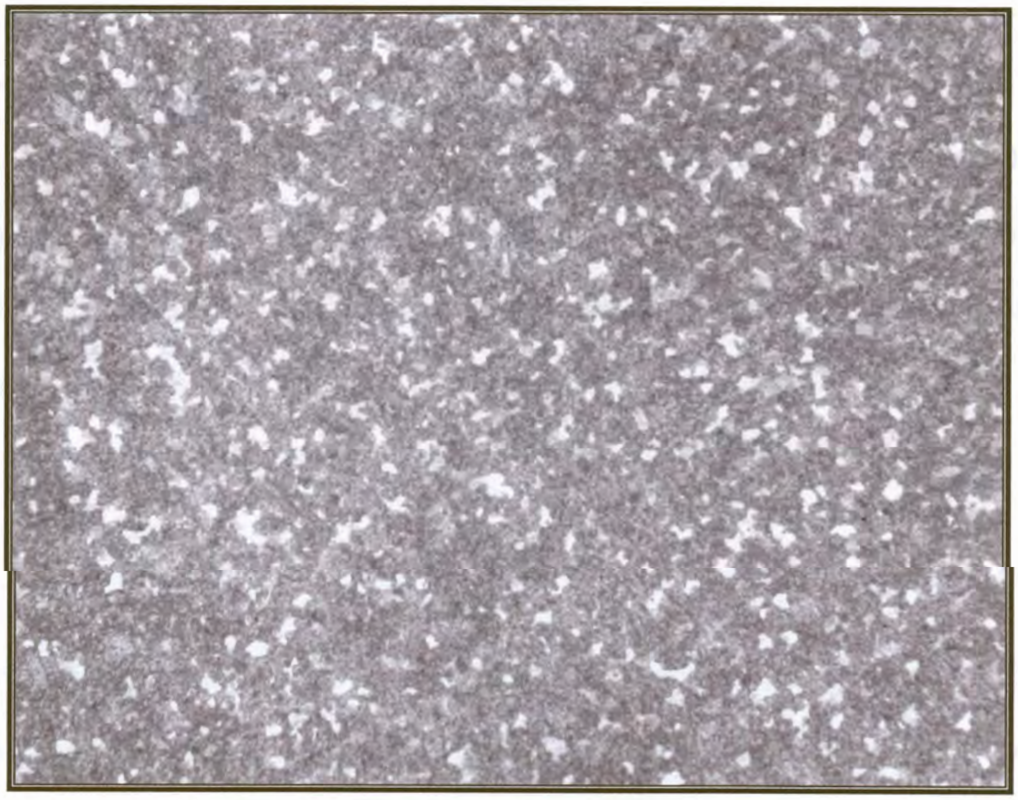


FIGURE 1.14 **Transverse section – x150**

FIGURE 1.15 Longitudinal section – x150

1.2.2.4 Nondestructive Testing

Internal flaws in the material can cause dies to fracture prematurely. Internal flaws are for example, inclusions caused by air bubbles and cracks that are formed during the solidification and cooling process. It is necessary to determine whether there are any defects in the material prior to any work being done on the material. This can be done by various nondestructive testing methods. Ultrasonic testing was used in this case.

Nondestructive testing (NDT) was done on the material by *Quality Testing Services* to check for internal flaws. An Ultrasonic test was done on the material and no defects were detected. The ultrasonic test report is included in Appendix A.

1.2.2.5 Hardness Test

The purpose of the test was to determine the hardness of the batch tool steel material that was obtained for the project. The hardness of the billets was measured to verify the specifications given by the manufacturer and to check the distribution of hardness between the billets. The hardness of the billets greatly affects the hobbing process and must therefore be well documented. Currently the hardness is not checked on incoming material.

The hardness of the billets is one of the variables that need to be kept constant at this stage and it is therefore important that the hardness distribution between the billets be small. Inconsistent results will be obtained during the deformation processes if the hardness of the billets varies greatly from batch to batch. This is an unacceptable situation, which can be avoided by ensuring a small hardness distribution. This is applicable to all incoming and custom produced material. Furthermore it is desirable for the material to be as soft as possible. This makes hobbing easier and reduces the stress on the driving die. The procedure that was followed to measure the hardness of the billets and the results of the test will now be discussed.

The tool steel batch consisted of five 40 mm diameter billets and sixteen 50 mm diameter billets. The hardness of every billet will be tested. Normally hardness tests of this kind would be done on the outer surface of the material. This can however be inaccurate since the surface conditions are not ideal. The surface of the raw material could be uneven or the surface could be affected to some extent due to the annealing process of the manufacturer. It is important that the measuring procedure is accurate and therefore it was decided to measure the hardness of the billets on the inner surface of the material (See Figure 1.16).


(a) (b)

FIGURE 1.16 Measuring point on the (a) outer and (b) inner surface

To measure the hardness on the inner surface it was necessary to cut a piece from every billet. A 70 mm piece was cut from each billet for this purpose. The measuring surface of each billet will be the newly revealed surface since the outer surface conditions are unknown. Work hardening effects might extend several millimeters into the billet due to the batch numbers that appear at the end of each billet.

The measuring surface was clearly marked and both surfaces were ground to a surface finish of N6. It is important that the two surfaces be parallel and smooth to ensure accurate results. The surfaces were ground slowly and excessive lubricant was used to ensure that the surface did not work harden during the grinding process. The hardness was measured on the Leco RT 2100 machine shown in

Figure 1.17. The calibration of the machine was checked with a 65 ± 1.0 HR_b calibration block. The reading on the block was 64.9 HR_b. The calibration certificate of the machine can be provided on request. Three measurements were taken randomly on the measuring surface of each billet and an average was calculated for each billet. The hardness results for the 40 and 50 mm billets are shown in Table 1.3. These results are presented graphically in Figure 1.18.

FIGURE 1.17 Leco RT 2100

Summary of results:

Average hardness of the 50 mm billets,

= 94.7 HR_b = 210 Brinell

Average hardness of the 40mm billets,

= 98.1 HR_b = 228 Brinell

The specification given by the manufacturer is 219 – 228 Brinell. The hardness of the 50 mm billets is slightly below the specification of the manufacturer. This does not present a problem, and it would be beneficial if the 40 mm billets were slightly below specification as well. This implicates that the material is slightly softer than expected. The most important result obtained from this test is that the bandwidth of the results is narrow. These inconsistencies in hardness must be monitored during the production process. The effect that the differences in hardness have on the behaviour of the material during the deformation processes will be evaluated during the development tests.

40 mm Billets Reading in HR_b

Reading		1	2	3	Average
Billet No.	1	98.1	98.7	98.6	98.5
	2	98.1	98.5	98.9	98.5
	3	97.8	97.7	98.0	97.8
	4	97.5	97.5	98.1	97.7
	5	97.5	97.9	98.4	97.9

50 mm Billets Reading in HR_b

Reading		1	2	3	Average
Billet No.	1	94.8	94.8	95.1	94.9
	2	94.6	94.2	92.5	93.8
	3	93.3	95.3	94.4	94.3
	4	93.5	94.9	95.9	94.8
	5	94.3	94.7	94.8	94.6
	6	94.5	95.1	94.9	94.8
	7	95.3	95.0	95.1	95.1
	8	94.7	94.9	94.3	94.6
	9	94.8	94.9	94.9	94.9
	10	95.0	94.7	94.6	94.8
	11	94.5	95.3	95.1	95.0
	12	93.4	95.1	95.2	94.6
	13	93.4	95.1	95.7	94.7
	14	94.0	95.1	95.2	94.8
	15	94.3	92.4	93.6	93.4
	16	94.7	94.8	95.5	95.0
	17	95.1	95.8	95.6	95.5

TABLE 1.3 Hardness of 2363 Billets

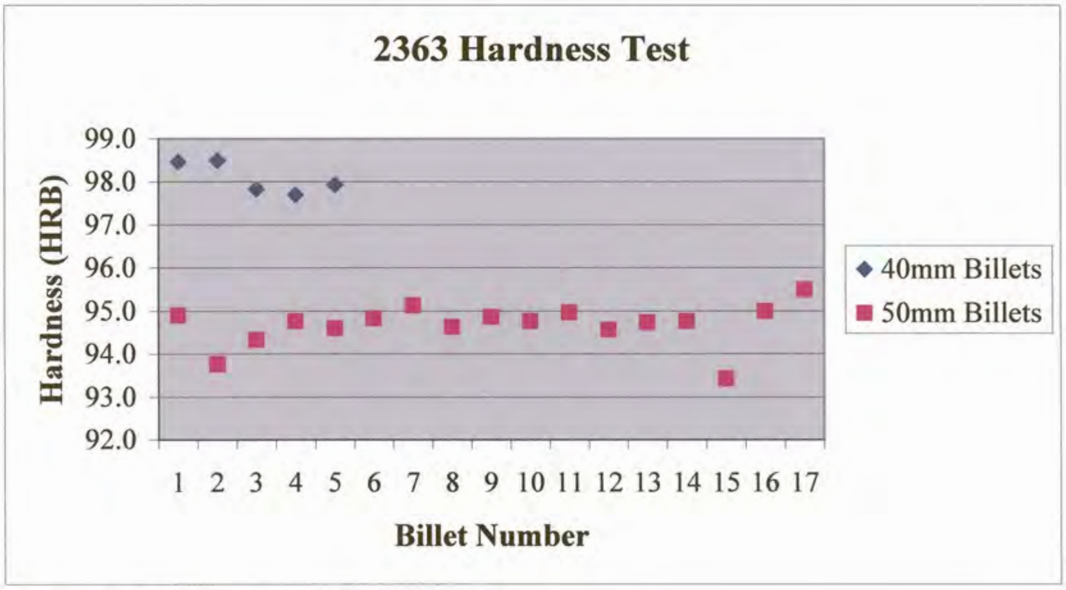


FIGURE 1.18 Results of Hardness Test

The hardness of the material is a very important property, which greatly affects the performance of the material. The difference in hardness between the 40 mm and 50 mm billets is undesirable and will cause the billets to behave differently during the hobbing processes.

It is recommended that the hardness of the billets be checked on all incoming material. If there is a large discrepancy between the specification and the actual results the material should be rejected or the material should be annealed a second time to ensure a homogenous hardness for all the billets. It is important to know the exact hardness of a batch since this could indicate why there are changes in the behaviour of the material in different batches. The behaviour of the material will be much more consistent if all the billets have the same hardness.

This ended the static evaluation of the material. It was now necessary to move on to dynamic tests to evaluate the deformation response of the material.

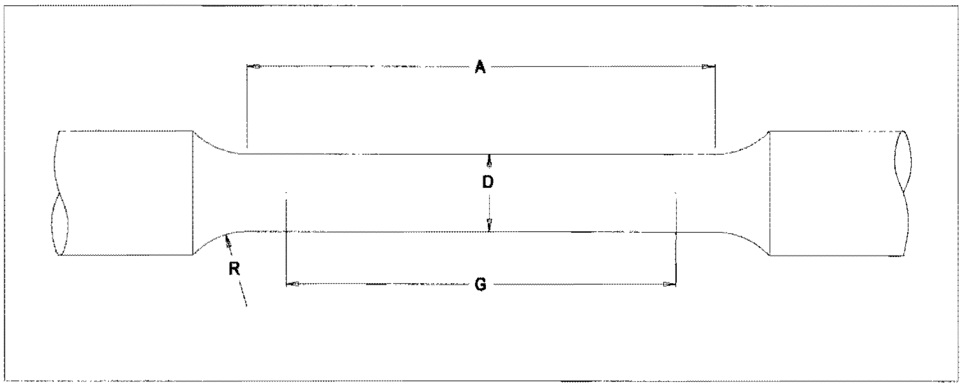
1.2.3 TENSILE TESTS (2363 Tool Steel)

The tensile tests were done to evaluate the elastic and plastic deformation response of the material. The material will undergo elastic and plastic deformation during the hobbing processes. During the coining process the dies will mostly deform elastically but plastic deformation will also occur to some extent. It is therefore imperative to know the deformation characteristics of the material in order to evaluate the response of the material during these processes.

To evaluate the elastic and plastic deformation characteristics of the material tensile tests were done on the material by ISCOR. The candidate made eight specimens for the tensile tests. The first three specimens were made in the longitudinal (casting) direction of the material. The Specimens were made according to the ASTM E8 specification. Figure 1.19 shows the details of the tensile samples. The results of these three specimens are detailed in the first tensile test report in Appendix B. All the tensile tests were done according to the ASTM specification.

The next five specimens were made according to the British Standard for Small Tensile Samples. (See figure 1.20(a)). This specification is designed for the use of small samples in ordinary chucks. Figure 1.20(b) shows the setup of the small samples in an ordinary chuck. Three of the five specimens were made in the transverse direction and the other two in the longitudinal direction. This was done to evaluate the difference in response of the material in the transverse and longitudinal directions. This was necessary because significant amounts of deformation occur in both directions during the hobbing process. It would be inaccurate to only assume response characteristics from the longitudinal direction.

The diameter of the billet was the size constraint on the specimens and thus necessitating the use of the small samples. The large samples were made to use as a reference to compare to the small longitudinal samples. The results from the small samples appear in the second tensile test report in Appendix B. The reader is referred to these reports to view the stress-strain plots for the specimens.



G – Gauge Length	62.5 ± 0.1 mm
D – Diameter	12.5 ± 0.2 mm
R – Radius of fillet, min	10 mm
A – Length of reduced section, min	75 mm

FIGURE 1.19 Round Tensile Samples (ASTM E8 Spec.)

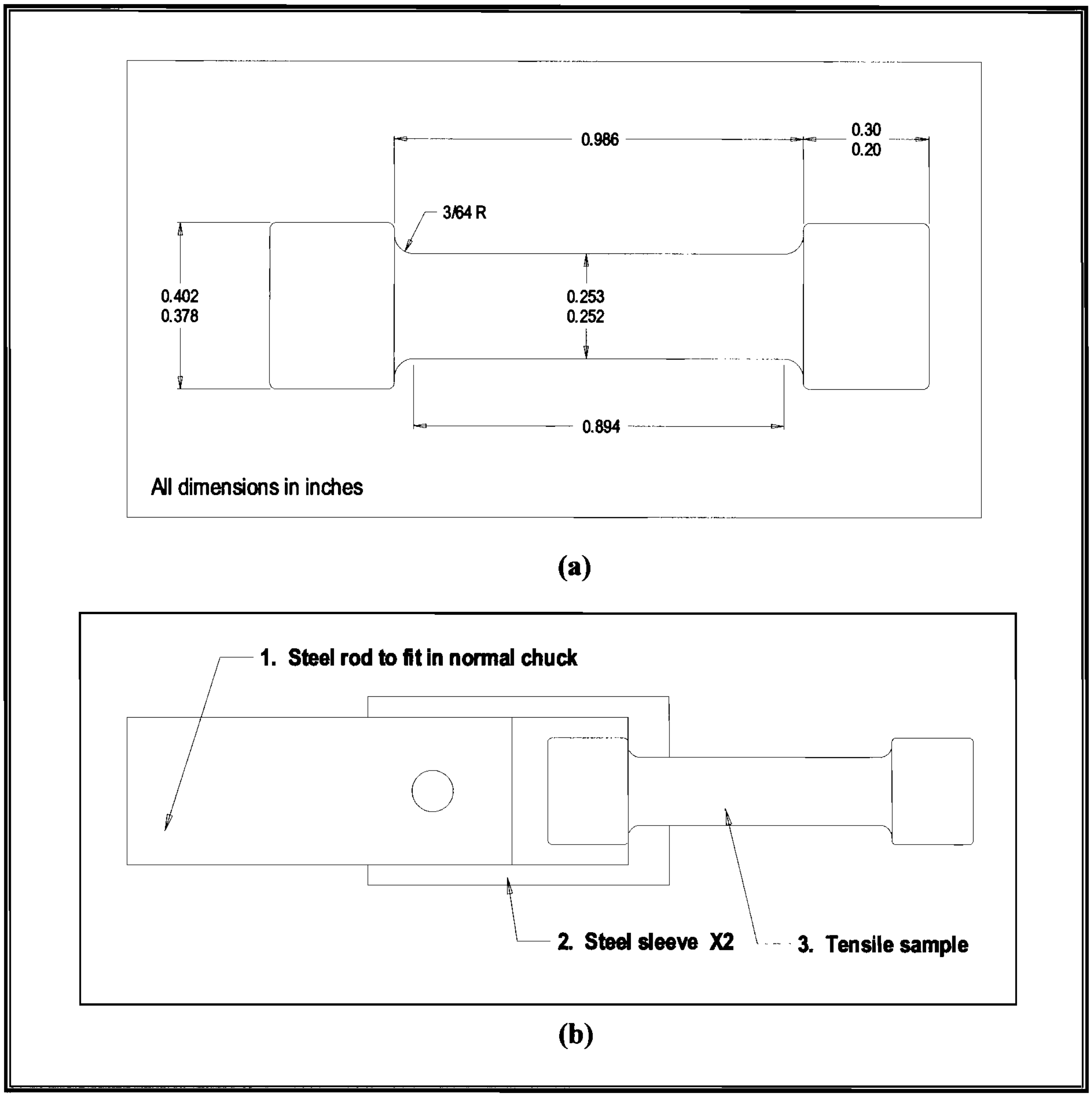


FIGURE 1.20 (a) British Standard small tensile sample. (b) Setup of small tensile in an ordinary chuck.

The longitudinal specimens revealed a fracture surface common to many tensile specimens (i.e. the cup-cone fracture appearance). The transverse specimens also produced a cup-cone fracture surface but the appearance and failure mechanisms are different. Figure 1.21 shows the fracture surface appearance of a longitudinal sample. Two distinct regions can be identified. The region in the middle of the sample (a) is called the fibrous zone. This zone is formed by stable crack propagation resulting from the coalescence of microvoids that are formed in the centre due to the high stress state present in the material. Region (b) indicates the shear lip that is formed at final fracture. This lip is formed by a shearing process along a surface that is oriented 45° to the stress axis. The shear lip is smoother than the fibrous zone since the crack propagation rate is much higher. Figure 1.22 shows the fracture surface appearance of the transverse tensile sample. In this sample there are three different zones. The fracture surface is totally different to the fracture surface shown in Figure 1.21. The first zone (a) varies greatly from the fibrous zone discussed previously. Horizontal lines can be seen across this entire region. These lines are flow lines that were formed during the casting process.

FIGURE 1.21 Fracture surface of longitudinal sample. (a) Fibrous zone, (b) Shear lip

In this sample, failure occurred due to the separation of these flow lines. Microvoids formed and crack propagation continued along these lines (i.e. the path of lowest resistance). The conical shear lip is still present but the appearance is different from the shear lip in Figure 1.21. The shear lip is much larger at (b) than at (c). The shear fracture surface at (b) also shows evidence of the flow lines. Region (c) of the shear lip shows the unstable formation and growth of the shear lip up to the point of final fracture.

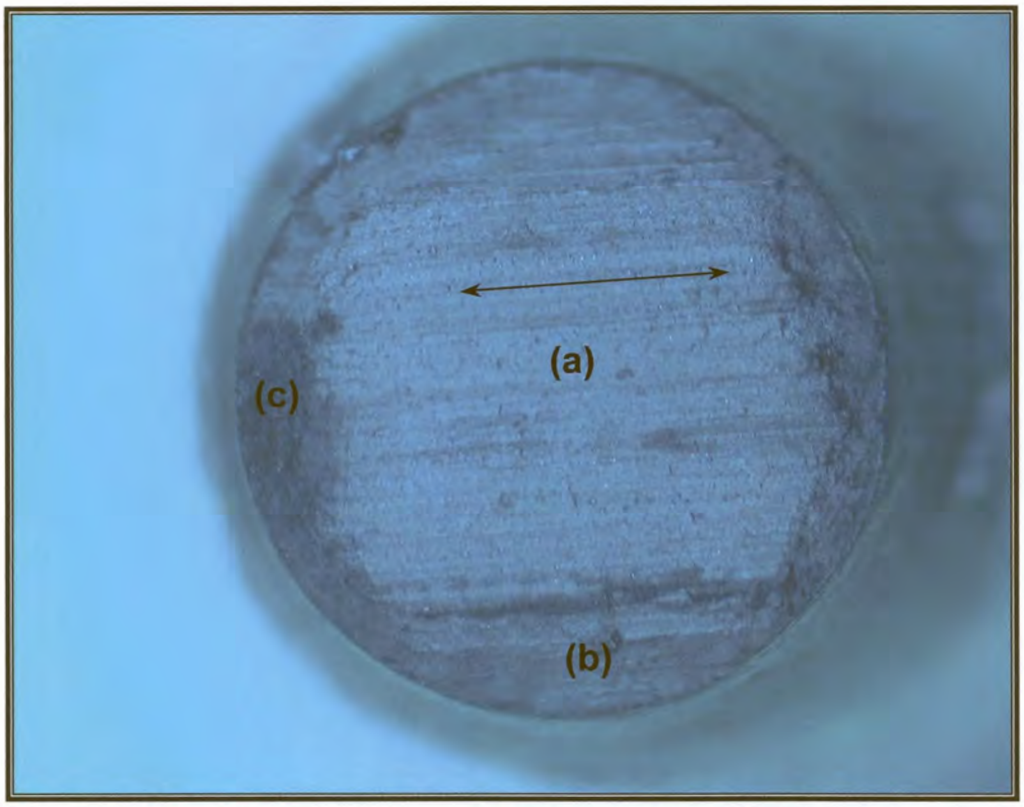


FIGURE 1.22 Fracture surface of transverse sample. (a) Stable crack growth zone, (b),(c) Shear lip.

If one could view the billets as a bunch of fibers closely packed together, then one would expect a lower tensile strength in the transverse direction. If stress is applied in the transverse direction the fibers will be torn apart whereas if stress is applied in the longitudinal direction the fibers will be broken. The results of the tensile tests prove this point. The yield strength and maximum percentage strain is lower for the transverse samples.

$\sigma_{y\ long} = 430$ MPa, $\varepsilon_{max\ long} = 23$ %

$\sigma_{y\ trans} = 390$ MPa, $\varepsilon_{max\ trans} = 18$ %

Therefore it can be said that the material has a lower strength and it can deform less in the transverse direction. This information can be used to identify the cause of die or punch failure during the production processes. If excessive strain is induced on the die or punch in the transverse direction microvoids can form. These voids can then grow during heat treatment and working processes and ultimately cause die failure. When a stress concentration is present at the top edge of the punch a crack can initiate at this site and then propagate along these flow lines. This point will be discussed in detail in Section 4.9.

1.2.4 CONCLUSION

The results of the material analysis revealed that the material is in good condition. This will be the only tool steel used for this project. Information is readily available on other tool steels and the S.A Mint can easily make an informed decision if a desire arises to change to a different tool steel. It was mentioned previously that the S.A Mint does not do a hardness test on the incoming material. Considering the importance of the hardness it is recommended that a baseline be established by doing a hardness test in addition to the material analysis. What the baseline should be will be discussed later.

1.3 Blanks

1.3.1 INTRODUCTION

The next step was to select a material for the blanks that will be used during the project. It was decided to use one of the materials currently used by the S.A Mint. This decision was taken to ensure that there would be material available for the project. It would also be beneficial for the Mint if a material were selected that they use for their blanks. Development and testing can then be done on the material and the results will be applicable to the blanks of the Mint. Only one material will be used for the blanks for the duration of the project. It was decided to opt for the material that causes the most problems during coining. It would not be very instructive to choose a material that coin easily.

There are three types of material that the Mint uses for most of their contracts. They are, Steel, Cupro-Nickel ($Cu75Ni25$) and Bronze ($CuZn4.5Sn0.5$). It was decided to use steel for the project since steel is the hardest of the three materials. Steel will work harden faster and coin more difficult than Cupro-Nickel or Bronze. It will be easier to spot coining defects and more problems will occur during the coining process if the blanks are relatively hard. Cost was also a consideration and since steel is the cheapest of the three materials it made sense to use it for the project. Once the material was chosen, it was necessary to analyse the material to determine its physical properties.

1.3.2 MATERIAL ANALYSIS (STEEL)

The steel that was used for the project was supplied by ISCOR. The steel is received in large coils. The steel strips are 3 mm thick and 1.225 m wide. These coils are slit into 170 mm wide strips. One of these 170 mm strips was obtained for the project. A sample was taken from the coil for analysis and the coil was put in bond for the exclusive use of this project. The test and analysis certificate given by ISCOR is shown in Appendix A.

A composition analysis and hardness test was done to verify the specifications given by the manufacturer. The results of this analysis are given in Table 1.4. The results showed that the material is typical low-Carbon steel and comply with the specifications of the manufacturer. The average hardness of the material is 115 H_v. More hardness tests will be done on the blanks prior to coining. The results will be discussed in Chapter 5.

Chemical Element Analysis (Steel)

Element	Concentration (%)	Specification (%)	
		Min	Max
Al	0.03	0.02	
As	< 0.01		
Cr	0.02		0.05
Cu	0.02		0.05
Mn	0.22	0.15	0.30
Ni	0.04		0.05
P	0.007		0.025
Si	0.01		0.04
Sn	< 0.01		
C	0.029		0.08
S	0.008		0.03

TABLE 1.4 Chemical Analysis of steel sample

1.3.3 TENSILE TESTS

Tensile tests were also done on the material. The results of these tests will provide very useful information about the coinability of the blanks since they are deformed plastically to a great extent during the coining process.

Six specimens were made according to the ASTM specifications. Three specimens were annealed and the other three were kept in the original state. It was necessary to anneal some of the samples because the blanks that are coined, are in the annealed state and we are interested in the deformation characteristics of the material during coining. It is also necessary to check the condition of the incoming material. The average hardness of the annealed samples was 98 H_v.

The results of these tests are included in Appendix B. It is seen from the results of the tensile test that the annealed samples have lower yield strength and a higher percentage strain.

$\sigma_{y\ \text{hard}} = 272$ MPa, $\varepsilon_{\text{max hard}} = 36$ %

$\sigma_{y\ \text{anneal}} = 218$ MPa, $\varepsilon_{\text{max anneal}} = 40$ %

The lower yield strength and higher percentage strain of the annealed samples implies improved coinability of the material. The annealing process and the effect of hardness on the coinability of the blanks will be discussed during the coining tests in Chapter 5.

CHAPTER 2

COIN DESIGN

2.1 Introduction

The selection of a coin design is a critical element of the project. The visual inspection of the coins forms an important part of the evaluation of the coining process. It was necessary to select an appropriate coin design that would be used throughout the duration of the project for the dies and the coins. One design will be used and the results obtained during the tests will be generalized. After the design protocol has been established the results can be used to develop any circulation coin regardless of the design details and the size of the coin. Various circulation coins were evaluated and a list was created of all the important attributes that are common to most circulation coins. Many different designs were considered and evaluated according to the list.

A finite element analysis will be done on the deformation of the blank during the coining process. The University of Pretoria will do the analysis in conjunction with this project. Due to the close cooperation between the two projects certain design decisions were taken with the finite element model in mind.

The major factors considered during the selection process were:

1. The design must be a good representation of actual circulation coins in terms of design size and depth.
2. The design must be symmetrical. This was a research decision. The decision was made to simplify the finite element model and to help identify coining defects. This decision will be discussed in the next paragraph.
3. The coin should have a design in the centre and lettering on the outside. This is synonymous with most circulation coins.

All the designs were evaluated according to these basic criteria. The design that is selected must be able to provide the researcher with ample information about the development and coining processes.

2.2 Design Selection

The selected design was adopted from a similar design that was used by the *MECCANO Research Centre* for an experimental analysis for the design of new coins [1]. The selected design and a description of the various components of the design are shown in Figure 2.1. A detailed drawing of the design is given in Appendix C. The design that was selected is a good representation of actual circulation coin designs. The depth of the design and the lettering will be varied according to the test objectives.

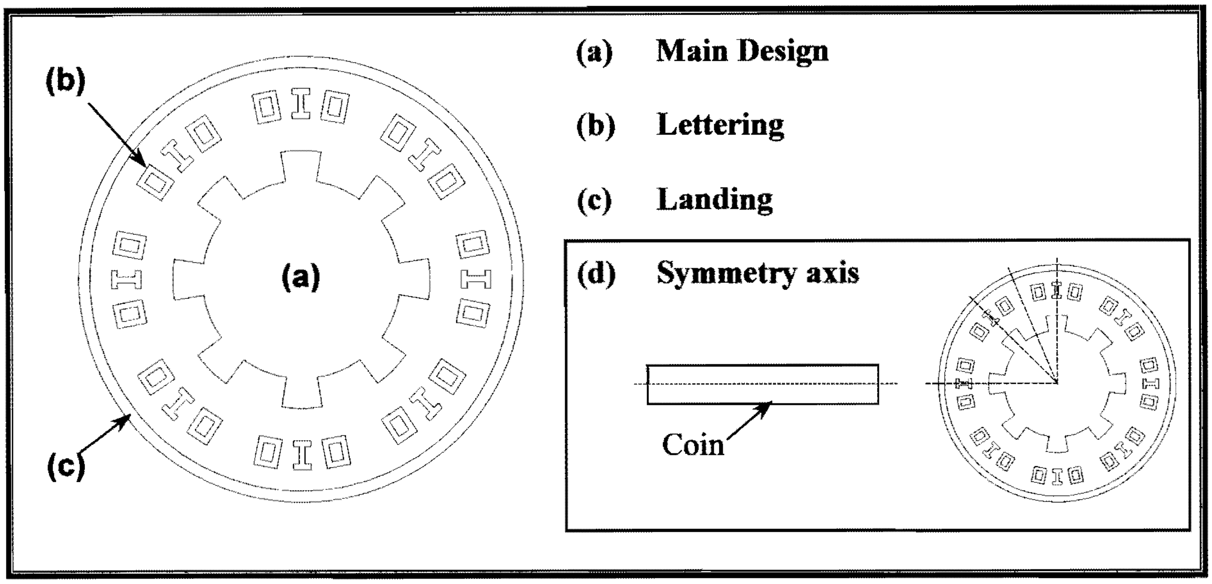


FIGURE 2.1 Coin design

A complicated design was selected so that coining defects can more readily be detected. The same design will be used for the obverse (front) and reverse (back) of the coin. The orientation of the design on the obverse relative to the reverse of the coin will be the same. This promotes material starvation, especially in the centre of the design. The design is symmetrical about eight axes and the coin is also symmetrical about the horizontal plane. It is therefore only necessary to model the top half of one-sixteenth of the coin in the finite element model. This translates to a dramatic reduction in computational time and cost.

There are other significant advantages in using a symmetrical design when it comes to the visual inspection of the coin. Coining defects can be explained more easily when a symmetrical design is used. The radial and axial flow of material should be exactly the same for all sixteen segments and therefore if some of the segments appear to coin unsatisfactory a coining pattern can be established and the problem can be pinpointed with greater ease. The problem could then be attributed to misalignment of the press, for example. The segments can also be compared with one another to see if a certain coining defect repeats itself in all the segments. The problem could then be related to the coin design or to defects on the dies. A lot of sharp edges were included in the design. This will help to identify the problem areas in the hobbing and coining processes. An extremely high force is necessary to produce a perfect sharp edge in the coining or hobbing processes. The radii of the lettering and the design will therefore be evaluated after coinage. These radii will be compared to the coining force. The minimum force necessary can then be determined by evaluating the radii.

A cutter with an included angle of 25° will be used to engrave the design and the lettering. This means that the design and lettering will slope at an angle of 12.5° from top to bottom relative to the vertical axis. See Figure 2.2.

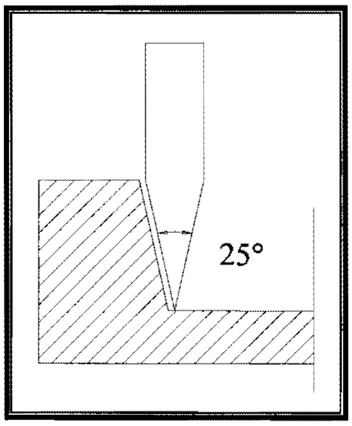


FIGURE 2.2 Cutter angle

The test coin was further complicated by the fact that a "full" design was used. The design of normal circulation coins has peaks and troughs, which makes it easier to coin since the competition for material is lower. The "full" design on both sides of the coin will promote material starvation in the centre of the coin. The main design and the lettering will have a constant height. This makes it easier to measure the coins and the dies. Details concerning the evaluation of the design during hobbing and coining will be discussed in the relevant sections.

REFERENCES

1. MECCANO Research Centre, **Finite elements and experimental analysis for the design of new coins,** XVII MDC, 1994

CHAPTER 3

BLANK DESIGN

3.1 Introduction

Blanks are pieces of steel that has been formed to accommodate the design on the coining dies. A blank is basically a coin without a picture. It was previously discussed that steel will be used as the core material for the blanks. The size and shape of the blanks must now be determined. Due to resource constraints it was decided to use RSA 50c blanks for the project. The RSA 50c is the largest denomination with a steel core in the RSA coin series. Since the RSA 50c blanks will be used, there is no need to manufacture special tooling for the production and coining of the blanks. It also simplifies the manufacturing process since this is a familiar denomination and the order can easily be requested through the system.

3.2 Blank Production

A new collar will be made because the test coin will not have a serrated edge like the RSA 50c. The size of the coin was developed according to the current development guidelines. Normally the blank size will be developed from the coin specifications but in this instance the blank size is fixed and the final coin size is a variable. The procedure that was followed to obtain the die neck size and the collar size will now be discussed.

Sizes 1 through 6 were obtained from the RSA 50c specification (Appendix D).

Blanking

1) Thickness of Blanks

size: 1.575 ± 20 µm
min: 1.555 mm
max: 1.595 mm

2) Diameter of Blanks

size: 21.740 ± 50 µm
min: 21.690 mm
max: 21.790 mm

Rimming

3) Thickness (Rimmed)

The thickness of the rimmed blanks is included in the specification for information purposes only, i.e the blanks will not be rejected if they fall outside this specification. The rimming process is described hereafter and shown in Figure 3.1.

size: 1.960 ± 100 µm
min: 1.860 mm
max: 2.060 mm

4) Diameter (Rimmed)

size: 21.490 ± 50 µm
min: 21.440 mm
max: 21.540 mm

Plating

5) Thickness (Plated)

Once again the plated thickness of the blanks are given for information only.

size: 2.050 ± 100 µm
min: 1.950 mm
max: 2.150 mm

6) Diameter (Plated)

size: 21.700 ± 80 μm
min: 21.620 mm
max: 21.780 mm

7) Collar

The collar is inserted in the coining press to restrict the radial flow of the blank during coining (See Figure 3.1). The collar size is determined empirically through previous experience based on trial and error development. To ensure proper feed of the blanks at high speed the collar inside diameter is 100 microns larger than the maximum blank size. This value varies according to the size of the coin.

Diameter = Plated blank (max) + 0.1 mm
= 21.780 + 0.1
= *21.880 mm*

FIGURE 3.1 Collar

8) Die neck

The die neck is the reduced section of the coining die that fits inside the collar during coining. The die neck is approximately 100 microns smaller than the collar to provide sufficient clearance between the collar and the dies during coining.

Diameter = Collar size – 0.1
= *21.780 mm*

9) Coin

Diameter = Collar size + 50 μm
= *21.930 mm* (Estimate)

The final coin size is slightly larger than the collar. This is due to the elastic expansion of the coin after it has been ejected from the collar. These values are estimates and will be used for coining tests.

A 170 mm wide steel coil was used for the blanks. The coil was rolled to a final thickness of 1.575 ± 0.02 mm according to the specifications (See Appendix D for the specifications). The coil was blanked and the blanks were upset with the RSA 50c rimming profile (Rimming profile given in Appendix C). The upsetting mill is directly after the blanking station. The coins are upset to remove burs on the blanks and to put extra material on the edge of the blank. This improves the material flow at the edge of the coin and leaves enough material for the landing to be formed at coinage. The upsetting mill is shown in Figure 3.2. The blanks are fed from the left and the right side. Each side is set up independently. The blanks move between the rotating marking ring and the rim block and the rim is formed. An example of a rimmed blank is shown in Figure 3.3.

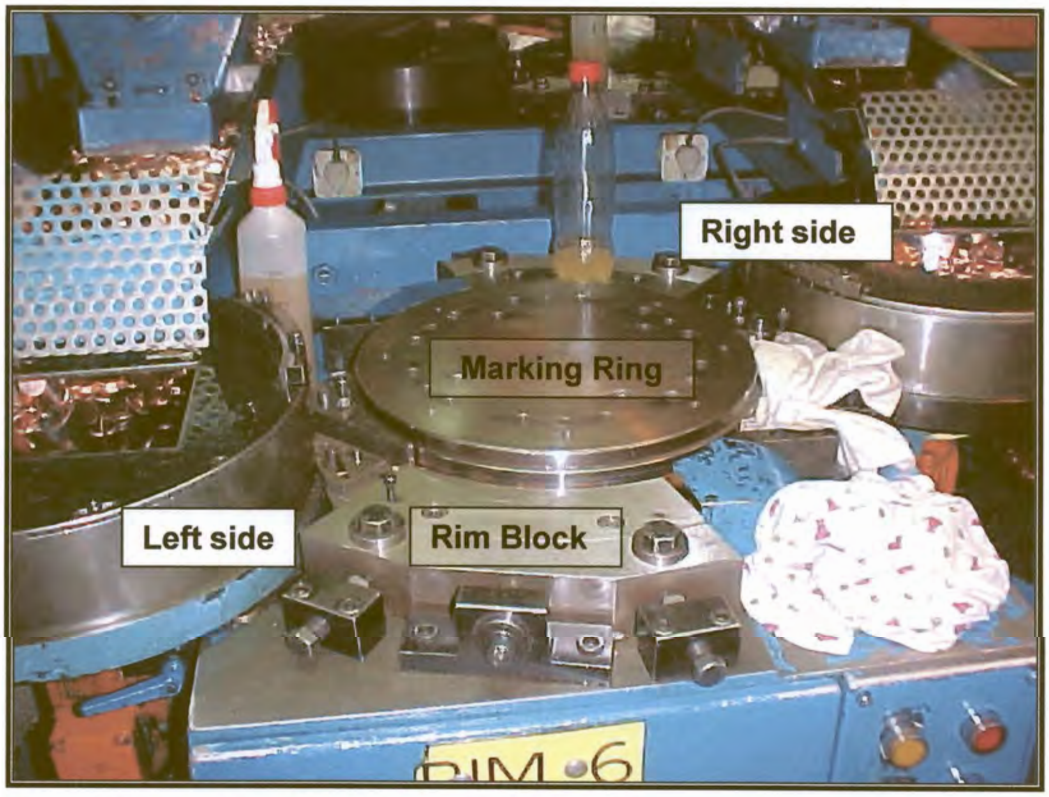


FIGURE 3.2 Upsetting Mill

The blanks were held in bond to prevent contamination with other blanks and to maintain confidence in the material analysis results. The blanks will be electroplated according to RSA product specification.

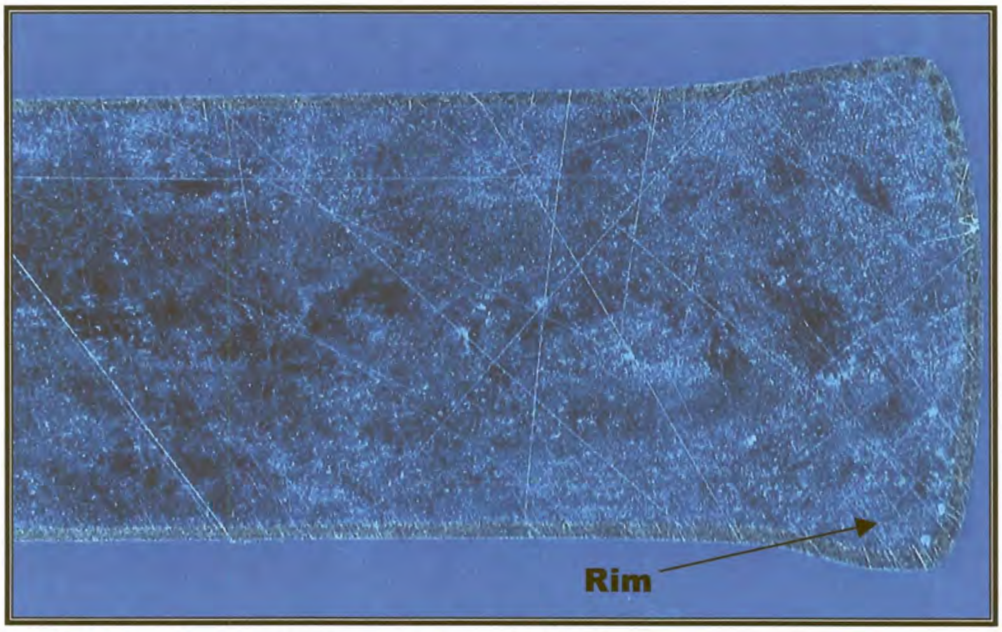


FIGURE 3.3 **Section of rimmed blank**

3.3 Blank Qualification

A qualification was done on the blanks after blanking and rimming to check if the blanks fall within the specification of the S.A Mint. The following qualifications were done:

1. The diameter was measured before and after rimming
2. The mass of the blanks was measured
3. The thickness of the blanks before rimming was measured.

This is by no means a complete and detailed qualification and aspects like the control limits and standard deviation plots will not be discussed in this report. The qualification was merely done to check if the blanks fall within the RSA 50c specifications.

One hundred and twenty five samples were taken from the un-rimmed blanks in subgroups of five. The samples were taken in evenly spaced intervals throughout the coil. The second sample set consisted of one hundred and fifty rimmed blanks in subgroups of five. The blanks are fed from both sides of the upsetting mill, thus fifteen subgroups were taken from each side. The data was processed and the results are shown in Figures 3.4 to 3.8.

Figure 3.4 and 3.5 presents the data for the un-rimmed blanks. The average was calculated for each subgroup and that value was plotted for each of the twenty-five subgroups. The minimum and maximum values on the y-axis correspond to the upper and lower limits according to the specification. The diameter and the thickness of the blanks fall within the RSA 50c specification. The diameter and thickness of the blanks remain relatively constant throughout the coil. The results for the un-rimmed blanks are satisfactory.

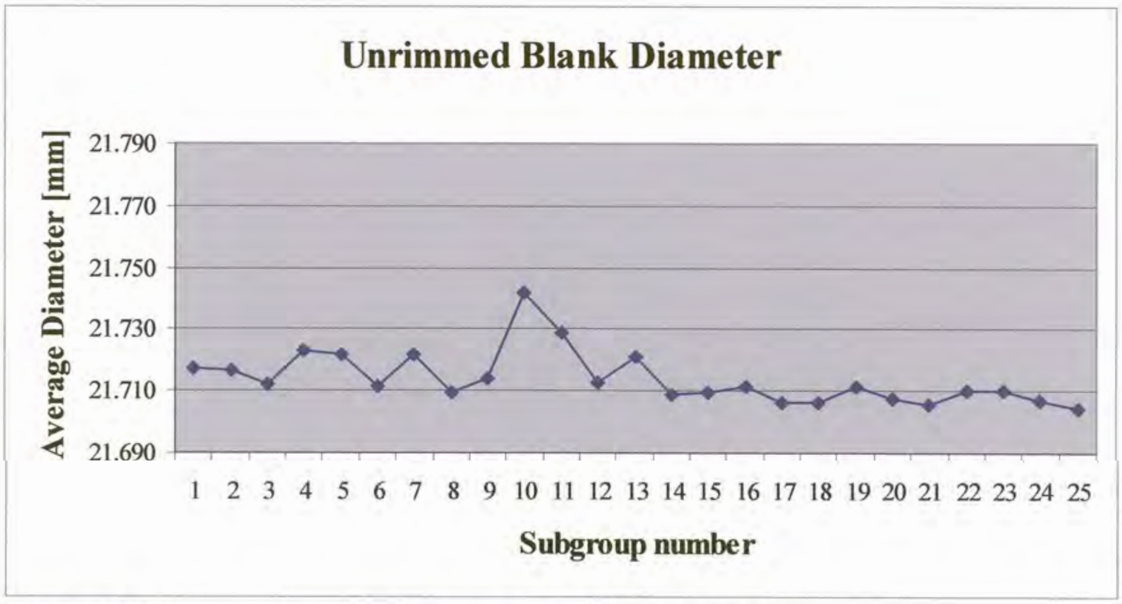


FIGURE 3.4 **Average diameter of un-rimmed blanks**

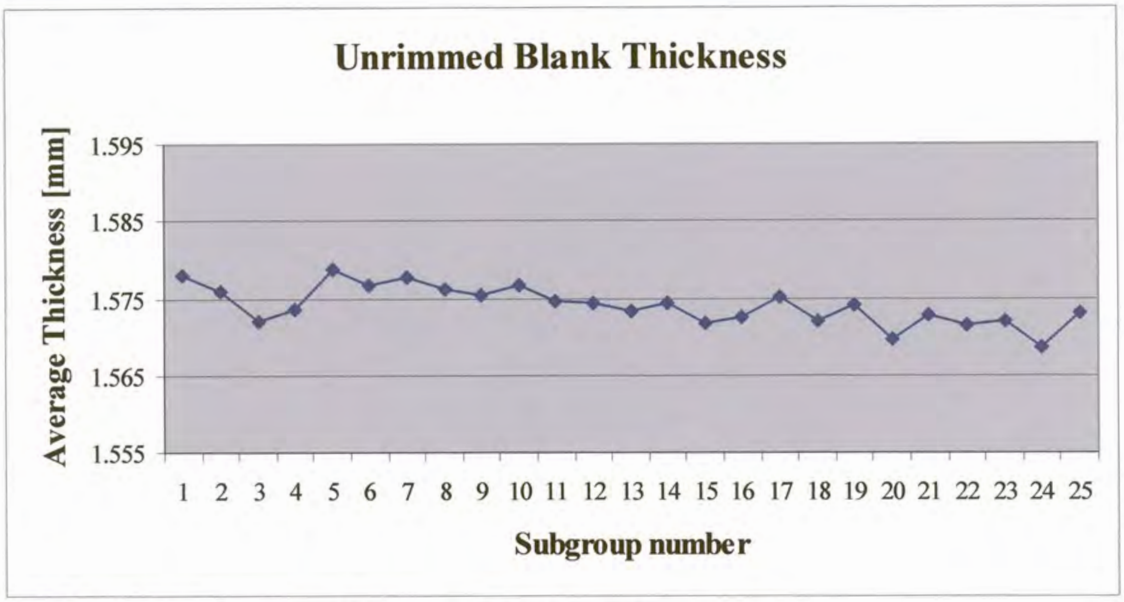


FIGURE 3.5 Average thickness of the un-rimmed blanks.

The data for the rimmed blank diameter is shown in Figure 3.7. Fifteen subgroups were taken from each side (i.e. left and right side as shown in Fig. 3.1). After subgroup one was taken it was noted that the diameter of the blanks rimmed on the right side approach the upper limit of the specification. To prevent the blanks falling out of spec the gap between the rim block and the marking ring was adjusted. All the subsequent subgroups lie well within the specification.

The results for the blank mass are shown in Figure 3.8. The average mass was calculated for all the subgroups using a *Sartorius* scale accurate to $^{1}/_{1000}$ of a gram. The scale is shown in Figure 3.6. The results obtained lie in the middle of the specification within a very narrow bandwidth.

FIGURE 3.6 Sartorius scale

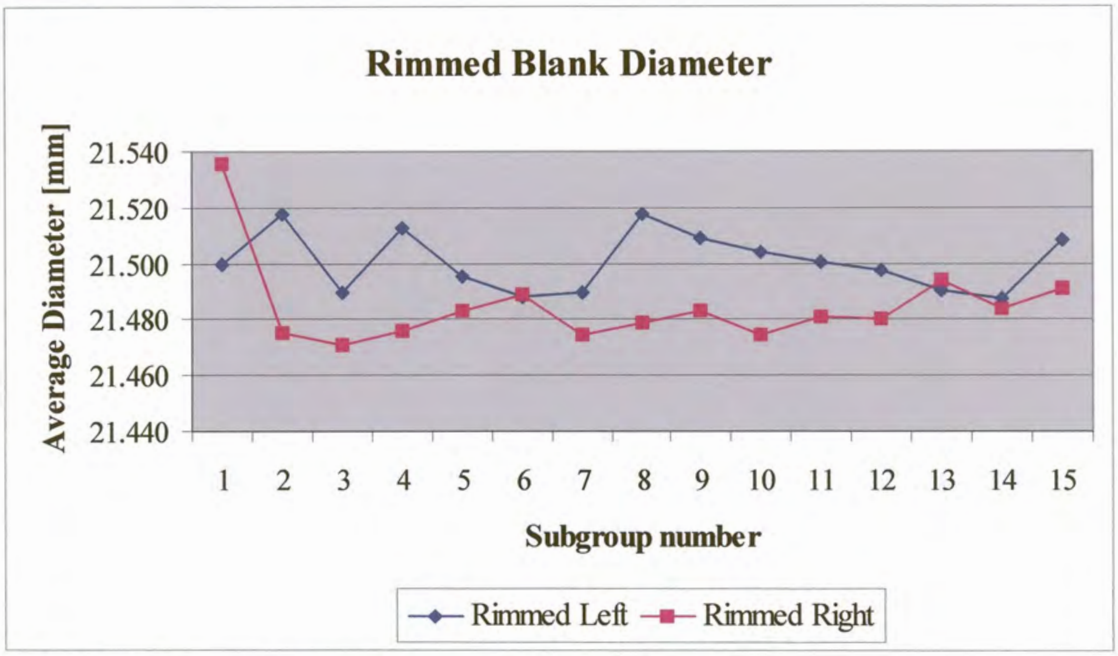


FIGURE 3.7 Average diameter of the rimmed blanks.

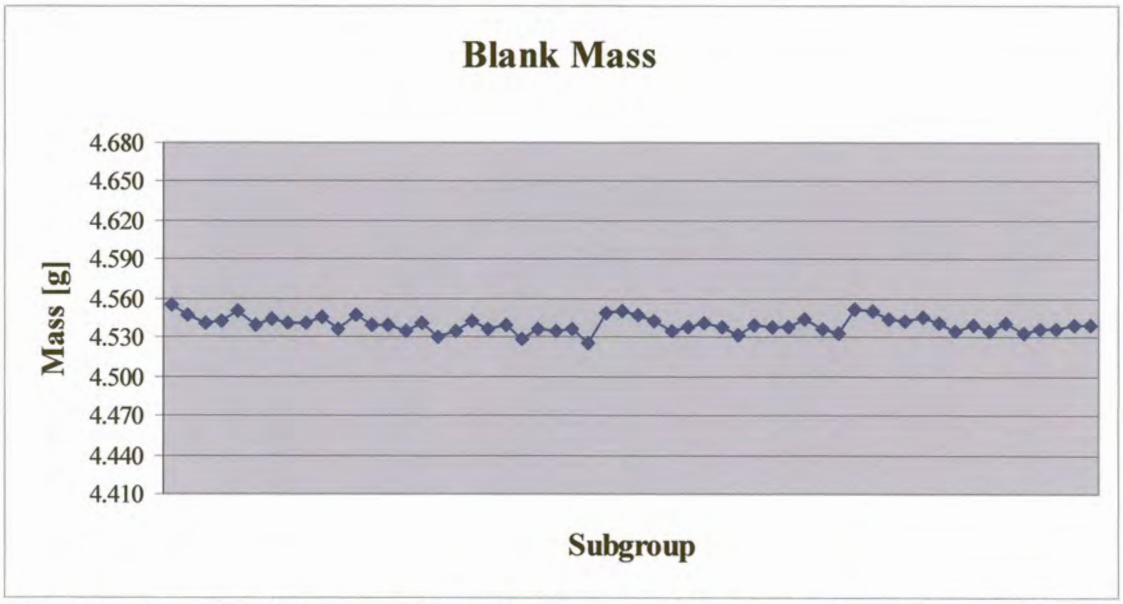


FIGURE 3.8 Blank mass for all subgroups. (Un-rimmed and rimmed blanks)

3.4 Conclusion

All the results obtained during the qualification proved to be satisfactory and the blanks were accepted for the project. It is highly recommended that a separate study be initiated to verify the current specifications.

CHAPTER 4

DEVELOPMENT TESTS

4.1 Introduction

This chapter will cover the development tests that were done regarding the production of the master punch and coining dies. The test objectives will be discussed for each test as well as the procedure that was followed in conducting the tests.

The procedure that was followed, during this project to produce the coining dies is summarized below. The reader is referred to *Section A. **Die development***, for a complete discussion about the die development process.

1. Generate computer model.
2. Machine matrix on CNC Engraver.
3. Machine relief into matrix.
4. Harden matrix.
5. Hob matrix on die blank to produce master punch.
6. Machine master to specifications.
7. Harden master.
8. Hob master on die blank to produce coining dies.
9. Machine coining dies to specification.
10. Harden coining dies.

There are various factors affecting the accuracy and quality of the dies and punches that are produced during this process. During the development tests these factors, which affect the accuracy and quality of the dies, will be identified and isolated. The effect of these factors will be quantified and discussed.

The major concern during the development process is the dimensional stability of the dies. The problem that faces the developer is that he often knows what the coining dies should look like but he has difficulty producing the coining dies according to his requirements.

To improve coinage a slight dome of about 50 microns is created on the coining dies. This dome ensures that the blanks start coining in the centre and coining then progress coining radially outward. The effect of the dome is that the force required to sufficiently coin the blanks is reduced. This improves die life. It is very important to determine the correct dome size. If the dome is too small, the centre design will not coin satisfactorily. If the dome is too large, the lettering on the outside of the design will not coin satisfactorily. Once the ideal dome size has been determined it must be reproduced on the coining dies. The way in which this is done, is by modeling a dome on a computer or by placing the rubber mould on a dome plate before the ureol is cast.

The problem lies therein that the dome does not reproduce accurately due to the dimensional change that occurs during the manufacturing process. These and other dimensional stability problems will receive attention during the development tests.

4.2 Test 1: Introduction to Development Tests

The purpose of the initial test was first and foremost to establish a detailed test protocol for the project tests. This was seen as a trial of the tests to come. The test was also used, as a guideline for what Test 2 should entail. The test was done to familiarize the candidate with the development process and the equipment that is used in the process.

It was decided that for this project no machine punch would be made. The process will start with the modeling of the design on computer. A matrix will then be engraved on the CNC engraving machine. This eliminates the process of creating a machine punch on the reduction machines. This saves a lot of time since the reduction from the ureol to the machine punch can take weeks. It is also more accurate to model the design on the computer and changes can easily be made if necessary. The use of the CNC engraver to create the matrix is gaining more popularity due to the significant reduction in development time and effort. New computer hardware and software technologies make this a very attractive means of creating the matrix.

The test procedure for test 1 was as follows.

1. The selected design was modeled on the computer (Appendix C).
2. A matrix was engraved and sent for heat treatment.
3. A master punch was hobbed from the hardened matrix.
4. The master punch was measured and then sent for heat treatment.
5. The master punch was again measured after heat treatment.

From the results of Test 1 it became evident that the measuring procedure is extremely important and that the dies and punches must be measured with an accuracy of a few microns. The candidate was not familiar with the measuring equipment and accurate results could not be guaranteed. It was necessary to establish a measuring procedure that would be followed every time something was measured. This had to be done before test 2 could commence.

The hobbing press had to be calibrated since a lot of work will be done on the press and the applied force is an important factor in all the tests. A calibration certificate for the digital readout gauge on the press was not available.

The main complications encountered during the process are the dimensional instability of the dies during the heat treatment process and the elastic recovery of the material during the forming process. These problems will be addressed in the subsequent tests.

Due to the irregular deformation that was observed, it was decided that the heat treatment and the hobbing processes should be separated for the next test. The effect of the heat treatment process can then be quantified properly without the additional effects of plastic deformation.

No formal results were documented for test 1 due to the lack of reliability of the results. The test protocol for the subsequent tests has been generated as an output. All problems regarding the test protocol have been sorted out.

4.3 Calibration Of Hobbing Press

4.3.1 PURPOSE

The hobbing press is used to hob the master punches from the matrix. A lot of effort will be put into this process and the applied force was an important criterion in all the experiments that were conducted. It was therefore imperative that the calibration of the press be checked to ensure that the indicated applied force was correct.

The press under discussion is the Sack & Kiesselbach Oil Hydraulic Press. The press has a 630-Ton maximum force and a minimum pressing speed of 2 mm/s. The hydraulic press has the advantage that the nominal force is available over the entire pressing stroke. The press is shown in Figure 4.1. A digital readout gauge on the press provides a readout of the applied force.

FIGURE 4.1 Sack & Kiesselbach Hobbing Press

The objective of the test was to check the calibration of the digital readout gauge fixed to the press. The digital gauge will be compared to the loadcell up to a force of 50 tons. The digital gauge will then be compared to an oil pressure gauge, fixed to the press, using a much higher tonnage.

4.3.2 PROCEDURE

The hobbing press was calibrated using a 50-ton loadcell. This was the largest loadcell available that could fit into the press cavity. The Laboratory of Advanced Engineering calibrated the loadcell. The calibration factor of the loadcell was 500 kN = 10 V.

The loadcell was placed on the bed of the press. A 50 mm diameter, 40 mm long hardened billet was placed on top of the loadcell. Both surfaces of the billet were ground to ensure that the surfaces were parallel. Note was taken of the zero load error before pressure was applied. Load was applied to the billet until the reading on the loadcell increased with 1000 mV. The reading on the digital gauge was taken on each occasion.

4.3.3 RESULTS

The processed data is shown in Table 4.1 and presented graphically in Figure 4.2. The equation, $y = 5.1082x - 2.2497$ was used to fit a linear trendline through the data. The data follow a linear trend since the trendline passes through all the data points.

Loadcell [mV]	Digital Gauge
0	-2.8
1025	3.2
2010	8.2
3001	13.2
4000	18.4
5003	23.4
6000	28.4
7000	33.4
8000	38.6
9000	43.6
9960	48.6

TABLE 4.1

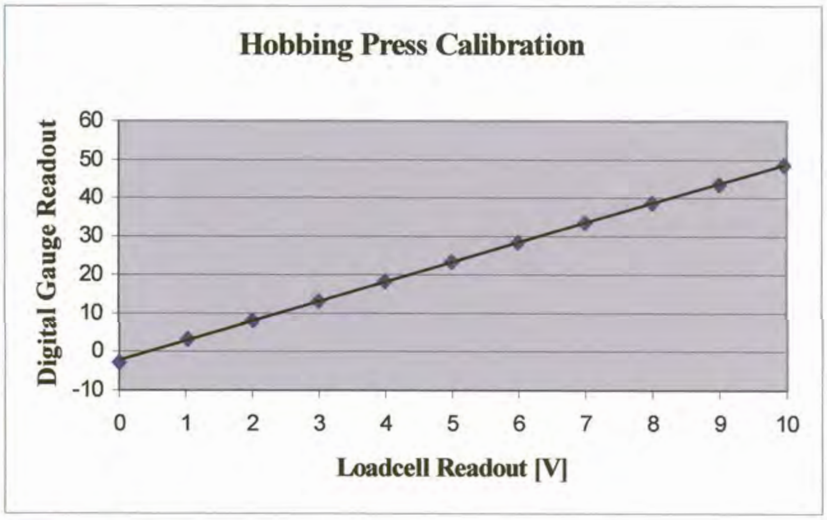


FIGURE 4.2

It is necessary to calculate the error between the actual tonnage and the reading given by the digital gauge. To determine the actual tonnage the reading from the loadcell must be converted from mV to tons. This was done using the calibration factor of the loadcell.

Calibration Factor of loadcell : $1V = 50\,kN$

$$Loadcell\ kN = \frac{Loadcell\ mV}{1000}\ x\ 50 = Applied\ Force\ [kN]$$

$$Applied\,Tonnage = \frac{Applied\ Force\ [kN]}{a}\ ; \qquad a\text{, gravitational accel. equal to } 9.81\ \mathrm{m/s^2}$$

The results are shown in Table 4.2. For each reading the actual tonnage and the digital reading are plotted. A graphical presentation of the results is shown in Figure 4.3. The difference between the actual load and the indicated load can now be calculated. The average difference calculated, can now be added to the digital reading to achieve greater accuracy. If the average difference is added to the digital reading the error is 0.07 % at 50 tons, which is extremely accurate. A quicker and more practical approach can be followed by subtracting the zero load reading, i.e -2.8 tons, from the digital reading. This produces an error of 1.25 % at a load of 50 tons. The percentage error will be much smaller at the working load of approximately 150 to 200 tons since the zero load error remains constant.

Example to calculate actual load:

$Digital\ readout = 48.6$

$Average\ difference = 2.19$

$Adjusted\ reading = 48.6 + 2.19 = \mathbf{50.79}$

$Actual\ load = \mathbf{50.76}$

$\%\ Error = 0.07$

Reading	*Actual Load [Tons]*	*Digital Gauge Reading*	*Difference*	*% Error*
0	0	-2.8	2.80	
1	5.22	3.2	2.02	3.23
2	10.24	8.2	2.04	1.45
3	15.30	13.2	2.10	0.64
4	20.39	18.4	1.99	1.01
5	25.50	23.4	2.10	0.37
6	30.58	28.4	2.18	0.04
7	35.68	33.4	2.28	0.24
8	40.77	38.6	2.17	0.04
9	45.87	43.6	2.27	0.17
10	50.76	48.6	2.16	0.07
		Average	**2.19**	

TABLE 4.2 Calculating the error of the digital readout gauge

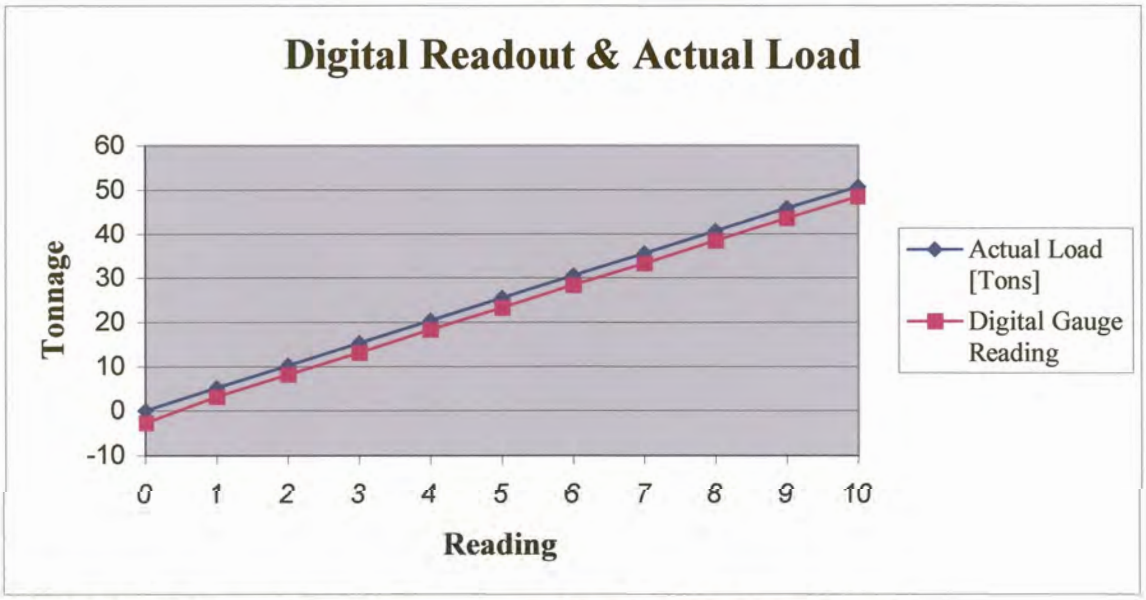


FIGURE 4.3 Comparison between actual load and indicated load

The next step is to check the accuracy of the digital gauge at increased loads. This will be done with the oil pressure gauge attached to the press. The pressure gauge has been calibrated by the installer and provides an accurate reading of the oil pressure. The load was gradually increased in increments of 1 MPa. Each time the digital readout was taken. Slight errors can occur during the reading of the analog pressure gauge and therefore the test was repeated to obtain two sets of data. The results are shown in Table 4.3.

	1st Set	2nd Set
Pressure Gauge [MPa]	*Digital Gauge [MPa]*	*Digital Gauge [MPa]*
1	12	11
2	22	22
3	37	37
4	48	49
5	64	64
6	78	77
7	90	90
8	102	101
9	114	114
10	130	128
11	140	141
12	154	152
13	164	165
14	177	177
15	190	189
16	202	202

TABLE 4.3 High Load Calibration

The two sets of data were plotted against pressure. The results are shown in Figure 4.4. The following equation, $y = 12.769x - 1.1$ was used to fit a linear trendline through the data. The linear behavior of the digital gauge is evident since the trendline passes through all the data points.

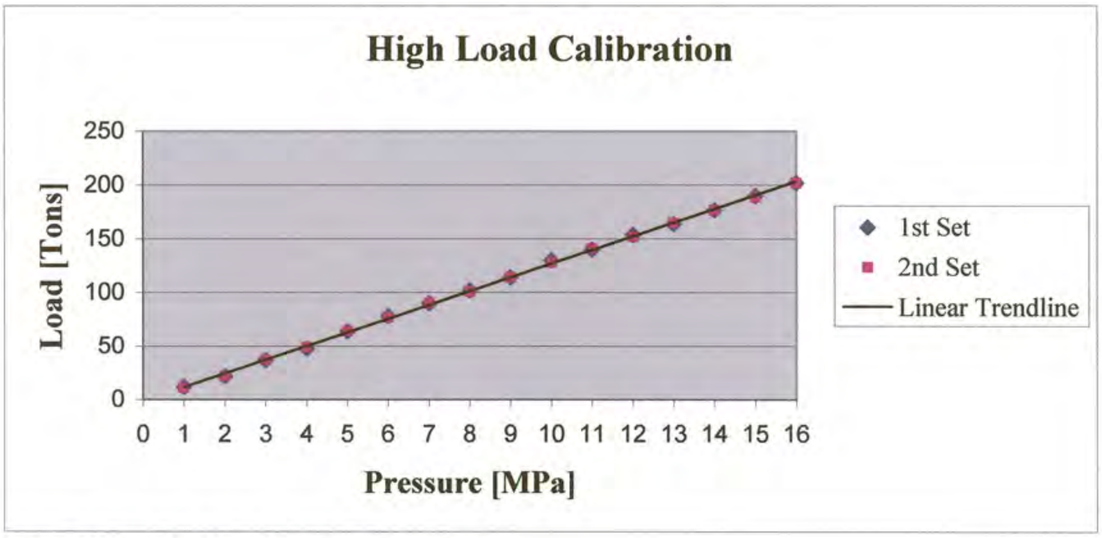


FIGURE 4.4 High load calibration

4.3.4 CONCLUSION

The results of the test showed that the digital gauge gives very accurate readings of the applied force up to 200 tons. The actual applied tonnage will be taken as the digital reading minus the zero load reading. This will give a reading with more than adequate accuracy.

Example :

Digital readout = 180

Zero load reading = -2.8

Actual applied load = 180 - (- 2.8) = **182.8 tons**.

4.4 Measuring Procedure

4.4.1 PURPOSE

It was necessary to establish a measuring procedure by which all measurements would be taken. It was noted during Test 1 that the measuring procedure is of great importance and accurate results are essential to the project. The measuring equipment that is used at the S.A Mint is very sophisticated and most of the measurements that will be taken must be accurate within a few microns. With accurate measurements one can better evaluate the response of the material. Therefore the candidate spent a lot of time familiarizing himself with the measuring equipment and the environment.

The linear height meter (LHM) is the most sensitive piece of equipment will be used. It is capable of giving a measurement accurate to 1 micron. This instrument will be used extensively during the project and it was therefore necessary for the candidate to do a qualification on the height meter. The calibration certificates were obtained for all the measuring equipment that was used during the project. The linear height meter is shown in Figure 4.5.

FIGURE 4.5 Linear Height Meter

The temperature and humidity of the metrology room where all the measurements are taken are controlled at all times. The temperature is held at a constant 20° ± 1°C. The humidity is held at 50 %. A Lambrecht Hydrograph controls the temperature and humidity of the room. The hydrograph is shown in Figure 4.6. A control chart for the hydrograph is shown in Appendix E. Before any measurements are taken the hydrograph is checked to ensure that the room is at the right temperature and humidity.

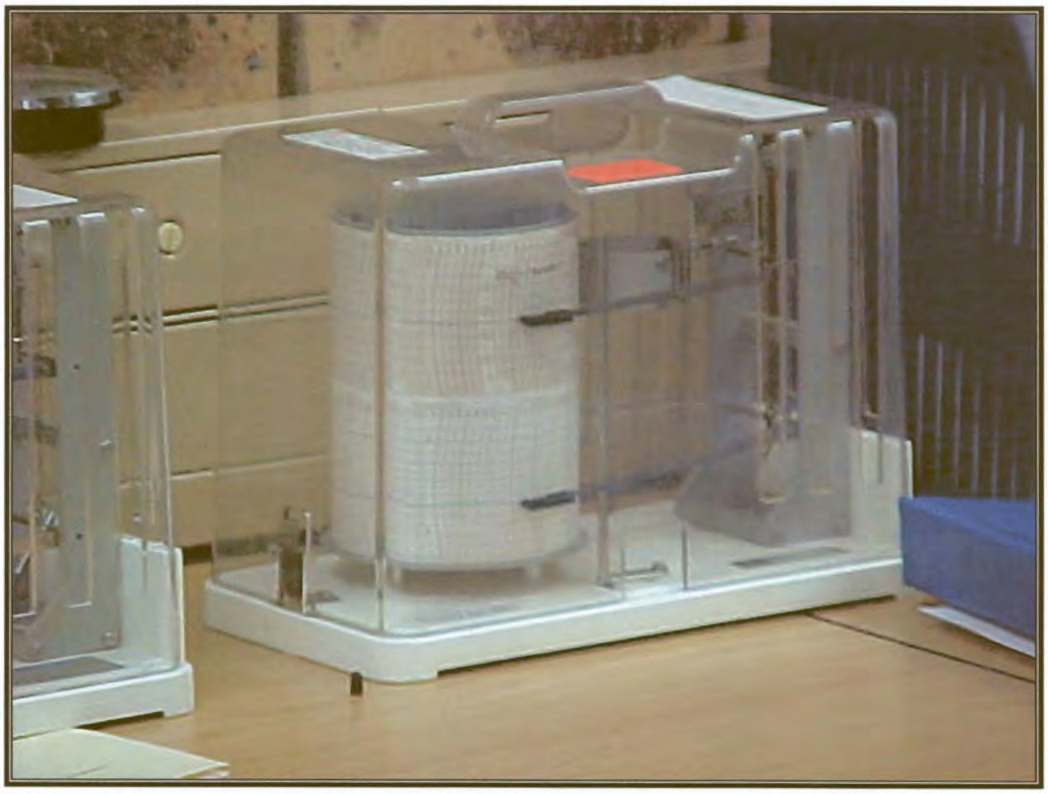


FIGURE 4.6 Hydrograph measuring temperature and humidity.

4.4.2 PROCEDURE

The procedure that was followed during the qualification will now be discussed.

1. Ensure that all equipment is clean, oil free and stabilized at 20°C. This includes the measuring table, the LHM and the object that will be measured. Prevent contact with measuring surface of the object.

2. For the qualification a 50 mm steel slip gauge was measured.
3. Calibrate LHM.
4. Prepare to take measurements. Slide object on measuring table to remove air between the object and the measuring table.
5. Zero stylus on the measuring table surface.
6. Cover digital readout so that the candidate cannot observe the readings.
7. Take 5 consecutive measurements.
8. Repeat twice.
9. Switch LHM off and stand up.
10. Repeat steps 3 to 9, five times.

4.4.3 RESULTS

The results of the qualification are given in Appendix E. The results obtained were very encouraging. The average range that was achieved is 1.4 microns. The measurements lie in a very narrow band close to the actual size of the slip gauge. The total test accuracy is smaller than a micron. It is evident that the candidate is conversant with the equipment and the process. Reliable results can be guaranteed.

4.4.4 CONCLUSION

A chart was developed according to which all dies will be measured. This chart indicates the positions where the die should be measured to obtain sufficient information about the die. The chart is shown below in Figure 4.7

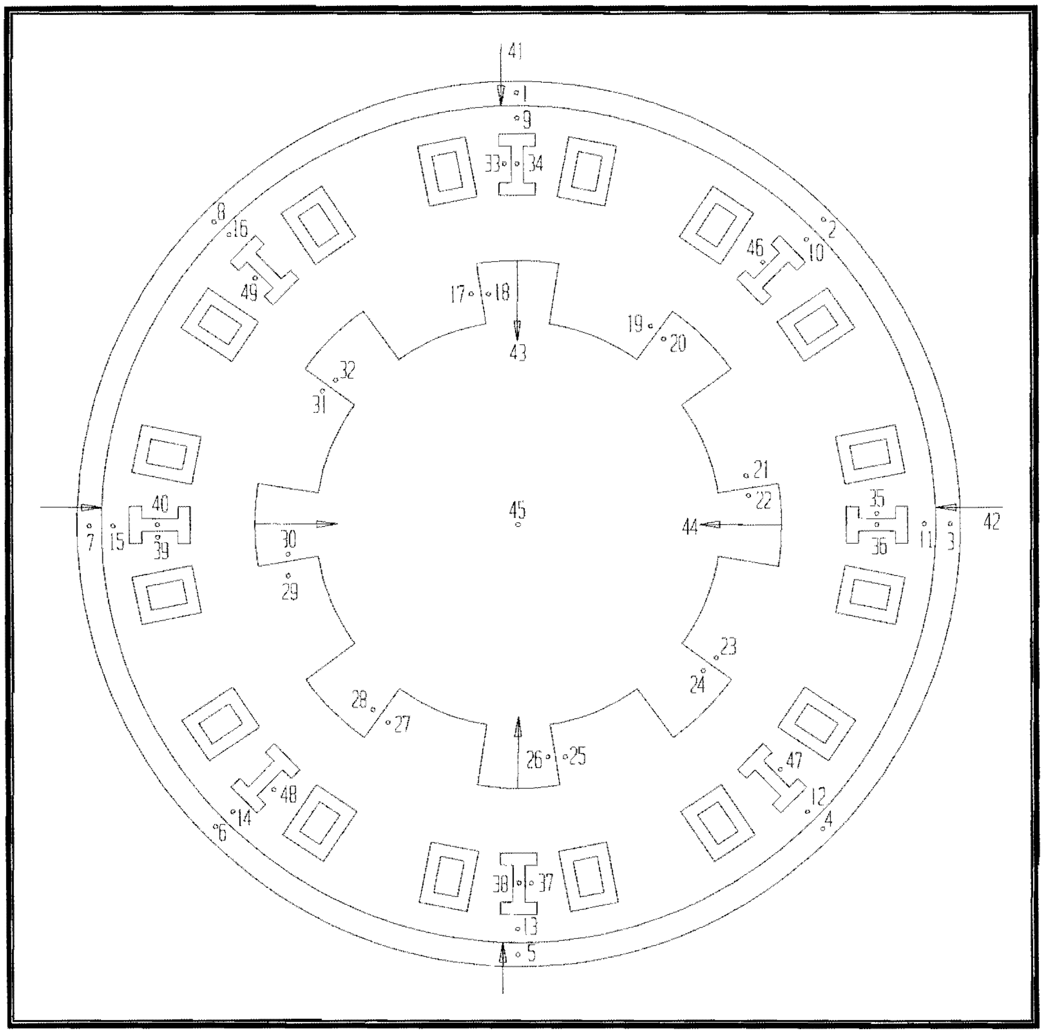


FIGURE 4.7 Die Measuring Chart

This chart will be used in future when measuring a die. Every die that is made for a test is given a clear reference point. This reference point indicates where to start the measuring procedure. The dies are placed in the metrology room to stabilize, 4 hours prior to the measuring procedure.

A Tolerance was calculated for the accuracy with which a measurement can be taken. The surface of the dies is uneven and the exact location of the measuring points is difficult to determine. Therefore, three measurements will be taken on each location and an average will be calculated. Considering all factors the accuracy tolerance of all the measurements taken on the LHM will be ± 4 microns.

4.5 Heat Treatment

All the dies and punches are heat treated before they are used as a hob in the hobbing and coining operations. The dies and punches are hardened to increase the strength of the material. An increase in hardness implies an increase in the yield strength of the material but also a decrease in the ductility of the material.

A sophisticated heat treatment furnace is used at the S.A Mint. The furnace temperature and holding times are controlled electronically to ensure accurate repeatability of the process. The material is heat treated in a nitrogen rich atmosphere to reduce the diffusion of carbon to the surface of the material. The furnace is shown in Figure 4.8(a). The material is heated slowly to above the austenitic temperature (970°C). This is done in three steps. The material is allowed to stabilize at each temperature before it is heated further, this ensures homogenous transformation to the austenite condition. The material is held at 970°C for 60 minutes before it is air quenched in an inert gas atmosphere using nitrogen. The nitrogen enters the back of the furnace, it is circulated through the furnace and exits at the top of the furnace.

Air quenching provides higher dimensional stability of the material during cooling and reduces the risk of cracking the dies. This is partly due to the reduction in thermal stresses that are induced on the die during cooling. The material is air quenched to produce a martensite structure. The martensite microstructure is extremely hard and the strength increases. The material also becomes more brittle. The quenching rate controls the hardness of the material. A faster quenching rate produces a harder material. This is mainly due to the increase in dislocation density of the martensite structure.

After the material has been cooled to room temperature it is tempered to make it softer and more ductile. This is done at a temperature below the eutectoid transformation temperature. During tempering the dislocation density is reduced and the material becomes softer. The final hardness of the material is dependent on the temper temperature. The hardness is specified before heat treatment and the temper temperature is then adjusted accordingly. The material specification in Appendix A shows a graph of hardness vs. temper temperature.

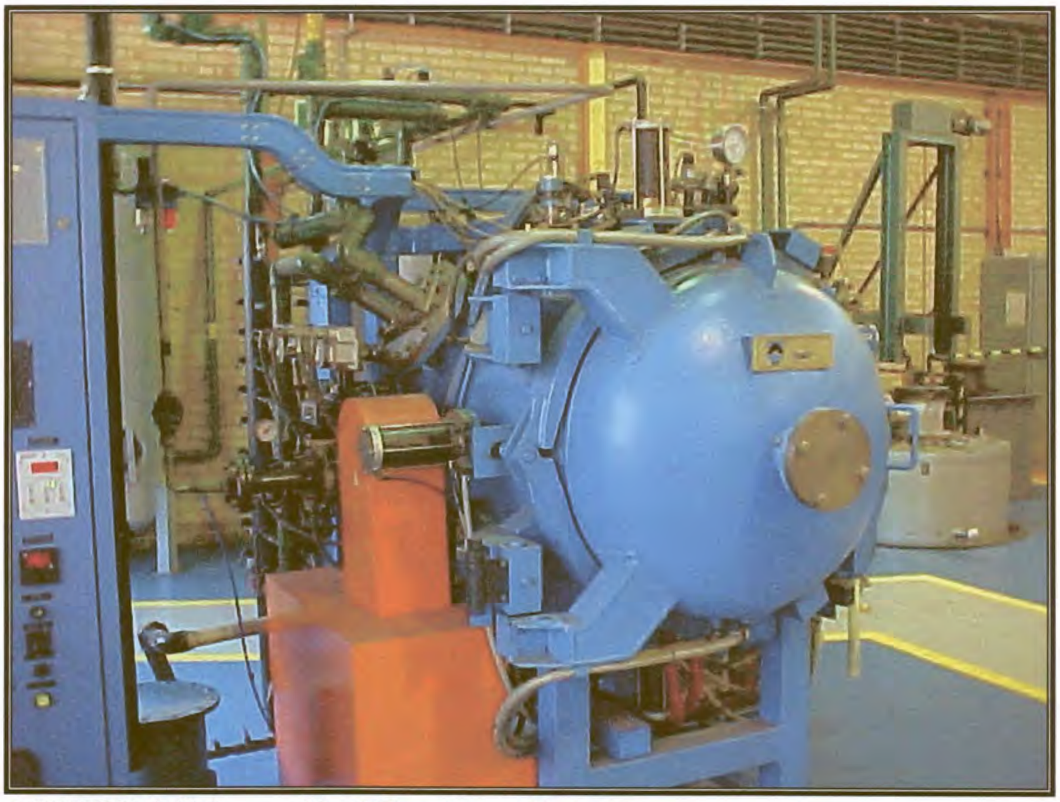


FIGURE 4.8(a) Heat Treatment Furnace

The details of a typical heat treatment process are shown below and are presented graphically in Figure 4.8(b). The effects of the heat treatment process on the punches and dies will be discussed during the development tests.

The Heat treatment process:

Hardening:

Heat:	20°C → 650 °C	Time: 65 min
Constant:	650°C	Time: 30 min
Heat:	650°C → 850°C	Time: 20 min
Constant:	850°C	Time: 30 min
Heat:	850°C → 970°C	Time: 18 min
Constant:	970°C	Time: 60 min
Quench:	970°C → 20°C	Time: 30 min

Tempering:

Heat:	20°C → 240°C	Time: 40 min
Constant:	240°C	Time: 120 min
Quench:	240°C → 20°C	Time: 30 min

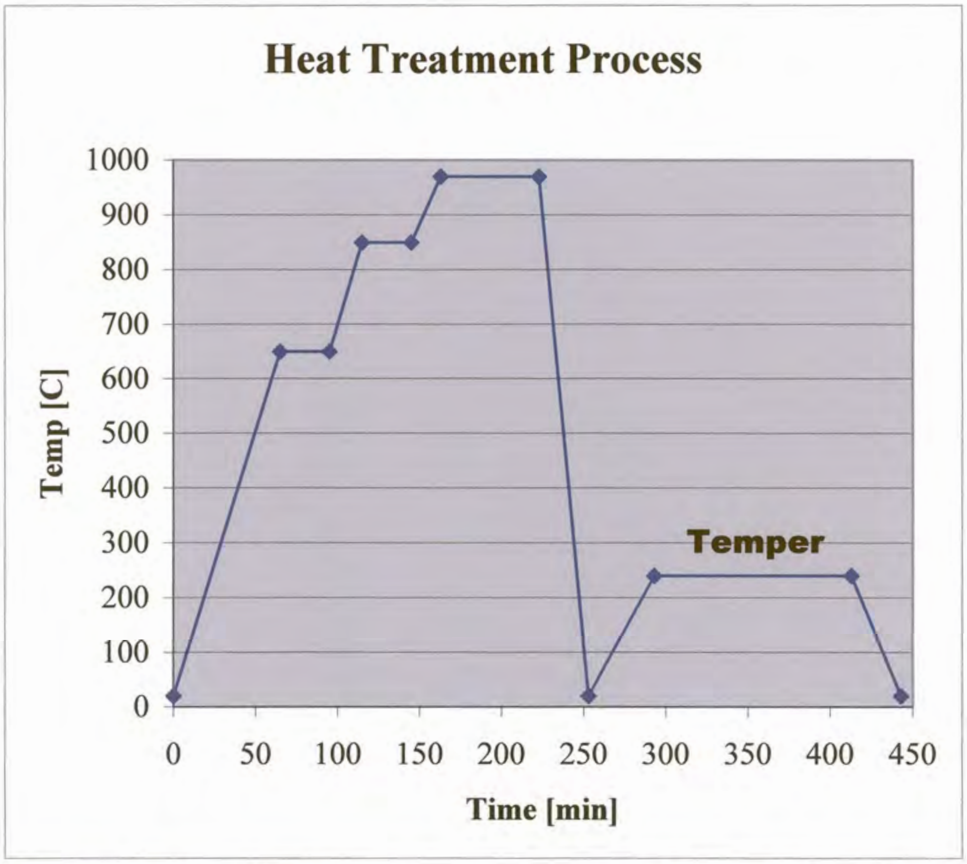


FIGURE 4.8(b) Temperature-time diagram of Heat Treatment process.

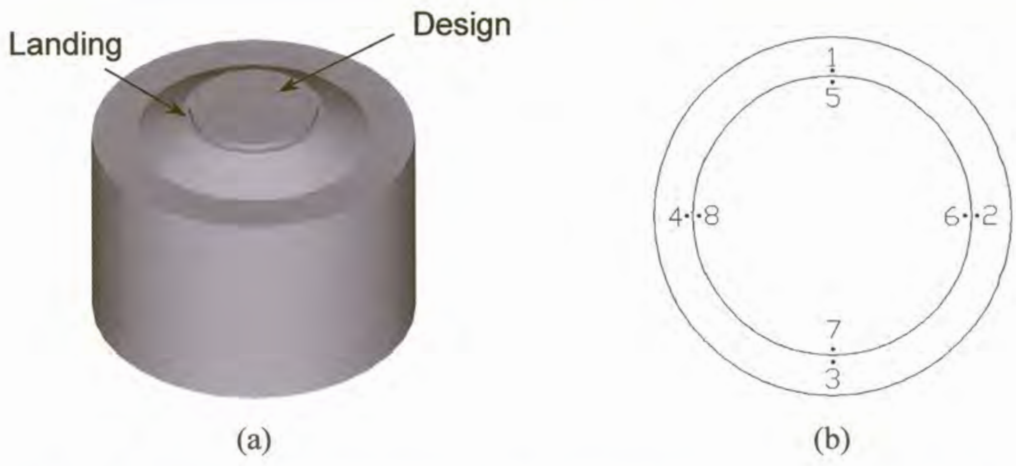
4.6 Test 2: Heat Treatment

4.6.1 PURPOSE

The purpose of the test was to quantify the shape change of the dies due to the heat treatment process. It was seen in Test 1 that the dies experience a shape change during heat treatment. Test 2 will concentrate on the effect of heat treatment alone, no plastic deformation will be induced on the dies. The shape change during heat treatment of a die, which has experienced plastic deformation, will be tested at a later stage. Since no plastic deformation will be induced on the dies, any shape change that occurs is entirely due to the phase transformation of the microstructure during heat treatment.

4.6.2 PROCEDURE

Two dies were made for the test, using Thyrodur 2363 billets with a diameter of 50 mm. The dies were turned on a lathe at a high speed to improve the surface finish. Liberal use was made of coolant to prevent the dies from work hardening. A landing was cut into the dies, 170 microns deep and 1mm wide (See Figure. 4.9). This was done to observe the relative stability of different planes under heat treatment. The dimensional stability of the landing relative to the design surface was also measured. Figure 4.9 (a) shows a computer model of the dies that were used for Test 2. Figure 4.9 (b) shows the measuring points on the dies. The dies were measured at four points on the circumference of the landing and four points on the design. The measurements were taken from the base of the design using the Linear Height Meter. After the two dies were measured they were sent for heat treatment to be hardened to a hardness of 60 HR_c. A hardness test was done on the two dies and the values were documented.



(a) (b)

FIGURE 4.9 (a) Computer model of Test 2 dies. (b) Layout of measuring points.

4.6.3 RESULTS

The hardness of the dies was measured at three randomly chosen points on the circumference of the die and an average was calculated. The Leco 2100 Hardness Tester was used for the hardness tests. The hardness of the dies is 59.3 and 59.8 HR_c respectively. The dies were once again measured and the sets of results were compared. The results are shown in the Table 4.4 and graphically in Figures 4.10 to 4.13. The results are accurate within a tolerance of ±4 microns. The measurement tolerance is also shown on the Figures.

The landing depth, i.e. the difference between the design height and the landing height was calculated because the landing depth is the size that will affect the coining process. This is the distance the material must flow during the coining or hobbing processes to fill the landing recess. It is evident that the stability of different planes relative to each other is very important. The results of the landing depth are shown in Table 4.5 and graphically in Figures 4.14 and 4.15.

Die Measurements

* All measurements are in millimeters

Reference Points	Die No. (Soft)	
	1	*2*
1	37.815	36.600
2	37.815	36.600
3	37.819	36.600
4	37.817	36.601
5	37.985	36.772
6	37.986	36.771
7	37.987	36.772
8	37.982	36.771

Reference Points	Die No. (Hardened)	
	1	*2*
1	37.828	36.616
2	37.827	36.623
3	37.832	36.626
4	37.830	36.622
5	38.001	36.789
6	37.998	36.795
7	37.999	36.798
8	38.000	36.794

TABLE 4.4 Die measurements in the soft and hardened state

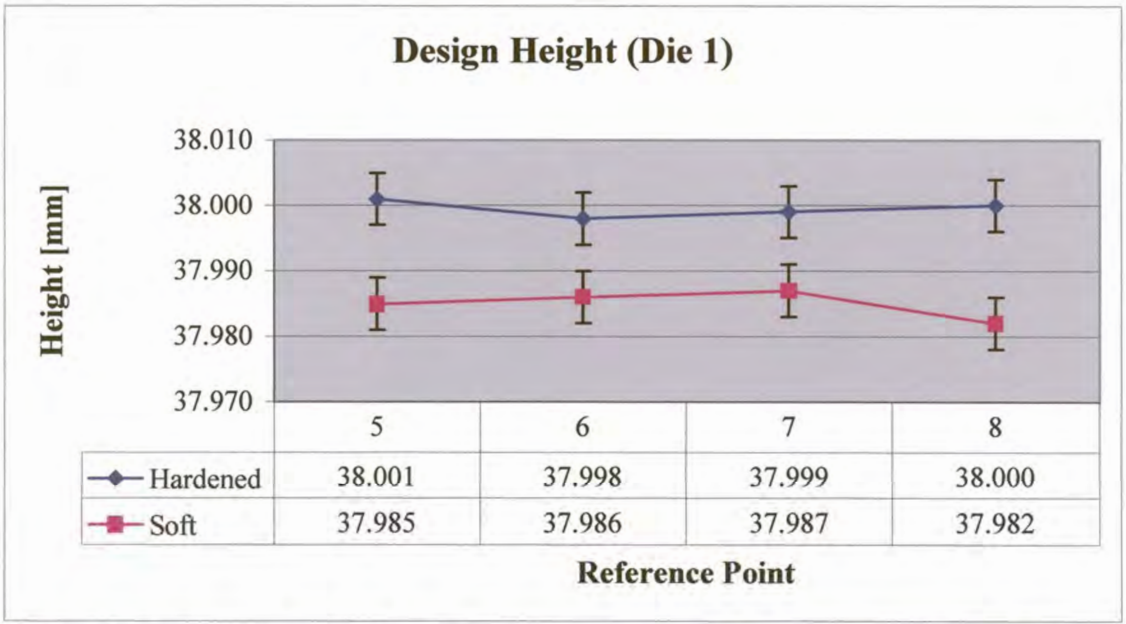
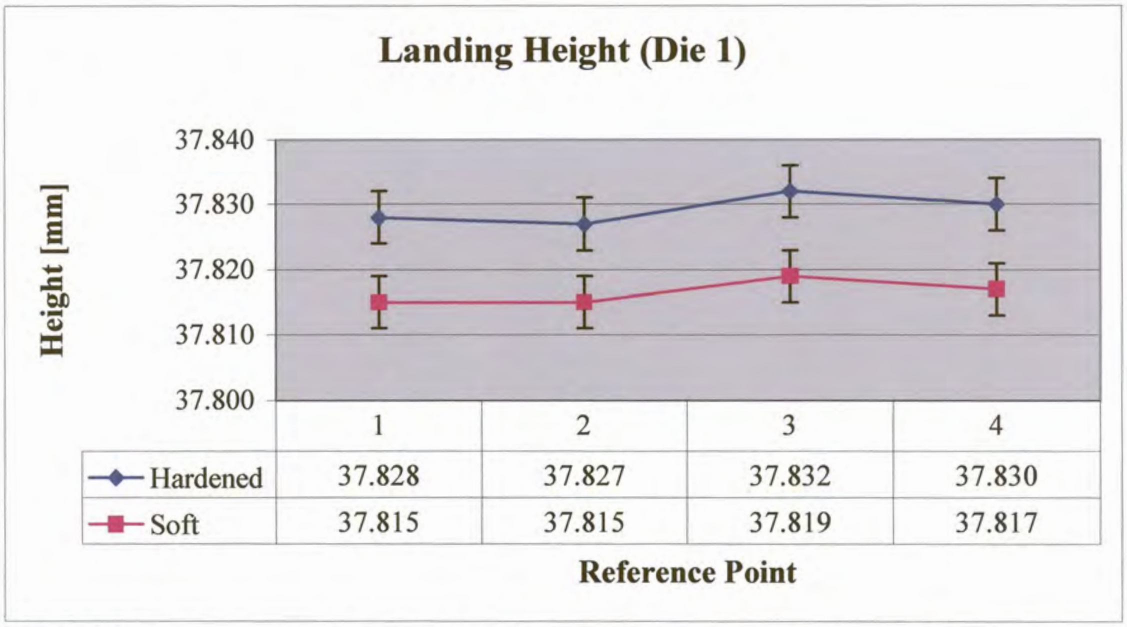
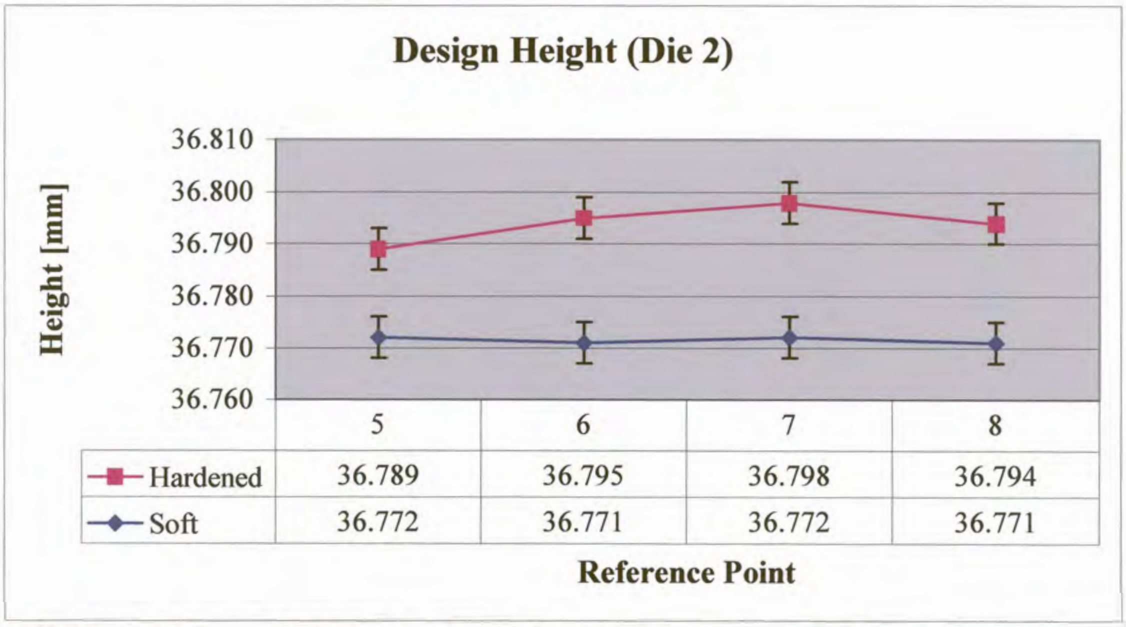


FIGURE 4.10 **Absolute height of the design surface before and after heat treatment (Die 1).**



	1	2	3	4
◆ Hardened	37.828	37.827	37.832	37.830
■ Soft	37.815	37.815	37.819	37.817

FIGURE 4.11 **Absolute height of the landing surface before and after heat treatment (Die 1).**



	5	6	7	8
■ Hardened	36.789	36.795	36.798	36.794
◆ Soft	36.772	36.771	36.772	36.771

FIGURE 4.12 **Absolute height of the design surface before and after heat treatment (Die 2).**

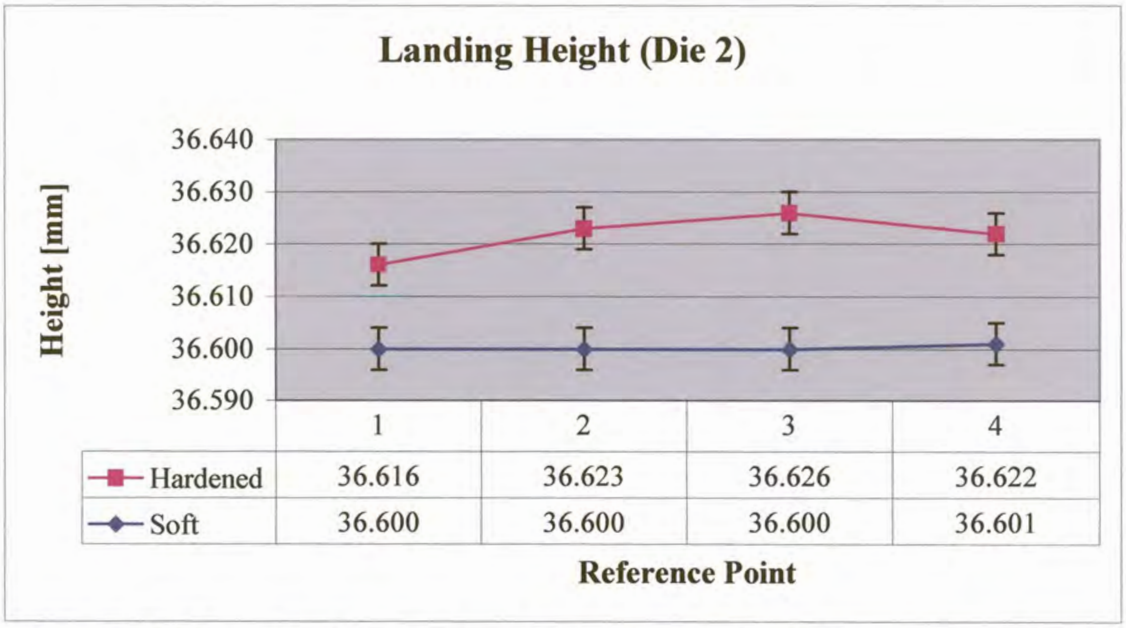


FIGURE 4.13 **Absolute height of the landing surface before and after heat treatment (Die 2).**

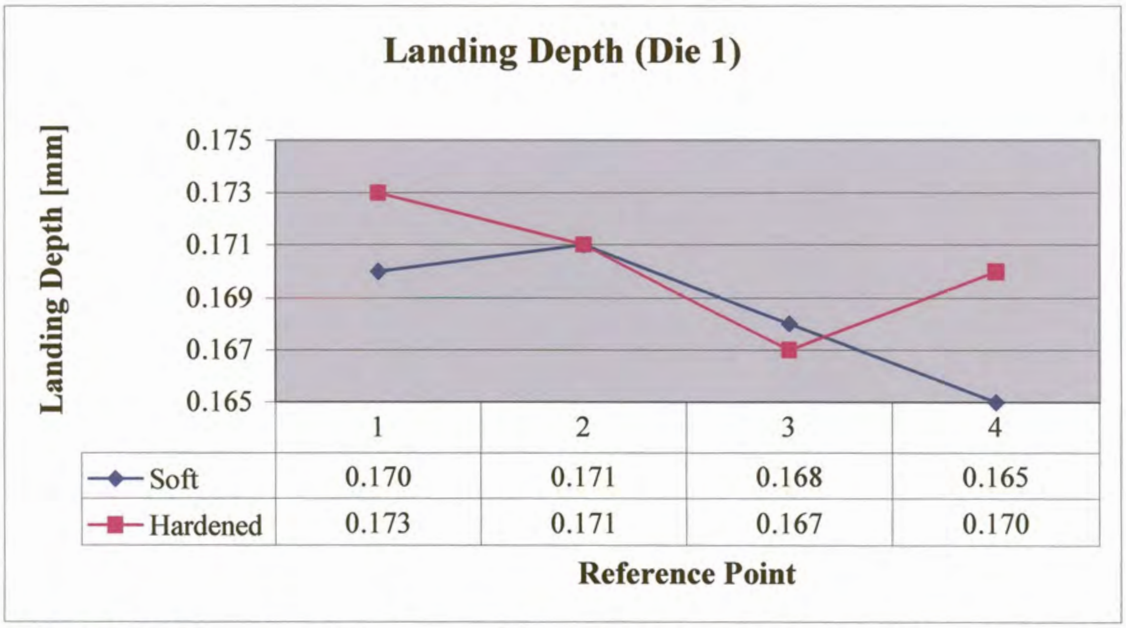
Landing Depth

Reference Points	Die 1 Soft	Die 1 Hardened	Die 2 Soft	Die 2 Hardened
1	0.170	0.173	0.172	0.173
2	0.171	0.171	0.171	0.172
3	0.168	0.167	0.172	0.172
4	0.165	0.170	0.170	0.172

* All measurements in mm

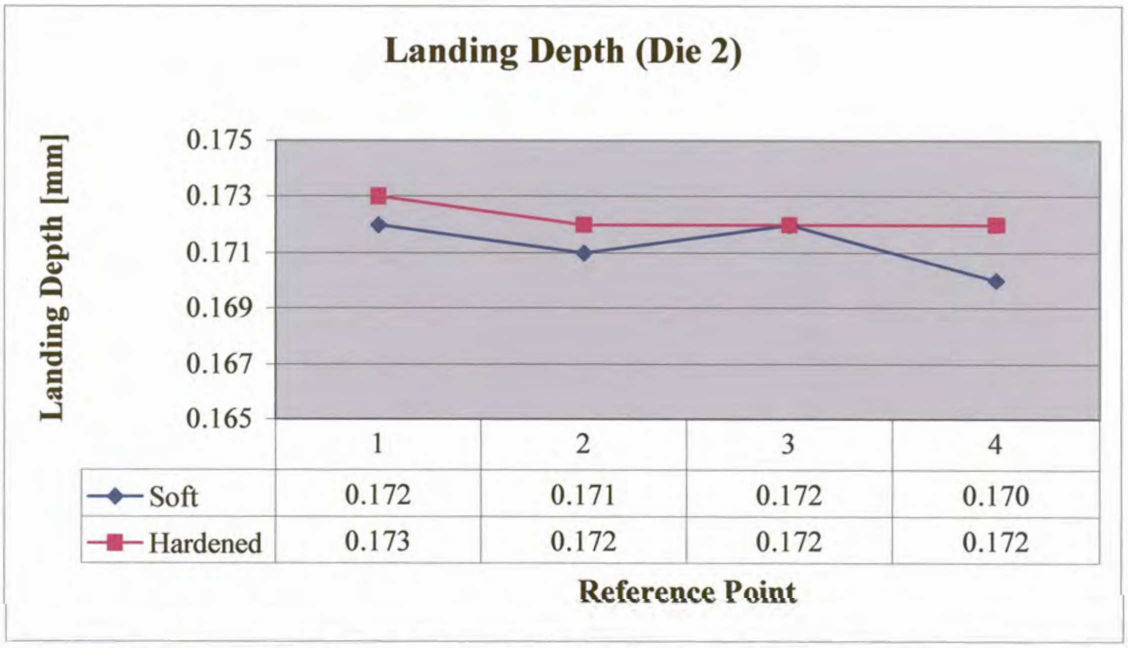
TABLE 4.5 **Landing depth at reference points 1 to 4**

Figure 4.14 and 4.15 were plotted using the data in Table 4.5. A tolerance of ± 4 microns is also applicable to the results of the landing depth. The tolerance was not plotted on the graphs since all the data points lie well within the tolerance.



	1	2	3	4
◆ Soft	0.170	0.171	0.168	0.165
■ Hardened	0.173	0.171	0.167	0.170

FIGURE 4.14 **Landing depth of die, before and after heat treatment (Die 1).**



	1	2	3	4
◆ Soft	0.172	0.171	0.172	0.170
■ Hardened	0.173	0.172	0.172	0.172

FIGURE 4.15 **Landing depth of die, before and after heat treatment (Die 2).**

From Figure 4.10 to 4.13 it can be seen that the dies expand a certain amount during heat treatment. Die no.1 expanded with an average of about 14 microns while Die no.2 expanded with an average of about 22 microns. A certain amount of shape change is expected due to the transformation of the microstructure. It is important to note that the landing depth (Figure 4.14 and 4.15) did not change significantly during the heat treatment process.

4.6.4 CONCLUSION

It is desired that the landing depth remain constant. Although a small variance in depth of a few microns is expected due to the heat treatment process it should be noted that the small differences in depth are within the accuracy tolerance of the measuring procedure.

The shape change of the dies was relatively stable but more data is needed before a conclusion can be reached. It was decided that Test 3 would be similar to Test 2.

4.7 Test 3: Heat Treatment

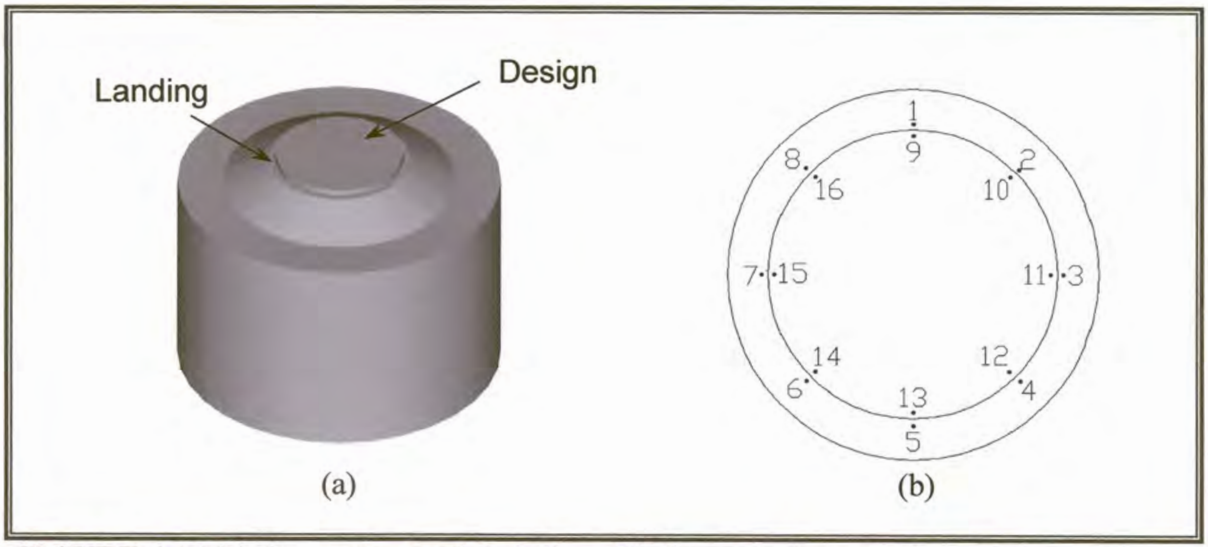
4.7.1 PURPOSE

The objective of Test 3 was the same as for Test 2, i.e. to determine the effect of heat treatment on the dimensional stability of the dies, without inducing plastic deformation on the dies prior to heat treatment. The same procedure was followed as for Test 2, except for a few minor changes that were made to the test protocol. These changes will be discussed shortly.

It was seen from the results of Test 2 that the dies experience a certain amount of shape change during the heat treatment process. It would be instructive to obtain more test data about this deformation. Once more data has been collected, a conclusion can be reached about the shape change of the dies during the heat treatment process.

4.7.2 PROCEDURE

Three dies were made for Test 3. The dies were turned on a lathe, with a landing but without a design. The landing is about 170 microns deep and 1 mm wide (See Figure 4.16(a)). Die 3.3 was also offset with about 25 microns to see if the skew plane would be maintained through the heat treatment process. The measuring points were increased from 8 to 16 so that more data can be obtained during the test. The layout of the measuring points is shown in Figure 4.16 (b). In addition to the 16 measuring points on the surface of the die, the diameter of the dies was also measured. The diameter was measured at the top, in the middle and at the bottom of the dies. Two measurements were taken perpendicular to each other at each of the three locations. Figure 4.17 shows the diametrical measurement locations. A reference mark was made on the dies to ensure consistency and repeatability when the measurements are taken. Diametrical measurements were taken with a digital micrometer. The three dies were made and then measured. After the measurements were taken the dies were sent for heat treatment, to be heat-treated to a hardness of 60 HR_c. A hardness test was done on the dies after which they were measured a second time.



(a) (b)

FIGURE 4.16 (a) Computer model of dies. (b) Layout of measuring points

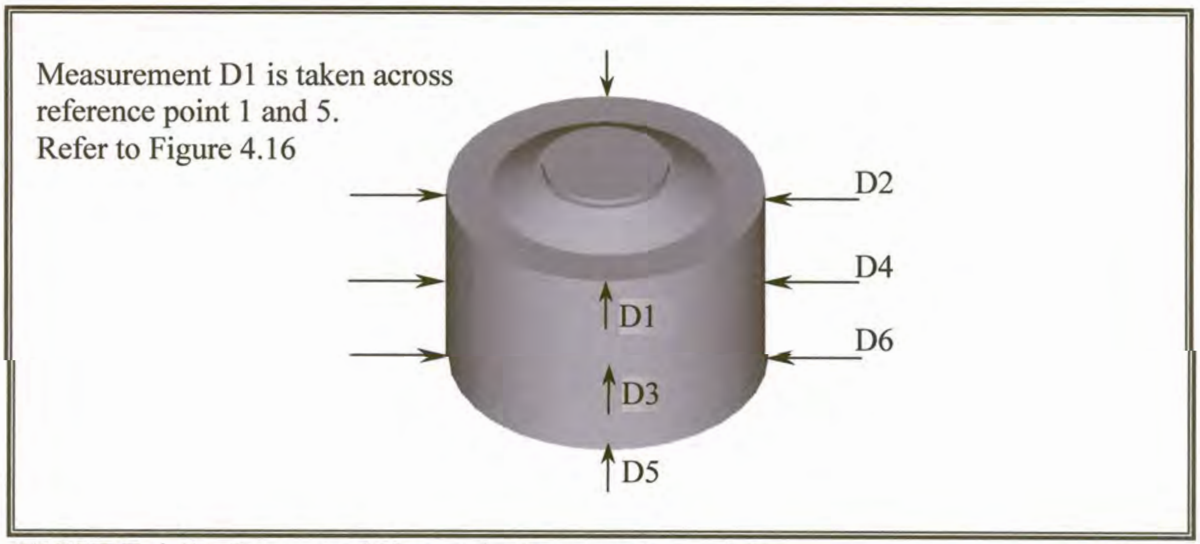

Measurement D1 is taken across reference point 1 and 5. Refer to Figure 4.16

FIGURE 4.17 Layout of diametrical measuring points

4.7.3 RESULTS

The results of the hardness test are shown in Table 4.6. The hardness of the dies is higher than expected. The difference in hardness can be due to non-uniform cooling rates experienced by the dies or due to incorrect temper temperatures. During the production process the hardness should be checked to ensure that the hardness is close to the required value. These factors will be discussed further in Section 4.8. The results of the diametrical measurements are shown in Table 4.7 and the results of the surface measurements are shown in Table 4.8.

Hardness Test.			
Die No.	**3.1**	**3.2**	**3.3**
Hardness [HR_c]	61.8	60.7	61.9

TABLE 4.6 Hardness results of dies

Diametrical mesurements

* All measurements are in millimeters

Die No. (Soft)

	Die 3.1	*Die 3.2*	*Die 3.3*
D1	50.028	50.018	49.909
D2	50.028	50.018	49.907
D3	50.025	49.995	49.916
D4	50.025	49.995	49.916
D5	50.019	49.984	50.008
D6	50.021	49.986	50.009

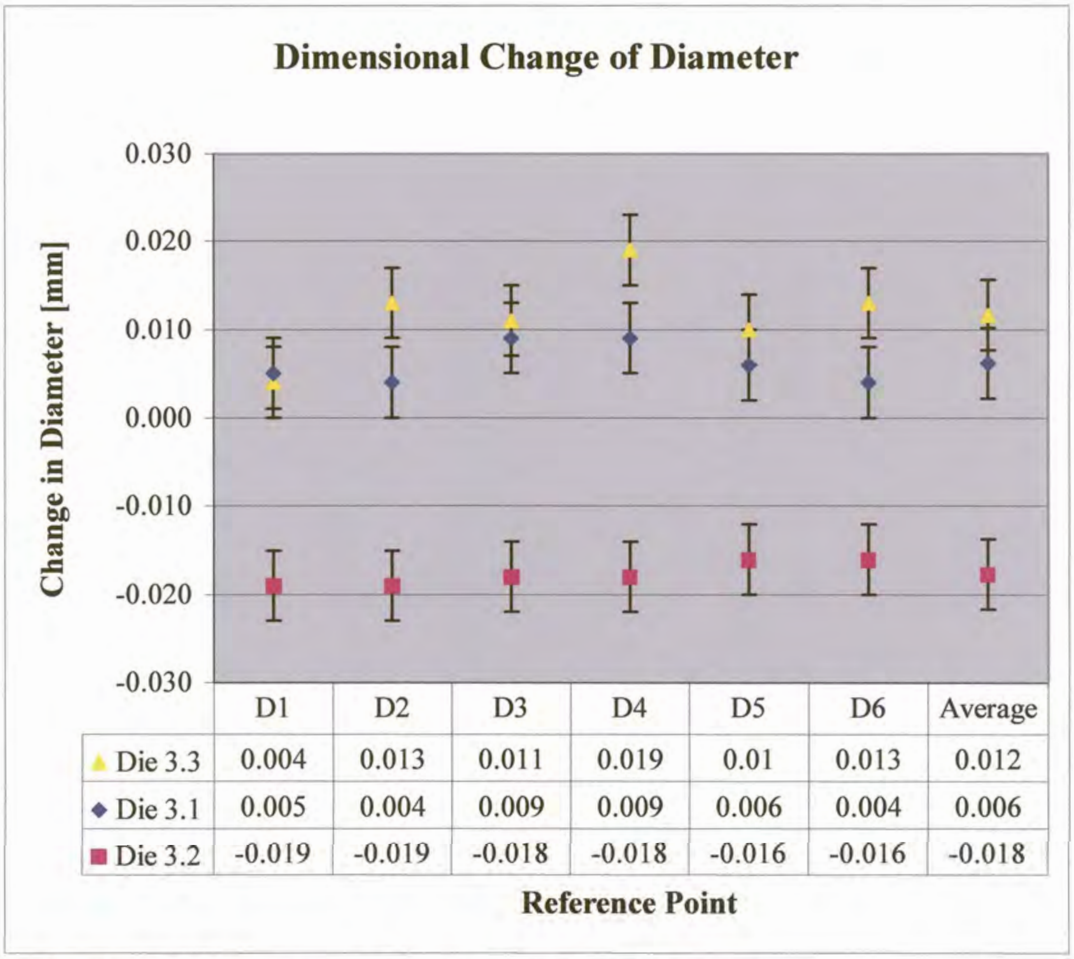
Die No. (Hardened)

	Die 3.1	*Die 3.2*	*Die 3.3*
D1	50.033	49.999	49.913
D2	50.032	49.999	49.920
D3	50.034	49.977	49.927
D4	50.034	49.977	49.935
D5	50.025	49.968	50.018
D6	50.025	49.970	50.022

TABLE 4.7 Diameter measurements of the dies in the soft and hardened state.

The exact diameter of the dies that were used for the test is of little importance since we are interested in the relative shape change of the die. Therefore only the differences in diameter will be plotted. Example for Die 3.1: $D1_{Hard} - D1_{Soft} = 0.005$ mm.

The results are shown in Figure 4.18. The average change in diameter was also calculated for each die and plotted on the graph. The measurement accuracy tolerance of ± 4 microns is shown on the graph.

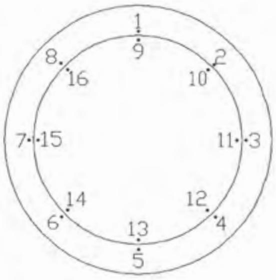


	D1	D2	D3	D4	D5	D6	Average
▲ Die 3.3	0.004	0.013	0.011	0.019	0.01	0.013	0.012
◆ Die 3.1	0.005	0.004	0.009	0.009	0.006	0.004	0.006
■ Die 3.2	-0.019	-0.019	-0.018	-0.018	-0.016	-0.016	-0.018

FIGURE 4.18 Change in diameter after heat treatment.

Die Surface Measurements

* All measurements are in millimeters



Die No. (Soft)

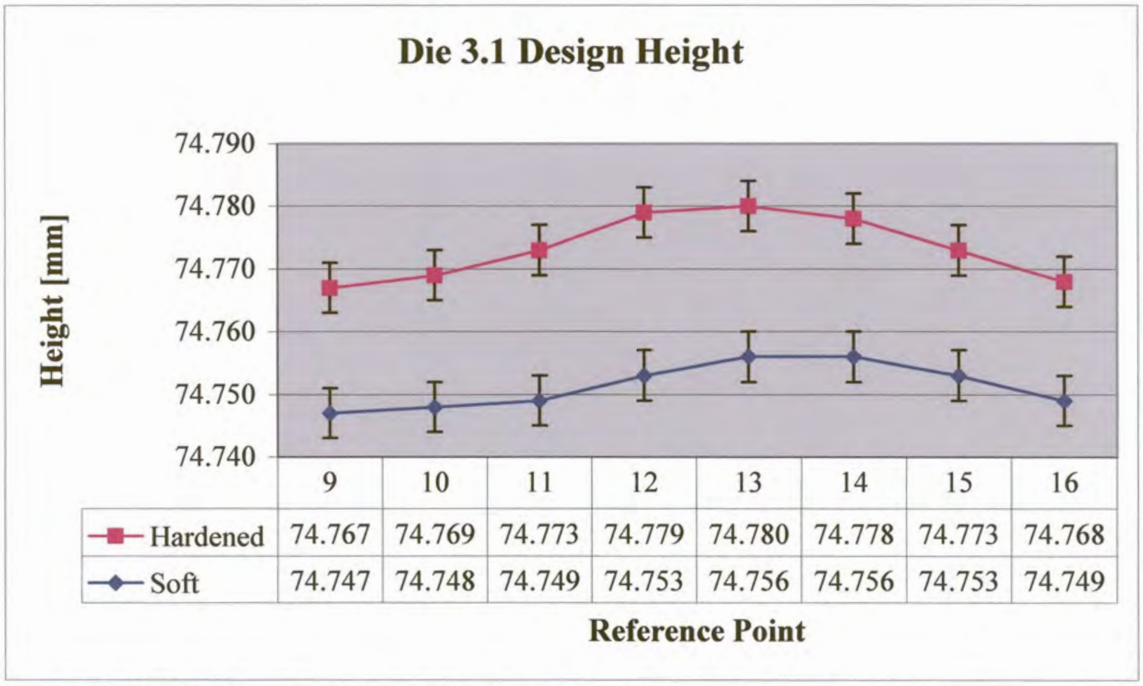
Reference points	*3.1*	*3.2*	*3.3*
1	74.569	74.452	73.663
2	74.569	74.452	73.658
3	74.572	74.452	73.647
4	74.572	74.453	73.637
5	74.574	74.453	73.633
6	74.573	74.453	73.639
7	74.573	74.451	73.649
8	74.570	74.451	73.660
9	74.747	74.631	73.814
10	74.748	74.631	73.810
11	74.749	74.632	73.802
12	74.753	74.633	73.792
13	74.756	74.633	73.790
14	74.756	74.633	73.796
15	74.753	74.634	73.804
16	74.749	74.633	73.812

Die No. (Hardened)

Reference points	*3.1*	*3.2*	*3.3*
1	74.591	74.440	73.692
2	74.592	74.441	73.686
3	74.593	74.439	73.675
4	74.596	74.440	73.667
5	74.601	74.439	73.662
6	74.596	74.441	73.669
7	74.593	74.441	73.680
8	74.591	74.441	73.689
9	74.767	74.621	73.842
10	74.769	74.620	73.839
11	74.773	74.620	73.830
12	74.779	74.620	73.821
13	74.780	74.621	73.819
14	74.778	74.622	73.826
15	74.773	74.622	73.835
16	74.768	74.623	73.841

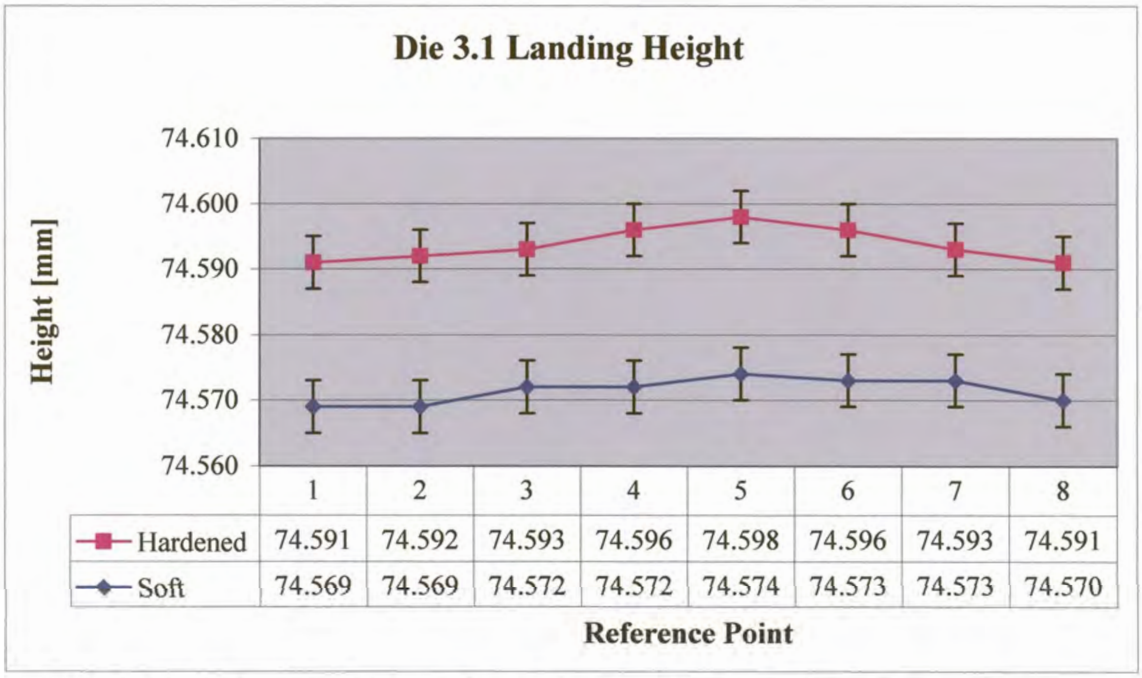
TABLE 4.8 Die measurements of landing and design surface height.

The results of Table 4.8 were processed and plotted in Figures 4.19 to 4.24. The measurement accuracy tolerance is shown on all the graphs.



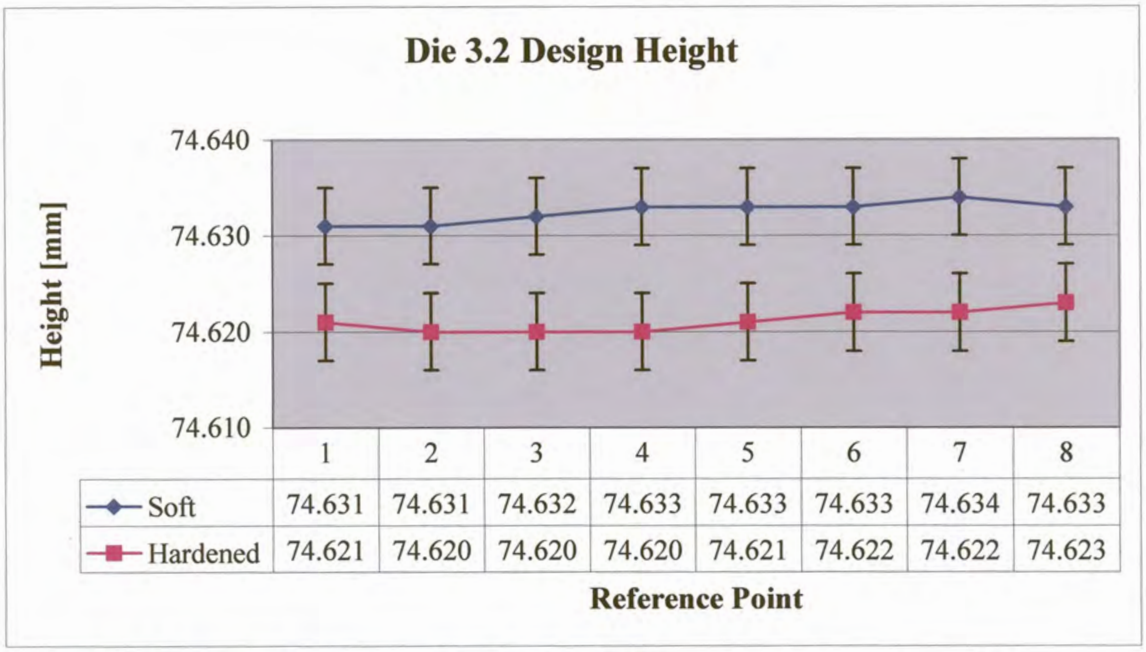
	9	10	11	12	13	14	15	16
■ Hardened	74.767	74.769	74.773	74.779	74.780	74.778	74.773	74.768
◆ Soft	74.747	74.748	74.749	74.753	74.756	74.756	74.753	74.749

FIGURE 4.19 Design surface height, before and after heat treatment.



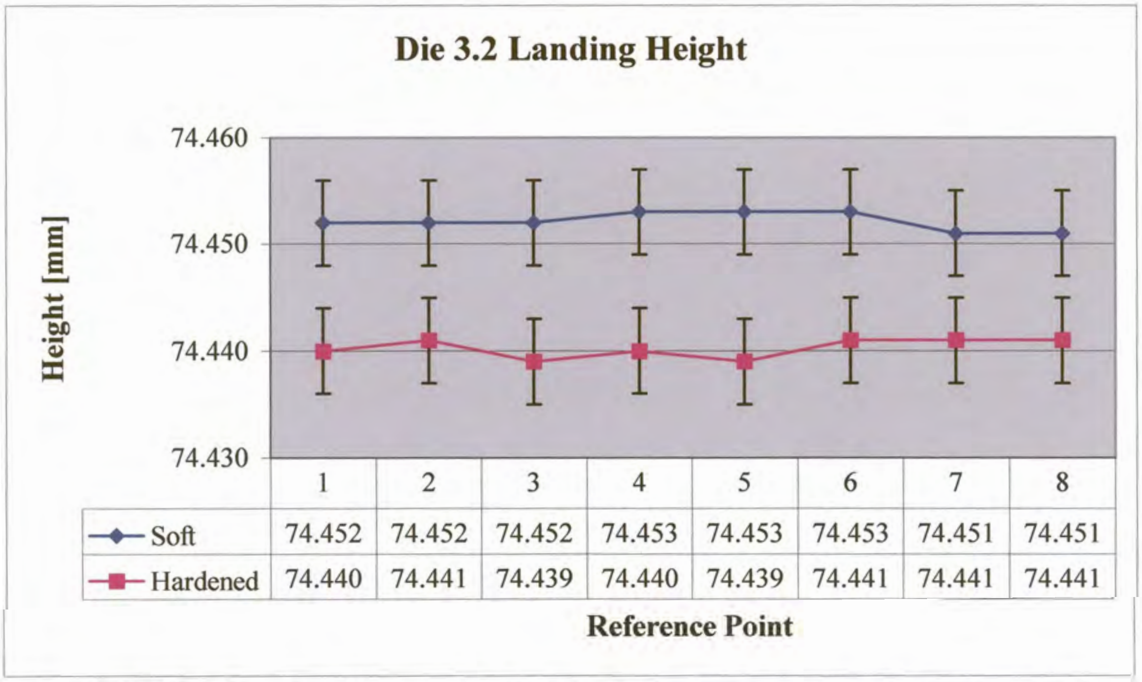
	1	2	3	4	5	6	7	8
■ Hardened	74.591	74.592	74.593	74.596	74.598	74.596	74.593	74.591
◆ Soft	74.569	74.569	74.572	74.572	74.574	74.573	74.573	74.570

FIGURE 4.20 Landing surface height, before and after heat treatment.



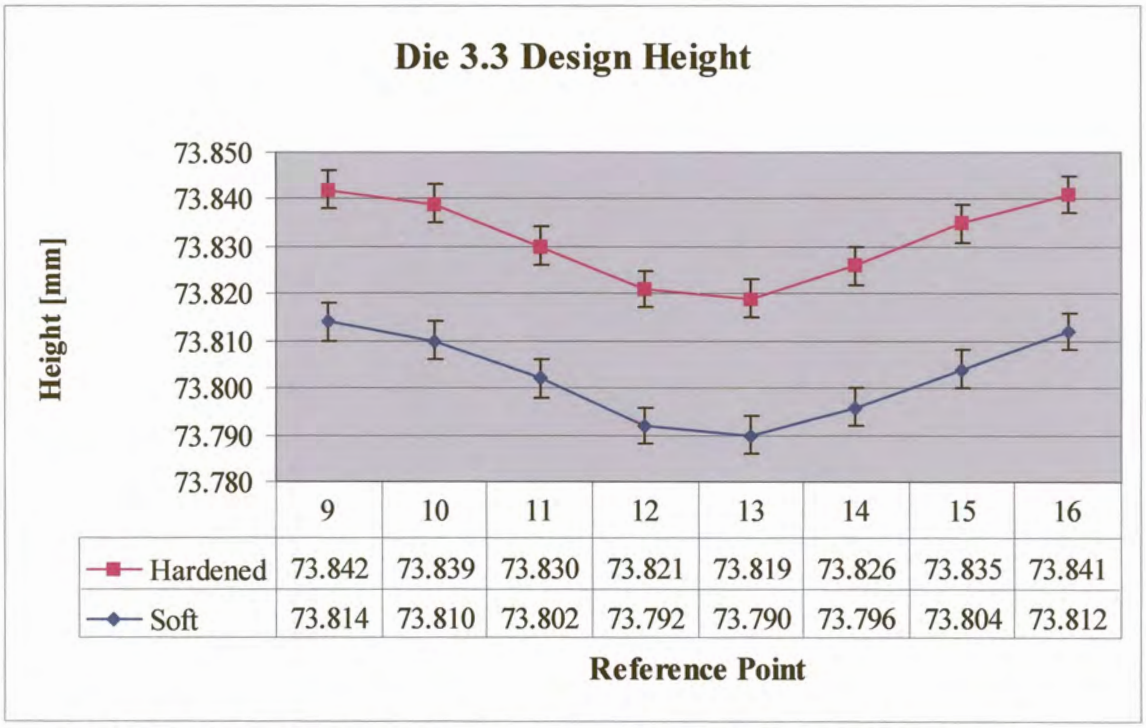
	1	2	3	4	5	6	7	8
◆ Soft	74.631	74.631	74.632	74.633	74.633	74.633	74.634	74.633
■ Hardened	74.621	74.620	74.620	74.620	74.621	74.622	74.622	74.623

FIGURE 4.21 Design surface height, before and after heat treatment.



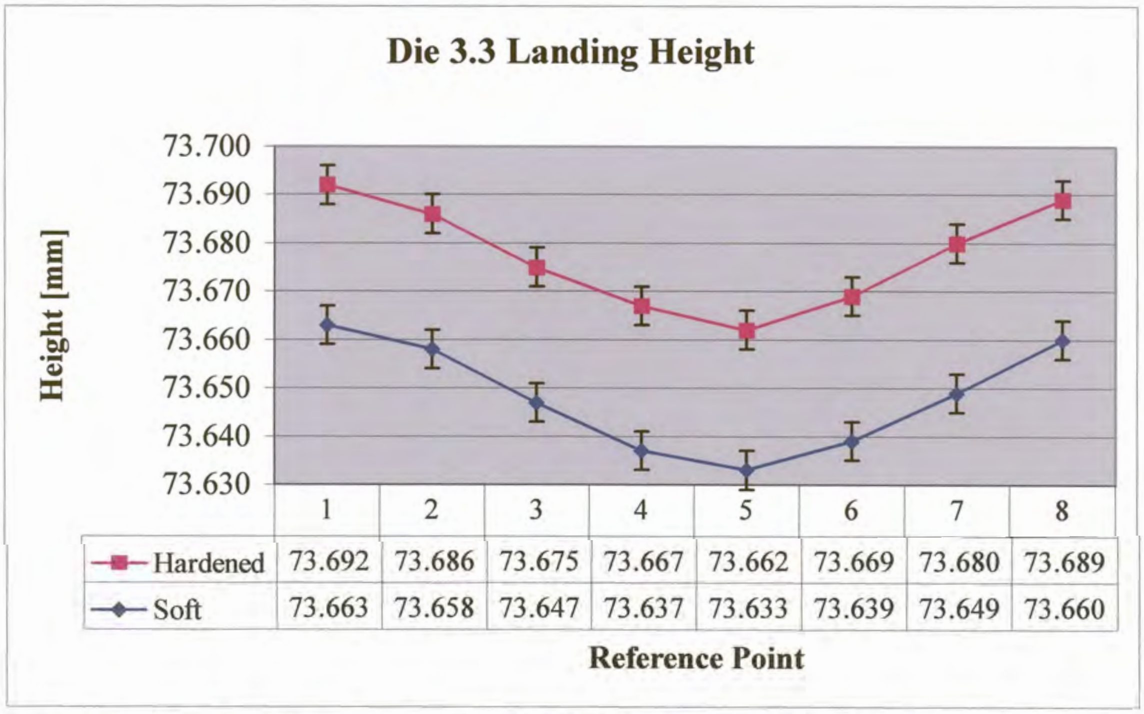
	1	2	3	4	5	6	7	8
◆ Soft	74.452	74.452	74.452	74.453	74.453	74.453	74.451	74.451
■ Hardened	74.440	74.441	74.439	74.440	74.439	74.441	74.441	74.441

FIGURE 4.22 Landing surface height, before and after heat treatment.



	9	10	11	12	13	14	15	16
Hardened	73.842	73.839	73.830	73.821	73.819	73.826	73.835	73.841
Soft	73.814	73.810	73.802	73.792	73.790	73.796	73.804	73.812

FIGURE 4.23 **Design surface height, before and after heat treatment.**



	1	2	3	4	5	6	7	8
Hardened	73.692	73.686	73.675	73.667	73.662	73.669	73.680	73.689
Soft	73.663	73.658	73.647	73.637	73.633	73.639	73.649	73.660

FIGURE 4.24 **Landing surface height, before and after heat treatment.**

Summary of results:

Die 3.1	Length:	+ 22 microns
	Diameter:	+ 6 microns
Die 3.2	Length:	- 12 microns
	Diameter:	- 18 microns
Die 3.3	Length:	+ 29 microns
	Diameter:	+ 12 microns

There are two main causes of dimensional change during heat treatment. The one is thermal stresses, which occur as a result of the contraction of the material during cooling. The other main cause is transformation stresses, which occur as a result of the martensite formation.

Thermal stresses occur because the outer layer of the object cools more quickly and contract. The inner, softer parts try to assume a spherical shape during this process. This is the shape to which they offer the least resistance during deformation. Therefore any body tries to assume the spherical shape during rapid cooling. The more drastic the cooling rate, the greater are the changes due to thermal contraction.

During the heat treatment process the steel is subject to various heating and cooling stages, during these stages the steel undergoes a series of structural transformations. Transformation stresses are created because the various structural phases possess different densities and hence differing values of specific volume.

Martensite has a greater specific volume than austenite therefore during cooling, the steel will experience a volumetric expansion due to the transformation of austenite to martensite. After cooling, the steel will contain a certain amount of retained austenite. If the retained austenite content is sufficiently high, a volumetric reduction will take place. The hardening temperature can control the amount of retained austenite in the steel. The volume of the object decreases with an increase in hardening temperature, this being due to the increased amount of retained austenite. The volume of the object decreases further during tempering when the martensite decomposes to form ferrite and cementite.

It is very difficult to calculate theoretical values for the shape change of tool steels during heat treatment. Theoretical calculations based on the specific volumes of the different structural phases are based on knowledge of the amount of each individual constituent present in the steel after hardening. These calculations also do not allow for dimensional changes due to thermal stresses or for the anisotropy of the steel. It is necessary to rely on empirical values obtain for different tool steels [1].

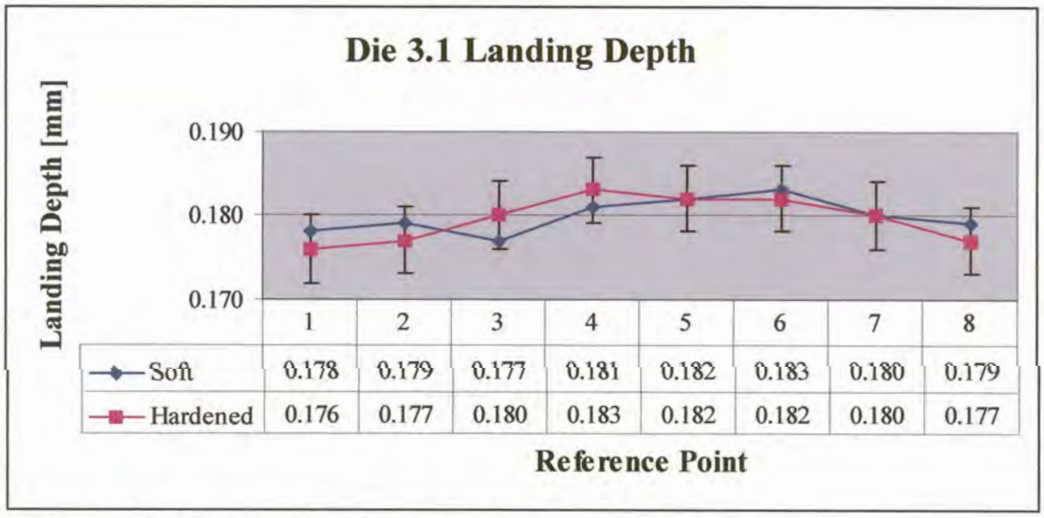
It was decided to calculate the percentage change in length and diameter of the dies to see if the deformation falls within typical dimensional change specifications given by manufacturers [2,3] for similar materials. The results are given in Table 4.9. The percentage change in length and diameter fall within typical specifications of manufacturers and therefore does not present a problem. It is however important to evaluate the relative stability of the surface planes as was discussed during Test 2.

% Dimensional Change

	Length	*Diameter*
Die 3.1	0.029	0.012
Die 3.2	-0.015	-0.035
Die 3.3	0.039	0.023

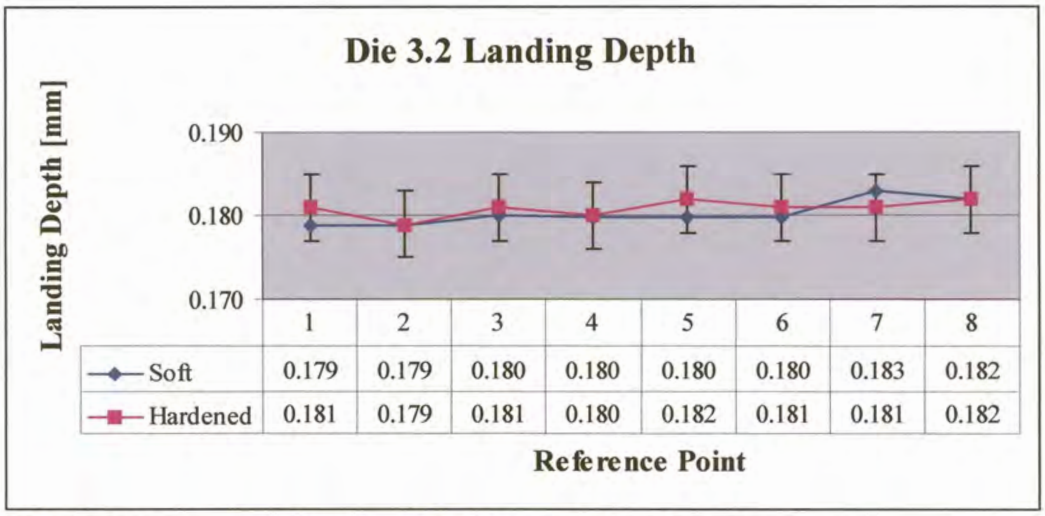
TABLE 4.9 Percentage dimensional change during heat treatment.

The landing depth was calculated before and after heat treatment and the results were plotted in Figures 4.25 to 4.27. It is evident that the landing depth remains close to constant and the differences seen in the graphs fall within the accuracy tolerance of the measuring procedure. This was also the case for Test 2 and one can therefore say that the relative dimensional stability of different planes is good. The last factor that will be considered is the relative stability of the design surface and the landing surface independently.



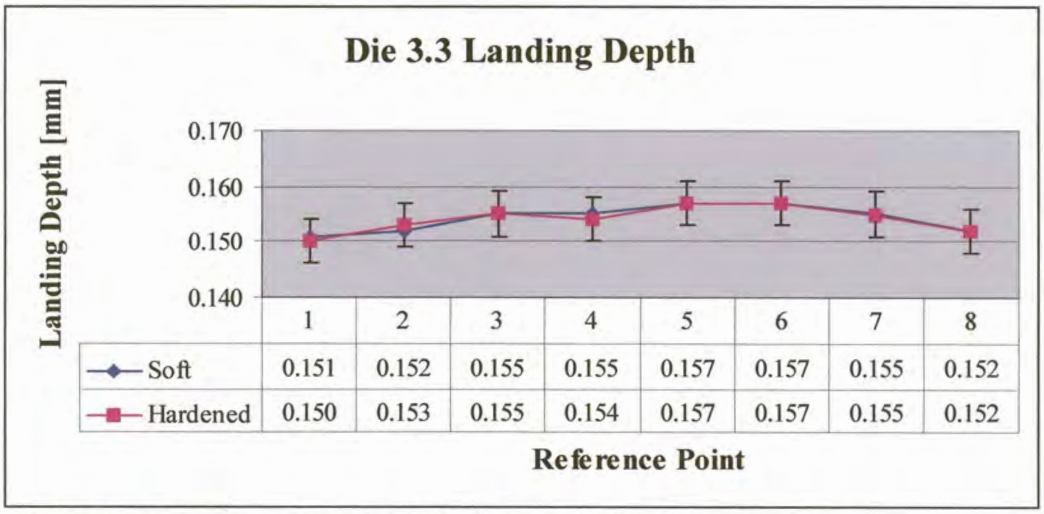
	1	2	3	4	5	6	7	8
◆ Soft	0.178	0.179	0.177	0.181	0.182	0.183	0.180	0.179
■ Hardened	0.176	0.177	0.180	0.183	0.182	0.182	0.180	0.177

FIGURE 4.25 Landing depth before and after heat treatment.



	1	2	3	4	5	6	7	8
Soft	0.179	0.179	0.180	0.180	0.180	0.180	0.183	0.182
Hardened	0.181	0.179	0.181	0.180	0.182	0.181	0.181	0.182

FIGURE 4.26 Landing depth before and after heat treatment.



	1	2	3	4	5	6	7	8
Soft	0.151	0.152	0.155	0.155	0.157	0.157	0.155	0.152
Hardened	0.150	0.153	0.155	0.154	0.157	0.157	0.155	0.152

FIGURE 4.27 Landing depth before and after heat treatment.

The question that must be asked is how does the shape of the design surface, for example, change during heat treatment. This can be easily evaluated by looking at the shape of the curves in Figure 4.19 to 4.24. The curves for the die in the soft and hardened state should have the same shape. This will suggest that although the design surface shifted upward or downward the actual design did not distort. From the figures it is evident that the surface stability for both the design surface and the landing surface is very good.

4.7.4 CONCLUSION

The shape change of the dies during heat treatment has now been properly quantified. A certain amount of change in diameter and length of the die can be expected during the heat treatment process (min: -0.04%, max: + 0.04%). The change in length does not present a problem since the dimensional changes are uniform across the entire die and this will not affect the coining or hobbing processes. It might be instructive to note the change in diameter when calculating die neck and collar sizes when very fine tolerances are required. The amount of shape change is however very small and can, for the most part, be regarded as insignificant.

The relative stability of the landing height, the landing surface and the design surface was also evaluated and the results showed very little dimensional distortion during the heat treatment process.

The importance of accurately controlling the heat treatment process cannot be overemphasized. Note that the hardness of Die 3.2 was merely 1 HR_c softer than the other two dies, however Die 3.2 experienced a volumetric contraction and the other two dies experienced a volumetric expansion.

The results of Test 2 and 3 can be used as a guideline for the shape changes that occur as a direct result of the heat treatment process. This will make it easier to identify the different components of distortion in subsequent tests when plastic deformation will be induced on the dies and punches.

4.8 Test 4: Hobbing

4.8.1 PURPOSE

Test 4 will concentrate on the production of the master punches. The test will primarily focus on the factors that affect the accuracy and the quality of the master punches and ultimately the coining dies. The main test objectives were:

1. **Evaluate the shape change of the master punches.**

   During the production process, the master punch undergoes several unwanted shape changes. The major factors contributing to these shape changes are:

   a) Elastic recovery of the material when the applied force is removed during the hobbing process.
   b) Transformation stresses during heat treatment.
   c) Thermal stresses during heat treatment.
   d) Residual stress relieving during heat treatment.

   Test 4 will concentrate on the combined effect of the heat treatment and deformation processes involved. The shape change attributed to the heat treatment process alone has been properly quantified in the previous tests. The shape change of the master punch due to residual stress relieving combined with the transformation of the microstructure and the cooling stresses during the heat treatment process must now be evaluated and quantified.

2. Determine optimum cone angle for the selected design.

Die blanks, which are conical shaped at the one end are used to hob the master punch from the matrix and to hob the coining dies from the master punch. Currently a cone angle of thirty degrees is used when the die blanks are manufactured. The cone angle is measured from the horizontal plane downward as shown in Figure 4.28. Different cone angles will be tested and evaluated. The results will be used to specify the cone angle, which produces the best results for the selected design.

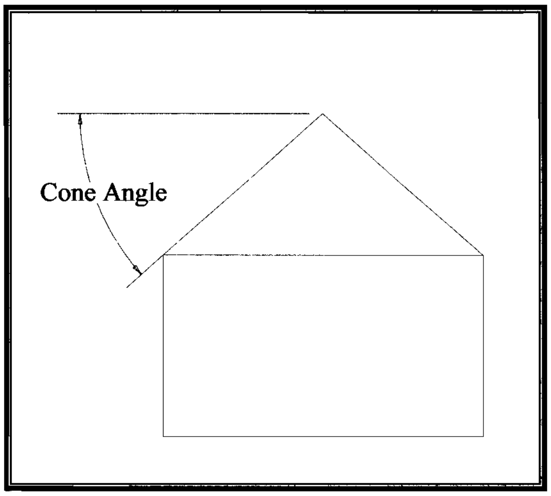


FIGURE 4.28 Cone angle

3. Evaluate the effect of die blank hardness on hobbing force.

Three die blanks will be annealed prior to hobbing. The effect of the reduced hardness on the hobbing force will be evaluated.

These were the three main objectives of the test. The procedure that was followed in conducting the test is shown below.

4.8.2 PROCEDURE

1. **Generate computer model**

A three-dimensional computer model must be generated of the design that will be used for the test. The two-dimensional design has already been established. It was now necessary to select the depth of the landing, the lettering and the design. A dome height had to be selected as well. The detail of the design was modeled relatively deep. By doing this, coining and hobbing defects are more likely to occur than with a shallow design. It will be easier to detect and evaluate the coining and hobbing defects if a deep design is used. A deep design will provide the analyst with more visual information about the process. The selected depths of the detail are as follows:

Design:	140 microns
Lettering:	115 microns
Landing:	160 microns

The next step was to select a dome size for the model. The dome spans the entire surface of the coining die. The dome height is specified as the vertical distance from the edge of the design surface to the centre of the projected design surface. The dome height was calculated in the following manner for the matrix. First the design height was added to reference point number 45 (See Figure 4.7), which is in the centre of the matrix. The average design surface height was then subtracted from this value to give the dome height (See Figure 4.29). A dome size of 40 microns was selected for the model.

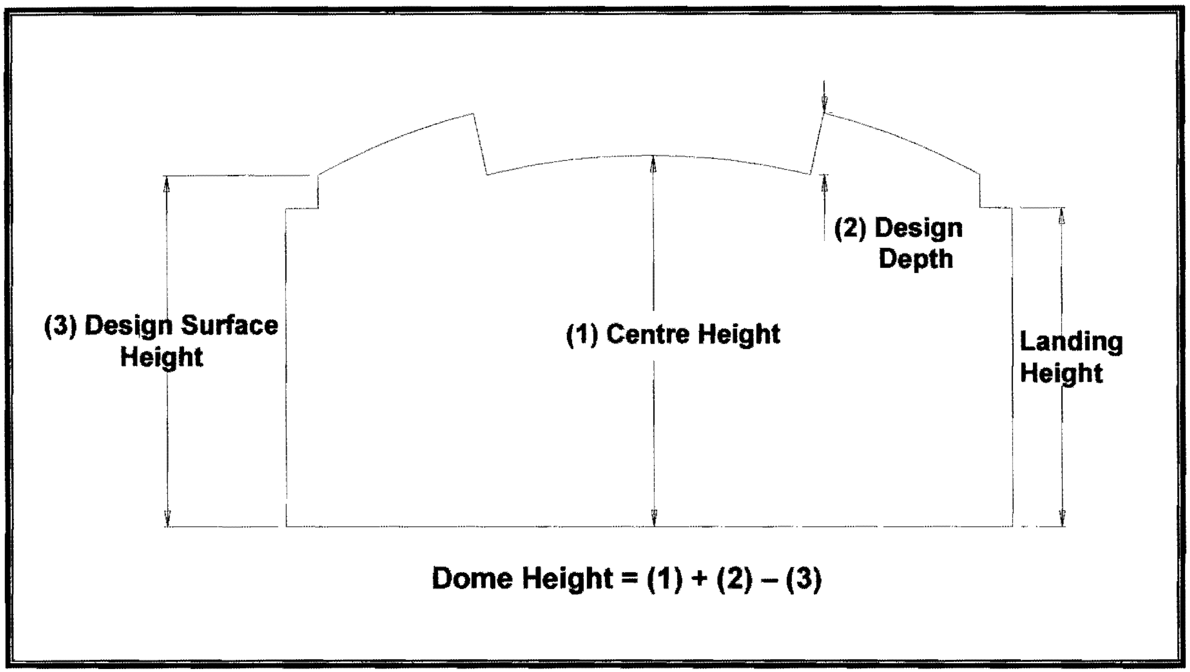


FIGURE 4.29 Procedure for calculating the dome height

2. Manufacture Matrix

a.) Prepare matrix blank

The matrix blank is a round billet of length 50 mm. Both sides of the billet are ground to ensure that the surfaces are parallel.

b.) Cut matrix on CNC engraver.

The matrix is fixed to the Engraver bed and the detail is engraved on the matrix.

c.) Machine relief into Matrix (See Figure 4.30(a)).

The matrix is removed from the engraver and a relief is machined into the matrix. The hobbing force that is required to produce the master punch is reduced if the access material is removed from the outer edge of the matrix.

d.) Remove cutter lines with grinding stone (By hand).

The engraver generates cutting lines on the cutting surface. These lines must be removed before the master punch is produced. The lines are removed with a small grinding stone by one of the diesinkers. This is often done before and after hardening. The amount of grinding was limited for this test to maintain dimensional accuracy of the matrix. The cutter lines can also provide valuable information regarding the reproducibility of fine detail during the hobbing process.

e.) **Measure Matrix**

The matrix was measured according to the Die Measuring Chart (Figure 4.7). The procedure discussed in Section 4.4 was followed during the measuring procedure. See Appendix F for the results.

f.) **Heat-treat Matrix.**

The matrix was hardened according to the process discussed in Section 4.5.

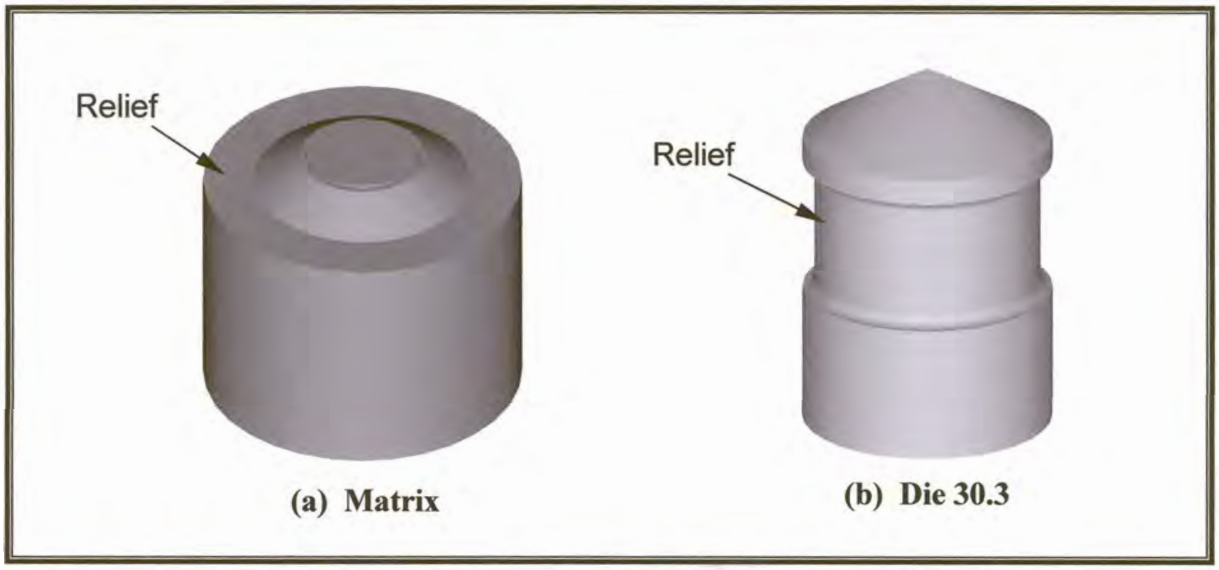
g.) **Measure Matrix again.**

The matrix was measured again after heat treatment to evaluate the shape change of the matrix during heat treatment. The results are given in Appendix F.

3. **Manufacture die blanks with different cone angles.**

Various die blanks were prepared with different cone angles. The cone angles range from 20 to 40 degrees with 5-degree intervals. Two die blanks of each cone angle were prepared. 8 Die blanks were prepared for the 30° series. These blanks will be used to hob master punches. The die blanks were numbered according to the cone angle, followed by a serial number. For example, die blank 25.2 has a cone angle of 25° and is the second die blank in the 25° series. These die blanks will go through the different hobbing and heat treatment procedures. The dimensional changes of the punches will be monitored through every step. The punches are placed in a collar during the hobbing process to restrict the radial flow of material. This forces the material to flow into the matrix design cavities. The transference of detail is much better than with unconstrained hobbing at the same tonnage but the amount of elastic recovery is much greater. To reduce the amount of elastic recovery during hobbing a relief zone was cut into the body of die blank 30.3. The diameter of the reduced section is 45 mm. See Figure 4.30 (b). The effect of the relief will be noted and if an improvement is observed additional tests will be done on die blank relief zones.

The results of constrained hobbing will be compared to the results of unconstrained hobbing by hobbing punch 30.5 in an open die process. Die blank 30.6 to 30.8 were annealed to reduce the hardness of the die blanks. These blanks were hobbed with a reduced hobbing force. The objective was to observe the quality of the detail transferred and the dimensional changes occurring for the different cone angles. The performance of each cone angle will be analyzed and evaluated.



(a) Matrix **(b) Die 30.3**

FIGURE 4.30 (a) Relief zone cut into matrix, (b) Relief zone machined into die blank

4. Manufacture Master Punches.

a.) Hob master punches from matrix

All the master punches were hobbed on the Sack & Kiesselbach Oil Hydraulic Press. The hobbing process is done at a constant speed and the duration is approximately 4 minutes. A dwell time of 10 seconds was specified for the test. All the normal master punches except one were hobbed with a maximum force of $180^{\pm 1}$ tons, punch 30.4 was hobbed with a maximum force of 200 tons. The softer die blanks were hobbed at 150, 160 and 170 tons respectively. The softer die blanks will not be measured nor heat-treated. The main purpose of these die blanks was to evaluate the detail transferred, compared to the normal die blanks.

b.) Machine master punches.

The master punches were turned according to specifications shown in Appendix C. A picture of the master punch is shown in Figure 4.31.

c.) Measure master punches

After the master punches have been machined they were measured according to the Die Measuring Chart. The results are shown in Appendix F.

d.) Heat-treat master punches.

The master punches were sent for heat treatment to be hardened. The hardness specification for the master punches is 59 HR_c. After heat treatment the hardness of the punches were measured and the results obtained are shown in Table 4.10. The differences in hardness are due to variances in the cooling rate during the heat treatment and tempering processes.

Punch No.	Hardness HR_c
20.1	59.8
20.2	58.8
25.1	59.9
25.2	59.4
30.1	60.1
30.2	58.1
30.3	59.2
30.4	57.7
30.5	59.3
35.1	59.7
35.2	59.9
40.1	60.2
40.2	59.5
Average	59.4

TABLE 4.10 Master Punch hardness

FIGURE 4.31 Master Punch

e.) Measure master punches

The master punches were measured a second time to evaluate the response of the punches during the heat treatment process. The results are given in Appendix F.

4.8.3 RESULTS

All the measurement data and the resulting graphs are included in Appendix F. A summary of the results will now be discussed. For each of the punches an average was calculated for the following: Design Surface Height, Landing Height, Design Depth, Landing Depth, Lettering Depth and Dome Height. The results are given in Table 4.11. The results of Table 4.11 are presented graphically in Figure 4.32 to Figure 4.36

Master Punch Averages

* All measurements are in millimeters

Surface Height

Soft		**Hardened**	
Die No.	*Height*	*Die No.*	*Height*
20.1	65.550	**20.1**	65.517
20.2	65.466	**20.2**	65.447
25.1	64.369	**25.1**	64.359
25.2	64.540	**25.2**	64.536
30.1	62.861	**30.1**	62.835
30.2	62.883	**30.2**	62.833
30.3	59.566	**30.3**	59.542
30.4	61.663	**30.4**	61.634
30.5	60.235	**30.5**	60.228
35.1	61.370	**35.1**	61.363
35.2	61.218	**35.2**	61.208
40.1	59.335	**40.1**	59.326
40.2	59.495	**40.2**	59.473

Landing Height

Soft		**Hardened**	
Die No.	*Height*	*Die No.*	*Height*
20.1	65.723	**20.1**	65.692
20.2	65.642	**20.2**	65.624
25.1	64.544	**25.1**	64.535
25.2	64.716	**25.2**	64.711
30.1	63.033	**30.1**	63.011
30.2	63.057	**30.2**	63.008
30.3	59.749	**30.3**	59.727
30.4	61.839	**30.4**	61.811
30.5	60.415	**30.5**	60.409
35.1	61.544	**35.1**	61.538
35.2	61.392	**35.2**	61.383
40.1	59.511	**40.1**	59.502
40.2	59.672	**40.2**	59.649

Design Depth

Soft		**Hardened**	
Die No.	*Depth*	*Die No.*	*Depth*
20.1	0.135	**20.1**	0.135
20.2	0.136	**20.2**	0.135
25.1	0.136	**25.1**	0.136
25.2	0.135	**25.2**	0.136
30.1	0.135	**30.1**	0.138
30.2	0.135	**30.2**	0.137
30.3	0.137	**30.3**	0.137
30.4	0.135	**30.4**	0.136
30.5	0.137	**30.5**	0.136
35.1	0.136	**35.1**	0.137
35.2	0.135	**35.2**	0.136
40.1	0.136	**40.1**	0.137
40.2	0.136	**40.2**	0.137

Landing Depth

Soft		**Hardened**	
Die No.	*Depth*	*Die No.*	*Depth*
20.1	0.173	**20.1**	0.176
20.2	0.176	**20.2**	0.177
25.1	0.175	**25.1**	0.177
25.2	0.176	**25.2**	0.175
30.1	0.172	**30.1**	0.176
30.2	0.174	**30.2**	0.175
30.3	0.183	**30.3**	0.185
30.4	0.176	**30.4**	0.176
30.5	0.180	**30.5**	0.181
35.1	0.175	**35.1**	0.176
35.2	0.175	**35.2**	0.176
40.1	0.176	**40.1**	0.177
40.2	0.177	**40.2**	0.176

TABLE 4.11 Height averages for master punches

Lettering Depth				**Dome Height**			
Soft		**Hardened**		**Soft**		**Hardened**	
Die No.	***Depth***	***Die No.***	***Depth***	***Die No.***	***Height***	***Die No.***	***Height***
20.1	0.108	**20.1**	0.108	**20.1**	0.046	**20.1**	0.036
20.2	0.109	**20.2**	0.108	**20.2**	0.046	**20.2**	0.033
25.1	0.108	**25.1**	0.110	**25.1**	0.048	**25.1**	0.035
25.2	0.108	**25.2**	0.108	**25.2**	0.046	**25.2**	0.036
30.1	0.109	**30.1**	0.111	**30.1**	0.044	**30.1**	0.039
30.2	0.108	**30.2**	0.110	**30.2**	0.044	**30.2**	0.038
30.3	0.108	**30.3**	0.107	**30.3**	-0.041	**30.3**	-0.056
30.4	0.109	**30.4**	0.111	**30.4**	0.042	**30.4**	0.042
30.5	0.108	**30.5**	0.108	**30.5**	-0.002	**30.5**	-0.010
35.1	0.110	**35.1**	0.111	**35.1**	0.041	**35.1**	0.046
35.2	0.110	**35.2**	0.109	**35.2**	0.042	**35.2**	0.042
40.1	0.110	**40.1**	0.111	**40.1**	0.036	**40.1**	0.041
40.2	0.111	**40.2**	0.111	**40.2**	0.034	**40.2**	0.039

TABLE 4.11 cont. Height averages for master punches

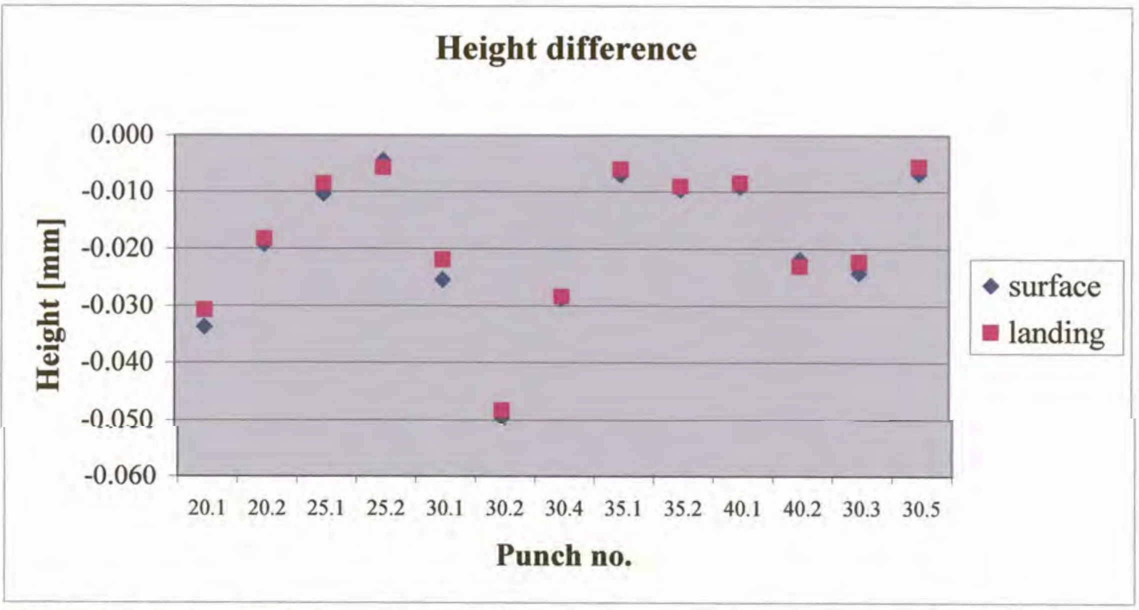


FIGURE 4.32 **Difference in height of the landing and design surface after heat treatment.**

All the punches underwent a reduction in length during the heat treatment process. The reasons for this reduction have been discussed in Section 4.7. The scatter that is observed in Figure 4.32 is due to the differences in hardness after the heat treatment process.

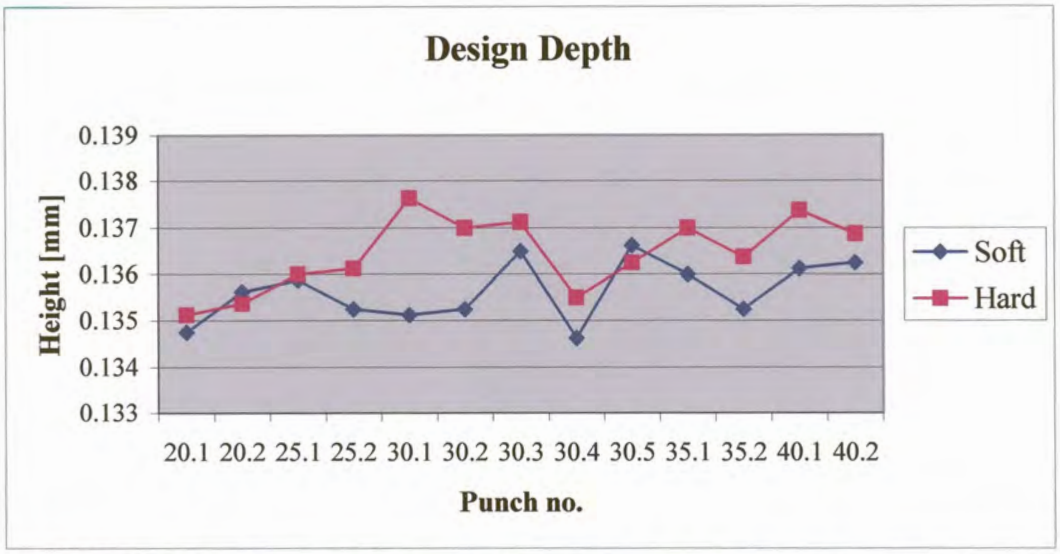


FIGURE 4.33 **Average design depth before and after heat treatment.**

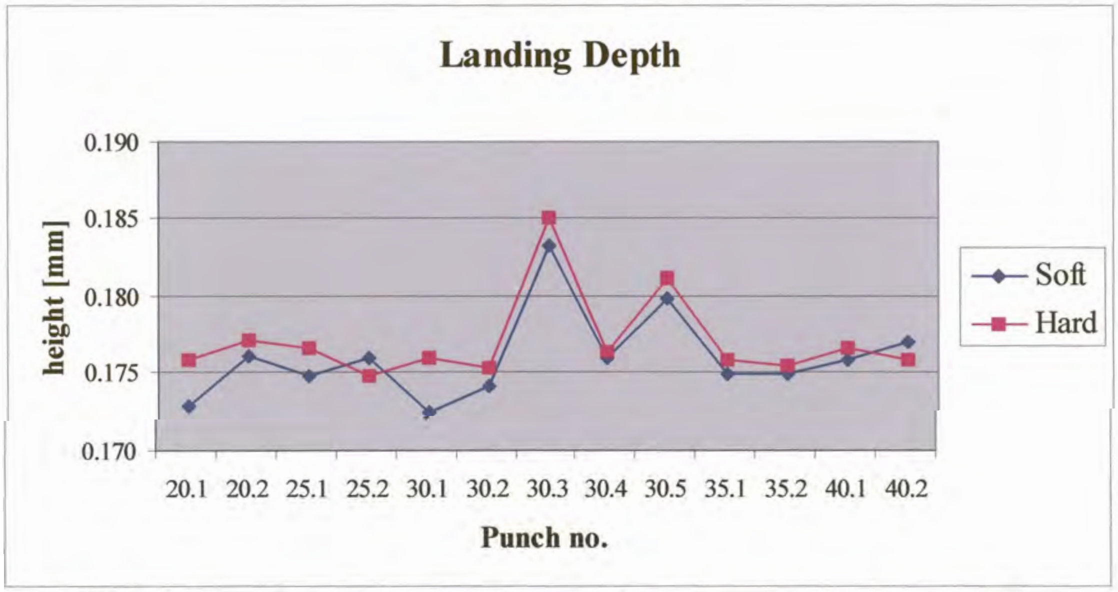


FIGURE 4.34 **Average landing depth before and after heat treatment.**

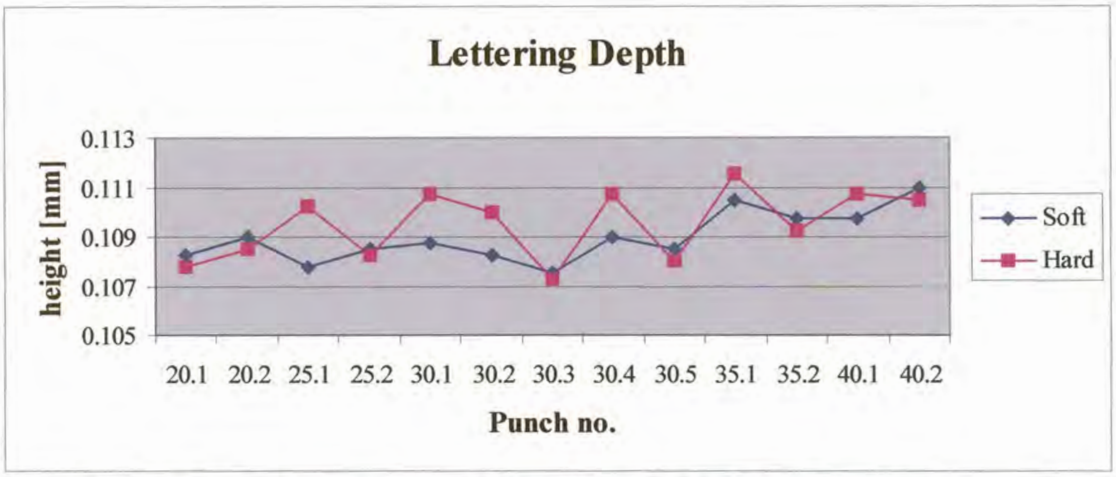


Figure 4.35 **Average lettering depth before and after heat treatment.**

Figures 4.33 to 4.35 displays the depth of the detail before and after heat treatment. The design, landing and lettering depth remained close to constant through the heat treatment process. Any differences are within the accuracy tolerance of the measuring procedure (± 4 microns).

The response of the dome height during the production process will now be evaluated. The dome height of the matrix was 33 microns after hardening. Very little change occurred in the dome height of the matrix during heat treatment. This is mainly due to the fact that no plastic deformation was induced on the matrix. However significant changes occurred in the dome size of the master punches during the hobbing and heat treatment processes. For instructive purposes the dome height of the punches was plotted before and after heat treatment. Punch 30.3, which had a relief zone in the body and punch 30.5, which was hobbed in an open die configuration, will not be included in the graph at this stage. The resulting plot is shown in Figure 4.36.

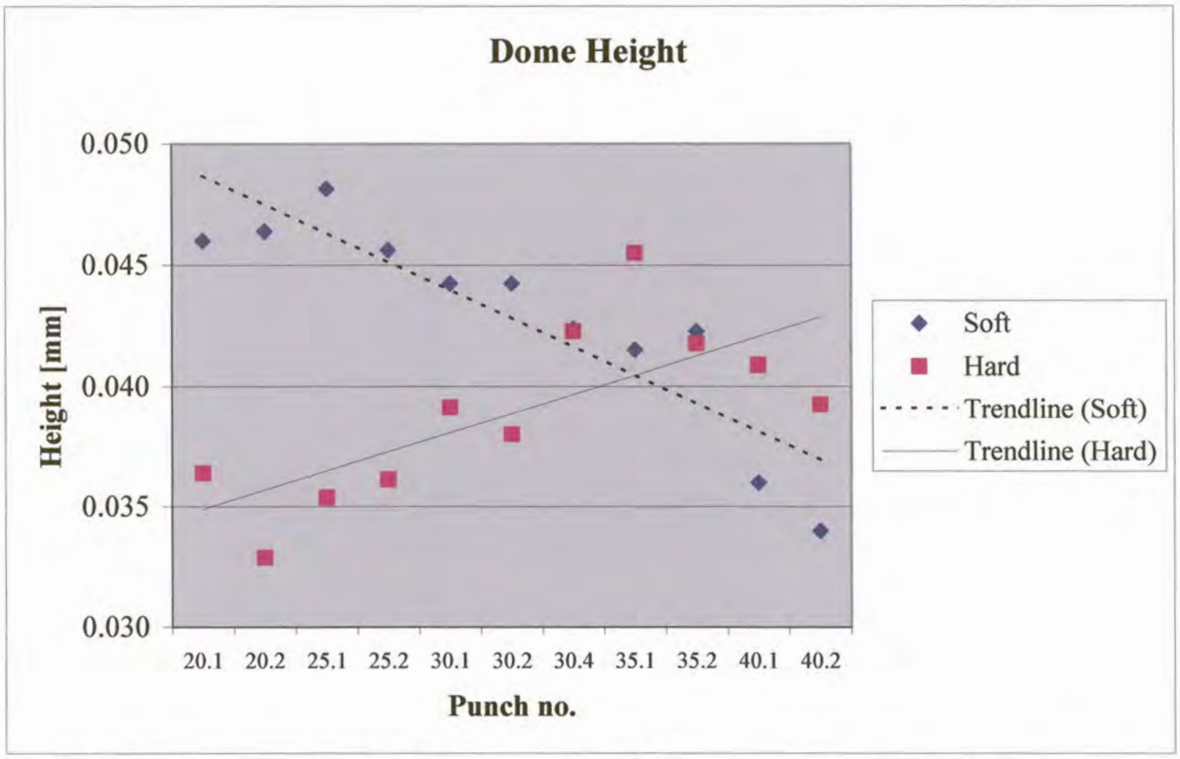


FIGURE 4.36 **Dome height of punches before and after heat treatment.**

If the die blanks that were used in the hobbing process were made from lead, one would expect that the dome height of the master punches would be about –33 microns after hobbing. However since a material is used that has a high yield strength a certain amount of elastic recovery will occur after the applied force is removed.

The amount of elastic recovery will be more in the centre of the punch since the material particles in the centre are constrained by adjoining particles and by friction due to contact with the matrix. The particles at the outer edge of the design is free to deform plastically due to the relief zone in the matrix thus there are less particles that are deformed elastically. The result is that the master punches have a positive dome of about 40 microns after hobbing.

The trendline that was fitted through the data for the soft punches clearly indicate that the amount of elastic recovery decrease with increasing cone angle (Figure 4.36). The punches with a large cone angle are subjected to more plastic deformation to fill the design. Particles that would have been under elastic strain are deformed past the yield point into the plastic zone. The result is less elastic recovery during hobbing.

During heat treatment the dome experience a further shape change. The punch undergoes a shape change due to transformation stresses and thermal stresses that are created during the heat treatment process (Ref. Section 4.7). Thermal stresses that cause the punch to contract are more pronounced in the center due to the temperature gradient present in the punch. These stresses cause the dome of the punch to shrink. This can clearly be seen in Figure 4.36 for the punches with a small cone angle. Note that the trendline that was fitted through the data of the hardened punches has a positive gradient.

The shrinking of the dome is counteracted by residual stress relieving. Residual stresses are set up in the punch during the hobbing process. Residual stresses are caused by an increase in the dislocation density of the material during plastic deformation. The dislocation density is reduced during heat treatment due to the phase transformation of the material to austenite, resulting in an increase in dome size. As was mentioned previously, the punches with a large cone angle endure more plastic deformation during hobbing therefore residual stress relieving increases with an increase in cone angle. At some point the shape change due to residual stress relieving exceeds the shape change due to thermal and transformation stresses. The net effect is that the dome rises during heat treatment. This point is evident from the results of the punches with a cone angle of 35° and higher.

It is also instructive to examine the dome height results of punch 30.4. The maximum hobbing force for punch 30.4 was 20 tons higher than the rest. The amount of elastic recovery was less for this punch than for the other punches with the same cone angle. The higher hobbing force induced more plastic deformation on the punch. Particles that were on the edge of plasticity at 180 tons were now deformed plastically, resulting in less elastic recovery. For the same reason the dislocation density increased and more residual stress relieving occurred during heat treatment. Caution should be taken when hobbing with a high hobbing force. An increased hobbing force could result in the premature failure of the punches.

To reduce the amount of elastic recovery a relief was cut into the body of punch 30.3. The relief zone allows more material to deform plastically. The result was a drastic reduction in the amount of elastic recovery after hobbing. However there was still a shape change during heat treatment and the dome shrunk with 11 microns. Therefore a relief zone does not guarantee a constant dome height during the manufacturing process.

The quality of the master punch is ultimately dictated by the amount of detail that was transferred from the matrix during the hobbing process. The approval of the master punches is subject to a visual inspection under 10 times magnification. Pictures were taken of the master punches after hobbing to evaluate the amount of detail transferred during the hobbing process from the matrix. These pictures are shown in Figure 4.38. The critical areas are highlighted in Figure 4.37. These areas will be evaluated for all the punches. All edges should be sharp and well defined.

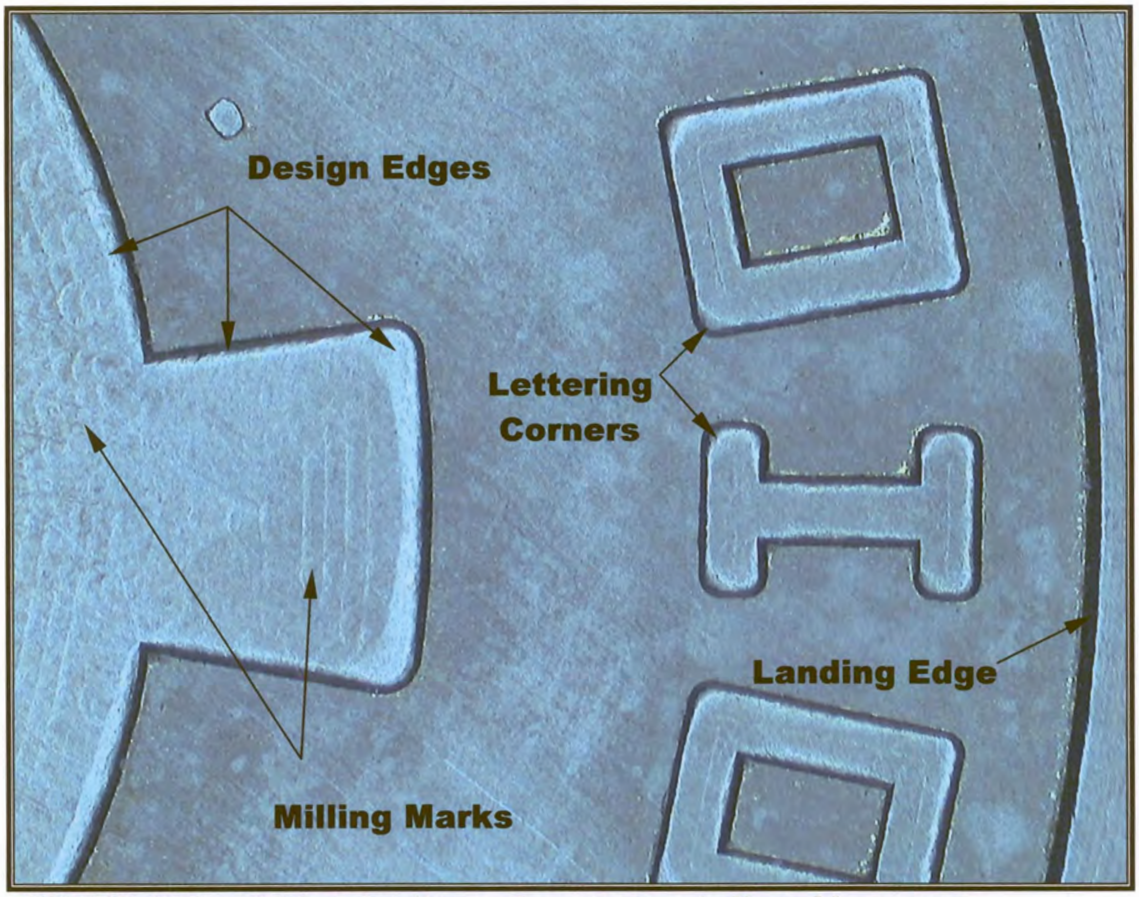


FIGURE 4.37 Critical detail transference areas indicated by arrows.

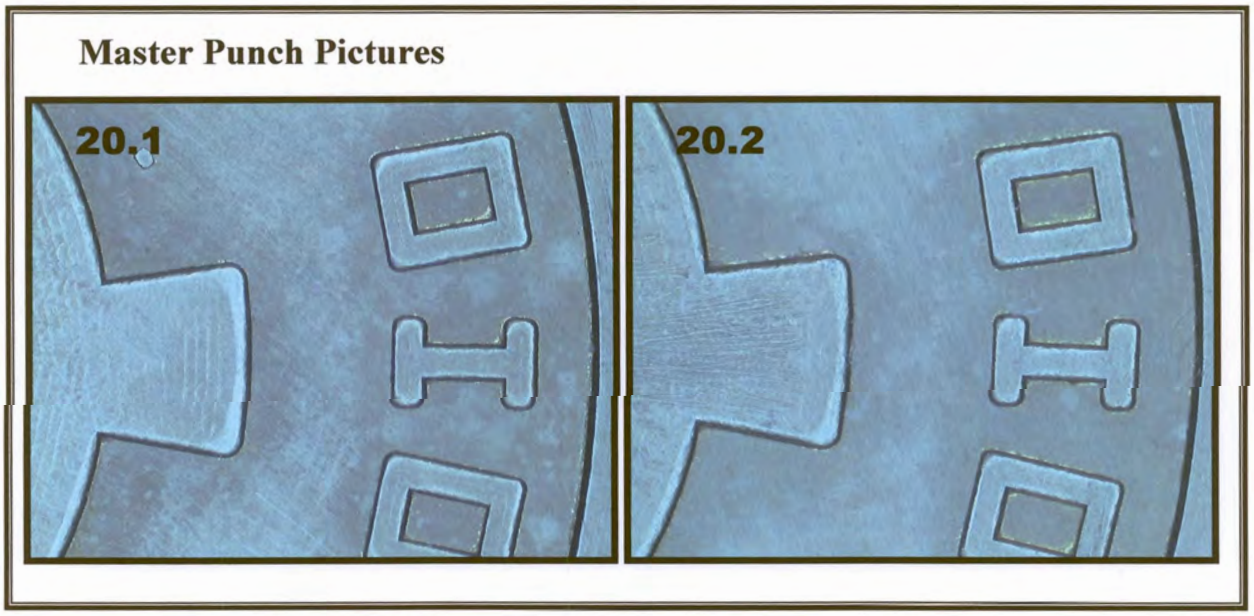


FIGURE 4.38 Pictures of Master Punches

Master Punch Pictures

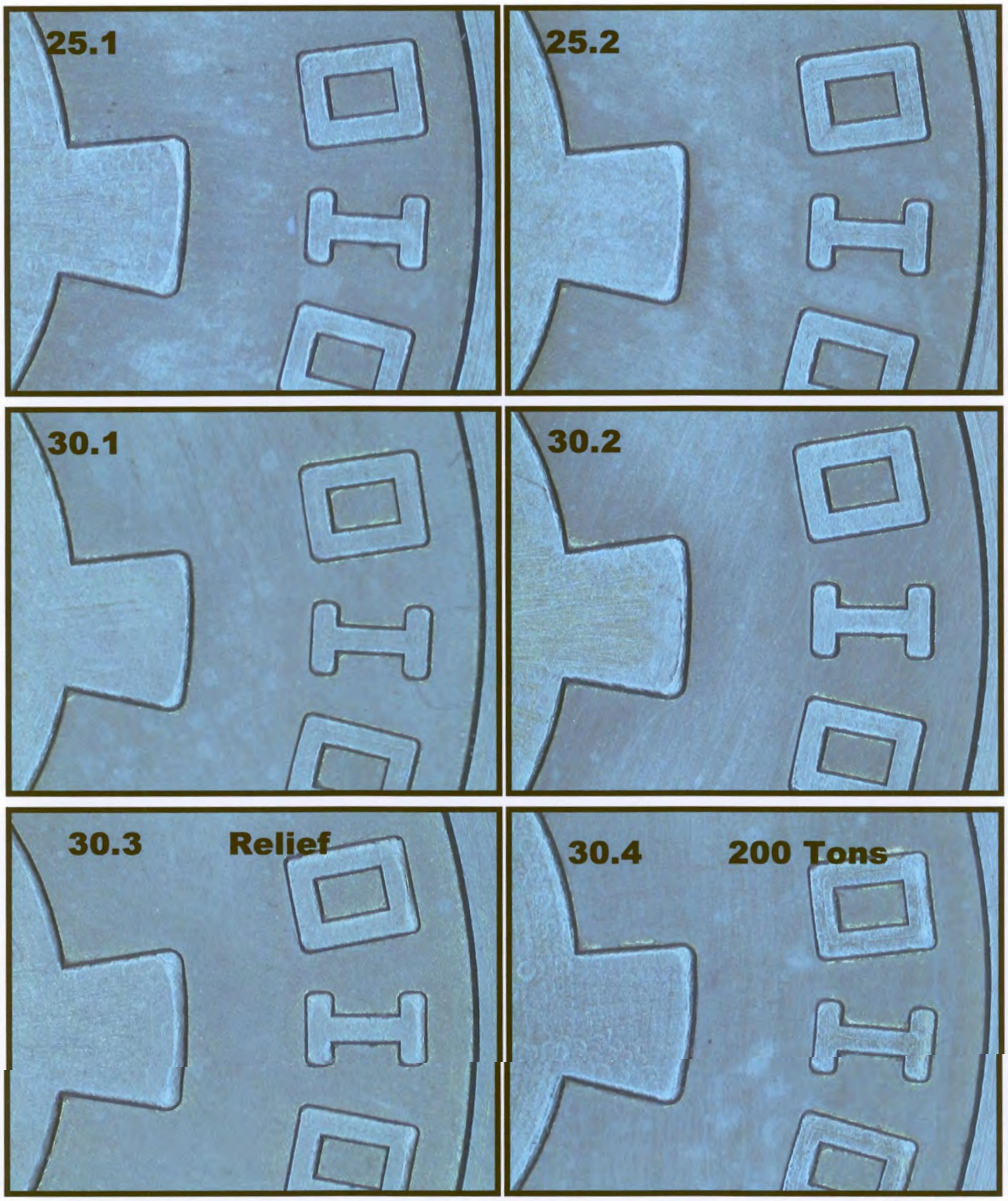


FIGURE 4.38 cont. Pictures of Master Punches

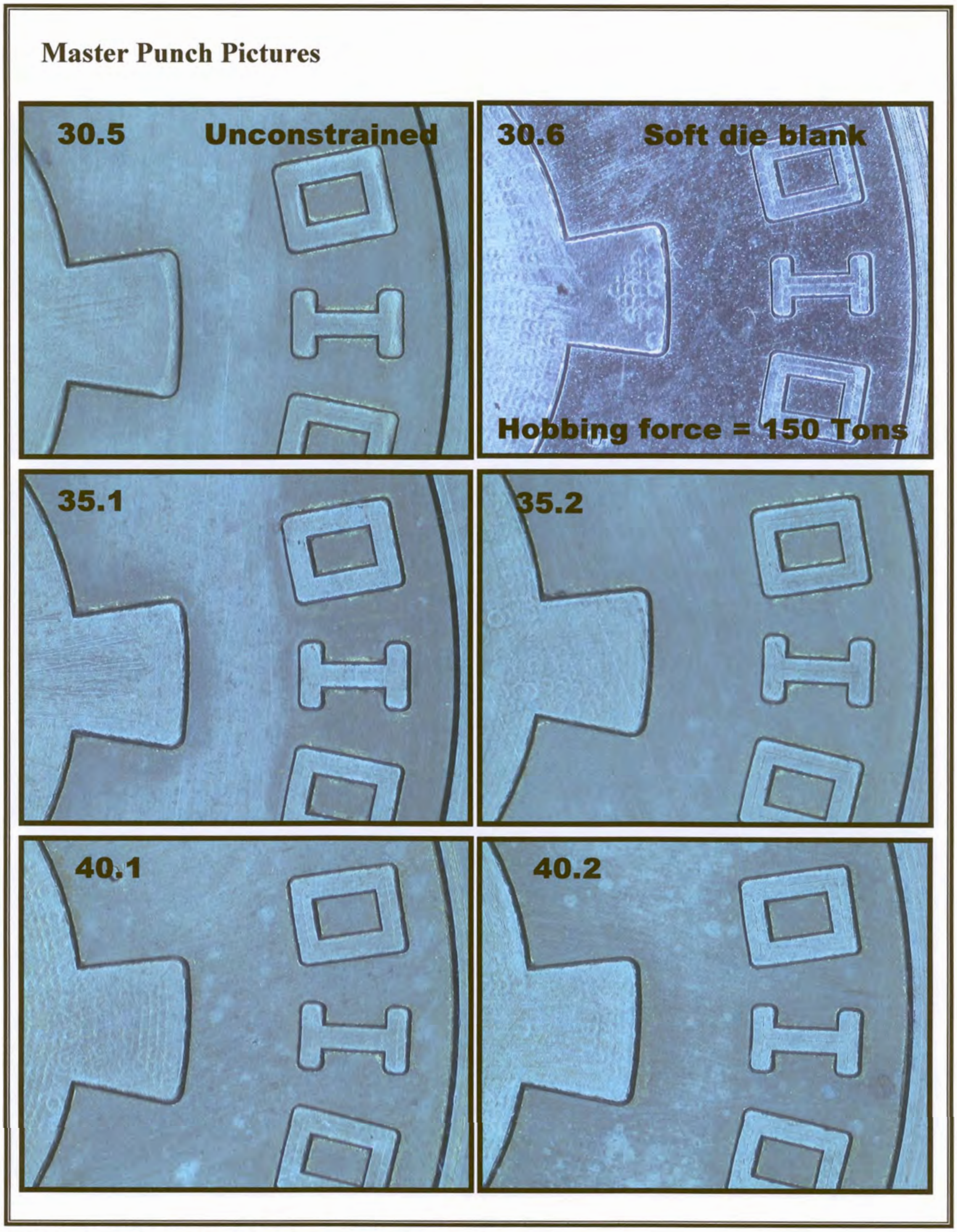


FIGURE 4.38 cont. Pictures of Master Punches

Upon inspection it was observed that all eight symmetrical sections of the design were identical. Therefore only one of the sections will be viewed. The sharpness of the detail increased with an increase in cone angle. When the matrix was manufactured the milling marks that was produced by the engraver cutter was not totally removed. The presence of these milling marks on some of the punches is a sign of high detail transference.

From Figure 4.38 it is evident that for this design the die blanks with a cone angle of 35° to 40° produced the best results regarding detail. The results obtained with cone angles of 20° to 25° produced results that are not acceptable. The results of punch 30.3 and 30.5 were also not acceptable. It is therefore evident that hobbing in a collar that restricts radial flow produces better results. Although the relief zone in punch 30.3 caused less elastic relaxation, the transference of detail was below standard and therefore no more test will be done on die blank relief zones.

Die blank 30.6 was annealed prior to hobbing. The hardness of the die blank after annealing was 92.8 HR_b compared to the average hardness of 94.7 HR_b of the normal die blanks. When compared to the master punch that was hobbed at 200 tons, with the same cone angle, it can be seen from Figure 4.38 that the soft die blank displays significant improvements in detail transfer at a hobbing load of 150 tons. This is a dramatic 25% reduction in hobbing force. The milling marks on the design and in the centre of the lettering are clearly visible on the softer punch.

There are two significant advantages for annealing the die blanks prior to hobbing. The first is that a smaller distribution in hardness can be ensured between the die blanks. This will improve consistency during hobbing. The other reason is that the required hobbing force can be reduced dramatically. The reduction in hobbing force will limit the amount of plastic deformation induced on the matrix and will allow for improved detail transference during hobbing.

4.8.4 CONCLUSION

During the hobbing and heat treatment processes the material undergoes various shape changes. It is not possible to avoid these shape changes altogether. The small percentage change in length and diameter that occurs during heat treatment is of little importance and does not present a problem during the production and development processes.

The amount of elastic recovery does present a problem as far as calculating the dome size is concerned. It was shown that the amount of elastic recovery could be controlled by increasing the hobbing force, by varying the cone angle or by introducing a relief zone in the body of the master punch. However it was also shown that a relief zone does not solve the problem.

The shape change of the dome during heat treatment is relatively small for cone angles of 30° and higher but it can be accounted for and with proper development it can be predicted.

The fact that there is a significant amount of shape change during the hobbing and heat treatment processes does not present a problem in itself. The problem lies therein that the shape change is often not consistent, and this presents a problem in accurately producing a coining die with a specified dome height. The key factor is consistency. If one can maintain consistency the developer can allow for these shape changes that occur. The solution to the problem is therefore to improve consistency in every aspect of the development process.

There is no specific hobbing force, die blank cone angle, dome height or any other characteristic that will produce the best results for all the projects. It is therefore imperative that significant amounts of data be obtained for all development projects. Successful development efforts rely on empirical data obtained from previous successful projects. This greatly improves consistency in all aspects. A few of the major aspects will be highlighted.

- The hobbing force.
- Die blank diameter.
- Die blank hardness.
- Matrix hardness.
- Dome height.
- Cone angle.
- Heat treatment temperatures.
- Machining practice

A change in any one of these factors can greatly affect consistency. With an extensive database in hand repeatability is easier to achieve and inconsistencies can be explained and properly managed.

Because hardness greatly affects the hobbing process, the raw material that is used during development should have a uniform hardness. The hardness should be measured on all raw materials to ensure uniformity. If the bandwidth of the hardness results is large an extra annealing process should be considered. The amount of elastic recovery will depend on the initial hardness of the punch and it is therefore extremely important that all the punches have the same hardness prior to hobbing. The results also showed that an extra annealing process will reduce the required hobbing force and will improve the quality of the master punch detail.

The heat treatment process should be modified to ensure homogeneous heating and cooling of all punches and dies. Dies should not be packed close together during heat treatment because this can adversely affect the cooling rate of the dies, resulting in differences in hardness. Recommendations regarding heat treatment will be given in the design protocol.

If consistency can be maintained significant improvements will be achieved during the development process. Note that a shape change of about 0.02 % can present a problem during the development process. It is impossible to maintain such accurate results if the hardness of the raw material, for example had a hardness deviation of 3 %.

4.9 Stress Concentrations

4.9.1 INTRODUCTION

Stress concentrations are present where there is a discontinuity or an abrupt change in the geometry of the material. High localized stresses are caused in the vicinity of the stress concentration. These high localized stresses can cause the dies and punches to fail prematurely. The severity of the stress concentrations should be reduced to increase die life.

4.9.2 STRESS CONCENTRATION CONSIDERATIONS

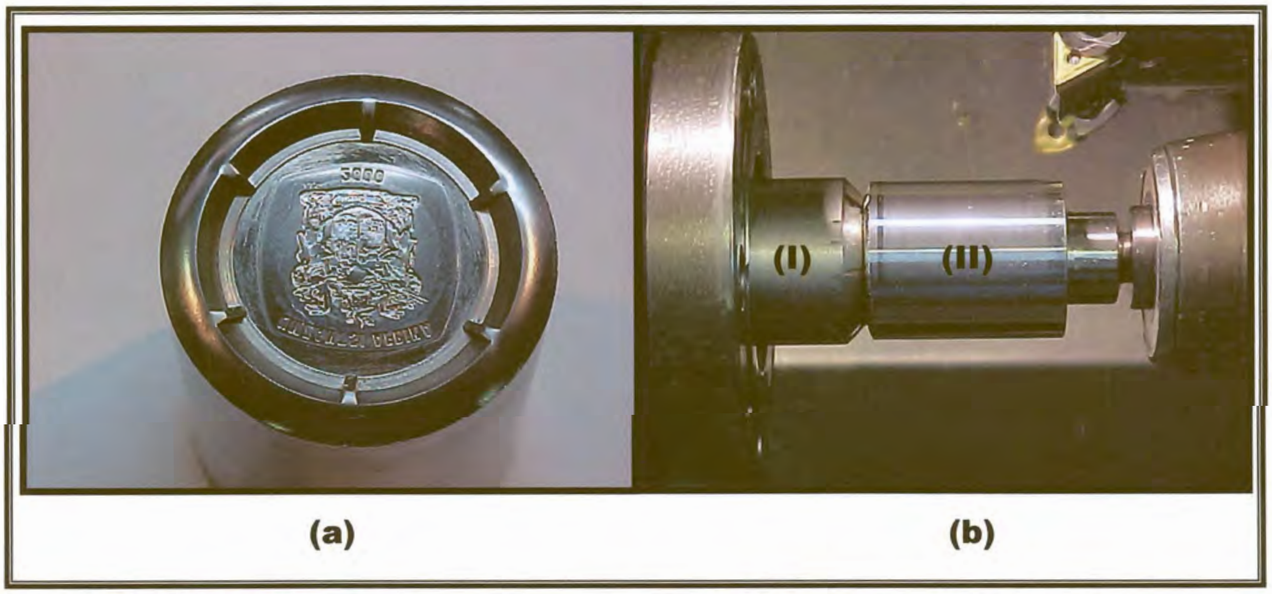
When a force is applied the maximum stress at the stress concentration can be 3 to 5 times higher than the nominal stress present in the rest of the die. This will cause the die to fail at a force much lower than expected. This high localized stress is raised even further at one edge of the die because the coining dies are never perfectly parallel during coining.

Die life can be improved by removing or by reducing stress concentrations present in the die. It is not always possible to remove a stress concentration and therefore this discussion will concentrate on the reduction of the stress concentrations and the effect thereof.

After hobbing the master punch is set up in the lathe and the punch is turned to the drawing specifications shown in Appendix C. The body of the punch is also turned so that it is concentric with the design. The master punch is removed from the lathe and locating slots are machined into the punch. These slots can be seen in Figure 4.39. The purpose of the slots is to locate the master punch on the coining dies when they are manufactured.

FIGURE 4.39 Master Punch Slots

When the master punch is hobbed on the coining die, the slots are transferred to the die (See Figure 4.40(a)). The die is now located on the master punch in the CNC lathe and the body of the die is turned (See Figure 4.40(b)). This process ensures that the design of the die is concentric with the body of the die. Failure of the master punch often occurs by crack propagation along a plane parallel to the longitudinal axis. The crack initiation site is often in the corner of one of the slots.



(a) (b)

FIGURE 4.40 (a) Slots transferred to coining die. (b) Master punch fixed in lathe chuck (I), Coining die located on master punch (II)

These slots introduce a large stress concentration into the master punches. By modifying the shape of the slots the severity of the stress concentration can be reduced. Currently there is no specification for the slots and therefore the shape of the slots cannot be accurately evaluated. The slots should have a semi-circular shape and the depth of the slots should be decreased as much as possible. The reduction in depth and edge sharpness will reduce the stress concentration intensity. A specification should be set up for the new slot design. The proposed shape of the slots can be produced with a ball-nose cutter with a large tip radius. The current and suggested slot shapes are shown in Figure 4.41.

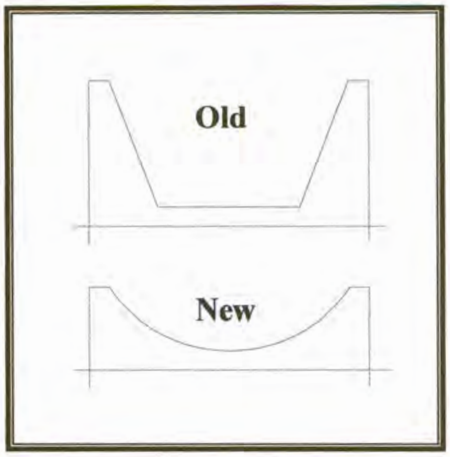


FIGURE 4.41 Slot Shapes

Another stress concentration point that is of major concern is on the coining dies. The point under discussion is the bottom end of the die neck as shown in Figure 4.42. According to the coining die drawing (Appendix C), there is no specification for a radius where the die neck and the body meets. During the manufacturing process a sharp edge is created at the bottom of the die neck. This causes the formation of a large stress concentration. During the investigation of die failures, a large number of failures could be attributed to crack initiation at the point of high localized stresses.

Introducing a radius in this area can reduce this stress concentration drastically. A minimum radius of 5 mm is suggested (See Figure 4.43). The transition from the die body to the die neck should be very gradual and smooth. A great improvement in die life will be observed if this stress concentration is reduced.

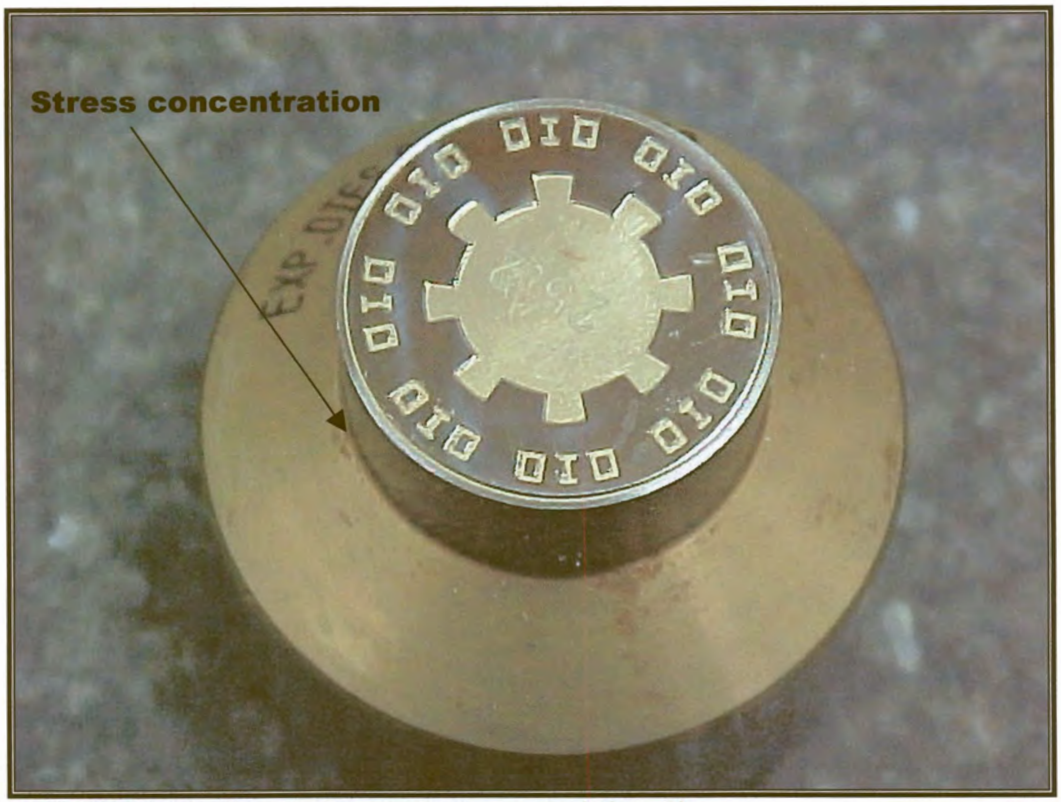


FIGURE 4.42 **Stress concentration on coining dies.**

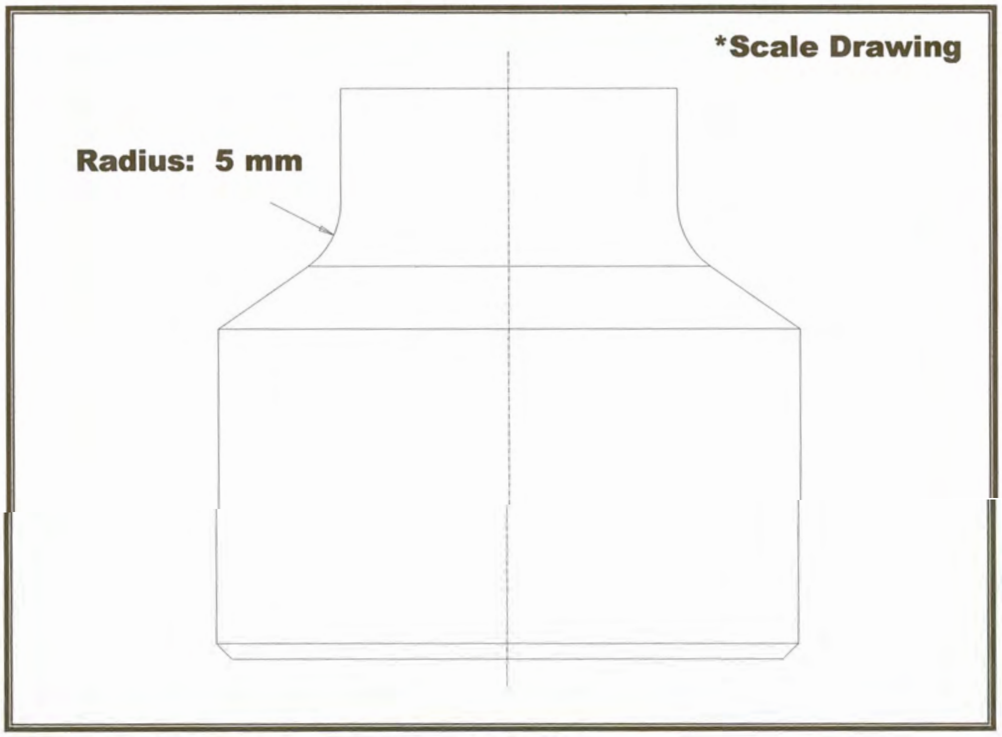


FIGURE 4.43 **Coining die modification.**

REFERENCES

1. Karl-Erik Thelning, **Steel and its heat treatment,** Butterworths, 1984, p. 581-604
2. ASSAB, **Calmax Material Specification,** pg. 4
3. ASSAB, **Viking Material Specification,** pg. 5

SECTION B

HIGH SPEED COINING

CHAPTER 5

HIGH SPEED COINING

5.1 Introduction

The final stage of the coin production process is the coining of the blanks. To properly evaluate the quality of the coining dies and the blanks, it is necessary to coin the blanks with the dies. The coining of the blanks is done on high speed coining presses, capable of producing coins at a rate of 750 per minute. The actual deformation of the blank to produce a coin occurs in less than 15 milliseconds at this coining rate.

The coining tests will concentrate on evaluating the behaviour of the coining dies and the blanks during the coining process. The effect of blank hardness on coining results and the annealing process will receive attention in this section. The test procedure for all the coining tests was the same. The design depths of the coining dies differed for each test according to the test objectives. The coining dies were manufactured according to current specifications. A drawing of the coining die is included in Appendix C. The same collar was used for all the tests.

5.2 Test 5: 1st Coining Test

5.2.1 PURPOSE

The purpose of Test 5 was to evaluate the progressive coining of the blanks. It is easier to identify the cause of a specific coining defect, as well as to visualize how the material flows during coining when a progressive coining test is done. The dome size can for example then be altered to control the flow of the material. The detail depths can also be modified to prevent a specific coining defect.

5.2.2 PROCEDURE

The coining test was done by gradually increasing the coining force from zero to the test maximum. Samples were taken during the test, starting at 10 kN and at subsequent 10 kN intervals. The coining tests were done on a Grabener high-speed coining press. The same press was used throughout the coining tests, to ensure consistency.

The detail specifications for the first set of coining dies were as follows:

Design depth:	80 microns
Lettering depth:	70 microns
Landing depth:	160 microns
Dome height:	60 microns

The detail depths, are average depths for coins with a diameter of about 20 mm.

Normally the depth of the landing is slightly more than the depth of the design. This ensures that the coin will not spin if it is rotated on a flat surface. If the coin spins it means that the centre of the design is higher than the landing. For this test the landing depth was much greater than the design depth. Normally the landing is one of the critical areas in the design. Coining defects often occur in the landing because the landing is on the outer edge of the design. To encourage these defects the landing was modeled relatively deep.

5.2.3 RESULTS

The results of the coining test are shown in Figure 5.1. The obverse and reverse of the coin revealed similar coining patterns. At 10 kN coining force the coins show that the dies were not perfectly parallel during coining since the detail start to coin on the right hand side but not on the left. The error is relatively small in this case but care should be taken in this regard to ensure that the dies are parallel during the production process. Premature die failure can occur due to the misalignment of the dies and due to a subsequent stress concentration that is present on the one side of the dies.

The criteria for approving a coin through visual inspection are a rather vague subject. The evaluation of the detail often depends on the requirements of the client. There is no formal specification by which the detail is evaluated. The S.A Mint has a very high visual quality standard. Evaluating the process capabilities through previous products has set this standard. To complicate matters this quality standard is continually rising because of increasing competitiveness across the world. A visual inspection involves a check for the following defects: Water stains, Material deviations, Colour, Oil stains, Coining defects, Die cracks and scratch marks.

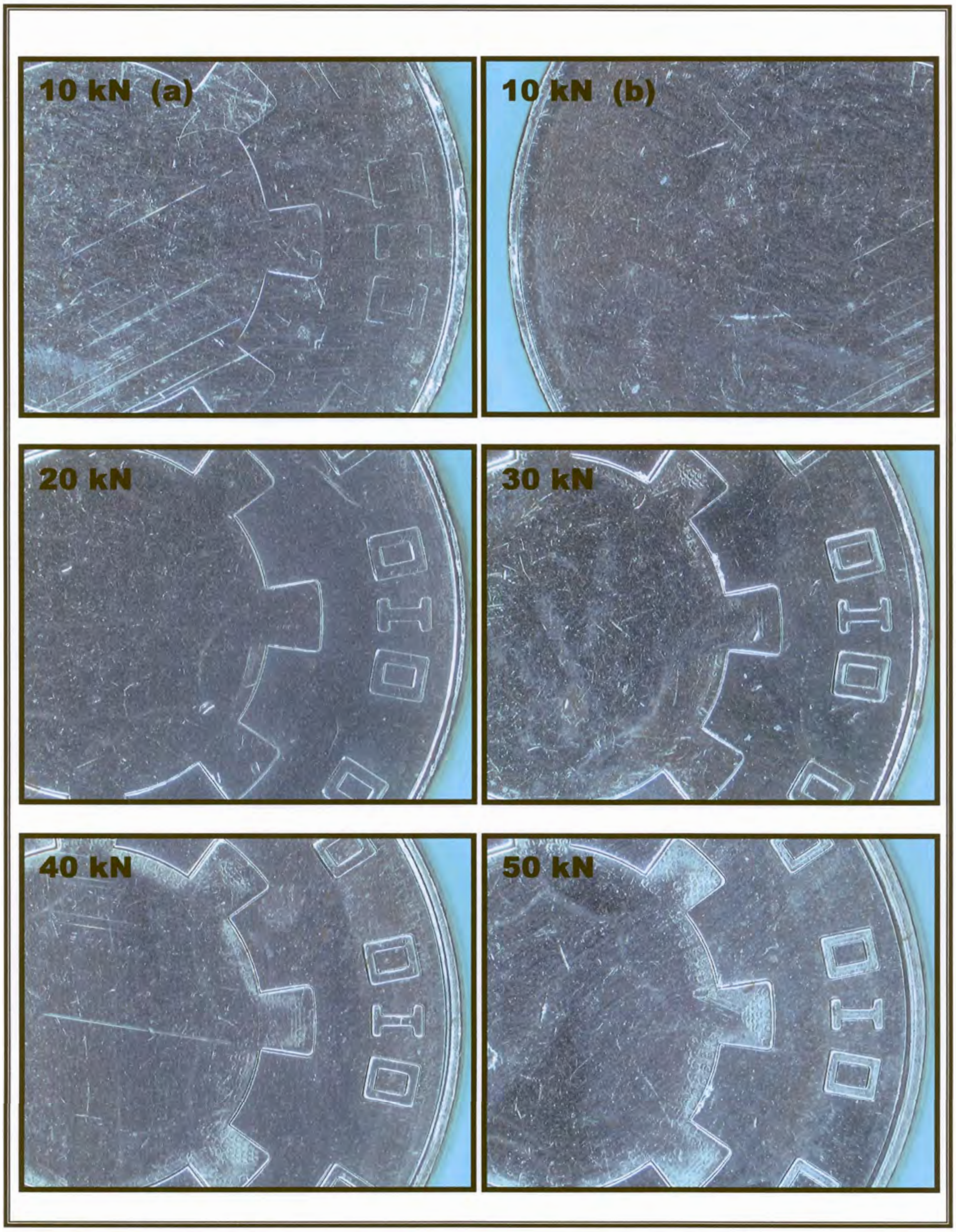


FIGURE 5.1 Coining test results. Coining force shown on each picture

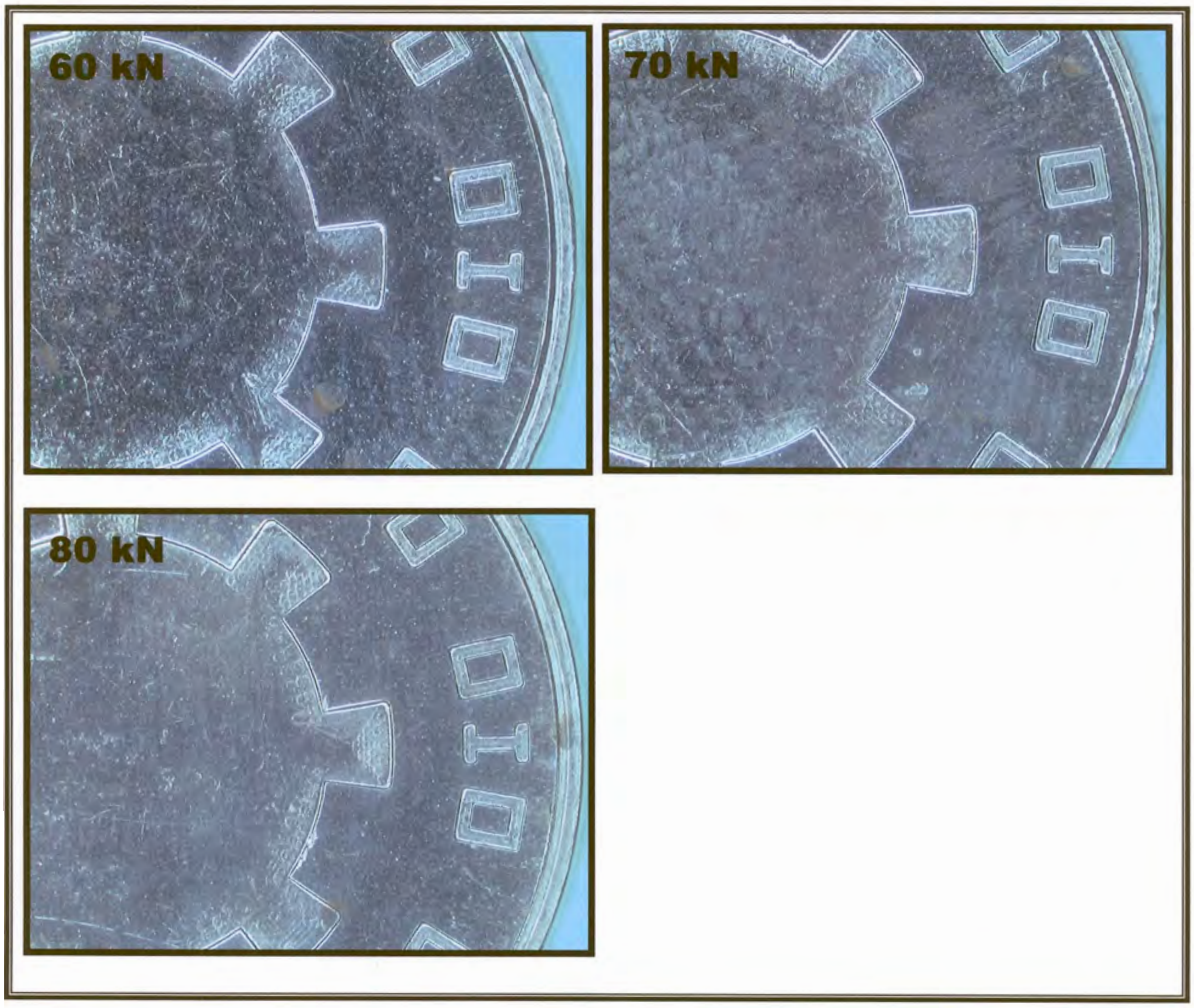


FIGURE 5.1 cont. Coining test results

The visual inspection for the products of this project will predominantly concentrate on coining defects and the evaluation of the detail transferred onto the coin. The detail is mainly evaluated according to the presence of fine detail and the sharpness of the detail transferred.

The hardness of the blanks was measured prior to coinage. 40 Samples were taken for this test. The hardness of the blanks was consistently between 100 H_v and 105 H_v. 1% of the blanks had a hardness between 130 H_v and 140 H_v. Such a large difference in hardness can cause serious problems during coining. If a hard blank is coined, the dies could fail due to the increased force required to coin the blank. To prevent such a difference, the blanks should be distributed evenly in the annealing furnace. The distribution of the blanks on the annealing furnace belt is not done properly. More distribution of the blanks on the belt is required. Foreign blanks should be prevented from entering the system and the coining press should be thoroughly cleaned if there is a denomination coining change as these blanks can cause serious damaged to the coining dies.

The progressive coining of the blanks was evaluated and it was seen that a coining force of 50 kN and higher produced coins with acceptable sharpness. Small improvements can be seen in the sharpness of the lettering and design edges for coining forces higher than 50 kN. The presence of milling marks on the coin is a sign of high quality detail transfer.

5.2.4 CONCLUSION

The sharpness of the detail is greatly influenced by the sharpness of the coalescence between different planes. The coining force is directly related to the sharpness of the detail. Due to the increasing standard in visual sharpness it is necessary to discover and investigate new ways to lower the coining force required to produce a certain amount of detail on the coin.

The coining force should also be kept as low as possible to prevent plastic deformation of the coining dies. Excessive coining forces can permanently deform the dies or it could cause the dies to crack. Lower coining forces will drastically increase die life. The most significant method of reducing the coining force and increasing die life is by reducing the hardness of the blanks. This aspect will receive attention during tests 6 and 7.

5.3 Test 6: 2nd Coining Test

5.3.1 PURPOSE

The purpose of Test 6 was to evaluate the progressive coining of the blanks with coining dies that has a deep design. Soft blanks will be tested and the results will be compared to the results of the normal blanks.

5.3.2 PROCEDURE

The procedure for conducting the test was similar to the procedure followed during Test 5. The detail specifications for the coining dies were as follows:

Design depth:	105 microns
Lettering depth:	135 microns
Landing depth:	185 microns
Dome height:	40 microns

The detail depths are very deep for a coin of this size. The landing was once again modeled relatively deep. More coining defects will be observed during this test because much more plastic flow of the blank is necessary to fill the coining die cavities.

5.3.3 RESULTS

The results obtained during the coining test are shown in Figure 5.2. The coining force that was applied is shown in the upper left hand corner of each picture. The coining dies were laser marked in the centre of the design during the manufacturing process. These markings can be seen on the coins, that were struck with a coining force of 60 kN and higher. This is a sign of high detail transfer.

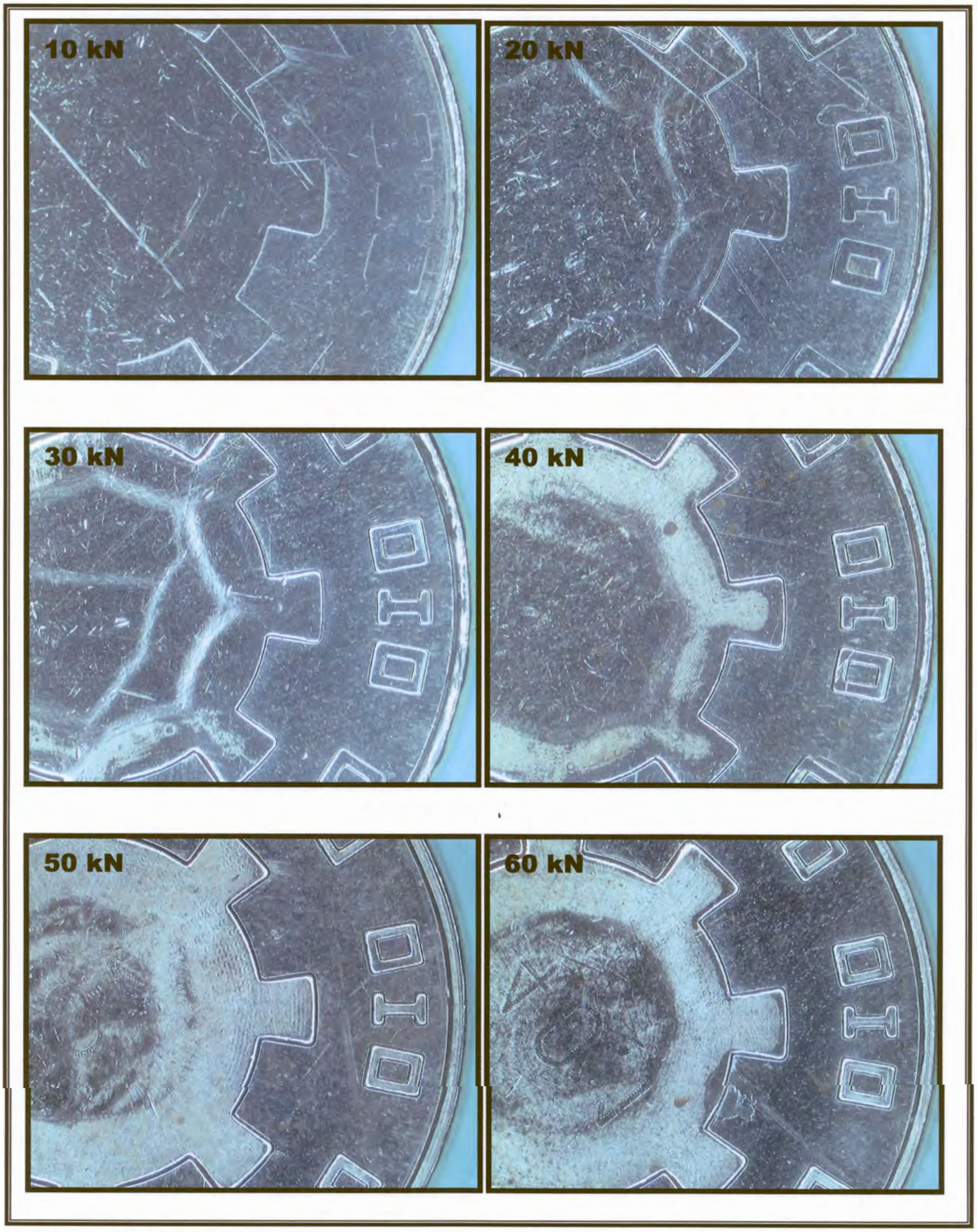


FIGURE 5.2 Coining test results.

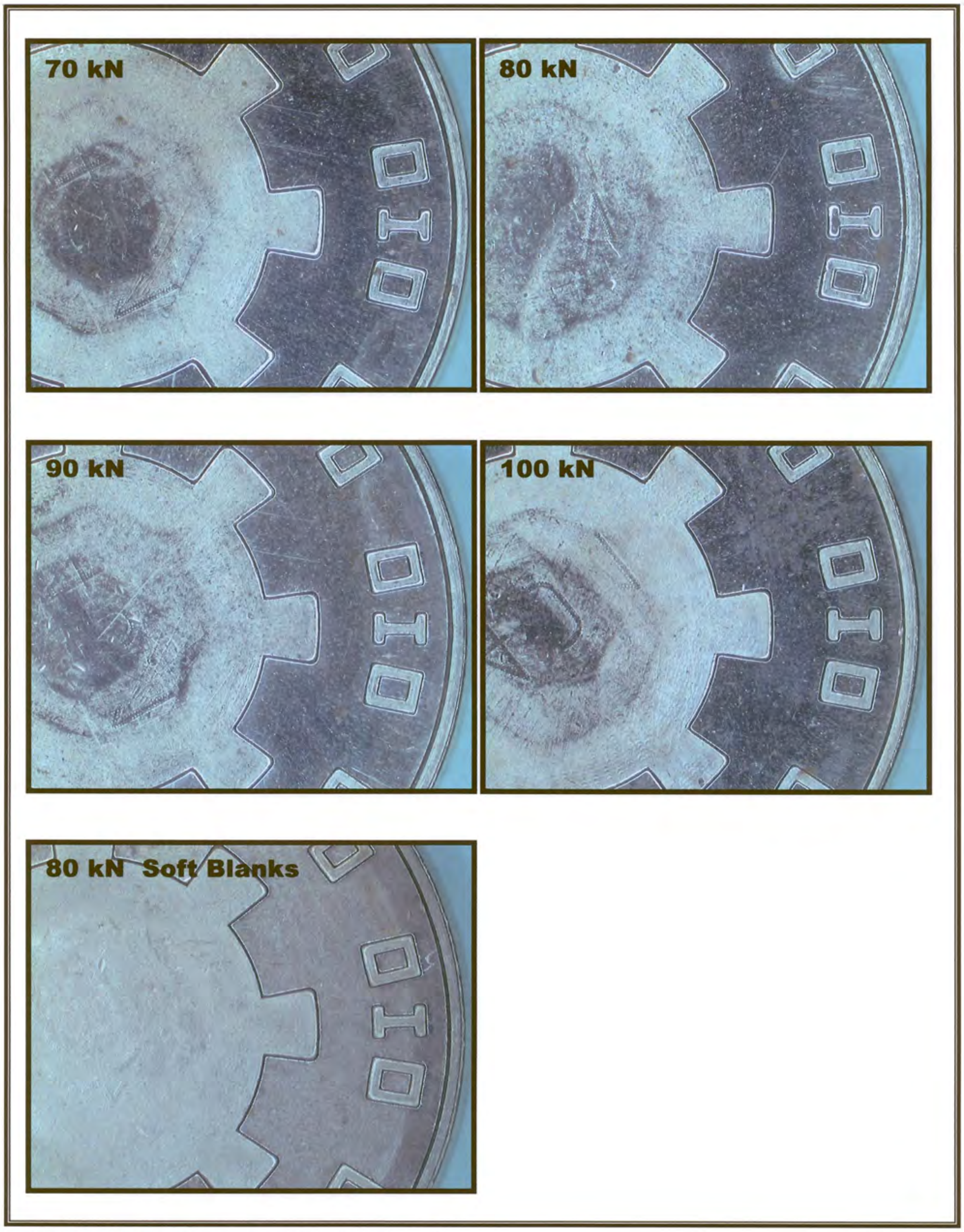


FIGURE 5.2 cont. Coining test results

At a coining load of 20 kN a wave is formed by material that flows from the outer edge of the design to the centre. This wave is created because there is not enough material in the centre of the blank to fill the die cavities. An increase in the sharpness of the design and lettering can be seen for increasing loads. The plastic deformation of the blank causes the dislocation density of the material to increase rapidly. The dislocation mobility decrease significantly and further plastic deformation becomes increasingly more difficult. The increased resistance to plastic deformation is called strain hardening. The yield strength of the blank increases dramatically and a further increase in the coining force can then cause the dies to fail. Due to strain hardening the wave that was created stops and the material starvation in the centre of the design cannot be completely removed, even at a coining load of 100 kN.

The hardness of the blanks was between 100 H_v and 105 H_V. A separate batch of blanks was annealed at a higher temperature to a hardness of 90 H_V. The softer blanks produced significant improvements in the sharpness of the design. At a coining load of 80 kN there was no sign of material starvation in the centre of the design and the sharpness of the design and the lettering is much better compared with the normal blanks coined at a load of 100 kN.

5.3.4 CONCLUSION

Increasing the dome height can reduce the material starvation that was observed in the centre of the design. This will be done during Test 7. It is important to note that a decrease of 10 H_v in the hardness of the blanks produced much better results. Due to the amount of strain hardening that occurred in the normal blanks excessive coining force will not improve the quality of the coins but will only lead to die failure.

5.4 Test 7: 3rd Coining Test

5.4.1 PURPOSE

The purpose of Test 7 was the same as Test 6. A few modifications were made to the coining dies for this test. Normal blanks as well as soft blanks were used during this coining test.

5.4.2 PROCEDURE

The procedure for conducting the test was similar to the procedure described for Test 5. The detail specifications for the coining dies were as follows:

Design depth: 100 microns
Lettering depth: 130 microns
Landing depth: 145 microns
Dome height: 90 microns

The landing height was decreased by 40 microns and the dome height was increase by 50 microns for this test. The increase in dome height will promote the coining of the design in the centre of the coin thereby reducing the amount of material starvation. Because the landing depth was reduced, slightly more material will be available to fill the remaining detail cavities. The same blanks were used for this test as was for Test 6.

5.4.3 RESULTS

The results obtained during the coining test are shown in Figure 5.3. The coining force that was applied is shown in the upper left hand corner of each picture.

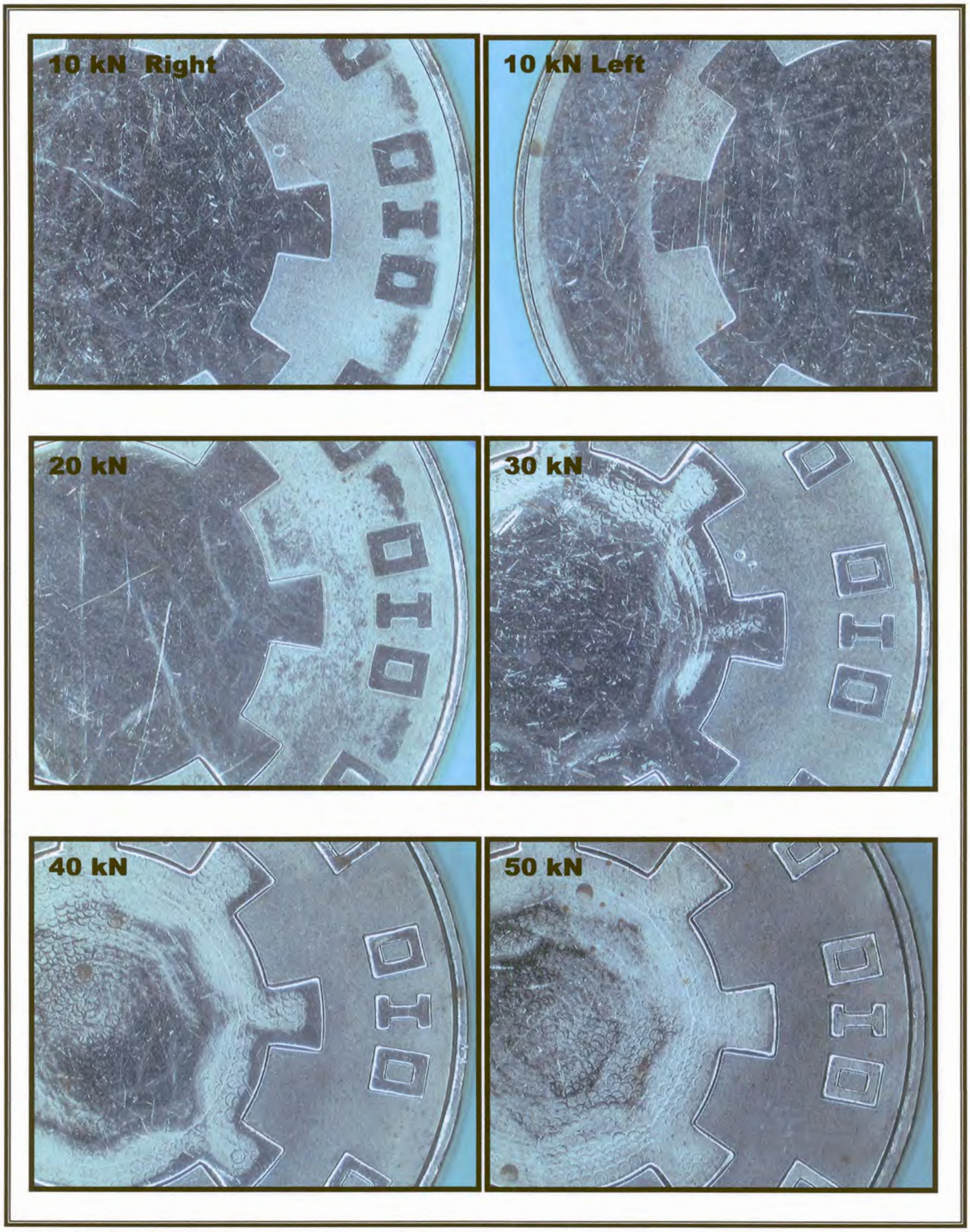


FIGURE 5.3 Coining test results. The coining load is shown on each picture.

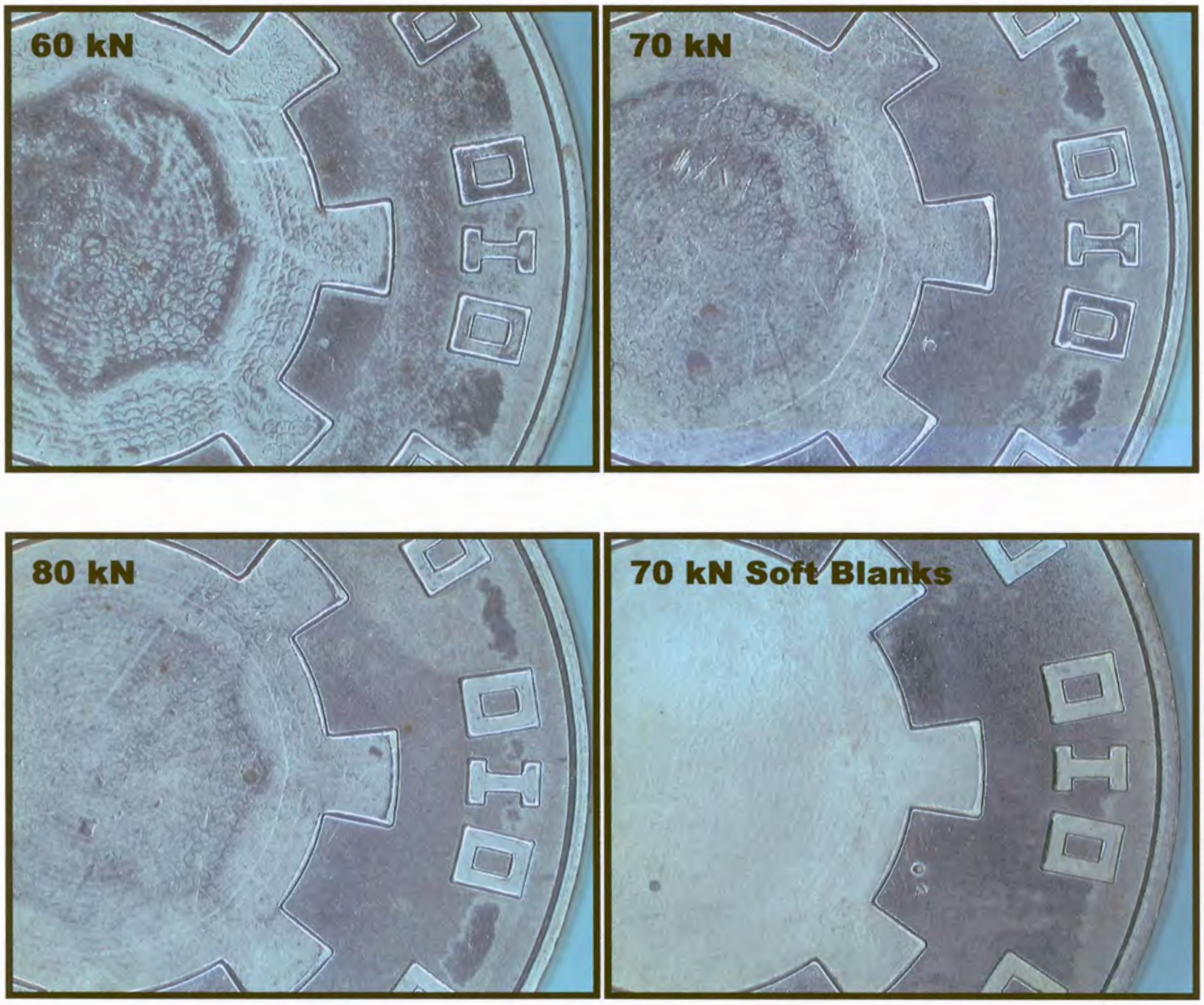


FIGURE 5.10 cont. Coining test results

At a coining load of 10 kN the misalignment of the dies can be seen. The lettering starts to coin on the right hand side of the coin but not on the left. The wave of material flow that was present in Test 6 can still be seen but it is much less. As expected the increase in dome size produced better coining results in the centre of the coin but the sharpness of the lettering and the edges of the design decreased. Once again much more detail was transferred to the soft blank.

During the final rolling of the steel sheets the hardness of the material increased from 100 H_v to above 200 H_v due to strain hardening. The amount of strain hardening that occurs, depends on the percentage reduction in thickness during the rolling process.

The coinability of the blanks is highly dependant on the hardness of the blanks prior to coining. Significant improvements can be obtained during coining by reducing the hardness of the blanks as was seen during the coining tests. This can be done in several ways. One method of reducing the hardness of the blank is by increasing the temperature of the annealing process. This can only be done to a certain extent since the plating layer forms bubbles if the annealing temperature is too high. The furnace belt speed can also be decreased, thereby increasing the annealing time.

Alternatively the blank material can thoroughly be annealed after final rolling and before blanking or after blanking and before plating. By annealing the material before blanking the amount of wear on the rim block and marking ring is reduced. During rimming the hardness of the edge will increase due to strain hardening. This hardening will prevent creep between the collar and the die during coining.

The minimum hardness of the blanks is limited by the grain size of the blank material. A large grain size will cause the surface finish of the blank to look like an orange peel. During the annealing process the metal structure will go through a series of changes namely, (1) recovery, (2) recrystallization and (3) grain growth. During cold working a lot of the strain energy is stored in the material in the form of dislocations. During annealing the dislocations are allowed to rearrange themselves in lower energy configurations and thereby the residual stresses are released. The recovery phase is followed by a recrystallization phase where new, strain free grains are nucleated and begin to grow in the metal structure. These new grains continue to grow until the entire structure is replaced by a recrystallized structure.

The amount of recrystallization that takes place depends on the annealing temperature and duration. During the annealing process the strength and hardness of the material is decreased while the ductility and therefore coinability of the metal is increased.

From the work of Petch [1] and Hall [2], the yield strength of a polycrystalline material could be given by,

$$\sigma_{ys} = \sigma_i + k_y d^{-1/2}$$

where σ_{ys} = yield strength of polycrystalline sample.

σ_i = overall resistance of lattice to dislocation movement.

k_y = "locking parameter" which measures relative hardening contribution of grain boundaries.

d = grain size.

It is clear that the strength of the material is proportional to dislocation density and inversely proportional to grain size. The grain boundaries act as barriers to the movement of dislocations and a structure with a small grain size effectively has more barriers [3,4].

5.4.4 CONCLUSION

During the coining tests it was seen that for a blank hardness of 90 H_v the grain size was sufficiently low, not to have any noticeable affect on the surface finish. Further research is recommended to determine the minimum hardness of the blanks that will still provided an acceptable surface finish.

Valuable information was obtained during the coining tests. The use of progressive coining tests, as described in this chapter, are recommended for all development projects. Information was obtained by means of this test method that would otherwise not have been possible. It is easy to see which part of the design starts to coin first and which areas have difficulty in coining properly. Modifications can now be made to the design to improve the coinability of the blanks.

5.5 Calibration of High Speed Coining Press

5.5.1 INTRODUCTION

The coining presses that are in use at the S.A Mint gives a digital readout of the applied force during coining. These presses should be calibrated to ensure that all the presses give the same readout for a certain applied force. The coining force necessary to produce coins for a specific denomination can then be compared to the results obtained through previous coining operations. By calibrating the presses a baseline is established and deviations in the coining force can easily be detected.

Ideally the coining presses should be calibrated to give an accurate reading of the coining force. The manufacturer of the coining press should do the calibration or the task should be outsourced to a company with the required capabilities. This may prove to be difficult and expensive, therefore an alternative procedure will be suggested whereby the coining presses can be calibrated.

5.5.2 PROCEDURE

It is not crucial that the coining presses give a very accurate reading of the applied force. What is of utmost importance is that all the presses give the same reading for a specific applied force even though it may not represent the actual applied force. A simplified procedure was developed that will enable the S.A Mint to do the calibration. The procedure is outlined below.

IMPORTANT: All tolerances on the specifications of the tooling and the material that will be used during the calibration test should be very tight to ensure accurate results during the calibration.

1. **Choose blanks**

   To simplify the process, any existing blank design can be used. A blank design must be chosen and specified for the test. The hardness of the blanks should be specified and one should ensure that all the blanks have the same hardness. This blank design must be used for all subsequent calibrations once it has been chosen.

2. **Choose design**

   A coining die design must be selected for the calibration procedure. An exaggerated profile of the suggested die design is shown in Figure 5.4. Any design that has a clear reference point can be used for the calibration. The detail dimensions of the die should be chosen such that the reference point starts coining at a force of about 60 or 70 kN. The evaluation criteria of the calibration coins should be clearly stated.

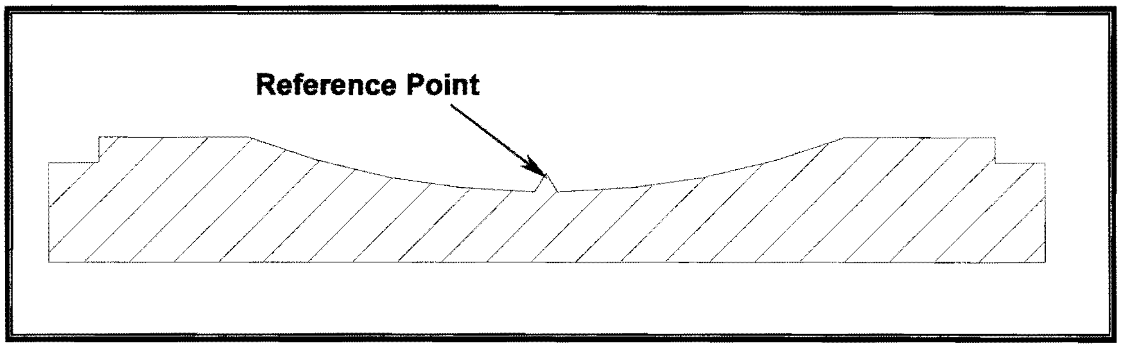


FIGURE 5.4 Calibration Die Design

3. Specify tooling sizes

This includes the diameter of the collar and the die neck.

4. Manufacture tooling

The hardness of the dies should be specified and checked. The material that will be used for the calibration dies should be specified.

A reference press is chosen and the calibration dies are used to coin the blanks at a specified speed. The coining force is gradually increased from zero. A soon as the reference mark start to coin, the applied force is noted and the coining operation is stopped. The calibration dies are then inserted into the second press and the same procedure is followed. As soon as the reference mark starts to coin the reading on the press is noted and must be adjusted to give the same reading as the reference press. This process continues until all the presses have been calibrated.

All the presses will now give the same reading for a certain applied force. This calibration should be done frequently to ensure consistency in the coining loads. If this is done it will be easier to determine the cause for coining force difference for a specific denomination. If, for example, one press coins at a higher load than the other presses a possible cause could be attributed to misalignment of the dies or to blank hardness differences.

REFERENCES

1. N.J Petch, **JISI 173,** 25 (1953)

2. E.O Hall, **Proc. Phys. Soc. B 64,** 747 (1951)

3. Richard W. Hertzberg, **Deformation and fracture Mechanics of Engineering Materials,** John Wiley & Sons Inc., p. 129 – 130, (1996)

4. William F. Smith, **Principles of Materials Science and Engineering,** McGraw-Hill, p. 290 – 296, (1990)

SECTION C

DESIGN PROTOCOL

CHAPTER 6

DESIGN PROTOCOL

6.1 Introduction

The tests that were conducted during the project revealed valuable information about the development and production process. The results and the recommendations for each test have already been discussed in the previous sections. A new design protocol will now be established using the information that was gathered during the tests. The protocol will not contain all the development and production details and it does not replace current development procedures. It should be regarded as an overview of the development process, which concentrates on certain critical development issues. Where recommendations are given the reader is referred to the relevant section in the report for a detail discussion regarding the rationale behind the recommendation.

The purpose of the design protocol is to enable the developer to achieve improved results during the development process. The design protocol can also be used as a tool to establish the cause and recourse for certain development problems. The main objective of the protocol is to improve consistency in the results that are obtained during the development process.

The design protocol will be presented in the form of a checklist and will span from the acquisition of the die and blank material to the final production of the coins. The protocol will be broken down into several sections. The heading of each section will refer to the chapter containing the relevant research material.

6.2 Design Protocol

I. Material Analysis CHAPTER 1

1. Tool Steel
   - Composition Analysis
   - Chemical Element distribution
   - Microstructure
   - Nondestructive Testing
   - Hardness Test (*Ref*: Par. 1.2.2.5)

     The hardness should be checked on all incoming material, especially the tool steel. The initial hardness of the tool steel greatly affects its behaviour during the deformation and heat treatment processes. An even hardness distribution is essential for consistent results.

2. Blank Material
   - Composition Analysis
   - Hardness Test

     The hardness of the blank material should be tested to ensure that the hardness is within the specifications.

II. Coin Design CHAPTER 2

1. CNC Engraver

- The development time is reduced dramatically if the design can be engraved on the CNC engraver. Therefore the CNC engraver software and hardware should continuously be upgraded to enhance its capabilities.

III. Blank Design CHAPTER 3

1. Development of blanks

- The blanks should be redeveloped for all denominations where coining problems occur, to ensure that all specifications are correct.
- Development of rimming profile.

  Future development should be done on the rimming profile to improve coining results. The rimming profile has a significant effect on material flow during coining.

IV. Development of Master Punch CHAPTER 4

1. Manufacturing of die blanks (*Ref*: par. 4.8)

- Manufacture die blanks with cone angle.

  Currently a cone angle of 30° is used for all the die blanks. For this project a cone angle of 35° yielded the best results regarding transfer of detail and dimensional stability. The optimal cone angle should be determined for each project by varying the cone angle and recording the results.

- Heat-treat die blanks.

  The die blanks should be annealed prior to hobbing. There are two main reasons for this. The first is to ensure an even hardness distribution between the die blanks. This will lead to greater consistency during the hobbing process. The second is to reduce the required hobbing force and to increase the amount of detail transfer. The decrease in hobbing force will reduce the amount of plastic deformation to the matrix during hobbing.

- Specify manufacturing process.

  The diameter and length of the die blanks should be specified with a close tolerance. This will improve consistency during the hobbing and heat treatment processes. The machining procedure should be specified and should remain constant.

- Collect data

  Data should be collected for all projects regarding the optimal die blank cone angle and hardness. This will improve repeatability.

2. Hobbing (*Ref*: par. 4.8)

- Hobbing alignment

  Ensure that centre of matrix is in-line with die blank point during hobbing. The die blank point must make contact with the centre of the matrix.

- Record required hobbing force and maintain that force for all subsequent hobbing processes for that specific denomination.

- Consistency of utmost importance.

3. Machine master punch.

- Machine master punch according to specifications.

  Specify concentricity of design relative to the body of the design.

  Keep machining practice constant.

- Modify shape and dimensions of master punch slots. (*Ref*: par. 4.9)

  The new slot dimensions should be specified to ensure consistency in the manufacturing process.

4. Heat treatment

- Ensure that correct temperatures are used according to the specifications.
- Avoid heat-treating objects with large size differences in one process.
- Distribute dies evenly in furnace.

  The packing of the dies and punches in the furnace has a significant effect on the dimensional stability of the dies. If the dies are packed close together the dies in the middle will experience a different cooling rate, and therefore dimensional change, than those on the outside. Ensure that the dies are spaced at equal distances apart in all directions. A template can be manufactured to ensure repeatability in the spacing distances.

- Attempt to heat-treat an equal number of dies.

  This will not always be possible but note that the amount of material in the furnace also has an effect on the cooling rate of the dies. Dummy dies can be used to make up numbers during heat treatment. These dies can be used repeatedly. The dummy dies can also be used to ensure that every die has an adjacent die on every side.

- Record dome size

  The shape change of the dome size during hobbing and heat treatment will vary for every denomination. The shape change should be recorded and can then be used as an input for future development.

V. Coining CHAPTER 5

1. Blanks (*Ref*: par. 5.1 - 5.4)

- Heat-treat blanks.

  The blanks should be annealed to reduce the hardness of the blanks. Softer blanks significantly improve coining results. The coining force is reduced and the detail transfer is superior to that of harder blanks. The relative importance of the dome height is also reduced if the coining force is reduced.

- Check hardness of blanks to establish hardness distribution.

2. Coining dies

- Stress concentration (*Ref*: par. 4.9)

  The stress concentration present at the bottom of the die neck should be reduced by introducing a minimum fillet radius of 5 mm at this location.

- Alignment of dies

  The coining dies should be aligned as parallel as possible, to reduce the high localized stresses that are set up at the edge of the die due to the skew alignment of the dies.

3. Calibration of coining presses. (*Ref*: par. 5.5)

   - The coining presses should be calibrated to ensure that all the presses give the same reading for a specific applied force.
   - Consistency in coining forces should be maintained.

At the end of the day a complete data sheet must be developed for all the denominations. When a specific denomination is produced, this data sheet can be obtained and used to produce repeatable results in the development and production processes.

6.3 Conclusion

The objectives of the project have been met successfully. The design protocol that has been established will allow the developer to achieve better results during the development and production of the coining dies.

The design protocol addresses the major contributing factors for successful die development. The key to successful die development lies in consistency. By improving consistency on all aspects of the development process, fewer problems will be encountered and less iteration will be required to achieve the desired results. Less iterations translates into a reduction in development time and a significant reduction in development cost.

The project concentrated on the development and production of the coining dies. Attention was given to the coining blanks but further development of the blanks is necessary since these two products are so closely related.

Further development efforts should concentrate on the reduction of the required coining force. Many of the problems that occur are problems that arise due to unnecessary high coining forces. Development of the blanks is one of the most significant ways to reduce the required coining force.

The Four Cartesian Rules:

- Never accept anything as true if you do not have objective evidence of its being so.
- Reduce each complex problem into separate parts, as many as are feasible and necessary to obtain a solution to the problem.
- Obtain a solution through ordered sequence of logical steps, ascending from simple to complex, from small to large.
- Make complete enumerations throughout, so as not to overlook anything.

> If you do this, there can be nothing too remote to be reached, or too well hidden to be discovered.
>
> René Descartes (1596-1650)

Appendix F

TEST 4 RESULTS

Test 4 Matrix Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	51.647	**26**	51.704
2	51.648	**27**	51.843
3	51.645	**28**	51.705
4	51.639	**29**	51.849
5	51.633	**30**	51.712
6	51.631	**31**	51.856
7	51.635	**32**	51.721
8	51.640	**33**	51.861
9	51.848	**34**	51.755
10	51.846	**35**	51.843
11	51.832	**36**	51.735
12	51.818	**37**	51.827
13	51.809	**38**	51.721
14	51.810	**39**	51.837
15	51.821	**40**	51.731
16	51.838	**41**	20.440
17	51.865	**42**	20.443
18	51.729	**43**	13.106
19	51.864	**44**	13.100
20	51.726	**45**	51.725
21	51.849	**46**	51.856
22	51.711	**47**	51.831
23	51.848	**48**	51.825
24	51.711	**49**	51.846
25	51.845		

Landing

Ref. Point	*Depth*
1	0.201
2	0.198
3	0.187
4	0.179
5	0.176
6	0.179
7	0.186
8	0.198
Average	**0.188**

Design

Ref. Point	*Depth*
17	0.136
19	0.138
21	0.138
23	0.137
25	0.141
27	0.138
29	0.137
31	0.135
Average	**0.138**

Lettering

Ref. Point	*Depth*
33	0.106
35	0.108
37	0.106
39	0.106
Average	**0.107**

Dome

0.035

Diameter

Ref. Point	*Diameter*
D1	49.938
D2	49.941
D3	49.946
D4	49.949
D5	49.951
D6	49.950

Test 4 Matrix Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	51.620	**26**	51.678
2	51.621	**27**	51.817
3	51.620	**28**	51.678
4	51.611	**29**	51.822
5	51.603	**30**	51.686
6	51.601	**31**	51.830
7	51.606	**32**	51.694
8	51.613	**33**	51.830
9	51.822	**34**	51.723
10	51.820	**35**	51.817
11	51.805	**36**	51.709
12	51.790	**37**	51.798
13	51.782	**38**	51.686
14	51.784	**39**	51.806
15	51.795	**40**	51.696
16	51.812	**41**	20.441
17	51.839	**42**	20.429
18	51.704	**43**	13.096
19	51.838	**44**	13.085
20	51.702	**45**	51.697
21	51.833	**46**	51.830
22	51.696	**47**	51.806
23	51.824	**48**	51.801
24	51.685	**49**	51.824
25	51.818		

Landing

Ref. Point	*Depth*
1	0.202
2	0.199
3	0.185
4	0.179
5	0.179
6	0.183
7	0.189
8	0.199
Average	**0.189**

Design

Ref. Point	*Depth*
17	0.135
19	0.136
21	0.137
23	0.139
25	0.140
27	0.139
29	0.136
31	0.136
Average	**0.137**

Lettering

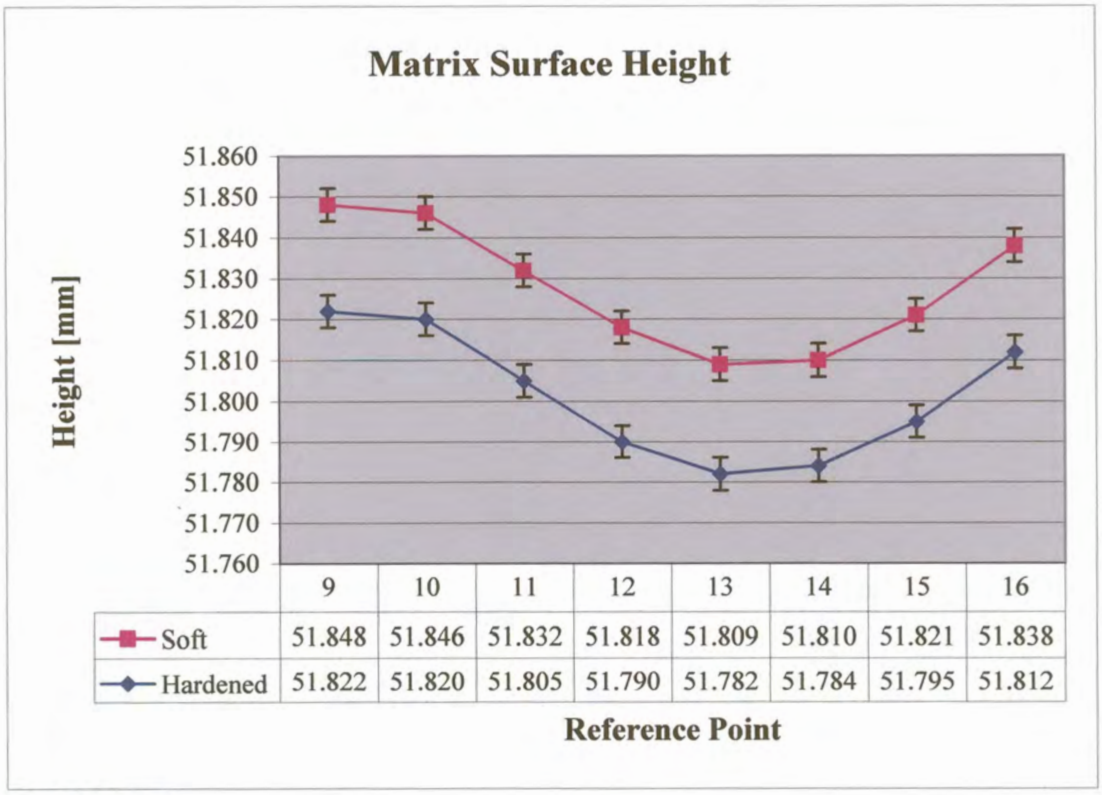
Ref. Point	*Depth*
33	0.107
35	0.108
37	0.112
39	0.110
Average	**0.109**

Dome

0.033

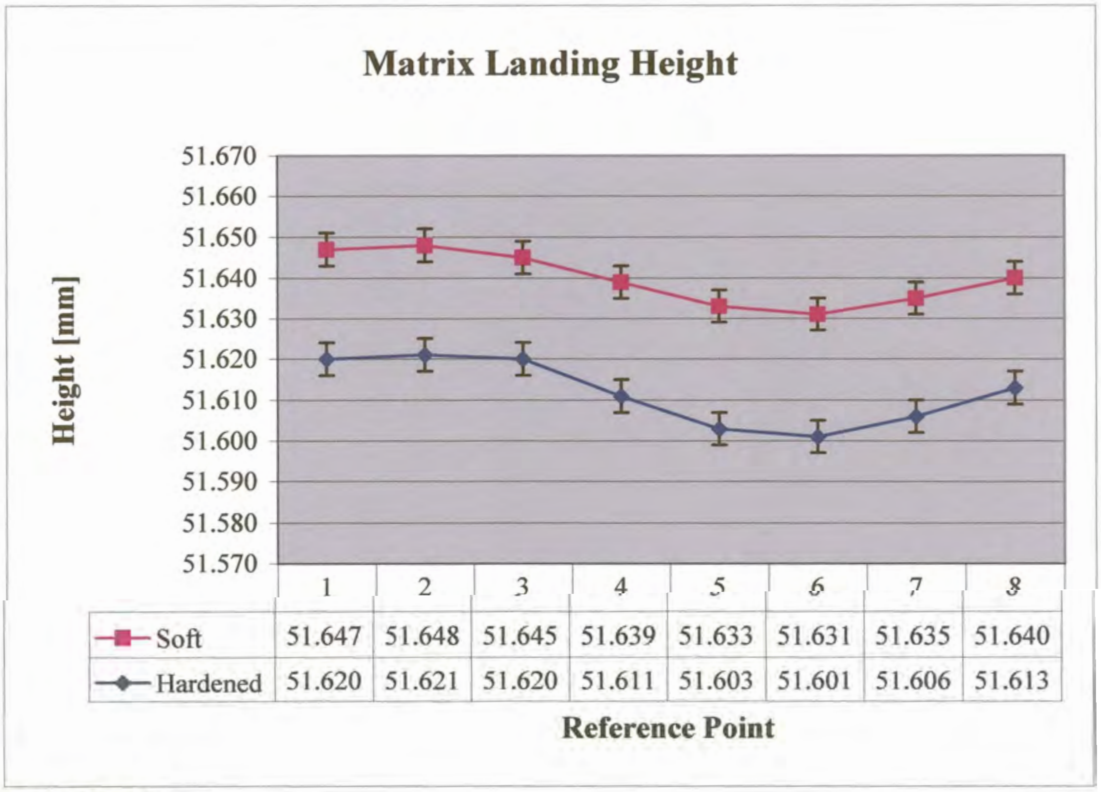
Diameter

Ref. Point	*Diameter*
D1	49.915
D2	49.910
D3	49.925
D4	49.921
D5	49.921
D6	49.922



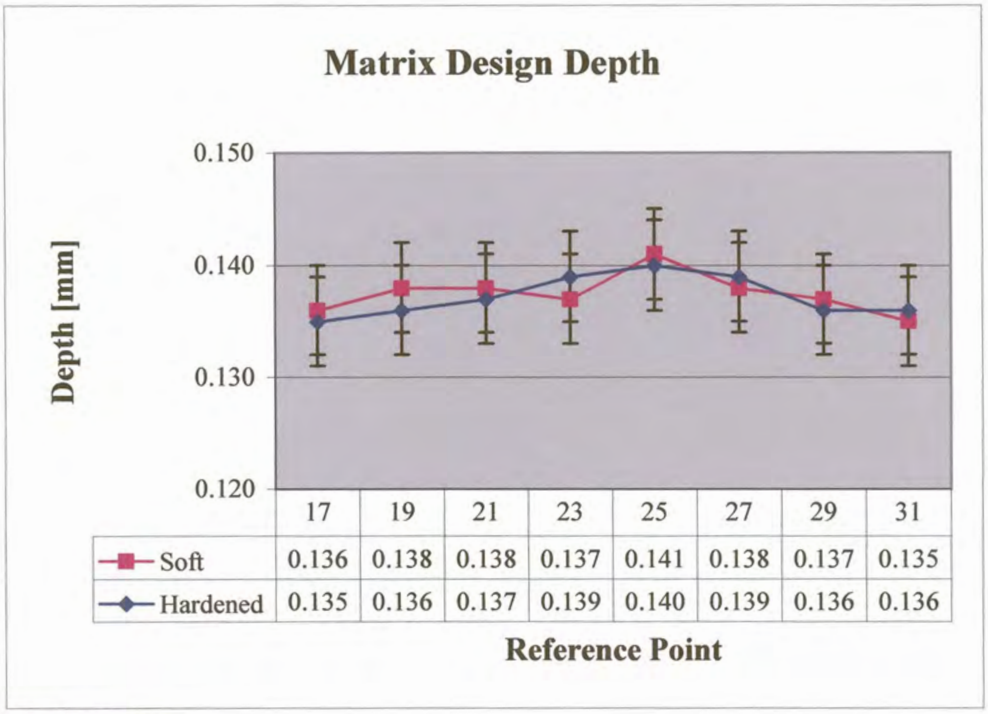
	9	10	11	12	13	14	15	16
🟥 Soft	51.848	51.846	51.832	51.818	51.809	51.810	51.821	51.838
◆ Hardened	51.822	51.820	51.805	51.790	51.782	51.784	51.795	51.812

FIGURE F 1



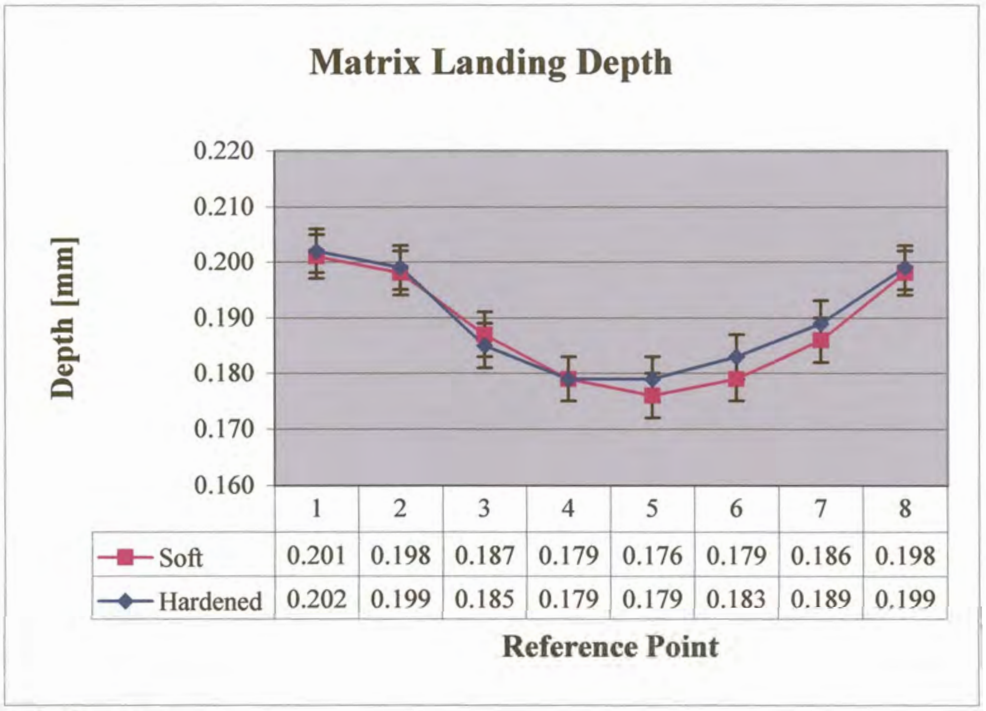
	1	2	3	4	5	6	7	8
🟥 Soft	51.647	51.648	51.645	51.639	51.633	51.631	51.635	51.640
◆ Hardened	51.620	51.621	51.620	51.611	51.603	51.601	51.606	51.613

FIGURE F 2



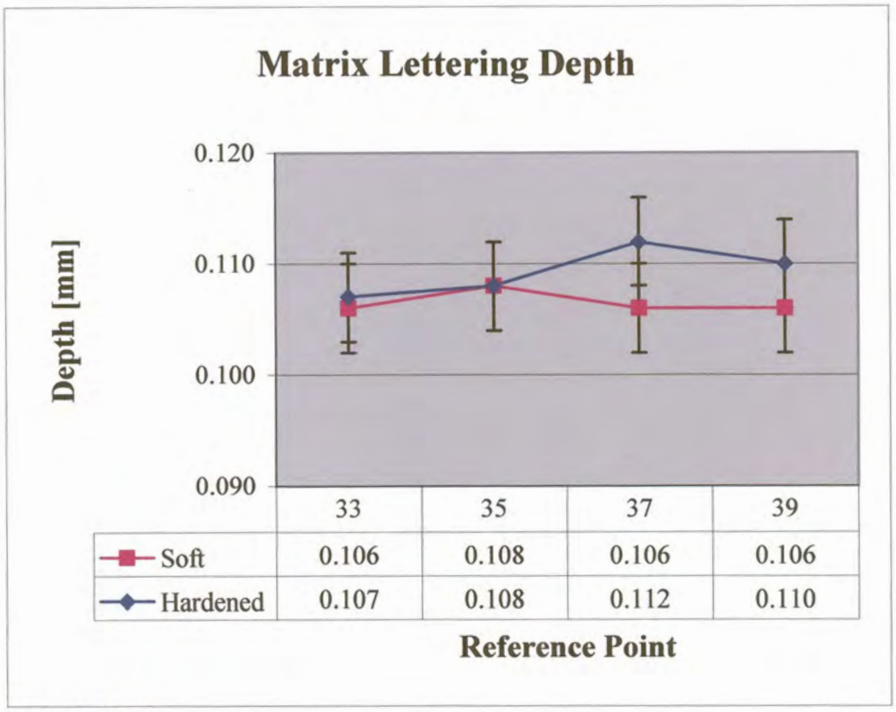
Reference Point	17	19	21	23	25	27	29	31
Soft	0.136	0.138	0.138	0.137	0.141	0.138	0.137	0.135
Hardened	0.135	0.136	0.137	0.139	0.140	0.139	0.136	0.136

FIGURE F 3



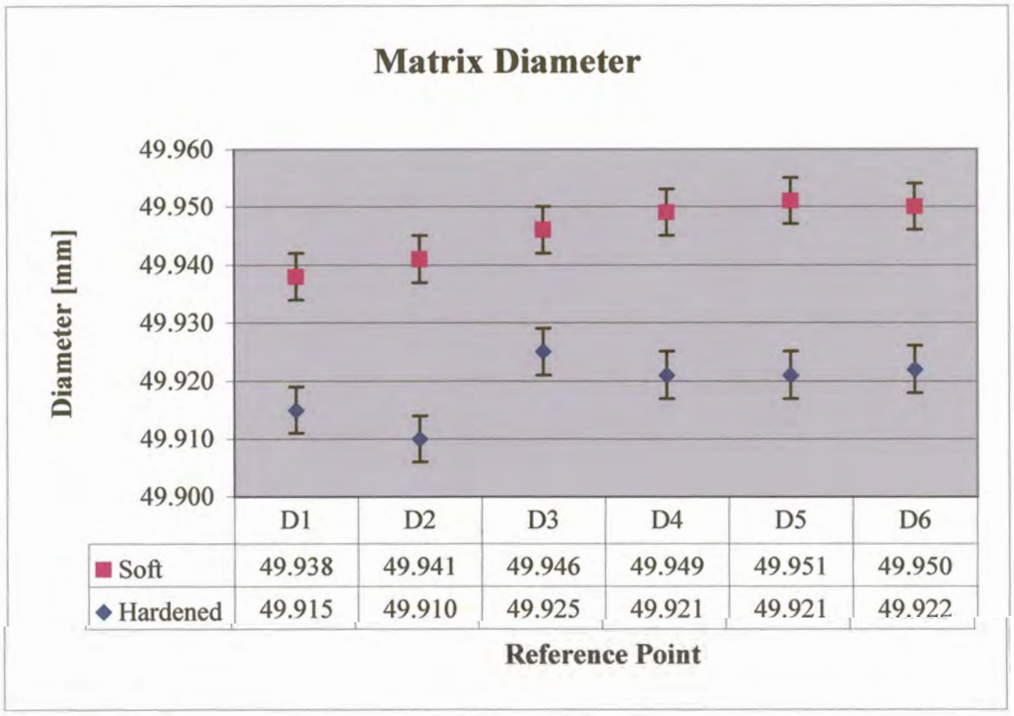
Reference Point	1	2	3	4	5	6	7	8
Soft	0.201	0.198	0.187	0.179	0.176	0.179	0.186	0.198
Hardened	0.202	0.199	0.185	0.179	0.179	0.183	0.189	0.199

FIGURE F 4



	33	35	37	39
Soft	0.106	0.108	0.106	0.106
Hardened	0.107	0.108	0.112	0.110

FIGURE F 5



	D1	D2	D3	D4	D5	D6
Soft	49.938	49.941	49.946	49.949	49.951	49.950
Hardened	49.915	49.910	49.925	49.921	49.921	49.922

FIGURE F 6

Master Punch 20.1 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	65.716	**26**	65.727
2	65.716	**27**	65.593
3	65.723	**28**	65.729
4	65.728	**29**	65.590
5	65.733	**30**	65.724
6	65.729	**31**	65.583
7	65.723	**32**	65.715
8	65.717	**33**	65.544
9	65.535	**34**	65.651
10	65.532	**35**	65.549
11	65.542	**36**	65.658
12	65.555	**37**	65.571
13	65.567	**38**	65.679
14	65.567	**39**	65.563
15	65.558	**40**	65.672
16	65.546	**41**	20.534
17	65.577	**42**	20.530
18	65.709	**43**	13.157
19	65.572	**44**	13.167
20	65.708	**45**	65.731
21	65.576	**46**	65.540
22	65.713	**47**	65.560
23	65.584	**48**	65.570
24	65.720	**49**	65.553
25	65.592		

Landing

Ref. Point	*Depth*
1	0.181
2	0.184
3	0.181
4	0.173
5	0.166
6	0.162
7	0.165
8	0.171
Average	**0.173**

Design

Ref. Point	*Depth*
17	0.132
19	0.136
21	0.137
23	0.136
25	0.135
27	0.136
29	0.134
31	0.132
Average	**0.135**

Lettering

Ref. Point	*Depth*
33	0.107
35	0.109
37	0.108
39	0.109
Average	**0.108**

Dome

0.046

Diameter

Ref. Point	*Diameter*
D1	40.045
D2	40.044
D3	40.015
D4	40.016
D5	40.000
D6	39.999

Master Punch 20.1 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	65.685	**26**	65.690
2	65.684	**27**	65.559
3	65.693	**28**	65.695
4	65.698	**29**	65.556
5	65.702	**30**	65.691
6	65.699	**31**	65.548
7	65.693	**32**	65.680
8	65.685	**33**	65.510
9	65.500	**34**	65.617
10	65.497	**35**	65.514
11	65.507	**36**	65.620
12	65.522	**37**	65.538
13	65.534	**38**	65.648
14	65.534	**39**	65.532
15	65.526	**40**	65.640
16	65.512	**41**	20.520
17	65.541	**42**	20.521
18	65.675	**43**	13.145
19	65.536	**44**	13.147
20	65.673	**45**	65.688
21	65.540	**46**	65.505
22	65.677	**47**	65.527
23	65.547	**48**	65.538
24	65.683	**49**	65.520
25	65.556		

Landing

Ref. Point	*Depth*
1	0.185
2	0.187
3	0.186
4	0.176
5	0.168
6	0.165
7	0.167
8	0.173
Average	**0.176**

Design

Ref. Point	*Depth*
17	0.134
19	0.137
21	0.137
23	0.136
25	0.134
27	0.136
29	0.135
31	0.132
Average	**0.135**

Lettering

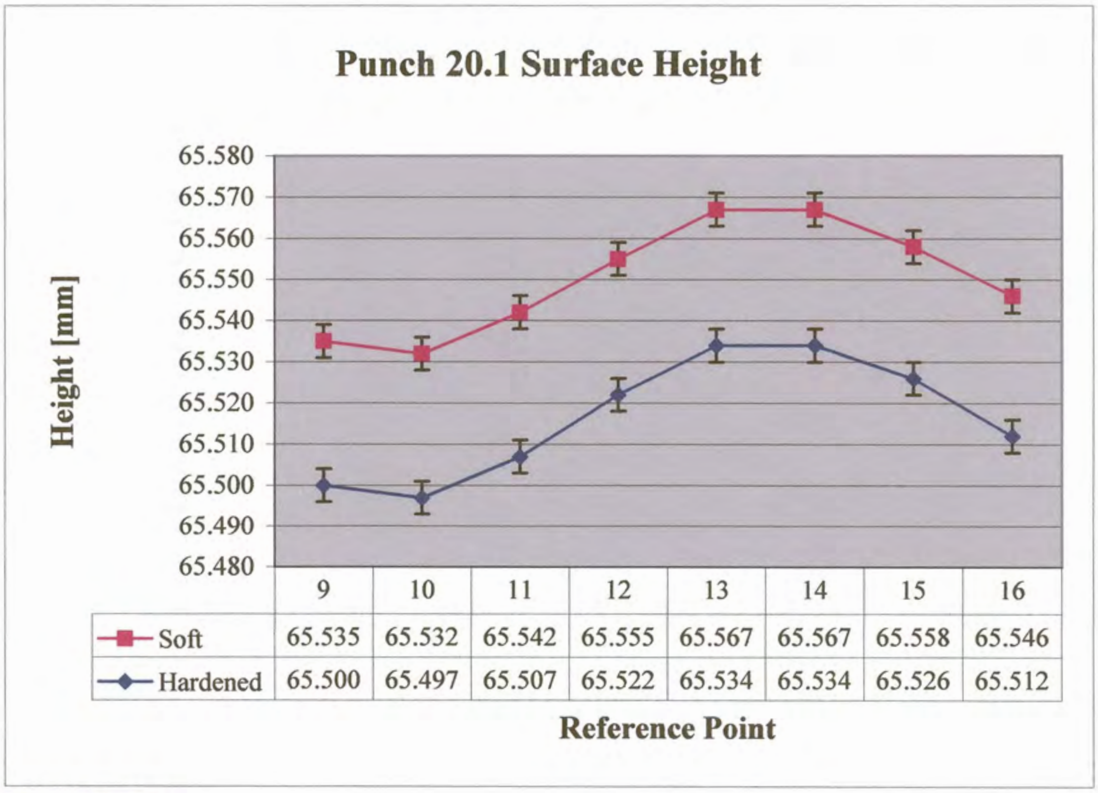
Ref. Point	*Depth*
33	0.107
35	0.106
37	0.110
39	0.108
Average	**0.108**

Dome

0.036

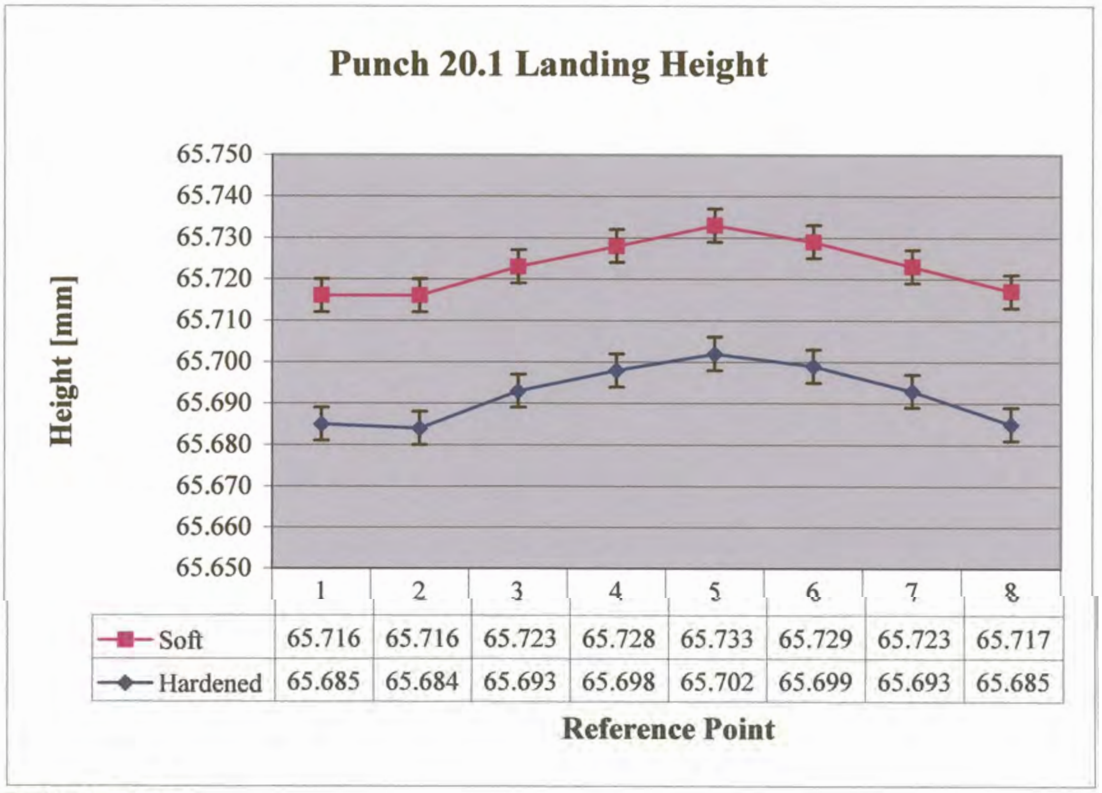
Diameter

Ref. Point	*Diameter*
D1	40.034
D2	40.035
D3	40.003
D4	40.003
D5	39.987
D6	39.989



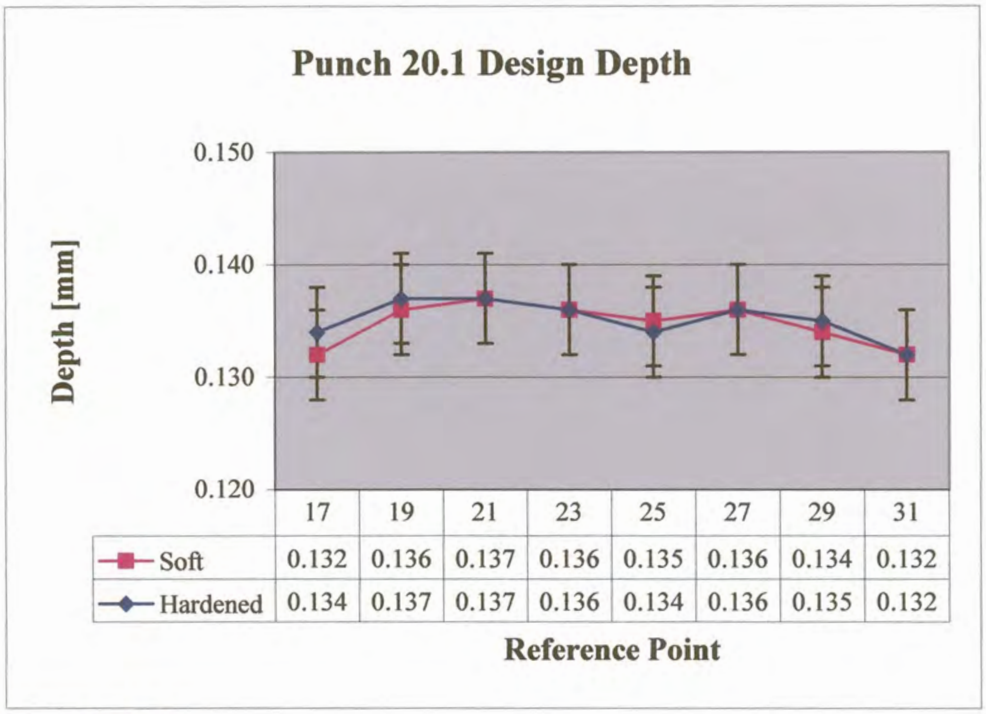
	9	10	11	12	13	14	15	16
Soft	65.535	65.532	65.542	65.555	65.567	65.567	65.558	65.546
Hardened	65.500	65.497	65.507	65.522	65.534	65.534	65.526	65.512

FIGURE F 7



	1	2	3	4	5	6	7	8
Soft	65.716	65.716	65.723	65.728	65.733	65.729	65.723	65.717
Hardened	65.685	65.684	65.693	65.698	65.702	65.699	65.693	65.685

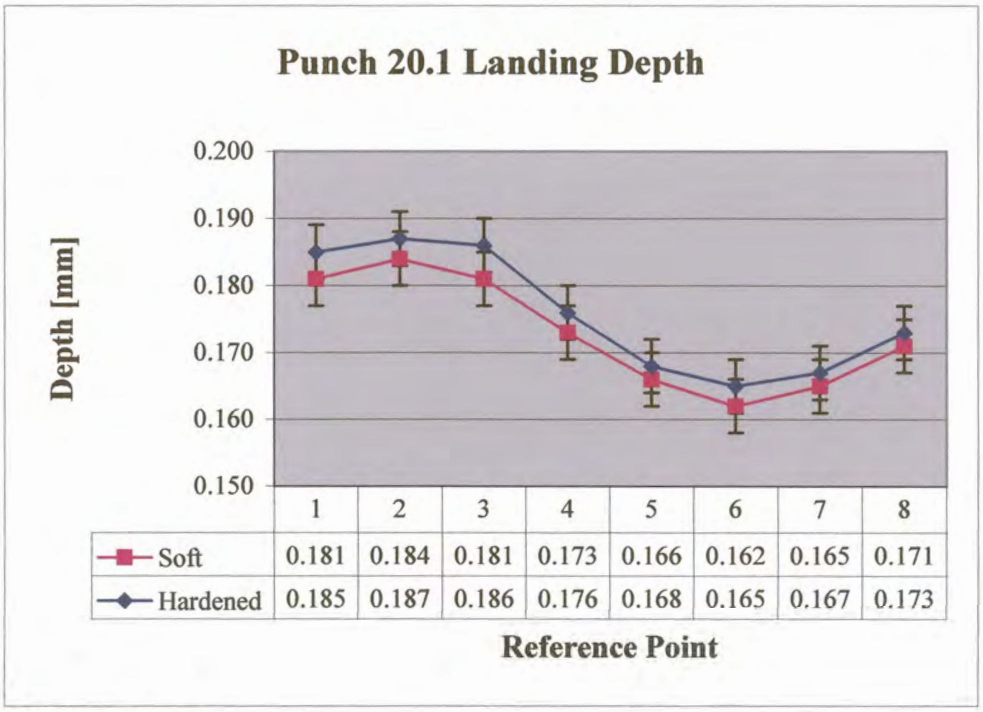
FIGURE F 8



Punch 20.1 Design Depth

	17	19	21	23	25	27	29	31
Soft	0.132	0.136	0.137	0.136	0.135	0.136	0.134	0.132
Hardened	0.134	0.137	0.137	0.136	0.134	0.136	0.135	0.132

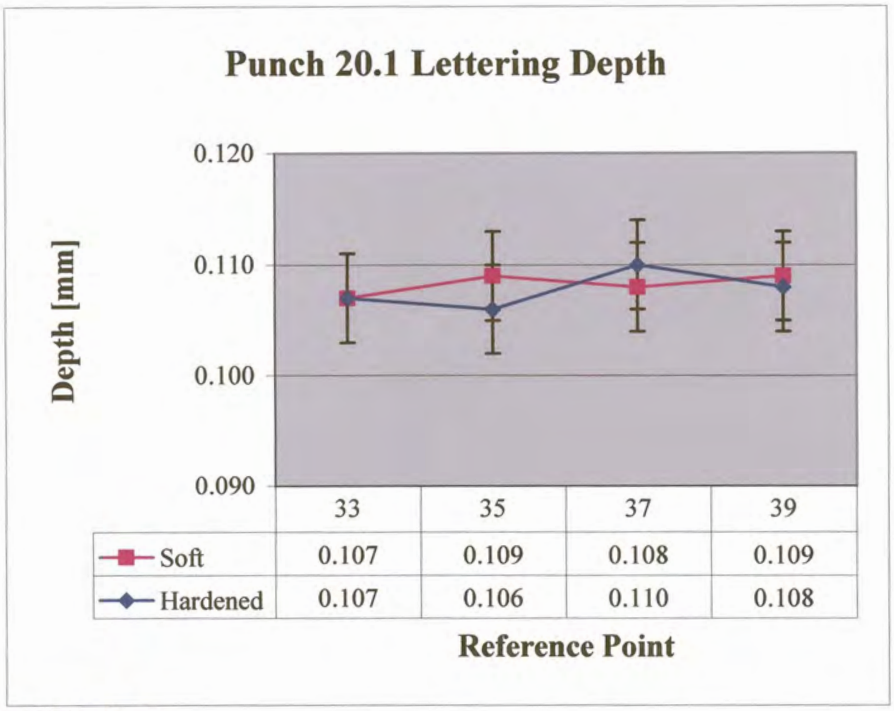
FIGURE F 9



Punch 20.1 Landing Depth

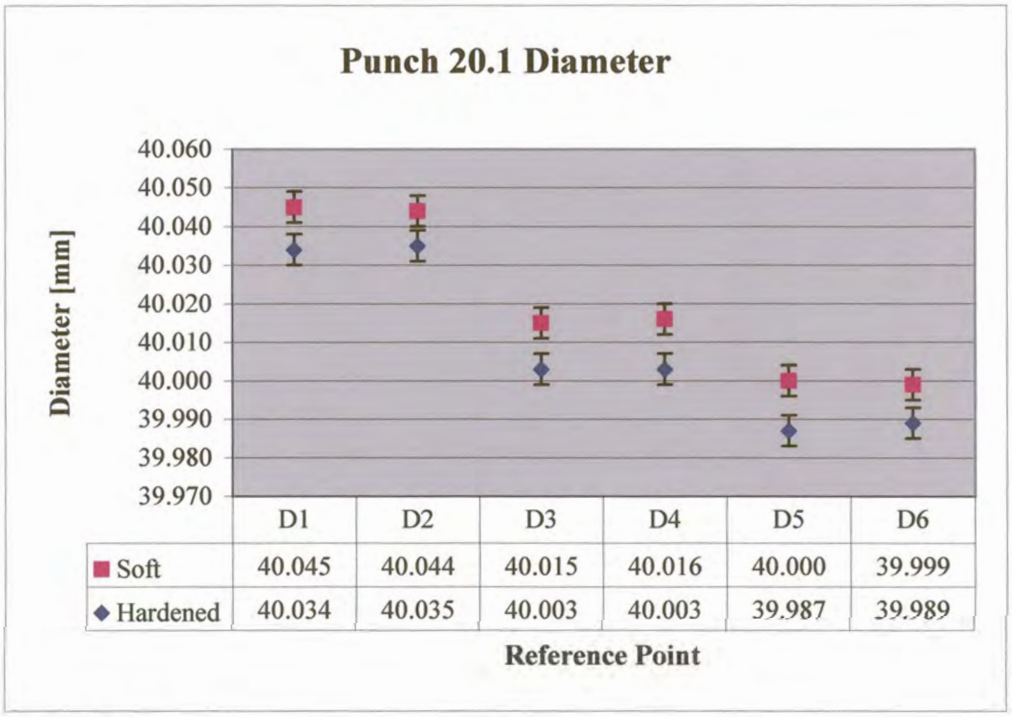
	1	2	3	4	5	6	7	8
Soft	0.181	0.184	0.181	0.173	0.166	0.162	0.165	0.171
Hardened	0.185	0.187	0.186	0.176	0.168	0.165	0.167	0.173

FIGURE F 10



	33	35	37	39
Soft	0.107	0.109	0.108	0.109
Hardened	0.107	0.106	0.110	0.108

FIGURE F 11



	D1	D2	D3	D4	D5	D6
■ Soft	40.045	40.044	40.015	40.016	40.000	39.999
◆ Hardened	40.034	40.035	40.003	40.003	39.987	39.989

FIGURE F 12

Master Punch 20.2 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	65.641	**26**	65.640
2	65.639	**27**	65.505
3	65.641	**28**	65.641
4	65.643	**29**	65.503
5	65.645	**30**	65.640
6	65.644	**31**	65.501
7	65.643	**32**	65.633
8	65.641	**33**	65.463
9	65.455	**34**	65.570
10	65.450	**35**	65.461
11	65.456	**36**	65.572
12	65.468	**37**	65.482
13	65.478	**38**	65.591
14	65.478	**39**	65.480
15	65.475	**40**	65.589
16	65.468	**41**	20.529
17	65.496	**42**	20.527
18	65.628	**43**	13.162
19	65.489	**44**	13.163
20	65.627	**45**	65.648
21	65.490	**46**	65.456
22	65.629	**47**	65.473
23	65.498	**48**	65.482
24	65.632	**49**	65.475
25	65.503		

Landing

Ref. Point	*Depth*
1	0.186
2	0.189
3	0.185
4	0.175
5	0.167
6	0.166
7	0.168
8	0.173
Average	**0.176**

Design

Ref. Point	*Depth*
17	0.132
19	0.138
21	0.139
23	0.134
25	0.137
27	0.136
29	0.137
31	0.132
Average	**0.136**

Lettering

Ref. Point	*Depth*
33	0.107
35	0.111
37	0.109
39	0.109
Average	**0.109**

Dome

0.046

Diameter

Ref. Point	*Diameter*
D1	40.010
D2	40.011
D3	39.975
D4	39.974
D5	39.962
D6	39.963

Master Punch 20.2 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	65.622	**26**	65.619
2	65.620	**27**	65.484
3	65.624	**28**	65.621
4	65.625	**29**	65.483
5	65.627	**30**	65.618
6	65.626	**31**	65.480
7	65.624	**32**	65.611
8	65.623	**33**	65.445
9	65.436	**34**	65.553
10	65.431	**35**	65.444
11	65.437	**36**	65.553
12	65.448	**37**	65.461
13	65.459	**38**	65.570
14	65.460	**39**	65.461
15	65.456	**40**	65.569
16	65.447	**41**	20.528
17	65.474	**42**	20.524
18	65.607	**43**	13.148
19	65.469	**44**	13.151
20	65.605	**45**	65.615
21	65.470	**46**	65.439
22	65.608	**47**	65.453
23	65.476	**48**	65.462
24	65.612	**49**	65.453
25	65.482		

Landing

Ref. Point	*Depth*
1	0.186
2	0.189
3	0.187
4	0.177
5	0.168
6	0.166
7	0.168
8	0.176
Average	**0.177**

Design

Ref. Point	*Depth*
17	0.133
19	0.136
21	0.138
23	0.136
25	0.137
27	0.137
29	0.135
31	0.131
Average	**0.135**

Lettering

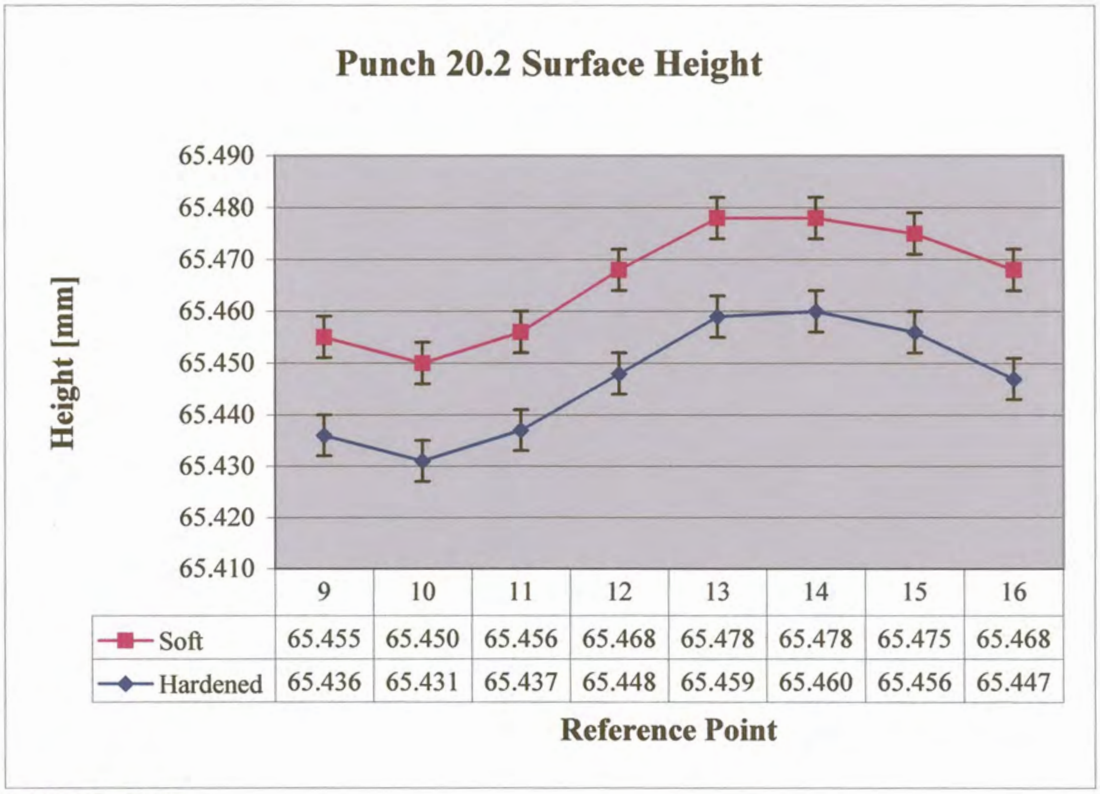
Ref. Point	*Depth*
33	0.108
35	0.109
37	0.109
39	0.108
Average	**0.108**

Dome

0.033

Diameter

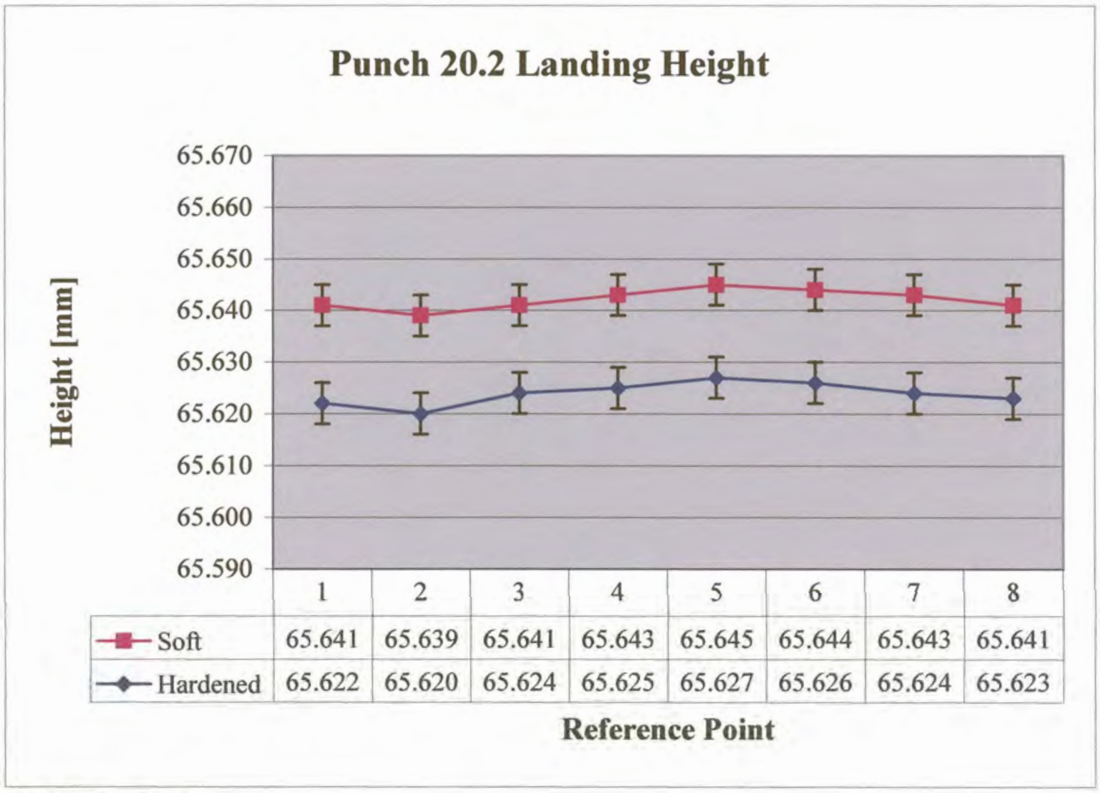
Ref. Point	*Diameter*
D1	40.009
D2	40.009
D3	39.972
D4	39.973
D5	39.957
D6	39.960



Punch 20.2 Surface Height

	9	10	11	12	13	14	15	16
Soft	65.455	65.450	65.456	65.468	65.478	65.478	65.475	65.468
Hardened	65.436	65.431	65.437	65.448	65.459	65.460	65.456	65.447

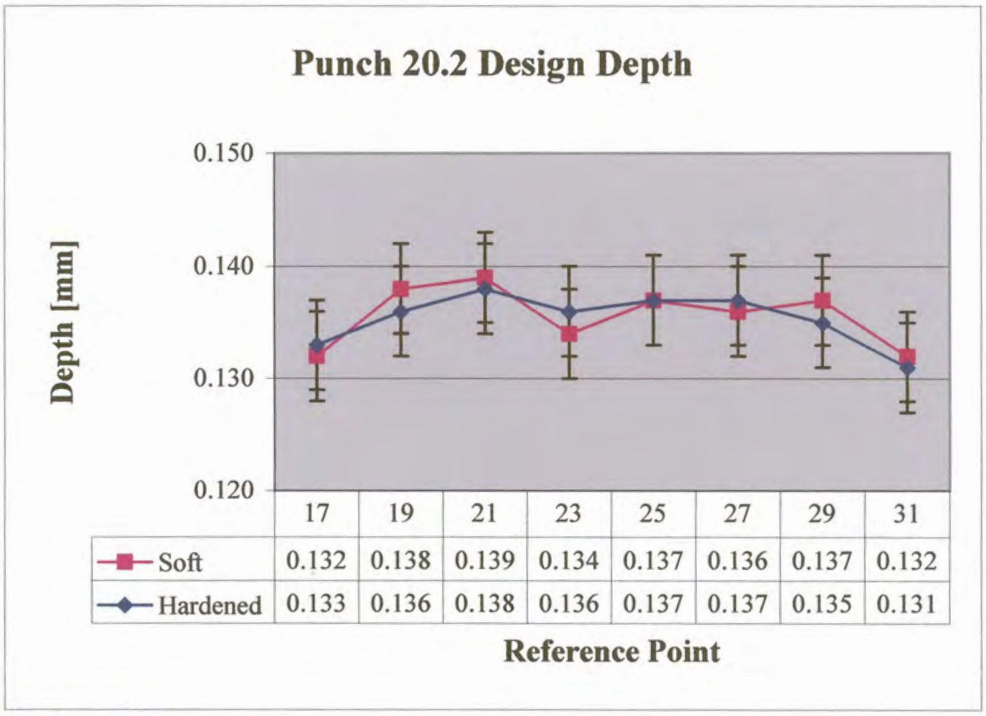
FIGURE F 13



Punch 20.2 Landing Height

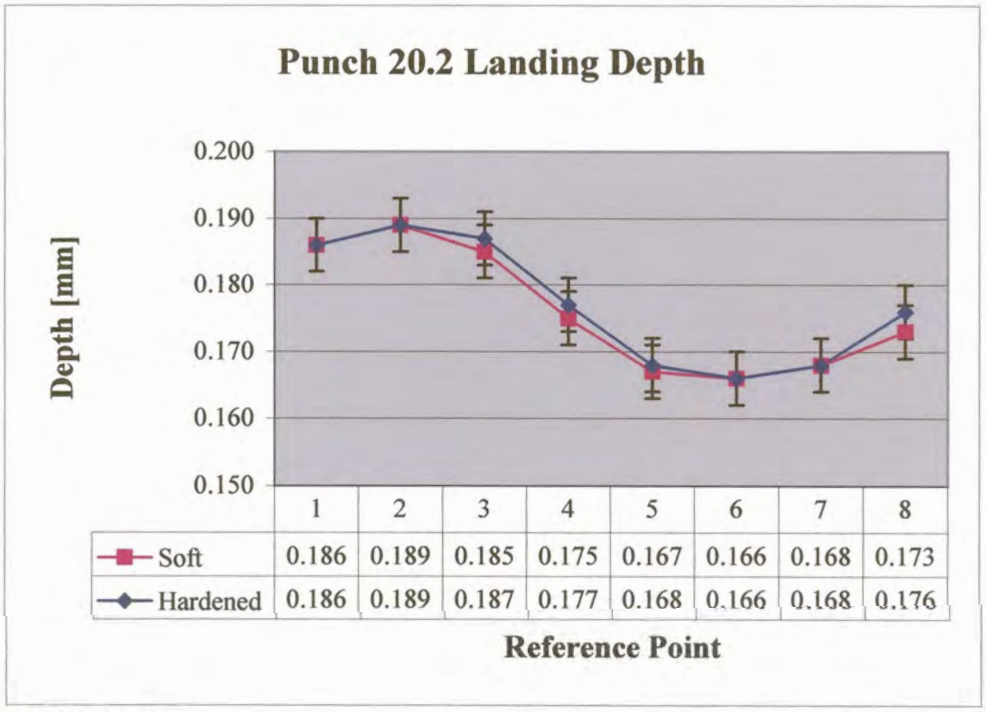
	1	2	3	4	5	6	7	8
Soft	65.641	65.639	65.641	65.643	65.645	65.644	65.643	65.641
Hardened	65.622	65.620	65.624	65.625	65.627	65.626	65.624	65.623

FIGURE F 14



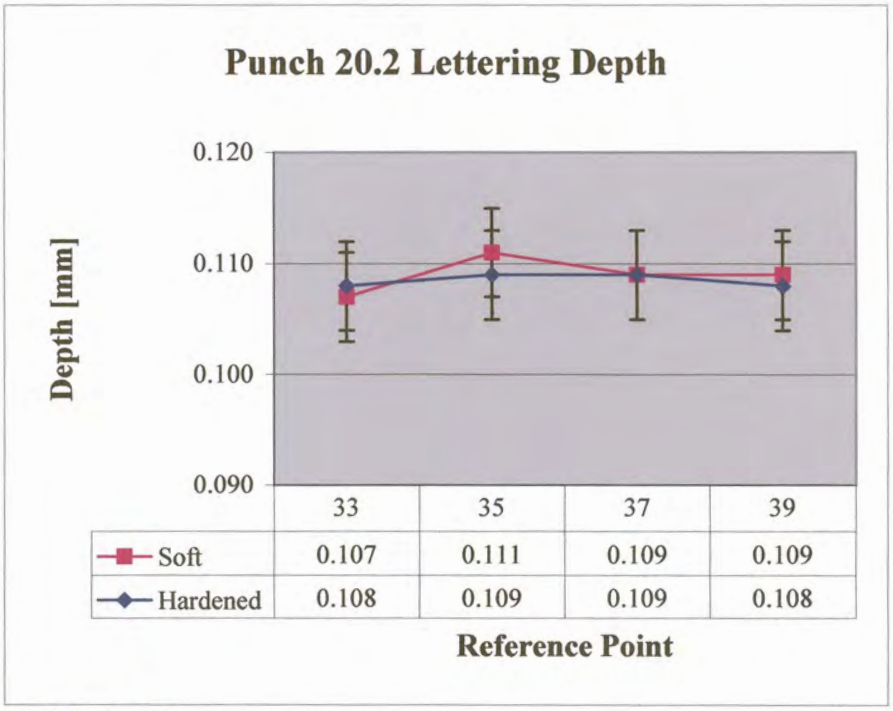
	17	19	21	23	25	27	29	31
Soft	0.132	0.138	0.139	0.134	0.137	0.136	0.137	0.132
Hardened	0.133	0.136	0.138	0.136	0.137	0.137	0.135	0.131

FIGURE F 15



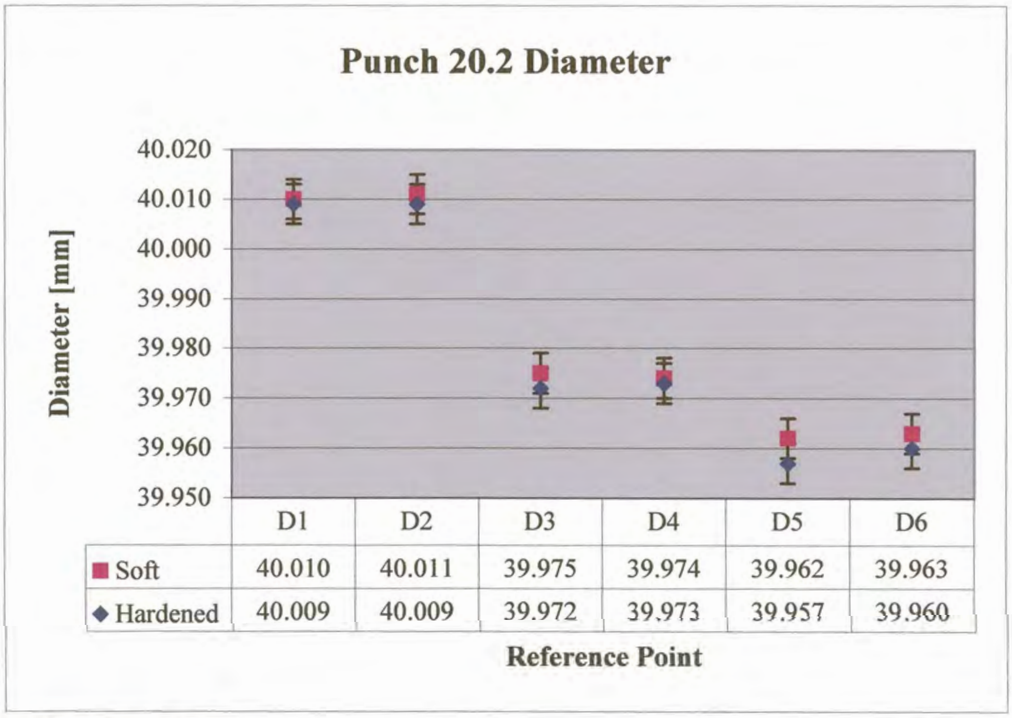
	1	2	3	4	5	6	7	8
Soft	0.186	0.189	0.185	0.175	0.167	0.166	0.168	0.173
Hardened	0.186	0.189	0.187	0.177	0.168	0.166	0.168	0.176

FIGURE F 16



	33	35	37	39
Soft	0.107	0.111	0.109	0.109
Hardened	0.108	0.109	0.109	0.108

FIGURE F 17



	D1	D2	D3	D4	D5	D6
Soft	40.010	40.011	39.975	39.974	39.962	39.963
Hardened	40.009	40.009	39.972	39.973	39.957	39.960

FIGURE F 18

Master Punch 25.1 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	64.541	**26**	64.545
2	64.538	**27**	64.411
3	64.540	**28**	64.550
4	64.542	**29**	64.413
5	64.547	**30**	64.548
6	64.550	**31**	64.407
7	64.548	**32**	64.539
8	64.544	**33**	64.367
9	64.358	**34**	64.476
10	64.349	**35**	64.365
11	64.355	**36**	64.473
12	64.368	**37**	64.387
13	64.382	**38**	64.494
14	64.386	**39**	64.391
15	64.382	**40**	64.498
16	64.372	**41**	20.537
17	64.401	**42**	20.528
18	64.532	**43**	13.155
19	64.393	**44**	13.160
20	64.530	**45**	64.553
21	64.392	**46**	64.360
22	64.531	**47**	64.375
23	64.399	**48**	64.391
24	64.536	**49**	64.381
25	64.408		

Landing

Ref. Point	*Depth*
1	0.183
2	0.189
3	0.185
4	0.174
5	0.165
6	0.164
7	0.166
8	0.172
Average	**0.175**

Design

Ref. Point	*Depth*
17	0.131
19	0.137
21	0.139
23	0.137
25	0.137
27	0.139
29	0.135
31	0.132
Average	**0.136**

Lettering

Ref. Point	*Depth*
33	0.109
35	0.108
37	0.107
39	0.107
Average	**0.108**

Dome

0.048

Diameter

Ref. Point	*Diameter*
D1	40.076
D2	40.075
D3	40.045
D4	40.047
D5	40.051
D6	40.047

Master Punch 25.1 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	64.535	**26**	64.531
2	64.531	**27**	64.399
3	64.532	**28**	64.537
4	64.532	**29**	64.400
5	64.536	**30**	64.536
6	64.539	**31**	64.397
7	64.539	**32**	64.530
8	64.538	**33**	64.358
9	64.349	**34**	64.468
10	64.341	**35**	64.354
11	64.345	**36**	64.465
12	64.356	**37**	64.374
13	64.368	**38**	64.484
14	64.373	**39**	64.377
15	64.371	**40**	64.487
16	64.366	**41**	20.534
17	64.390	**42**	20.531
18	64.523	**43**	13.148
19	64.381	**44**	13.150
20	64.520	**45**	64.530
21	64.382	**46**	64.350
22	64.519	**47**	64.363
23	64.388	**48**	64.378
24	64.525	**49**	64.370
25	64.396		

Landing

Ref. Point	*Depth*
1	0.186
2	0.190
3	0.187
4	0.176
5	0.168
6	0.166
7	0.168
8	0.172
Average	**0.177**

Design

Ref. Point	*Depth*
17	0.133
19	0.139
21	0.137
23	0.137
25	0.135
27	0.138
29	0.136
31	0.133
Average	**0.136**

Lettering

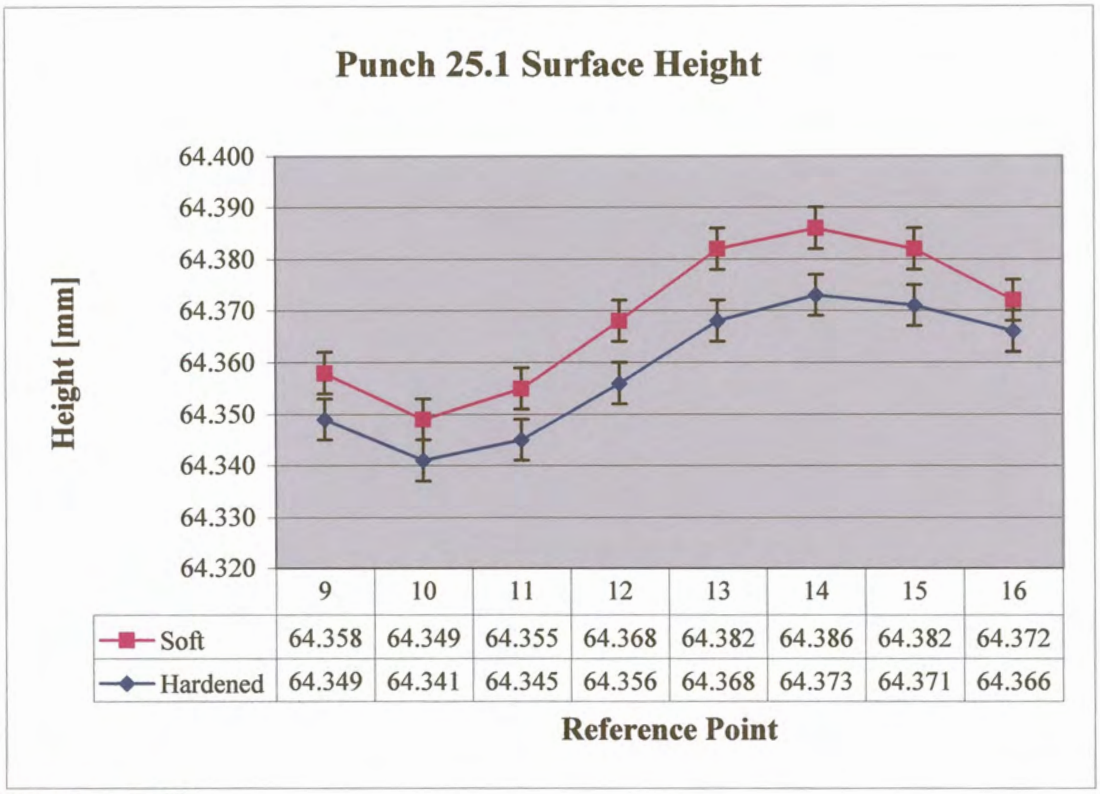
Ref. Point	*Depth*
33	0.110
35	0.111
37	0.110
39	0.110
Average	**0.110**

Dome

0.035

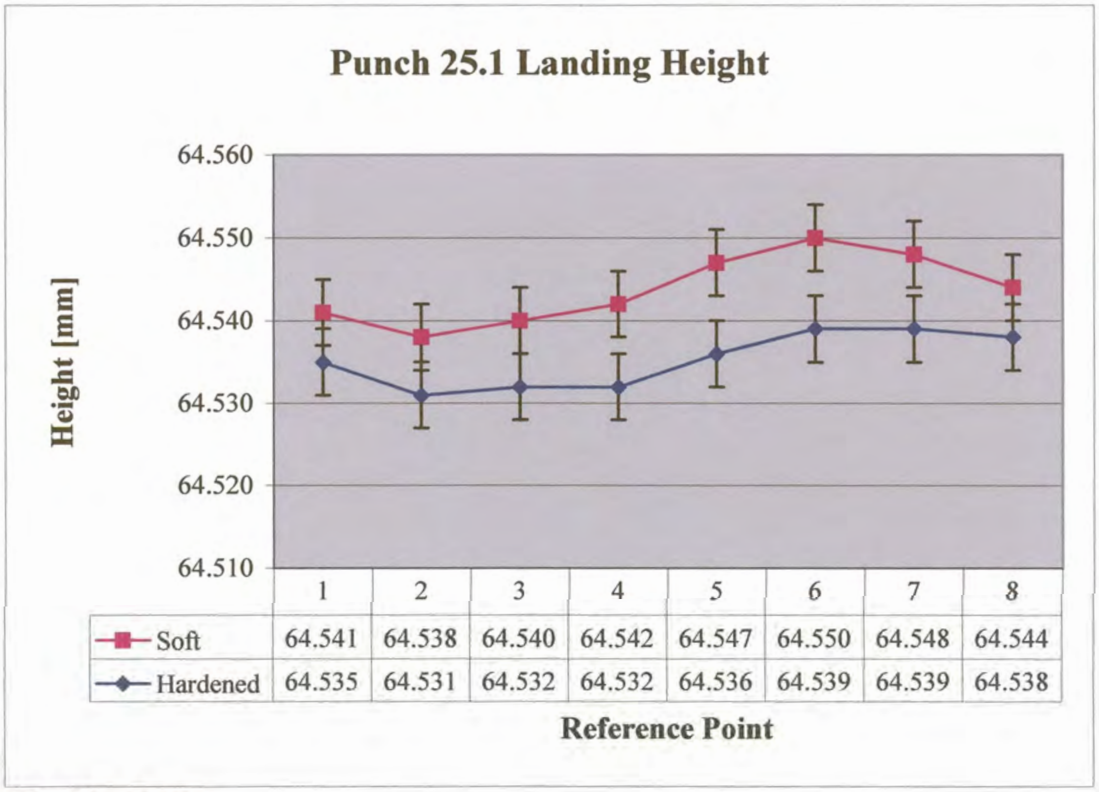
Diameter

Ref. Point	*Diameter*
D1	40.076
D2	40.079
D3	40.044
D4	40.047
D5	40.032
D6	40.033



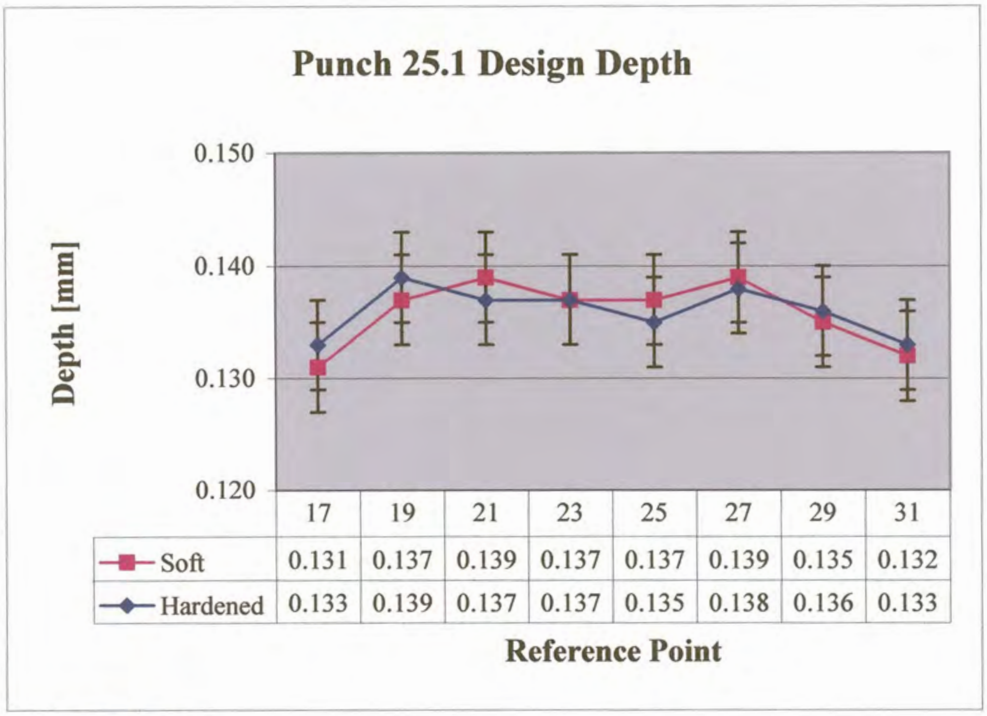
	9	10	11	12	13	14	15	16
Soft	64.358	64.349	64.355	64.368	64.382	64.386	64.382	64.372
Hardened	64.349	64.341	64.345	64.356	64.368	64.373	64.371	64.366

FIGURE F 19



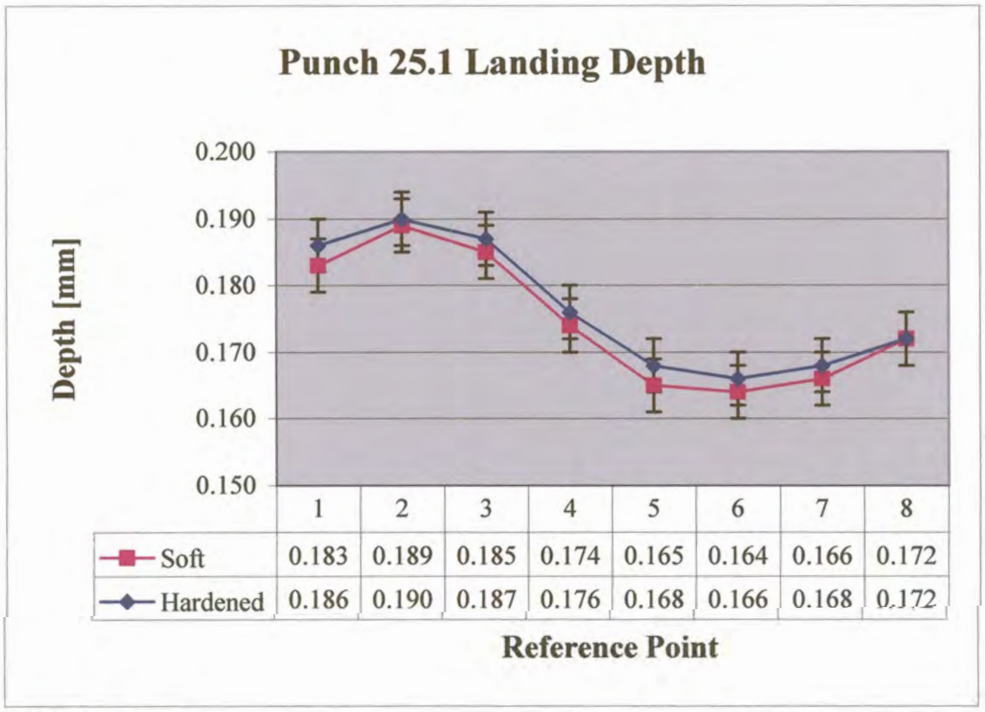
	1	2	3	4	5	6	7	8
Soft	64.541	64.538	64.540	64.542	64.547	64.550	64.548	64.544
Hardened	64.535	64.531	64.532	64.532	64.536	64.539	64.539	64.538

FIGURE F 20



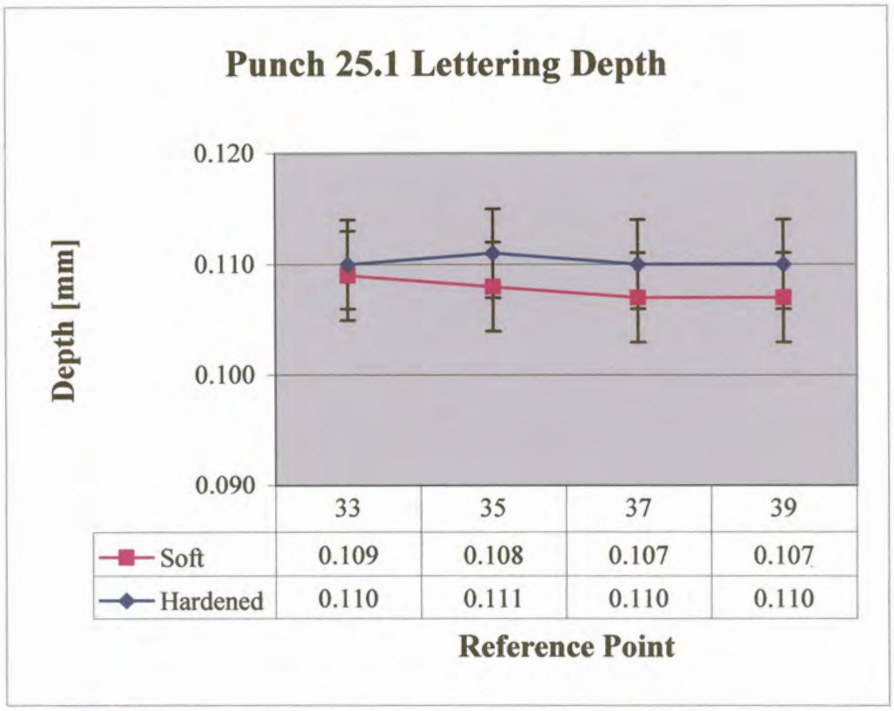
	17	19	21	23	25	27	29	31
Soft	0.131	0.137	0.139	0.137	0.137	0.139	0.135	0.132
Hardened	0.133	0.139	0.137	0.137	0.135	0.138	0.136	0.133

FIGURE F 21



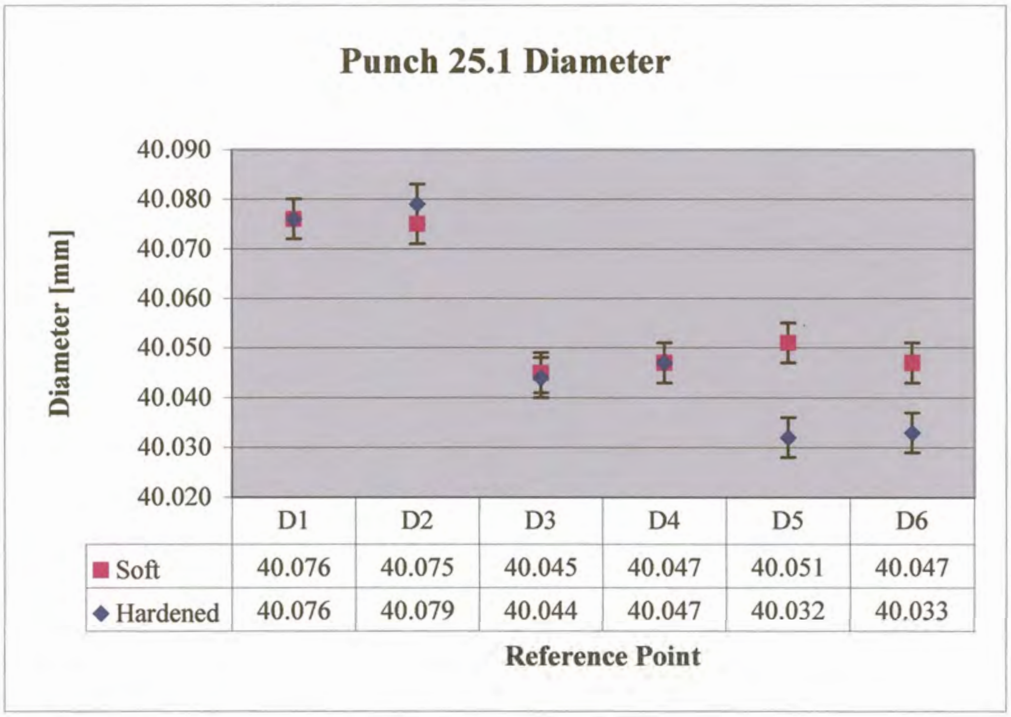
	1	2	3	4	5	6	7	8
Soft	0.183	0.189	0.185	0.174	0.165	0.164	0.166	0.172
Hardened	0.186	0.190	0.187	0.176	0.168	0.166	0.168	0.172

FIGURE F 22



	33	35	37	39
Soft	0.109	0.108	0.107	0.107
Hardened	0.110	0.111	0.110	0.110

FIGURE F 23



	D1	D2	D3	D4	D5	D6
Soft	40.076	40.075	40.045	40.047	40.051	40.047
Hardened	40.076	40.079	40.044	40.047	40.032	40.033

FIGURE F 24

Master Punch 25.2 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	64.714	**26**	64.715
2	64.719	**27**	64.579
3	64.726	**28**	64.716
4	64.723	**29**	64.577
5	64.720	**30**	64.710
6	64.713	**31**	64.572
7	64.707	**32**	64.703
8	64.707	**33**	64.535
9	64.528	**34**	64.645
10	64.530	**35**	64.546
11	64.538	**36**	64.653
12	64.548	**37**	64.557
13	64.554	**38**	64.666
14	64.549	**39**	64.548
15	64.541	**40**	64.656
16	64.533	**41**	20.532
17	64.569	**42**	20.538
18	64.702	**43**	13.160
19	64.567	**44**	13.162
20	64.704	**45**	64.721
21	64.570	**46**	64.536
22	64.710	**47**	64.552
23	64.577	**48**	64.553
24	64.713	**49**	64.542
25	64.580		

Landing

Ref. Point	*Depth*
1	0.186
2	0.189
3	0.188
4	0.175
5	0.166
6	0.164
7	0.166
8	0.174
Average	**0.176**

Design

Ref. Point	*Depth*
17	0.133
19	0.137
21	0.140
23	0.136
25	0.135
27	0.137
29	0.133
31	0.131
Average	**0.135**

Lettering

Ref. Point	*Depth*
33	0.110
35	0.107
37	0.109
39	0.108
Average	**0.108**

Dome

0.046

Diameter

Ref. Point	*Diameter*
D1	40.050
D2	40.051
D3	40.029
D4	40.027
D5	40.019
D6	40.019

Master Punch 25.2 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	64.708	**26**	64.711
2	64.711	**27**	64.575
3	64.715	**28**	64.712
4	64.715	**29**	64.574
5	64.714	**30**	64.708
6	64.709	**31**	64.570
7	64.706	**32**	64.702
8	64.706	**33**	64.537
9	64.524	**34**	64.644
10	64.522	**35**	64.540
11	64.531	**36**	64.649
12	64.540	**37**	64.555
13	64.549	**38**	64.664
14	64.547	**39**	64.549
15	64.540	**40**	64.657
16	64.533	**41**	20.534
17	64.565	**42**	20.536
18	64.698	**43**	13.150
19	64.559	**44**	13.153
20	64.699	**45**	64.708
21	64.563	**46**	64.533
22	64.703	**47**	64.548
23	64.569	**48**	64.552
24	64.706	**49**	64.543
25	64.575		

Landing

Ref. Point	*Depth*
1	0.184
2	0.189
3	0.184
4	0.175
5	0.165
6	0.162
7	0.166
8	0.173
Average	**0.175**

Design

Ref. Point	*Depth*
17	0.133
19	0.140
21	0.140
23	0.137
25	0.136
27	0.137
29	0.134
31	0.132
Average	**0.136**

Lettering

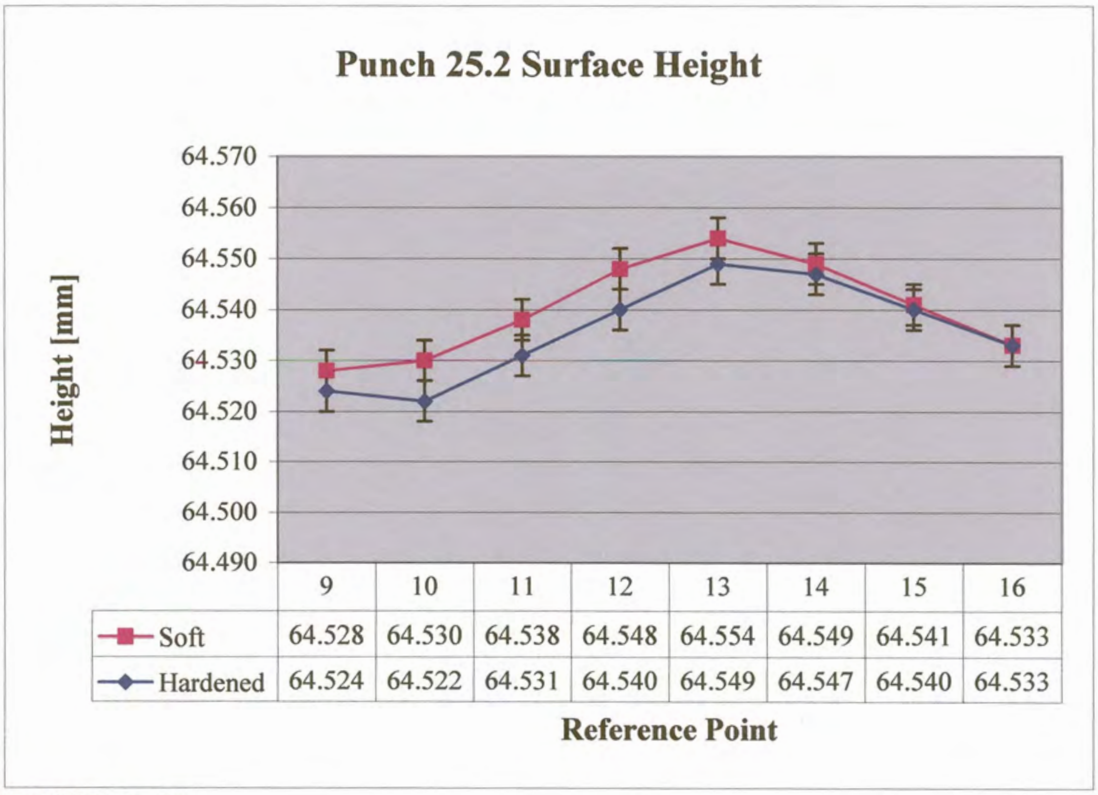
Ref. Point	*Depth*
33	0.107
35	0.109
37	0.109
39	0.108
Average	**0.108**

Dome

0.036

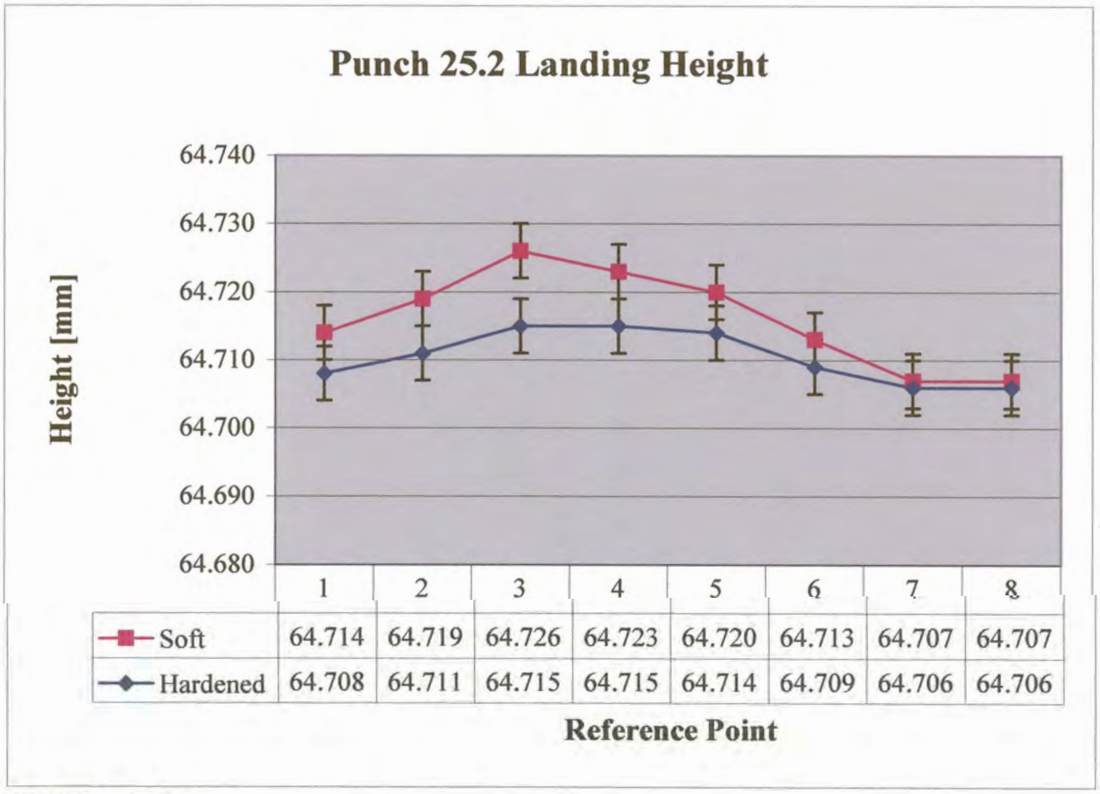
Diameter

Ref. Point	*Diameter*
D1	40.056
D2	40.056
D3	40.029
D4	40.029
D5	40.018
D6	40.020



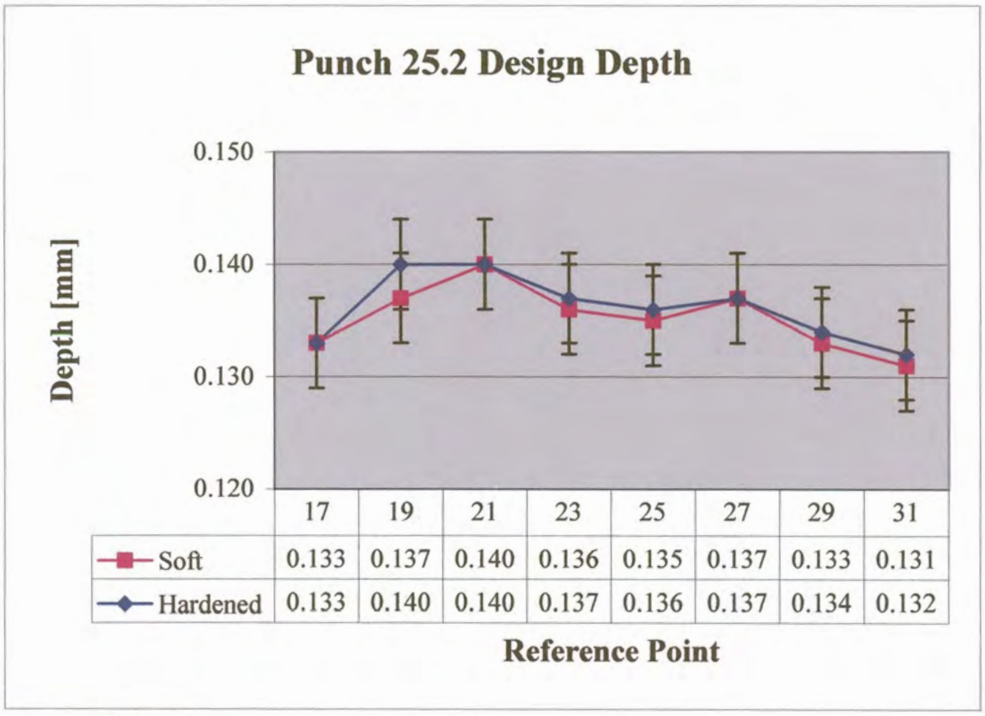
	9	10	11	12	13	14	15	16
Soft	64.528	64.530	64.538	64.548	64.554	64.549	64.541	64.533
Hardened	64.524	64.522	64.531	64.540	64.549	64.547	64.540	64.533

FIGURE F 25



	1	2	3	4	5	6	7	8
Soft	64.714	64.719	64.726	64.723	64.720	64.713	64.707	64.707
Hardened	64.708	64.711	64.715	64.715	64.714	64.709	64.706	64.706

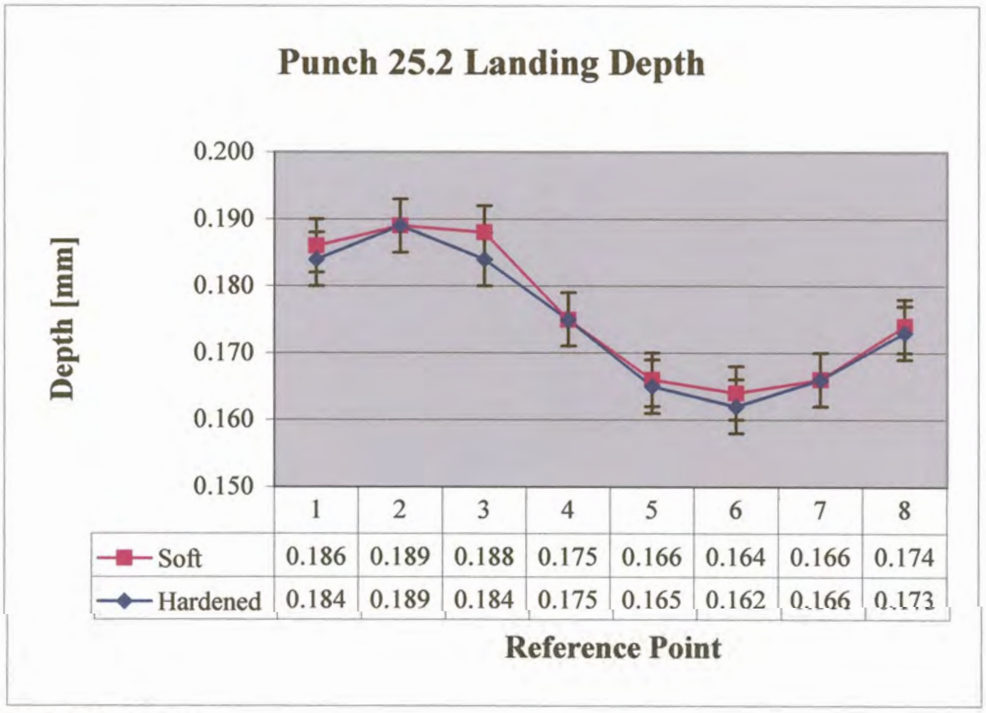
FIGURE F 26



Punch 25.2 Design Depth

	17	19	21	23	25	27	29	31
Soft	0.133	0.137	0.140	0.136	0.135	0.137	0.133	0.131
Hardened	0.133	0.140	0.140	0.137	0.136	0.137	0.134	0.132

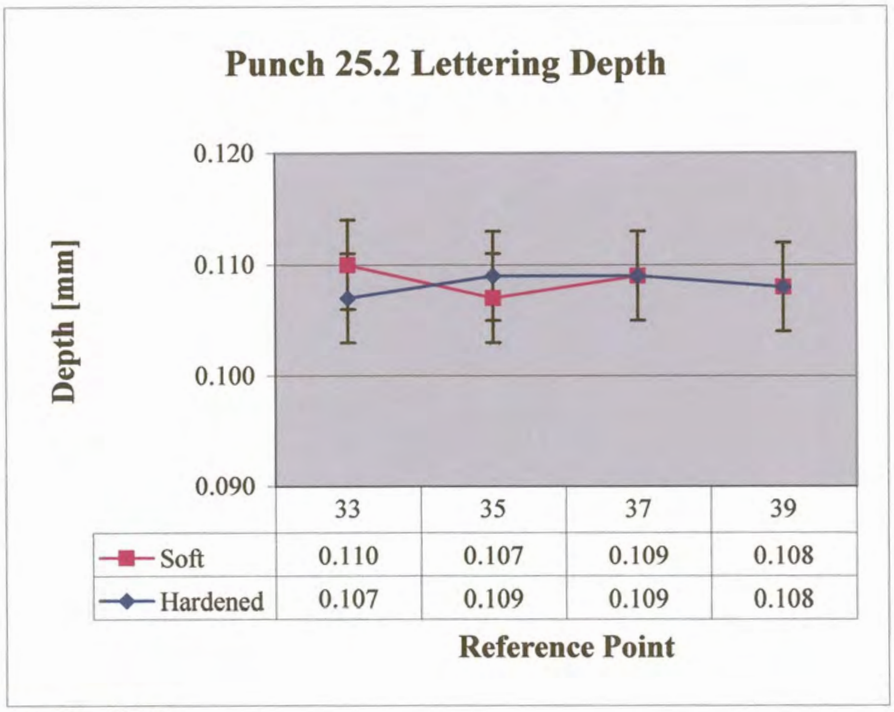
FIGURE F 27



Punch 25.2 Landing Depth

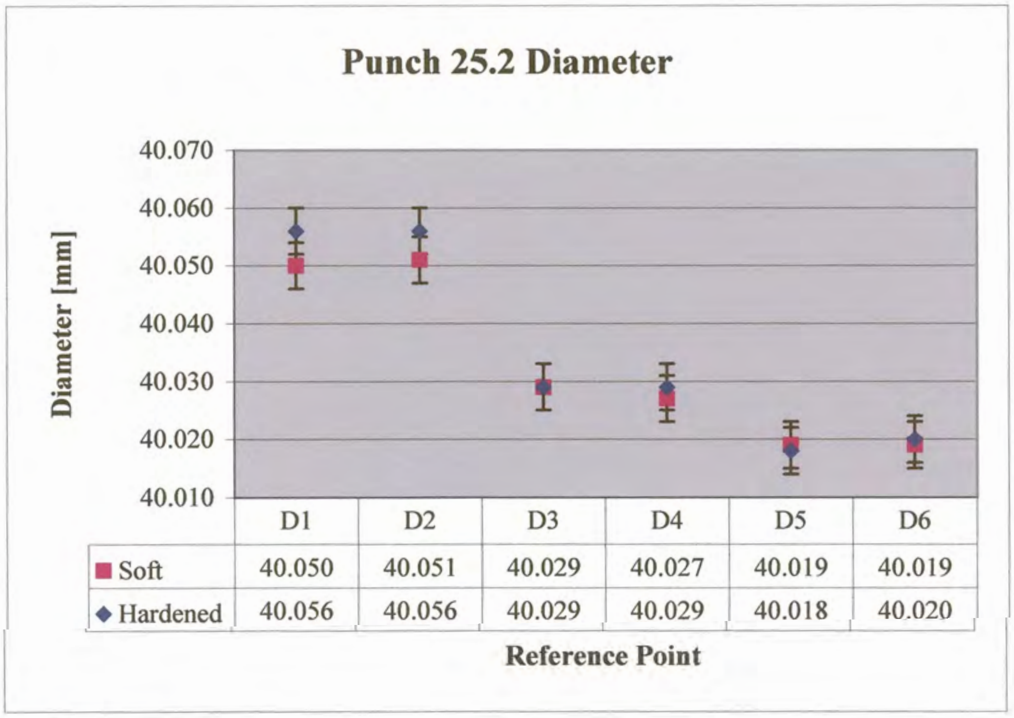
	1	2	3	4	5	6	7	8
Soft	0.186	0.189	0.188	0.175	0.166	0.164	0.166	0.174
Hardened	0.184	0.189	0.184	0.175	0.165	0.162	0.166	0.173

FIGURE F 28



	33	35	37	39
Soft	0.110	0.107	0.109	0.108
Hardened	0.107	0.109	0.109	0.108

FIGURE F 29



	D1	D2	D3	D4	D5	D6
■ Soft	40.050	40.051	40.029	40.027	40.019	40.019
◆ Hardened	40.056	40.056	40.029	40.029	40.018	40.020

FIGURE F 30

Master Punch 30.1 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	63.031	**26**	63.032
2	63.031	**27**	62.901
3	63.032	**28**	63.037
4	63.033	**29**	62.900
5	63.034	**30**	63.035
6	63.036	**31**	62.897
7	63.035	**32**	63.028
8	63.033	**33**	62.858
9	62.850	**34**	62.967
10	62.845	**35**	62.859
11	62.850	**36**	62.967
12	62.860	**37**	62.875
13	62.870	**38**	62.985
14	62.875	**39**	62.877
15	62.871	**40**	62.985
16	62.864	**41**	20.543
17	62.890	**42**	20.546
18	63.022	**43**	13.153
19	62.883	**44**	13.160
20	63.021	**45**	63.040
21	62.887	**46**	62.853
22	63.024	**47**	62.867
23	62.891	**48**	62.879
24	63.028	**49**	62.870
25	62.897		

Landing

Ref. Point	*Depth*
1	0.181
2	0.186
3	0.182
4	0.173
5	0.164
6	0.161
7	0.164
8	0.169
Average	**0.172**

Design

Ref. Point	*Depth*
17	0.132
19	0.138
21	0.137
23	0.137
25	0.135
27	0.136
29	0.135
31	0.131
Average	**0.135**

Lettering

Ref. Point	*Depth*
33	0.109
35	0.108
37	0.110
39	0.108
Average	**0.109**

Dome

0.044

Diameter

Ref. Point	*Diameter*
D1	40.023
D2	40.025
D3	39.995
D4	39.993
D5	39.976
D6	39.978

Master Punch 30.1 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	63.010	**26**	63.013
2	63.007	**27**	62.878
3	63.008	**28**	63.018
4	63.011	**29**	62.878
5	63.014	**30**	63.016
6	63.016	**31**	62.874
7	63.013	**32**	63.009
8	63.011	**33**	62.836
9	62.824	**34**	62.946
10	62.817	**35**	62.833
11	62.822	**36**	62.944
12	62.835	**37**	62.853
13	62.846	**38**	62.964
14	62.852	**39**	62.856
15	62.847	**40**	62.967
16	62.839	**41**	20.535
17	62.867	**42**	20.538
18	63.001	**43**	13.149
19	62.861	**44**	13.153
20	63.000	**45**	63.012
21	62.862	**46**	62.830
22	63.001	**47**	62.843
23	62.869	**48**	62.858
24	63.006	**49**	62.847
25	62.874		

Landing

Ref. Point	*Depth*
1	0.186
2	0.190
3	0.186
4	0.176
5	0.168
6	0.164
7	0.166
8	0.172
Average	**0.176**

Design

Ref. Point	*Depth*
17	0.134
19	0.139
21	0.139
23	0.137
25	0.139
27	0.140
29	0.138
31	0.135
Average	**0.138**

Lettering

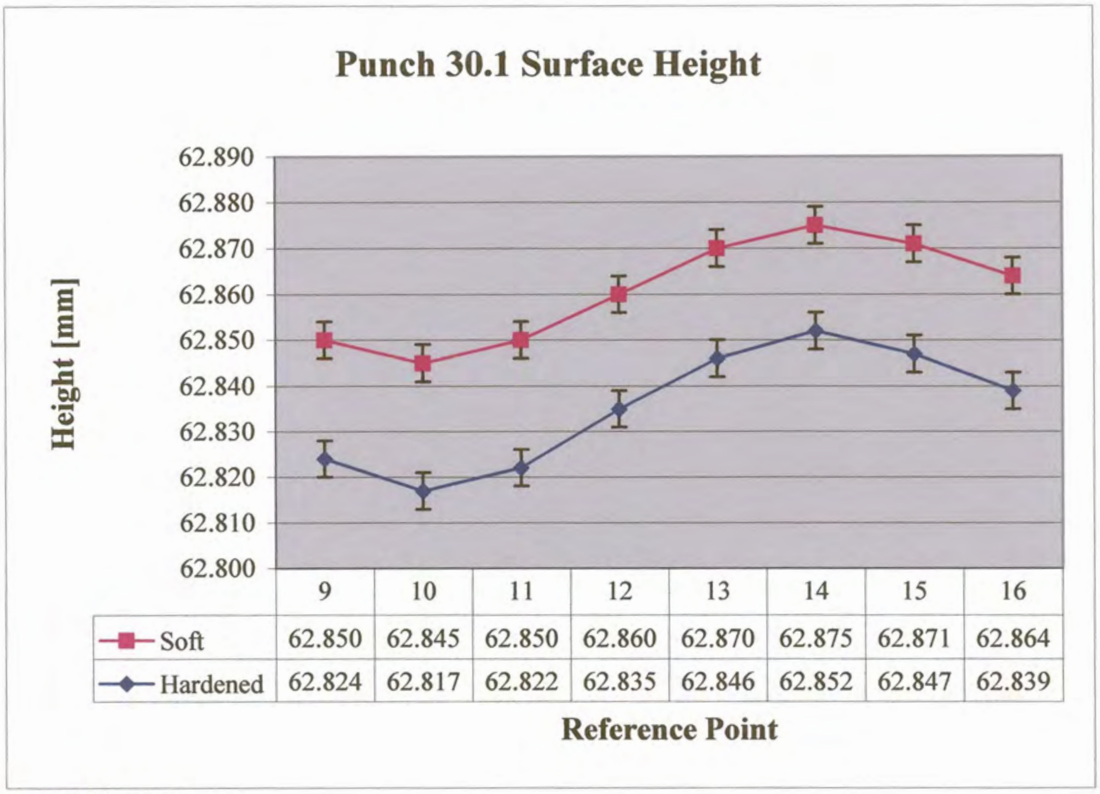
Ref. Point	*Depth*
33	0.110
35	0.111
37	0.111
39	0.111
Average	**0.111**

Dome

0.039

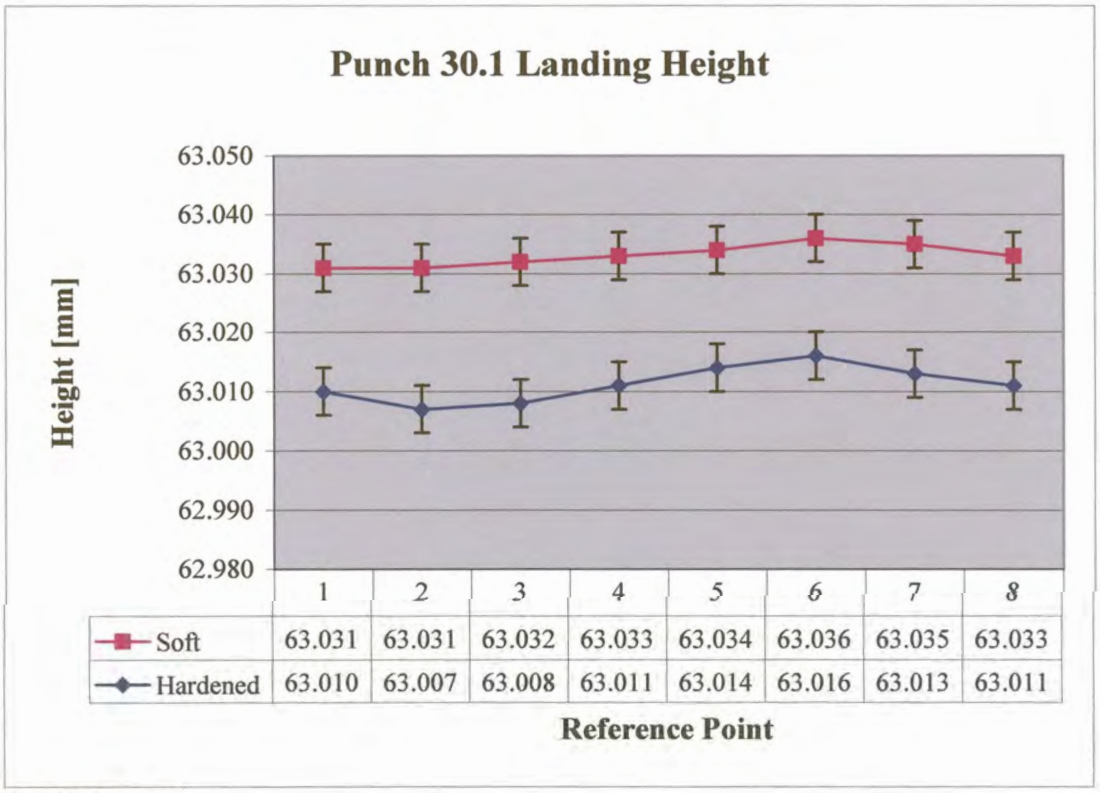
Diameter

Ref. Point	*Diameter*
D1	40.015
D2	40.019
D3	39.983
D4	39.984
D5	39.966
D6	39.966



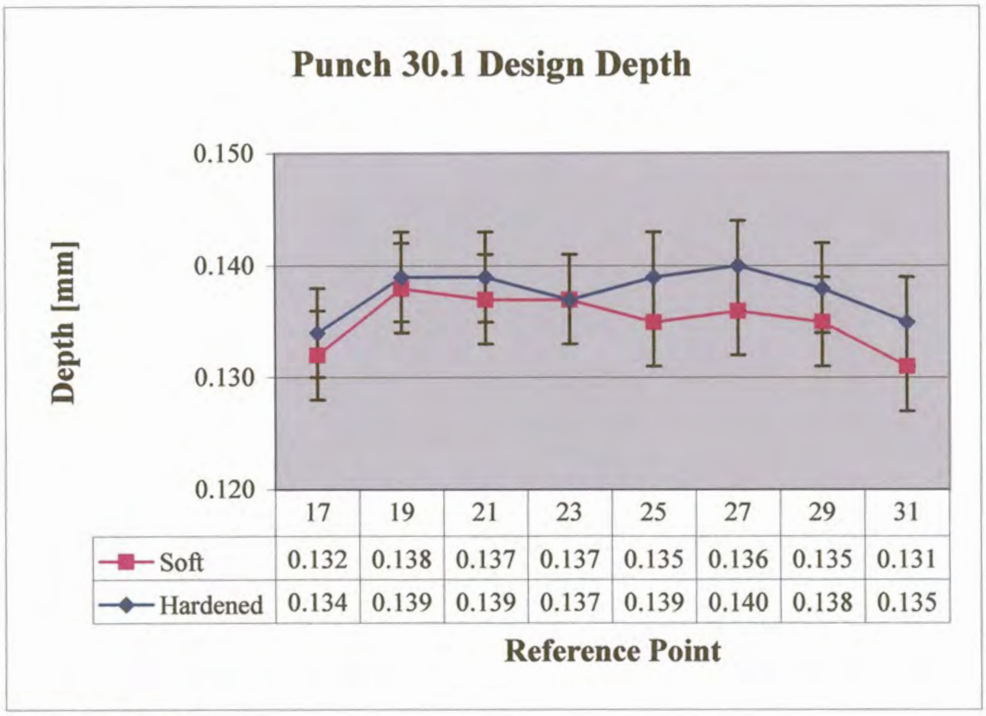
	9	10	11	12	13	14	15	16
Soft	62.850	62.845	62.850	62.860	62.870	62.875	62.871	62.864
Hardened	62.824	62.817	62.822	62.835	62.846	62.852	62.847	62.839

FIGURE F 31



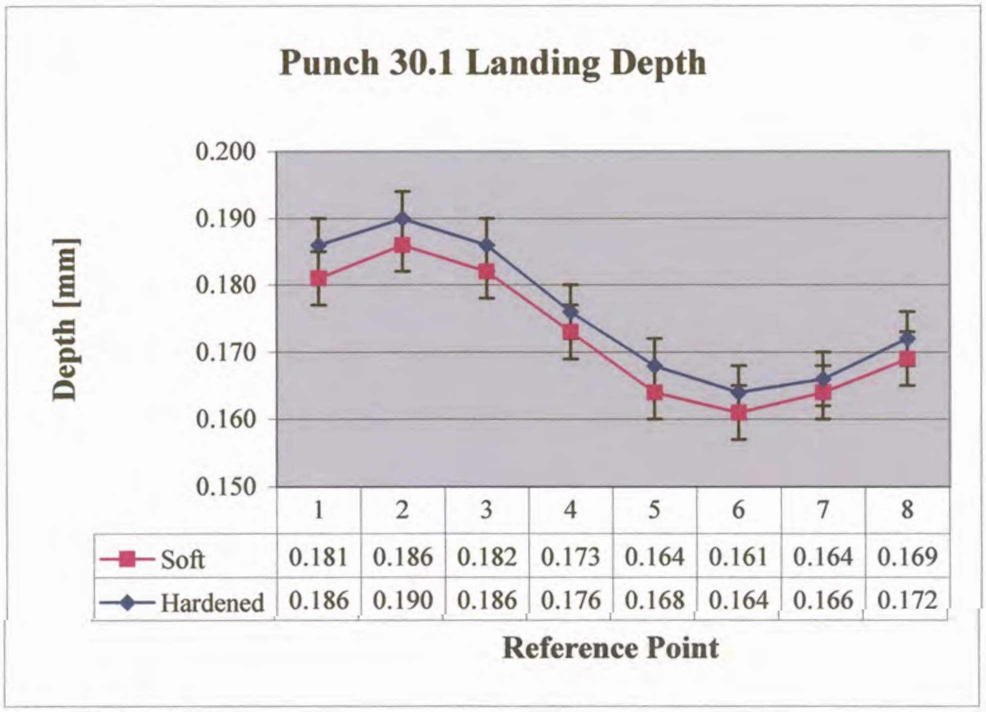
	1	2	3	4	5	6	7	8
Soft	63.031	63.031	63.032	63.033	63.034	63.036	63.035	63.033
Hardened	63.010	63.007	63.008	63.011	63.014	63.016	63.013	63.011

FIGURE F 32



	17	19	21	23	25	27	29	31
Soft	0.132	0.138	0.137	0.137	0.135	0.136	0.135	0.131
Hardened	0.134	0.139	0.139	0.137	0.139	0.140	0.138	0.135

FIGURE F 33



	1	2	3	4	5	6	7	8
Soft	0.181	0.186	0.182	0.173	0.164	0.161	0.164	0.169
Hardened	0.186	0.190	0.186	0.176	0.168	0.164	0.166	0.172

FIGURE F 34

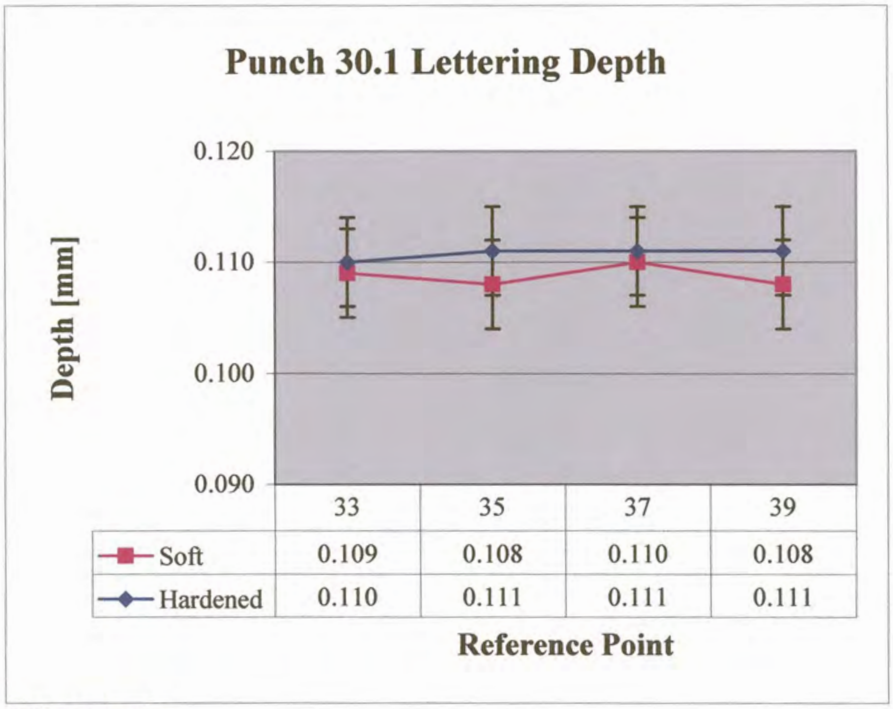


FIGURE F 35

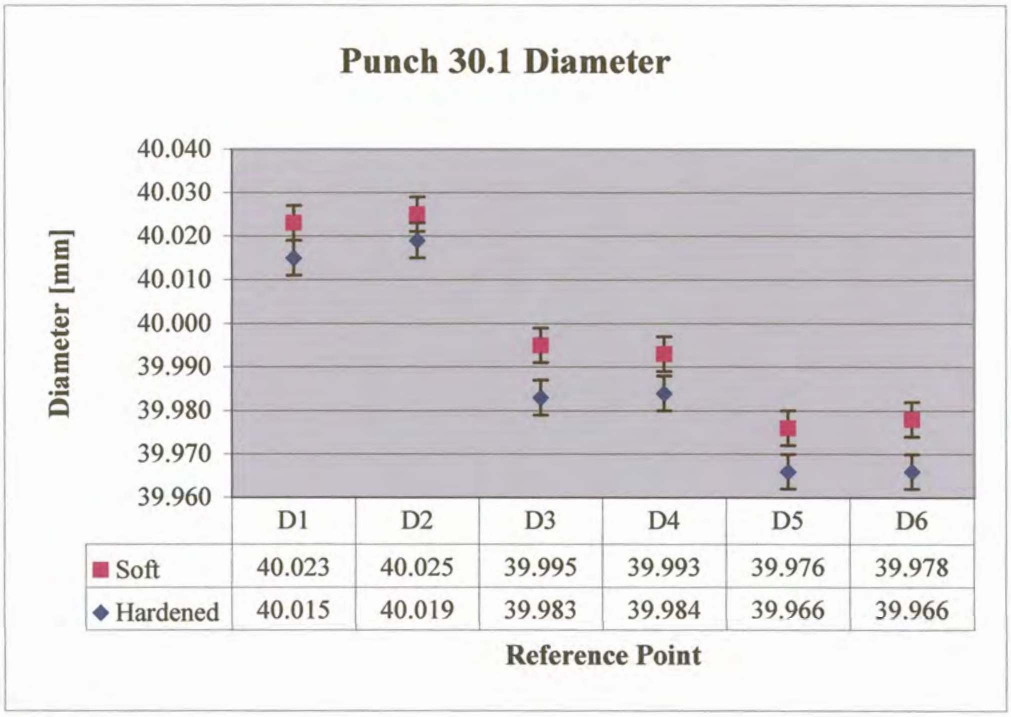


FIGURE F 36

Master Punch 30.2 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	63.058	**26**	63.052
2	63.049	**27**	62.923
3	63.046	**28**	63.061
4	63.049	**29**	62.926
5	63.055	**30**	63.061
6	63.064	**31**	62.923
7	63.066	**32**	63.055
8	63.066	**33**	62.881
9	62.871	**34**	62.989
10	62.860	**35**	62.869
11	62.861	**36**	62.977
12	62.875	**37**	62.897
13	62.893	**38**	63.004
14	62.905	**39**	62.906
15	62.903	**40**	63.016
16	62.892	**41**	20.538
17	62.915	**42**	20.539
18	63.046	**43**	13.158
19	62.905	**44**	13.160
20	63.040	**45**	63.062
21	62.901	**46**	62.869
22	63.039	**47**	62.881
23	62.907	**48**	62.903
24	63.043	**49**	62.900
25	62.915		

Landing

Ref. Point	*Depth*
1	0.187
2	0.189
3	0.185
4	0.174
5	0.162
6	0.159
7	0.163
8	0.174
Average	**0.174**

Design

Ref. Point	*Depth*
17	0.131
19	0.135
21	0.138
23	0.136
25	0.137
27	0.138
29	0.135
31	0.132
Average	**0.135**

Lettering

Ref. Point	*Depth*
33	0.108
35	0.108
37	0.107
39	0.110
Average	**0.108**

Dome

0.044

Diameter

Ref. Point	*Diameter*
D1	40.058
D2	40.056
D3	40.025
D4	40.023
D5	40.004
D6	40.004

Master Punch 30.2 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	63.006	**26**	63.008
2	62.999	**27**	62.876
3	62.998	**28**	63.016
4	63.003	**29**	62.879
5	63.009	**30**	63.016
6	63.016	**31**	62.875
7	63.020	**32**	63.009
8	63.016	**33**	62.833
9	62.822	**34**	62.942
10	62.811	**35**	62.824
11	62.813	**36**	62.933
12	62.828	**37**	62.849
13	62.843	**38**	62.961
14	62.854	**39**	62.859
15	62.852	**40**	62.969
16	62.841	**41**	20.530
17	62.866	**42**	20.533
18	62.999	**43**	13.144
19	62.856	**44**	13.150
20	62.993	**45**	63.008
21	62.854	**46**	62.822
22	62.991	**47**	62.835
23	62.859	**48**	62.858
24	62.998	**49**	62.850
25	62.869		

Landing

Ref. Point	*Depth*
1	0.184
2	0.188
3	0.185
4	0.175
5	0.166
6	0.162
7	0.168
8	0.175
Average	**0.175**

Design

Ref. Point	*Depth*
17	0.133
19	0.137
21	0.137
23	0.139
25	0.139
27	0.140
29	0.137
31	0.134
Average	**0.137**

Lettering

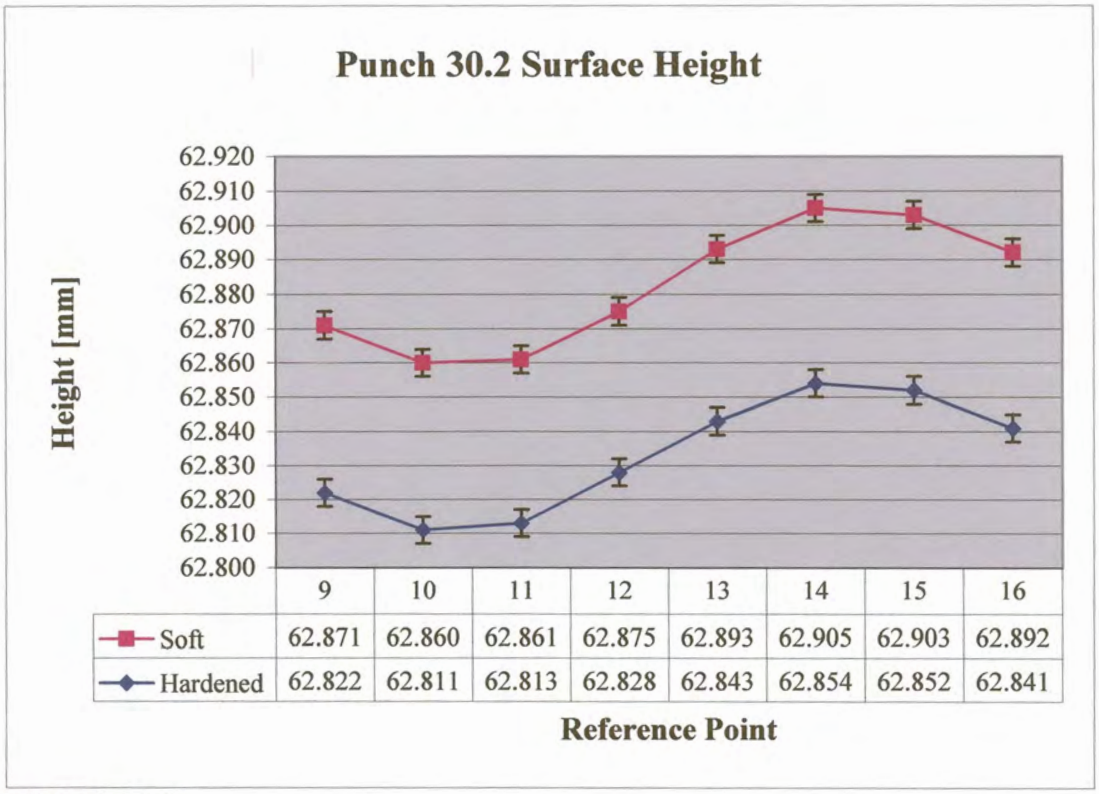
Ref. Point	*Depth*
33	0.109
35	0.109
37	0.112
39	0.110
Average	**0.110**

Dome

0.038

Diameter

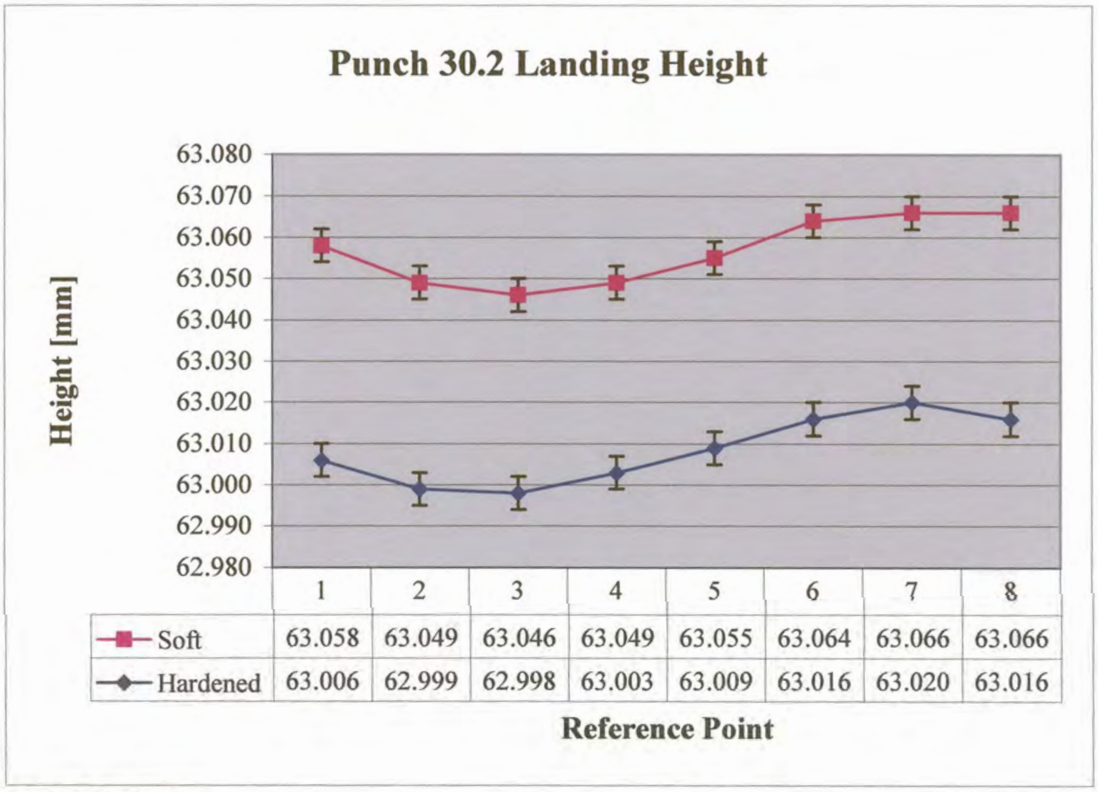
Ref. Point	*Diameter*
D1	40.042
D2	40.040
D3	40.004
D4	40.003
D5	39.985
D6	39.988



Punch 30.2 Surface Height

	9	10	11	12	13	14	15	16
■ Soft	62.871	62.860	62.861	62.875	62.893	62.905	62.903	62.892
◆ Hardened	62.822	62.811	62.813	62.828	62.843	62.854	62.852	62.841

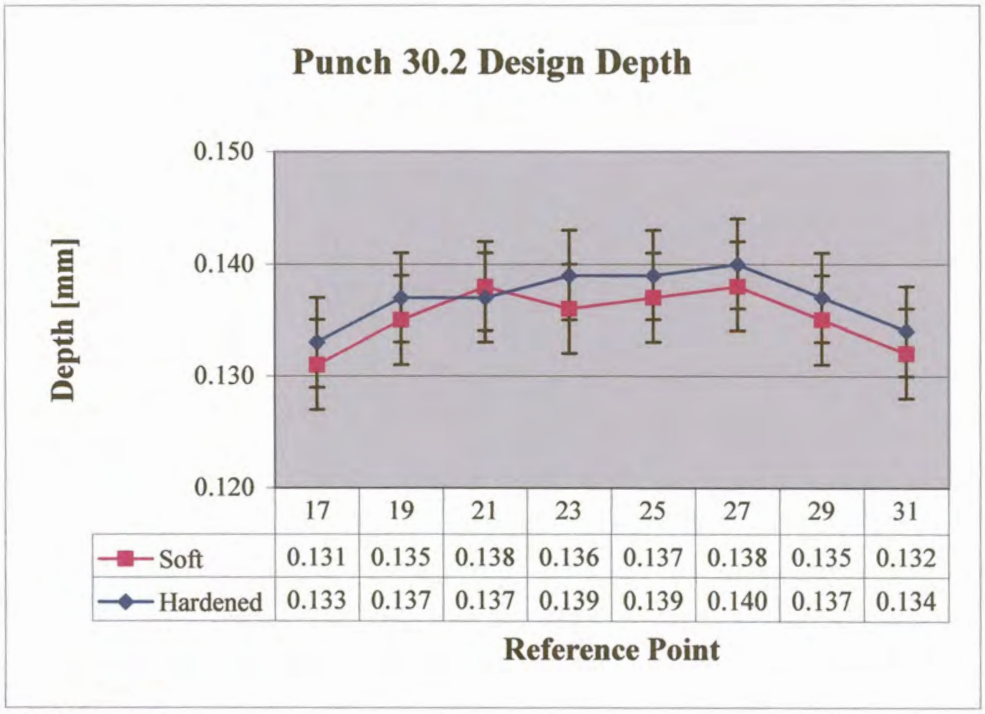
FIGURE F 37



Punch 30.2 Landing Height

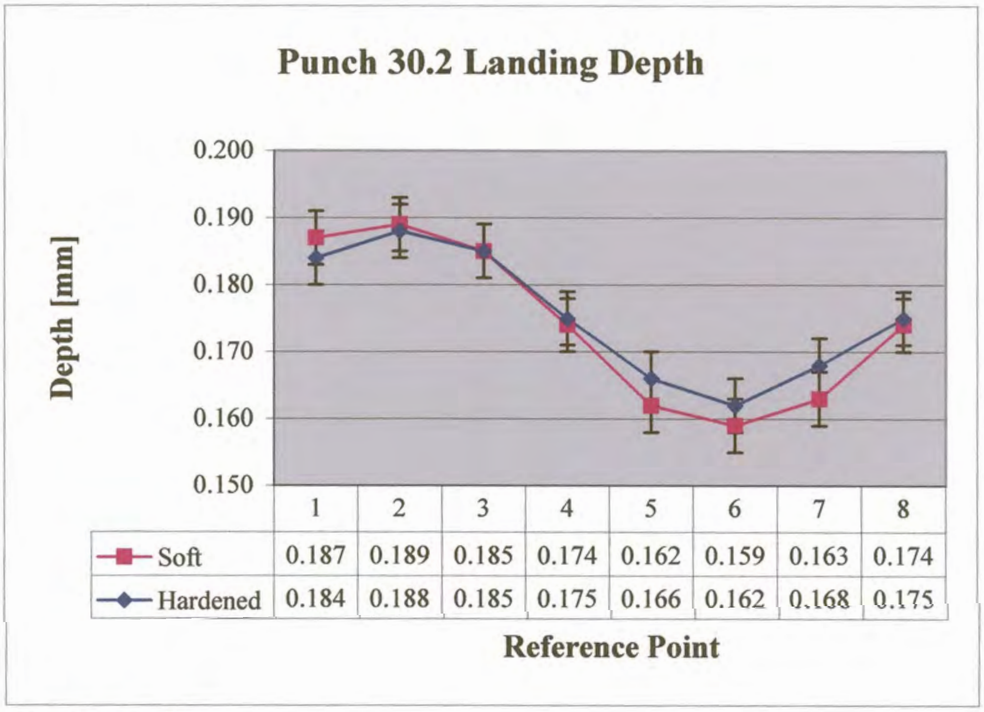
	1	2	3	4	5	6	7	8
■ Soft	63.058	63.049	63.046	63.049	63.055	63.064	63.066	63.066
◆ Hardened	63.006	62.999	62.998	63.003	63.009	63.016	63.020	63.016

FIGURE F 38



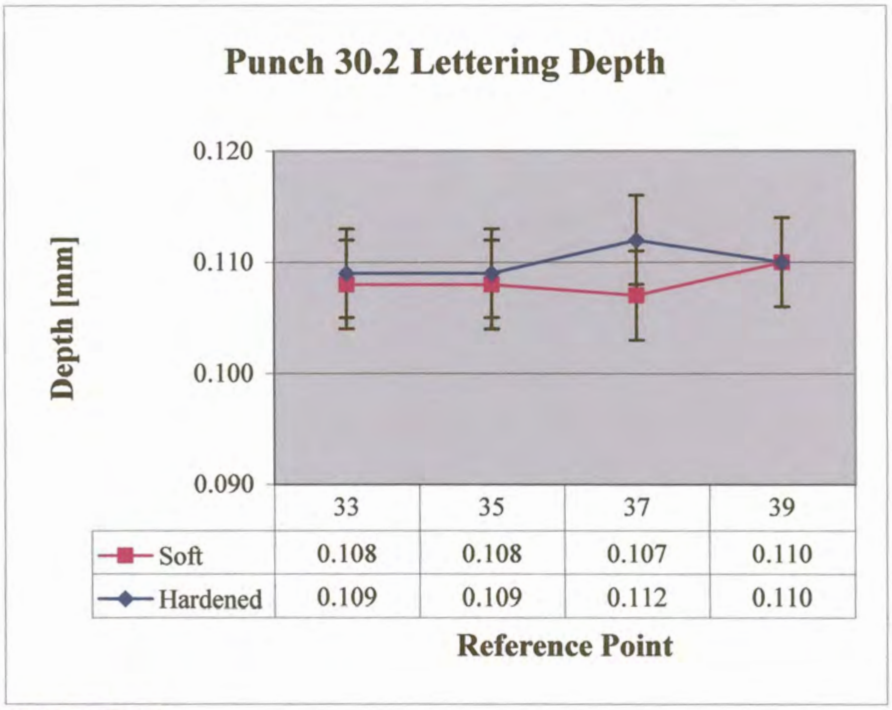
	17	19	21	23	25	27	29	31
Soft	0.131	0.135	0.138	0.136	0.137	0.138	0.135	0.132
Hardened	0.133	0.137	0.137	0.139	0.139	0.140	0.137	0.134

FIGURE F 39



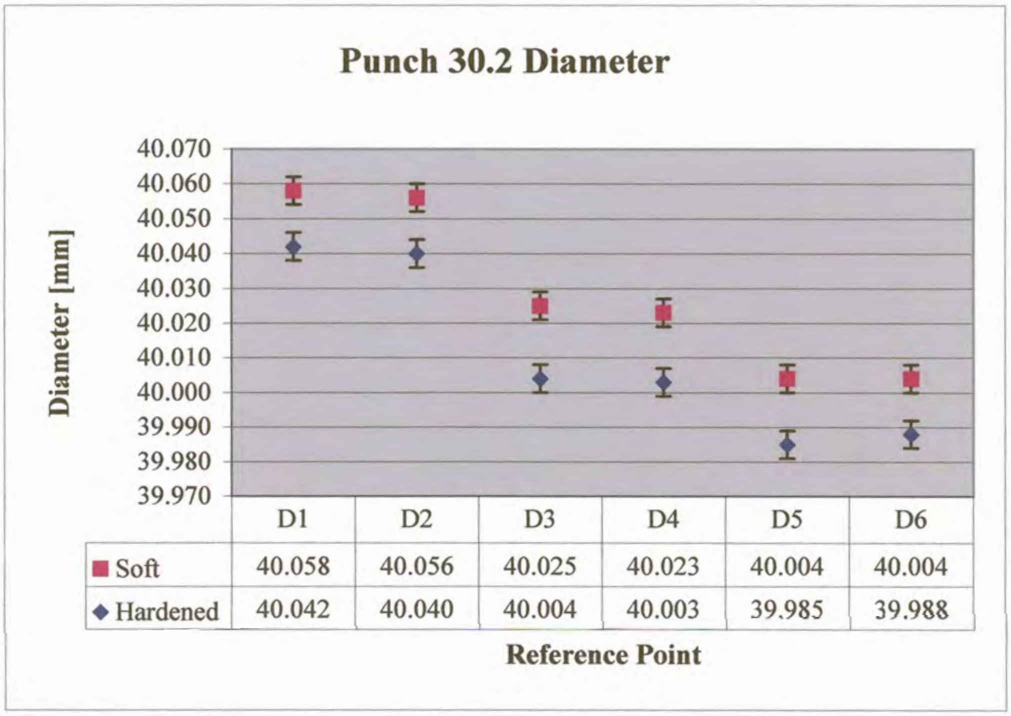
	1	2	3	4	5	6	7	8
Soft	0.187	0.189	0.185	0.174	0.162	0.159	0.163	0.174
Hardened	0.184	0.188	0.185	0.175	0.166	0.162	0.168	0.175

FIGURE F 40



	33	35	37	39
■ Soft	0.108	0.108	0.107	0.110
◆ Hardened	0.109	0.109	0.112	0.110

FIGURE F 41



	D1	D2	D3	D4	D5	D6
■ Soft	40.058	40.056	40.025	40.023	40.004	40.004
◆ Hardened	40.042	40.040	40.004	40.003	39.985	39.988

FIGURE F 42

Master Punch 30.3 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	59.758	**26**	59.681
2	59.753	**27**	59.549
3	59.747	**28**	59.686
4	59.741	**29**	59.553
5	59.740	**30**	59.691
6	59.744	**31**	59.555
7	59.753	**32**	59.690
8	59.757	**33**	59.560
9	59.565	**34**	59.666
10	59.555	**35**	59.547
11	59.553	**36**	59.653
12	59.558	**37**	59.556
13	59.567	**38**	59.665
14	59.574	**39**	59.568
15	59.578	**40**	59.677
16	59.577	**41**	20.447
17	59.552	**42**	20.445
18	59.684	**43**	13.101
19	59.542	**44**	13.103
20	59.680	**45**	59.661
21	59.537	**46**	59.549
22	59.676	**47**	59.549
23	59.540	**48**	59.562
24	59.675	**49**	59.568
25	59.543		

Landing

Ref. Point	*Depth*
1	0.193
2	0.198
3	0.194
4	0.183
5	0.173
6	0.170
7	0.175
8	0.180
Average	**0.183**

Design

Ref. Point	*Depth*
17	0.132
19	0.138
21	0.139
23	0.135
25	0.138
27	0.137
29	0.138
31	0.135
Average	**0.137**

Lettering

Ref. Point	*Depth*
33	0.106
35	0.106
37	0.109
39	0.109
Average	**0.108**

Dome

-0.041

Diameter

Ref. Point	*Diameter*
D1	40.020
D2	40.021
D3	39.997
D4	39.998
D5	39.987
D6	39.986

Master Punch 30.3 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	Height	Ref. Point	Height
1	59.738	26	59.650
2	59.730	27	59.519
3	59.724	28	59.658
4	59.715	29	59.524
5	59.716	30	59.663
6	59.722	31	59.528
7	59.732	32	59.663
8	59.738	33	59.538
9	59.544	34	59.645
10	59.531	35	59.521
11	59.528	36	59.629
12	59.531	37	59.531
13	59.541	38	59.639
14	59.549	39	59.548
15	59.556	40	59.654
16	59.554	41	20.440
17	59.522	42	20.444
18	59.658	43	13.084
19	59.515	44	13.088
20	59.652	45	59.623
21	59.509	46	59.526
22	59.647	47	59.523
23	59.509	48	59.540
24	59.645	49	59.549
25	59.513		

Landing

Ref. Point	Depth
1	0.194
2	0.199
3	0.196
4	0.184
5	0.175
6	0.173
7	0.176
8	0.184
Average	**0.185**

Design

Ref. Point	Depth
17	0.136
19	0.137
21	0.138
23	0.136
25	0.137
27	0.139
29	0.139
31	0.135
Average	**0.137**

Lettering

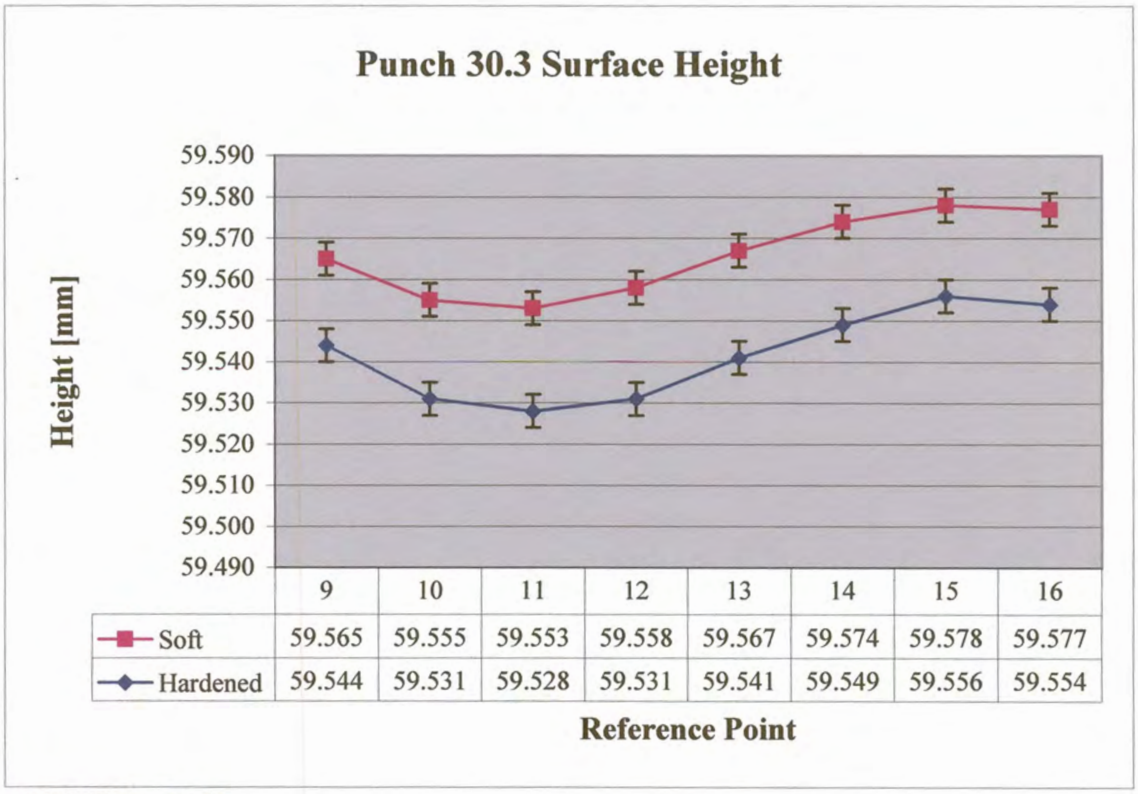
Ref. Point	Depth
33	0.107
35	0.108
37	0.108
39	0.106
Average	**0.107**

Dome

-0.056

Diameter

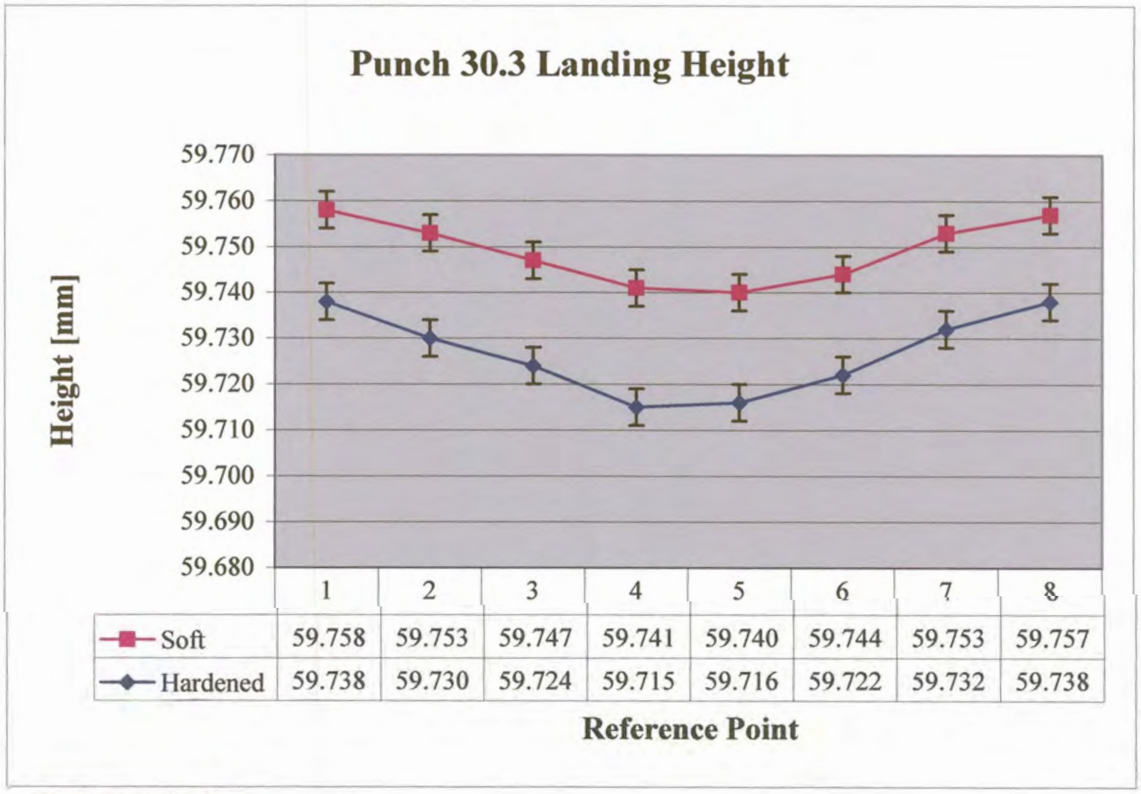
Ref. Point	Diameter
D1	40.004
D2	40.006
D3	39.984
D4	39.987
D5	39.978
D6	39.979



Punch 30.3 Surface Height

	9	10	11	12	13	14	15	16
Soft	59.565	59.555	59.553	59.558	59.567	59.574	59.578	59.577
Hardened	59.544	59.531	59.528	59.531	59.541	59.549	59.556	59.554

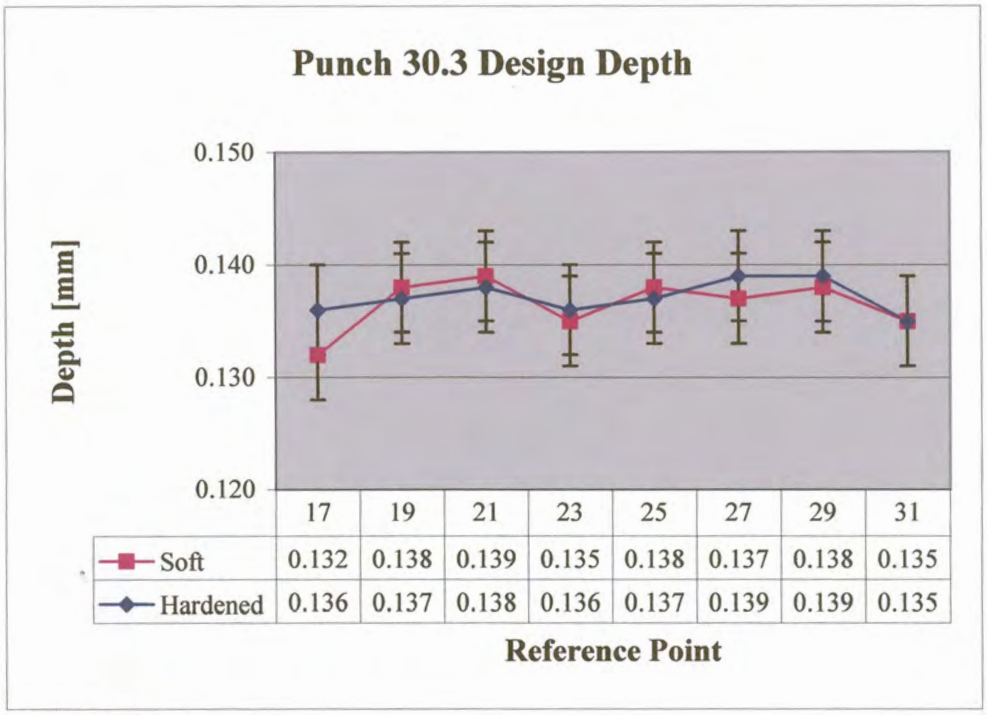
FIGURE F 43



Punch 30.3 Landing Height

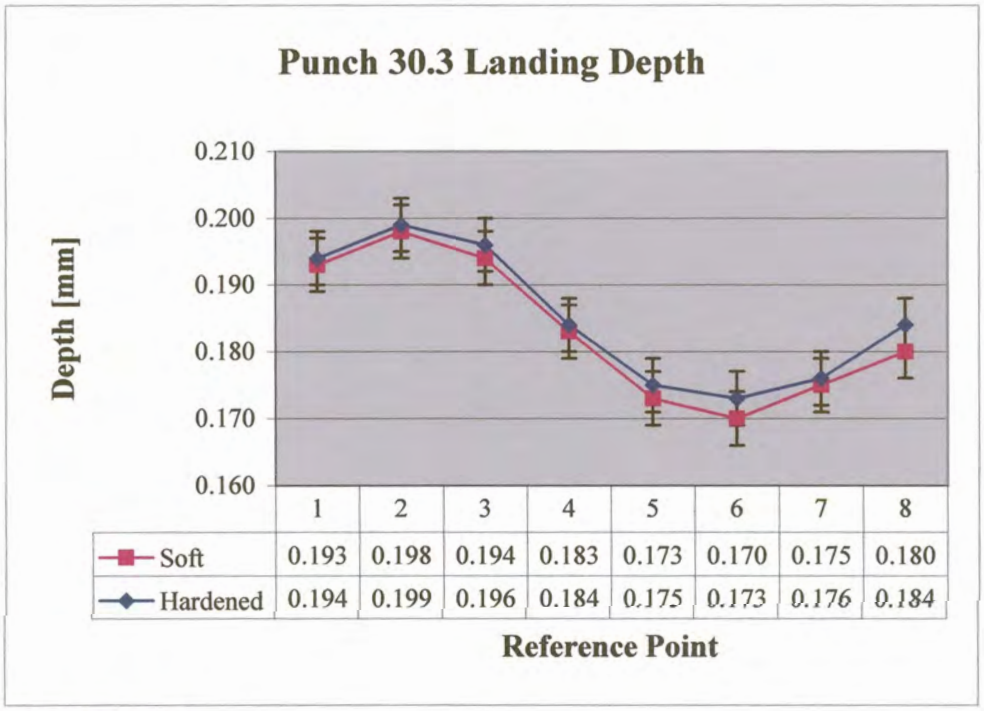
	1	2	3	4	5	6	7	8
Soft	59.758	59.753	59.747	59.741	59.740	59.744	59.753	59.757
Hardened	59.738	59.730	59.724	59.715	59.716	59.722	59.732	59.738

FIGURE F 44



	17	19	21	23	25	27	29	31
Soft	0.132	0.138	0.139	0.135	0.138	0.137	0.138	0.135
Hardened	0.136	0.137	0.138	0.136	0.137	0.139	0.139	0.135

FIGURE F 45



	1	2	3	4	5	6	7	8
Soft	0.193	0.198	0.194	0.183	0.173	0.170	0.175	0.180
Hardened	0.194	0.199	0.196	0.184	0.175	0.173	0.176	0.184

FIGURE F 46

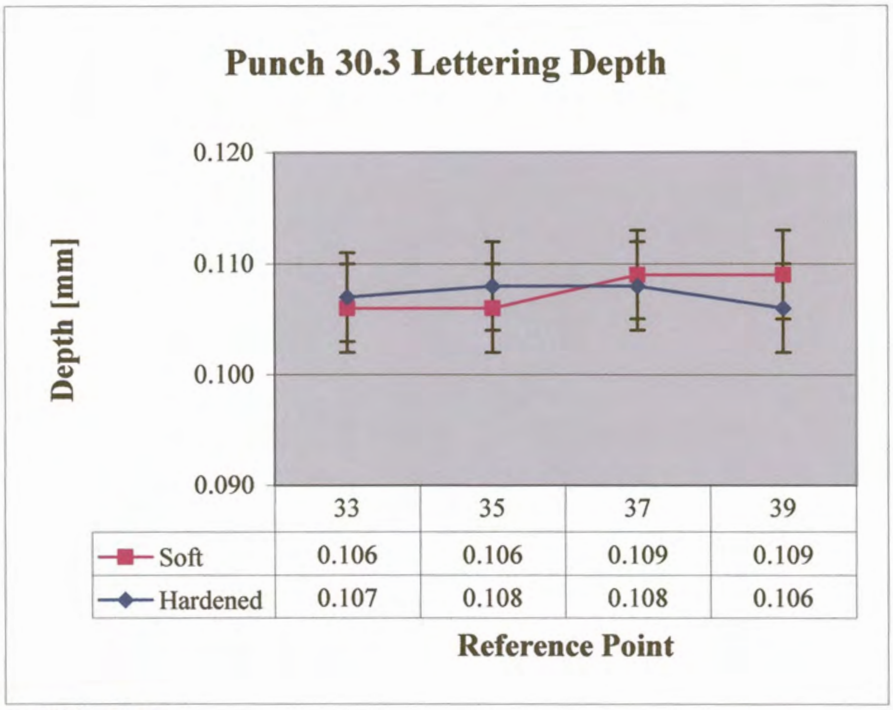


FIGURE F 47

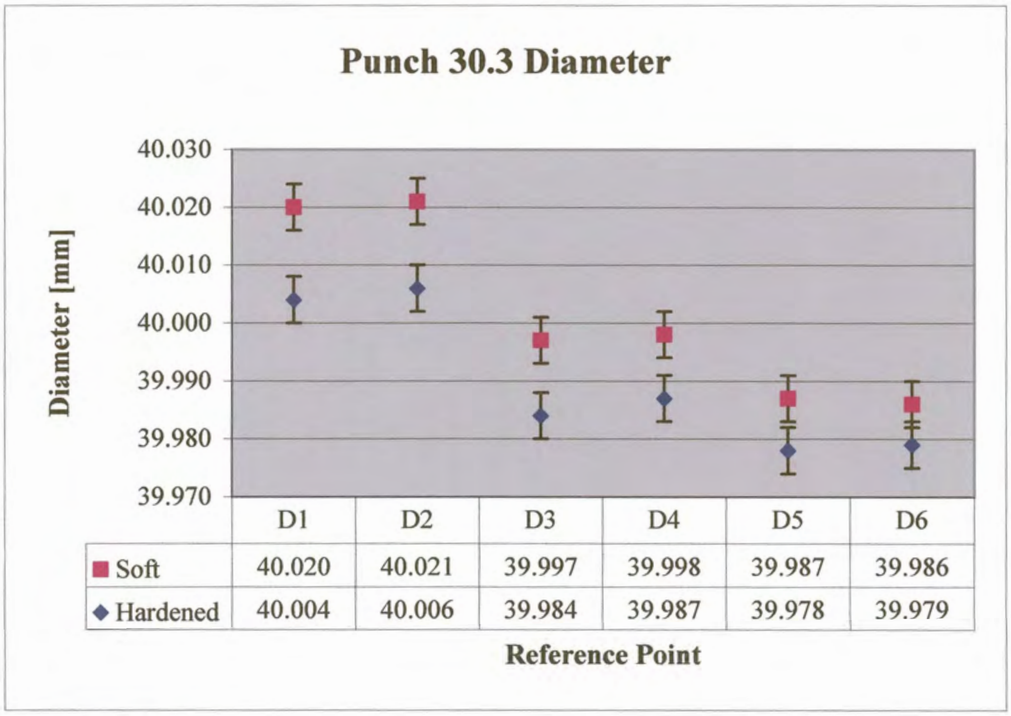


FIGURE F 48

Master Punch 30.4 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	61.841	**26**	61.831
2	61.841	**27**	61.698
3	61.840	**28**	61.835
4	61.838	**29**	61.699
5	61.838	**30**	61.834
6	61.837	**31**	61.697
7	61.838	**32**	61.830
8	61.839	**33**	61.664
9	61.655	**34**	61.771
10	61.650	**35**	61.660
11	61.654	**36**	61.770
12	61.663	**37**	61.675
13	61.671	**38**	61.784
14	61.674	**39**	61.676
15	61.671	**40**	61.786
16	61.666	**41**	20.533
17	61.695	**42**	20.530
18	61.826	**43**	13.160
19	61.689	**44**	13.157
20	61.826	**45**	61.840
21	61.689	**46**	61.656
22	61.824	**47**	61.668
23	61.693	**48**	61.676
24	61.828	**49**	61.671
25	61.697		

Landing

Ref. Point	*Depth*
1	0.186
2	0.191
3	0.186
4	0.175
5	0.167
6	0.163
7	0.167
8	0.173
Average	**0.176**

Design

Ref. Point	*Depth*
17	0.131
19	0.137
21	0.135
23	0.135
25	0.134
27	0.137
29	0.135
31	0.133
Average	**0.135**

Lettering

Ref. Point	*Depth*
33	0.107
35	0.110
37	0.109
39	0.110
Average	**0.109**

Dome

0.042

Diameter

Ref. Point	*Diameter*
D1	40.046
D2	40.045
D3	40.017
D4	40.019
D5	40.001
D6	40.001

Master Punch 30.4 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	61.812	**26**	61.808
2	61.810	**27**	61.675
3	61.811	**28**	61.812
4	61.810	**29**	61.676
5	61.810	**30**	61.811
6	61.809	**31**	61.673
7	61.810	**32**	61.806
8	61.813	**33**	61.636
9	61.626	**34**	61.746
10	61.621	**35**	61.635
11	61.625	**36**	61.746
12	61.634	**37**	61.649
13	61.643	**38**	61.760
14	61.645	**39**	61.650
15	61.643	**40**	61.761
16	61.637	**41**	20.526
17	61.670	**42**	20.527
18	61.802	**43**	13.145
19	61.664	**44**	13.143
20	61.801	**45**	61.812
21	61.665	**46**	61.632
22	61.802	**47**	61.643
23	61.667	**48**	61.650
24	61.804	**49**	61.646
25	61.672		

Landing

Ref. Point	*Depth*
1	0.186
2	0.189
3	0.186
4	0.176
5	0.167
6	0.164
7	0.167
8	0.176
Average	**0.176**

Design

Ref. Point	*Depth*
17	0.132
19	0.137
21	0.137
23	0.137
25	0.136
27	0.137
29	0.135
31	0.133
Average	**0.136**

Lettering

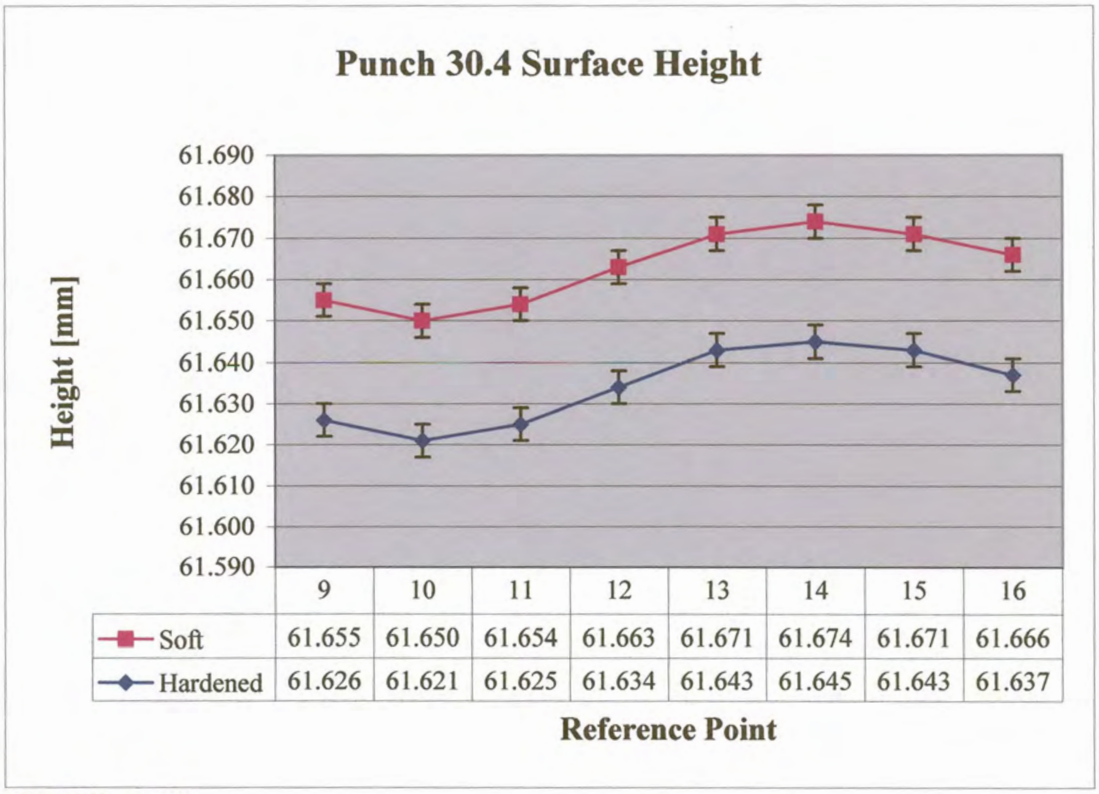
Ref. Point	*Depth*
33	0.110
35	0.111
37	0.111
39	0.111
Average	**0.111**

Dome

0.042

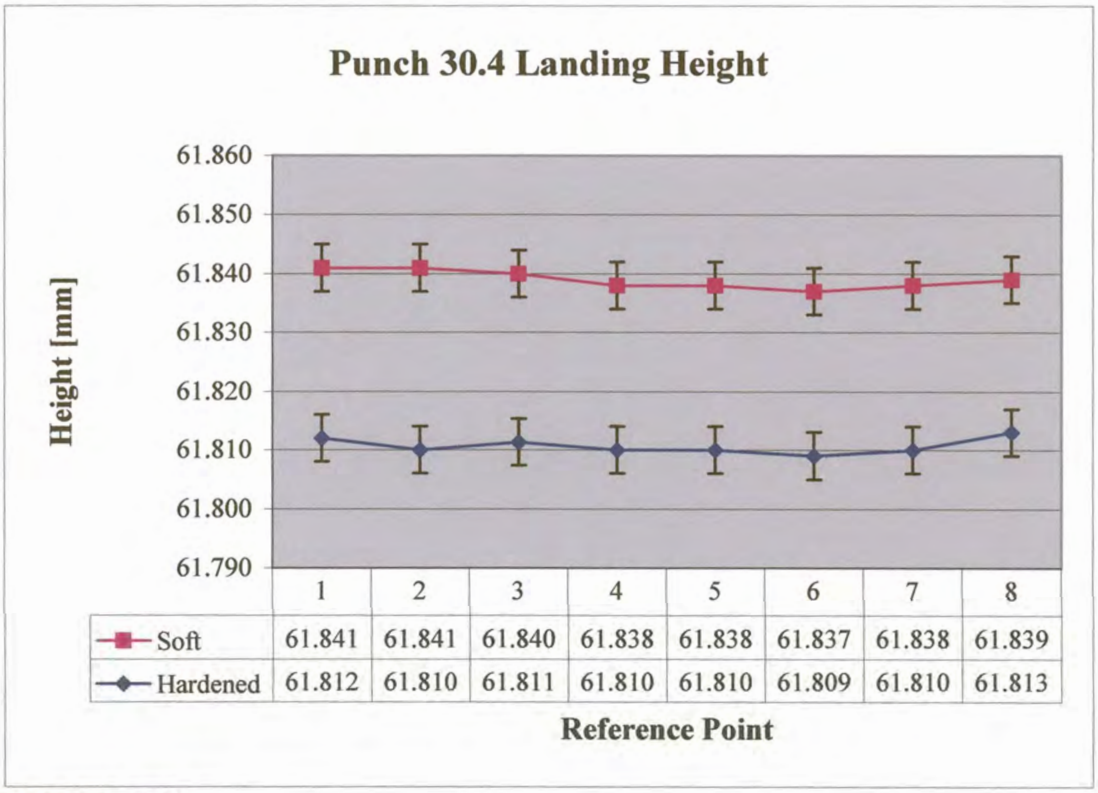
Diameter

Ref. Point	*Diameter*
D1	40.043
D2	40.042
D3	40.017
D4	40.015
D5	40.000
D6	39.995



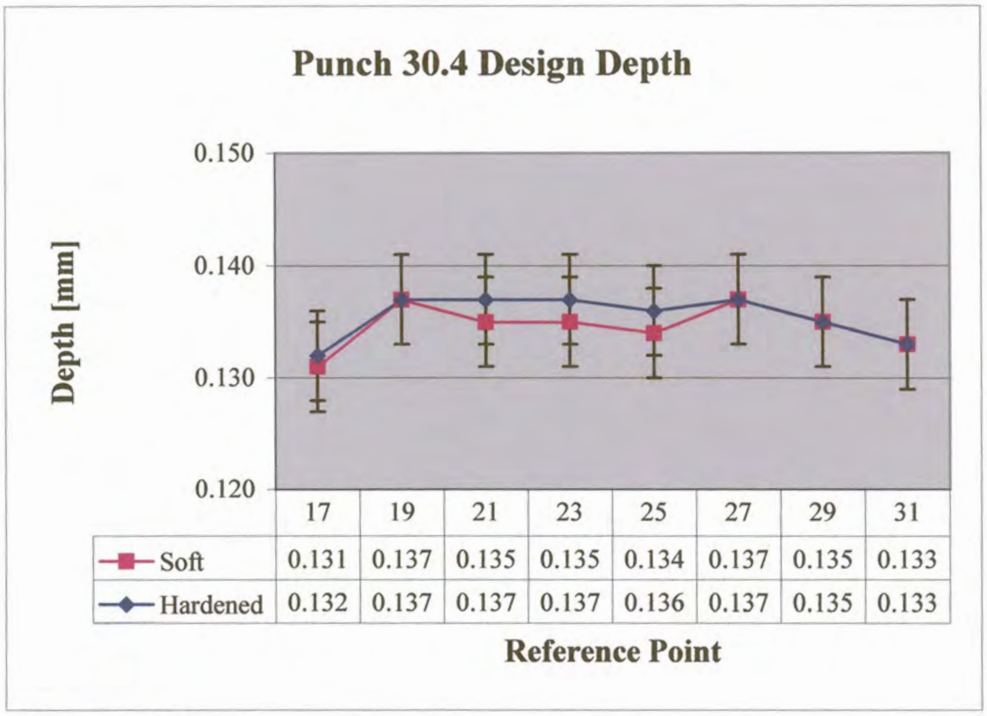
	9	10	11	12	13	14	15	16
Soft	61.655	61.650	61.654	61.663	61.671	61.674	61.671	61.666
Hardened	61.626	61.621	61.625	61.634	61.643	61.645	61.643	61.637

FIGURE F 49



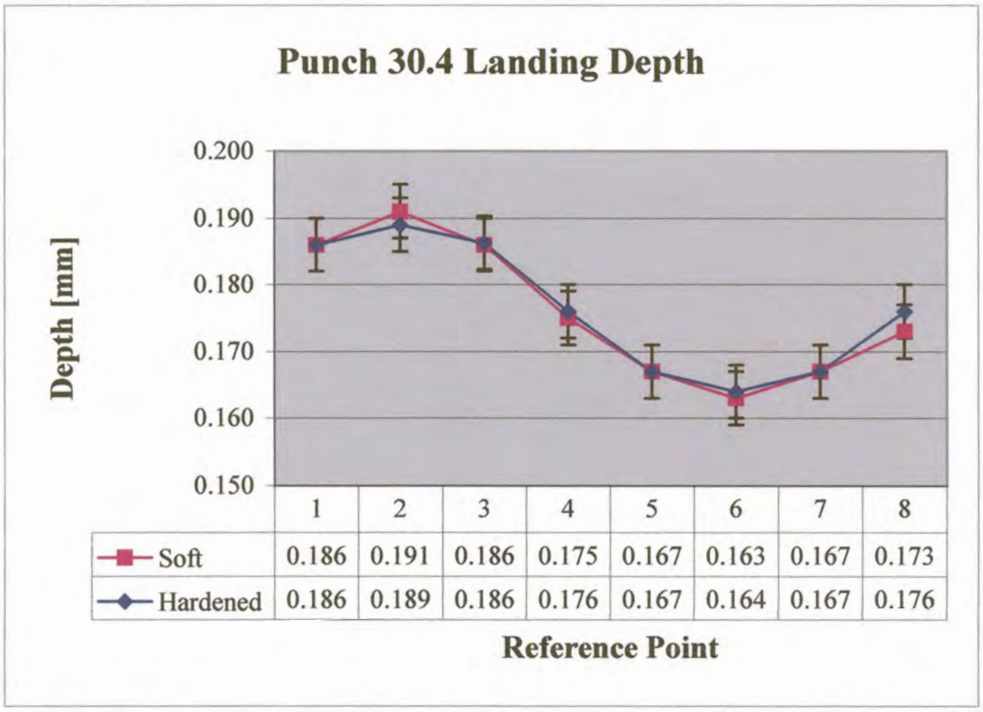
	1	2	3	4	5	6	7	8
Soft	61.841	61.841	61.840	61.838	61.838	61.837	61.838	61.839
Hardened	61.812	61.810	61.811	61.810	61.810	61.809	61.810	61.813

FIGURE F 50



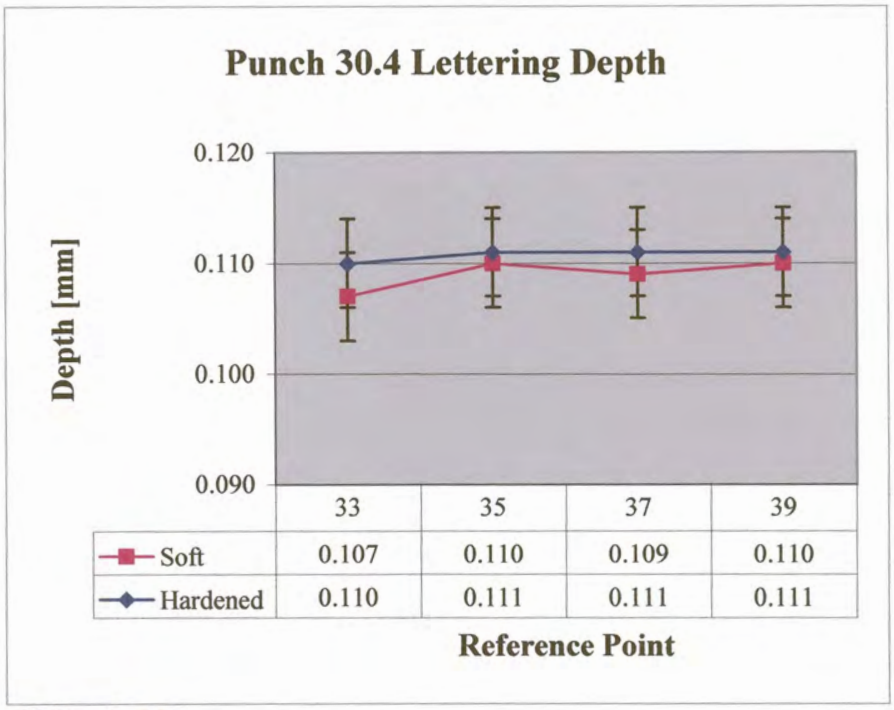
	17	19	21	23	25	27	29	31
Soft	0.131	0.137	0.135	0.135	0.134	0.137	0.135	0.133
Hardened	0.132	0.137	0.137	0.137	0.136	0.137	0.135	0.133

FIGURE F 51



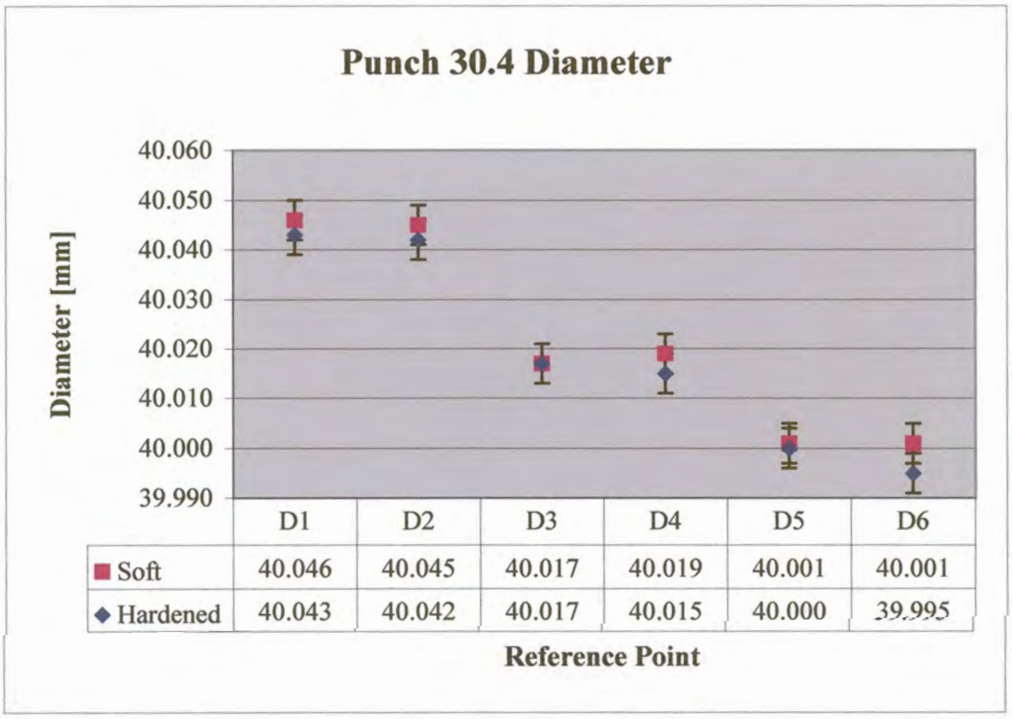
	1	2	3	4	5	6	7	8
Soft	0.186	0.191	0.186	0.175	0.167	0.163	0.167	0.173
Hardened	0.186	0.189	0.186	0.176	0.167	0.164	0.167	0.176

FIGURE F 52



	33	35	37	39
🟥 Soft	0.107	0.110	0.109	0.110
◆ Hardened	0.110	0.111	0.111	0.111

FIGURE F 53



	D1	D2	D3	D4	D5	D6
🟥 Soft	40.046	40.045	40.017	40.019	40.001	40.001
◆ Hardened	40.043	40.042	40.017	40.015	40.000	39.995

FIGURE F 54

Master Punch 30.5 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	60.410	**26**	60.381
2	60.415	**27**	60.245
3	60.420	**28**	60.382
4	60.420	**29**	60.242
5	60.419	**30**	60.378
6	60.415	**31**	60.238
7	60.409	**32**	60.372
8	60.408	**33**	60.224
9	60.223	**34**	60.332
10	60.223	**35**	60.228
11	60.230	**36**	60.337
12	60.240	**37**	60.243
13	60.246	**38**	60.352
14	60.246	**39**	60.238
15	60.238	**40**	60.346
16	60.231	**41**	20.481
17	60.233	**42**	20.486
18	60.369	**43**	13.124
19	60.231	**44**	13.127
20	60.370	**45**	60.369
21	60.236	**46**	60.223
22	60.374	**47**	60.238
23	60.240	**48**	60.242
24	60.377	**49**	60.231
25	60.245		

Landing

Ref. Point	*Depth*
1	0.187
2	0.192
3	0.190
4	0.180
5	0.173
6	0.169
7	0.171
8	0.177
Average	**0.180**

Design

Ref. Point	*Depth*
17	0.136
19	0.139
21	0.138
23	0.137
25	0.136
27	0.137
29	0.136
31	0.134
Average	**0.137**

Lettering

Ref. Point	*Depth*
33	0.108
35	0.109
37	0.109
39	0.108
Average	**0.108**

Dome

-0.002

Diameter

Ref. Point	*Diameter*
D1	39.943
D2	39.945
D3	39.913
D4	39.914
D5	39.892
D6	39.893

Master Punch 30.5 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	60.406	**26**	60.374
2	60.414	**27**	60.237
3	60.419	**28**	60.373
4	60.415	**29**	60.235
5	60.410	**30**	60.372
6	60.404	**31**	60.232
7	60.401	**32**	60.365
8	60.403	**33**	60.221
9	60.216	**34**	60.328
10	60.218	**35**	60.227
11	60.229	**36**	60.335
12	60.233	**37**	60.235
13	60.238	**38**	60.344
14	60.236	**39**	60.231
15	60.230	**40**	60.339
16	60.223	**41**	20.477
17	60.229	**42**	20.480
18	60.363	**43**	13.115
19	60.227	**44**	13.120
20	60.365	**45**	60.354
21	60.230	**46**	60.220
22	60.367	**47**	60.231
23	60.233	**48**	60.234
24	60.370	**49**	60.222
25	60.236		

Landing

Ref. Point	*Depth*
1	0.190
2	0.196
3	0.190
4	0.182
5	0.172
6	0.168
7	0.171
8	0.180
Average	**0.181**

Design

Ref. Point	*Depth*
17	0.134
19	0.138
21	0.137
23	0.137
25	0.138
27	0.136
29	0.137
31	0.133
Average	**0.136**

Lettering

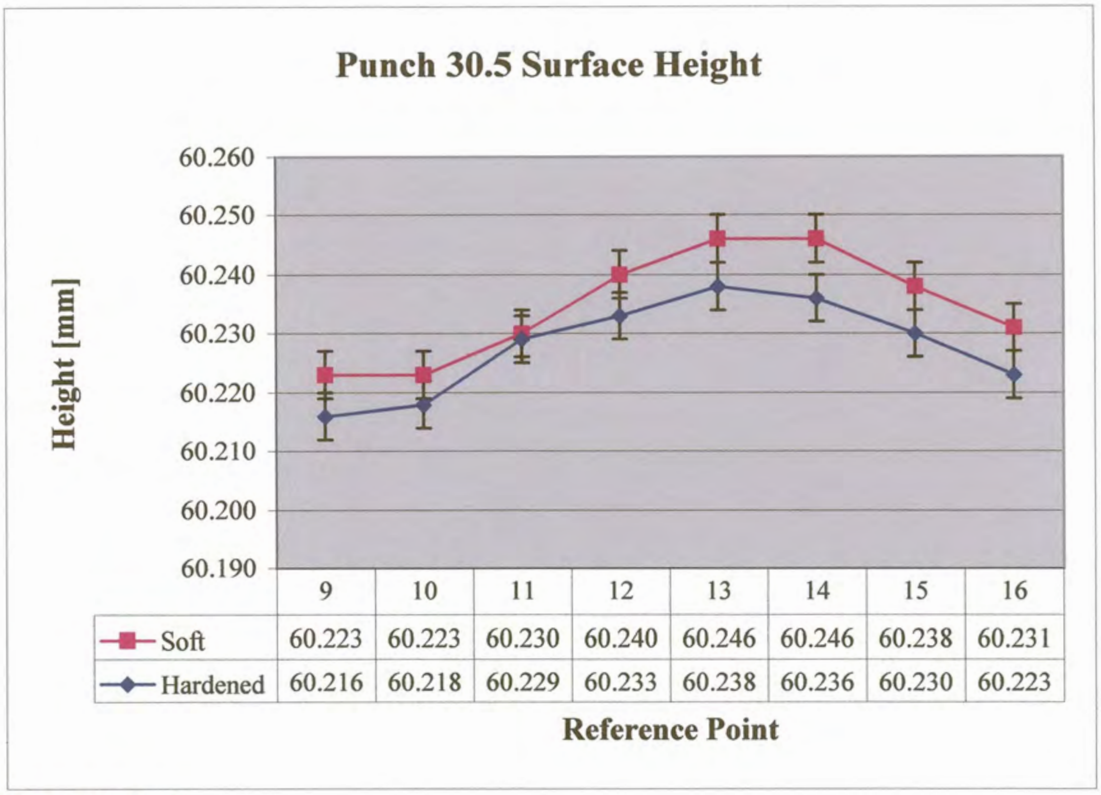
Ref. Point	*Depth*
33	0.107
35	0.108
37	0.109
39	0.108
Average	**0.108**

Dome

-0.010

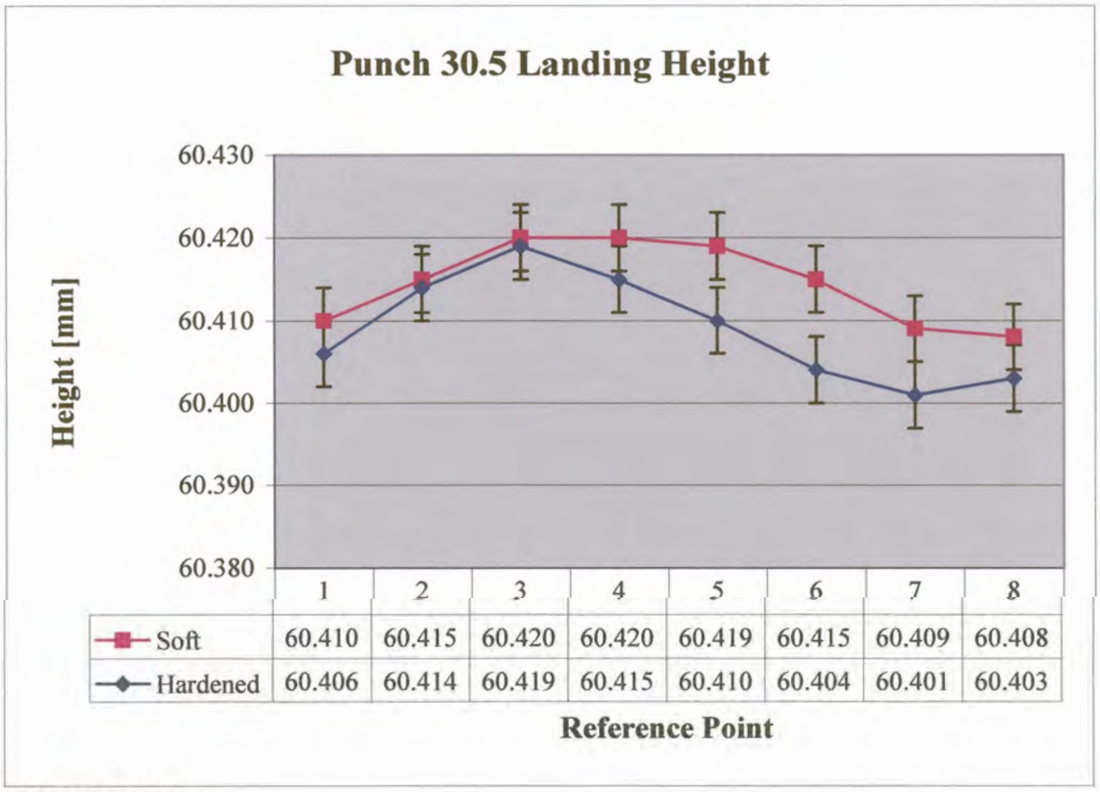
Diameter

Ref. Point	*Diameter*
D1	39.935
D2	39.933
D3	39.914
D4	39.913
D5	39.893
D6	39.892



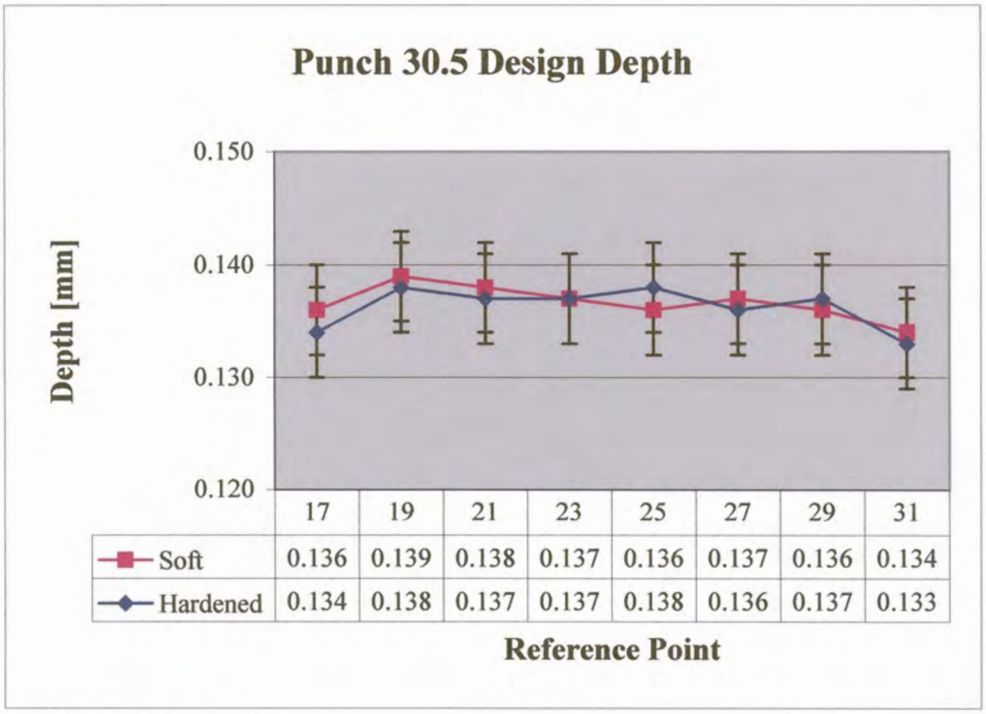
	9	10	11	12	13	14	15	16
Soft	60.223	60.223	60.230	60.240	60.246	60.246	60.238	60.231
Hardened	60.216	60.218	60.229	60.233	60.238	60.236	60.230	60.223

FIGURE F 55



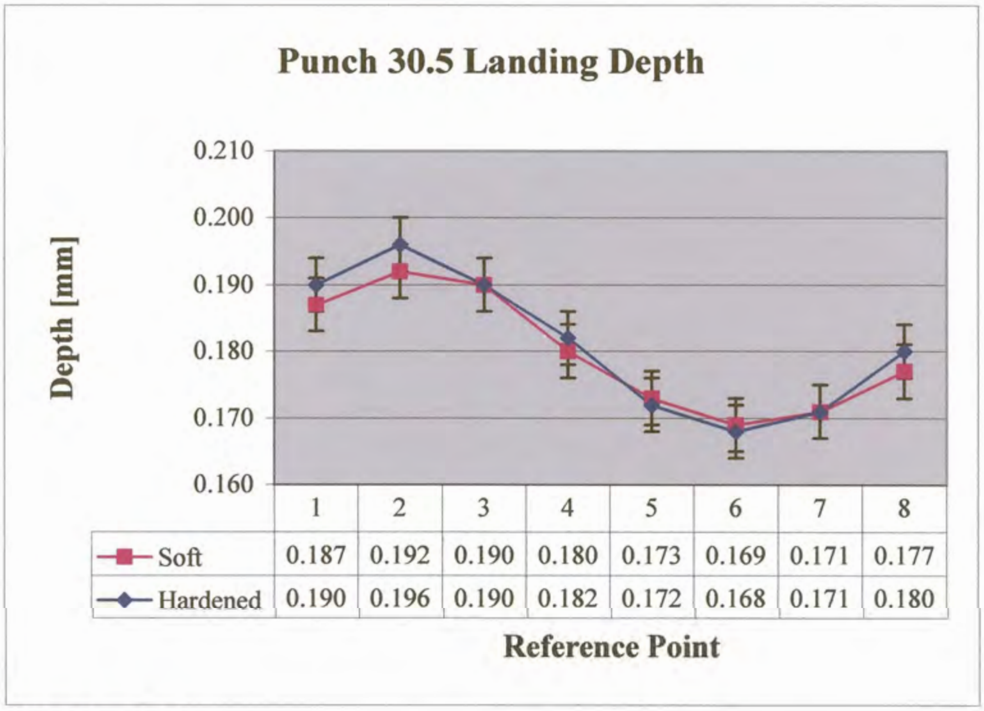
	1	2	3	4	5	6	7	8
Soft	60.410	60.415	60.420	60.420	60.419	60.415	60.409	60.408
Hardened	60.406	60.414	60.419	60.415	60.410	60.404	60.401	60.403

FIGURE F 56



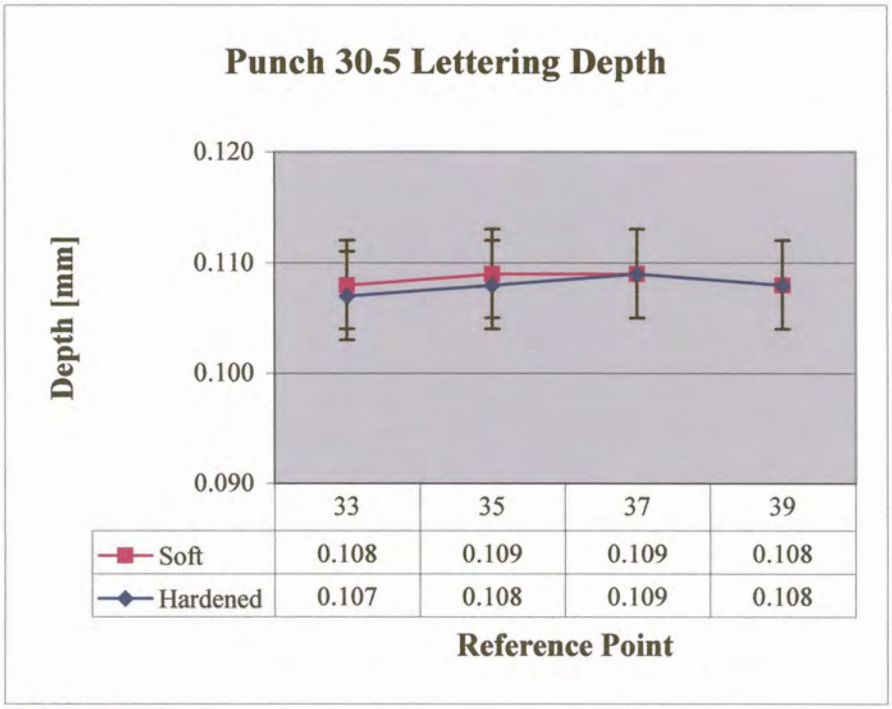
Reference Point	17	19	21	23	25	27	29	31
Soft	0.136	0.139	0.138	0.137	0.136	0.137	0.136	0.134
Hardened	0.134	0.138	0.137	0.137	0.138	0.136	0.137	0.133

FIGURE F 57



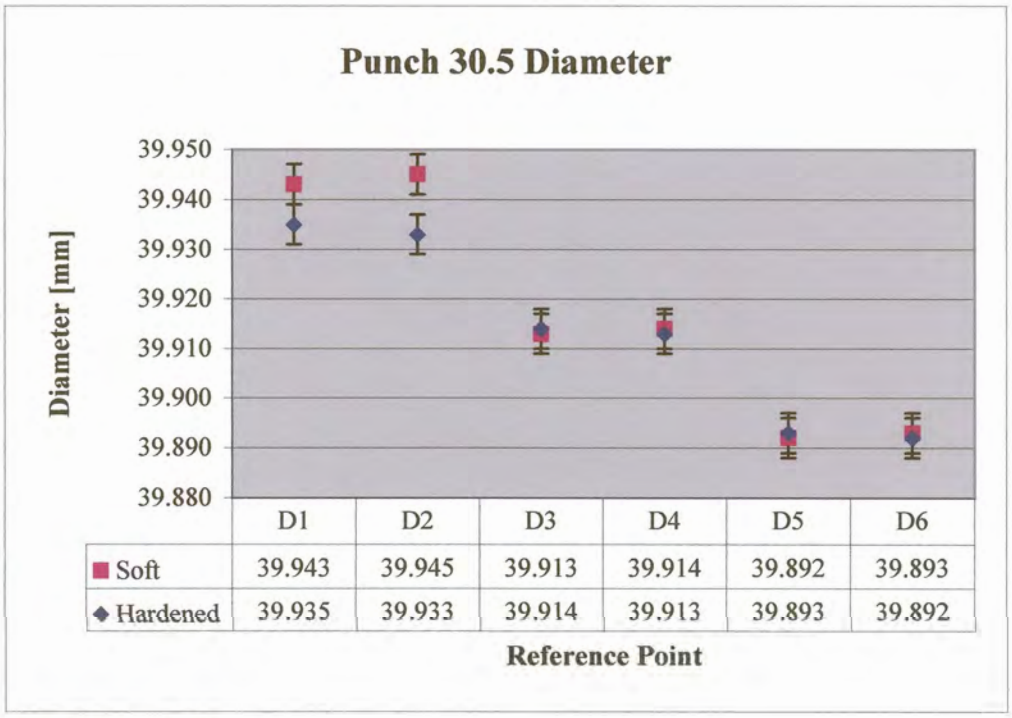
Reference Point	1	2	3	4	5	6	7	8
Soft	0.187	0.192	0.190	0.180	0.173	0.169	0.171	0.177
Hardened	0.190	0.196	0.190	0.182	0.172	0.168	0.171	0.180

FIGURE F 58



	33	35	37	39
🟥 Soft	0.108	0.109	0.109	0.108
◆ Hardened	0.107	0.108	0.109	0.108

FIGURE F 59



	D1	D2	D3	D4	D5	D6
🟥 Soft	39.943	39.945	39.913	39.914	39.892	39.893
◆ Hardened	39.935	39.933	39.914	39.913	39.893	39.892

FIGURE F 60

Master Punch 35.1 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	61.548	**26**	61.538
2	61.544	**27**	61.405
3	61.542	**28**	61.543
4	61.539	**29**	61.408
5	61.541	**30**	61.544
6	61.545	**31**	61.407
7	61.547	**32**	61.540
8	61.549	**33**	61.371
9	61.362	**34**	61.481
10	61.354	**35**	61.365
11	61.356	**36**	61.474
12	61.366	**37**	61.378
13	61.379	**38**	61.491
14	61.383	**39**	61.387
15	61.381	**40**	61.497
16	61.375	**41**	20.543
17	61.402	**42**	20.544
18	61.535	**43**	13.162
19	61.394	**44**	13.161
20	61.532	**45**	61.547
21	61.393	**46**	61.362
22	61.531	**47**	61.374
23	61.397	**48**	61.385
24	61.533	**49**	61.384
25	61.402		

Landing

Ref. Point	*Depth*
1	0.186
2	0.190
3	0.186
4	0.173
5	0.162
6	0.162
7	0.166
8	0.174
Average	**0.175**

Design

Ref. Point	*Depth*
17	0.133
19	0.138
21	0.138
23	0.136
25	0.136
27	0.138
29	0.136
31	0.133
Average	**0.136**

Lettering

Ref. Point	*Depth*
33	0.110
35	0.109
37	0.113
39	0.110
Average	**0.110**

Dome

0.041

Diameter

Ref. Point	*Diameter*
D1	40.053
D2	40.053
D3	40.028
D4	40.027
D5	40.012
D6	40.012

Master Punch 35.1 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	61.543	**26**	61.537
2	61.538	**27**	61.403
3	61.535	**28**	61.542
4	61.532	**29**	61.405
5	61.533	**30**	61.544
6	61.539	**31**	61.406
7	61.542	**32**	61.539
8	61.545	**33**	61.368
9	61.356	**34**	61.479
10	61.348	**35**	61.360
11	61.349	**36**	61.471
12	61.358	**37**	61.373
13	61.369	**38**	61.485
14	61.375	**39**	61.382
15	61.375	**40**	61.494
16	61.370	**41**	20.537
17	61.401	**42**	20.540
18	61.534	**43**	13.153
19	61.392	**44**	13.158
20	61.531	**45**	61.545
21	61.389	**46**	61.359
22	61.528	**47**	61.366
23	61.394	**48**	61.381
24	61.531	**49**	61.379
25	61.400		

Landing

Ref. Point	*Depth*
1	0.187
2	0.190
3	0.186
4	0.174
5	0.164
6	0.164
7	0.167
8	0.175
Average	**0.176**

Design

Ref. Point	*Depth*
17	0.133
19	0.139
21	0.139
23	0.137
25	0.137
27	0.139
29	0.139
31	0.133
Average	**0.137**

Lettering

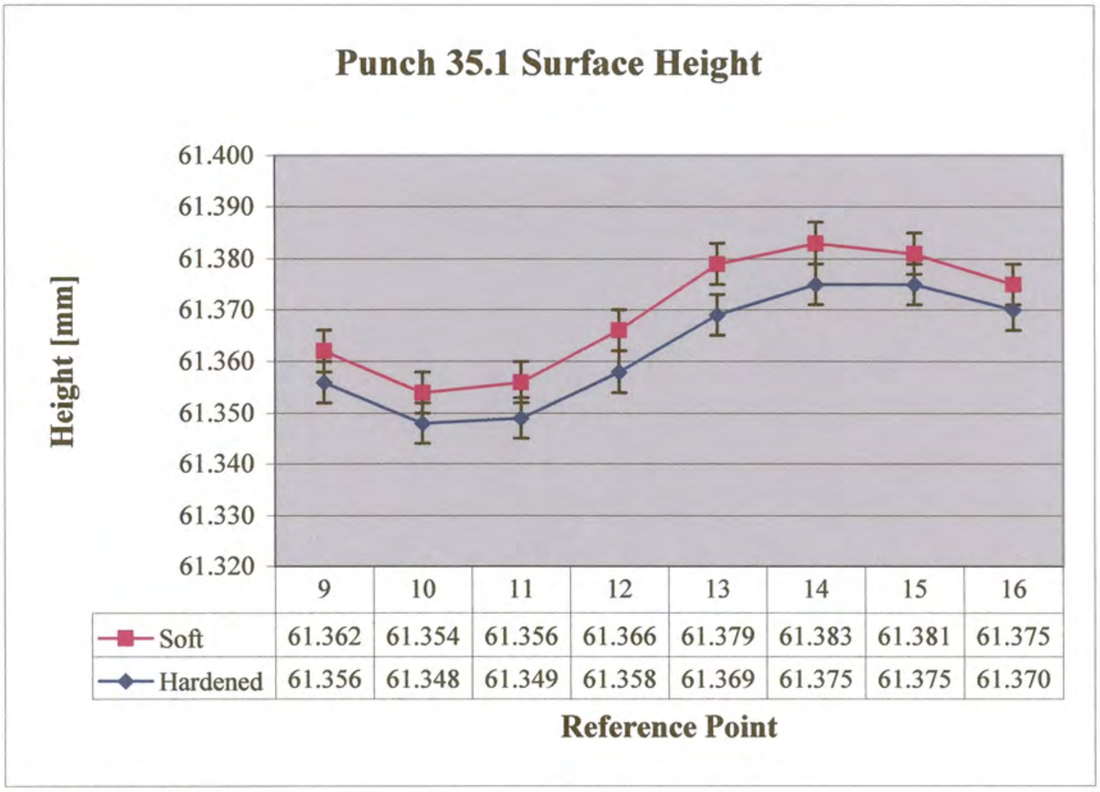
Ref. Point	*Depth*
33	0.111
35	0.111
37	0.112
39	0.112
Average	**0.111**

Dome

0.046

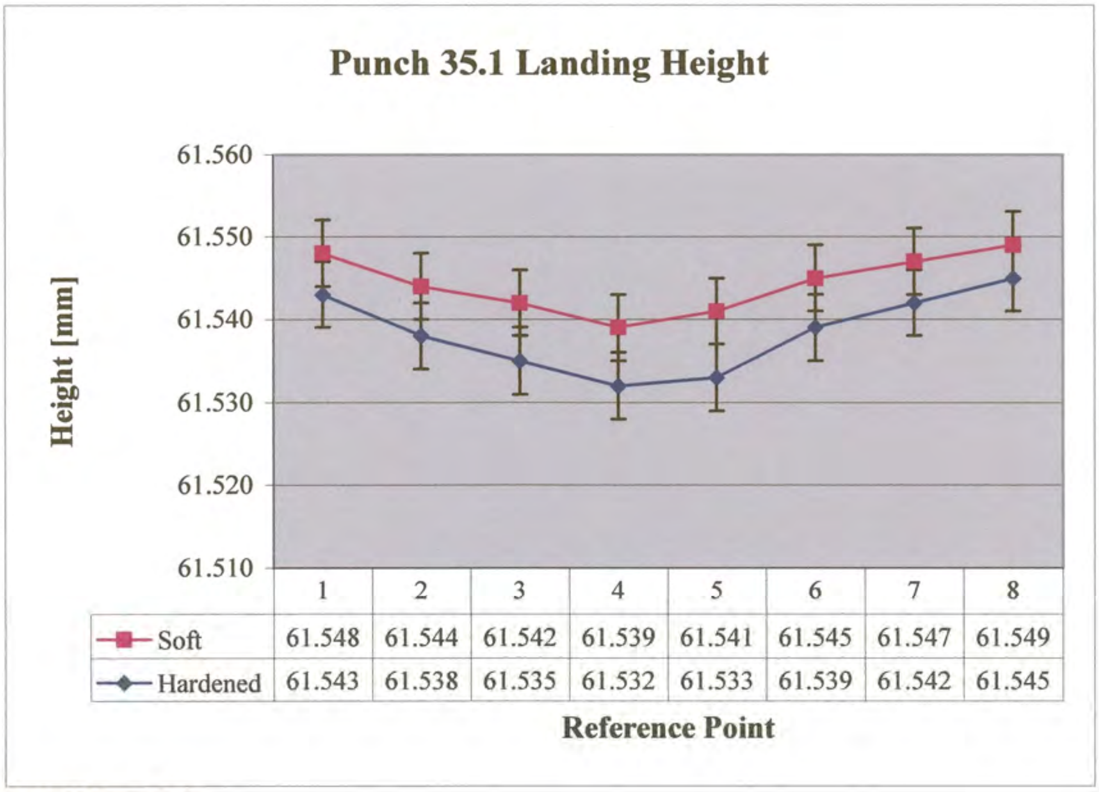
Diameter

Ref. Point	*Diameter*
D1	40.059
D2	40.058
D3	40.031
D4	40.032
D5	40.011
D6	40.011



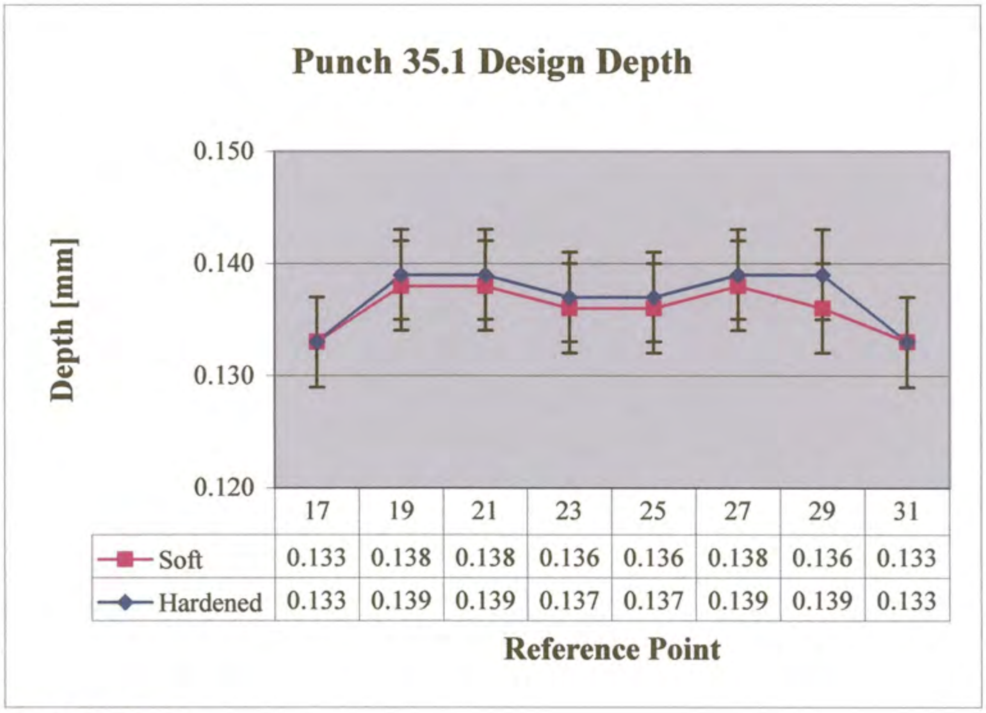
	9	10	11	12	13	14	15	16
Soft	61.362	61.354	61.356	61.366	61.379	61.383	61.381	61.375
Hardened	61.356	61.348	61.349	61.358	61.369	61.375	61.375	61.370

FIGURE F 61



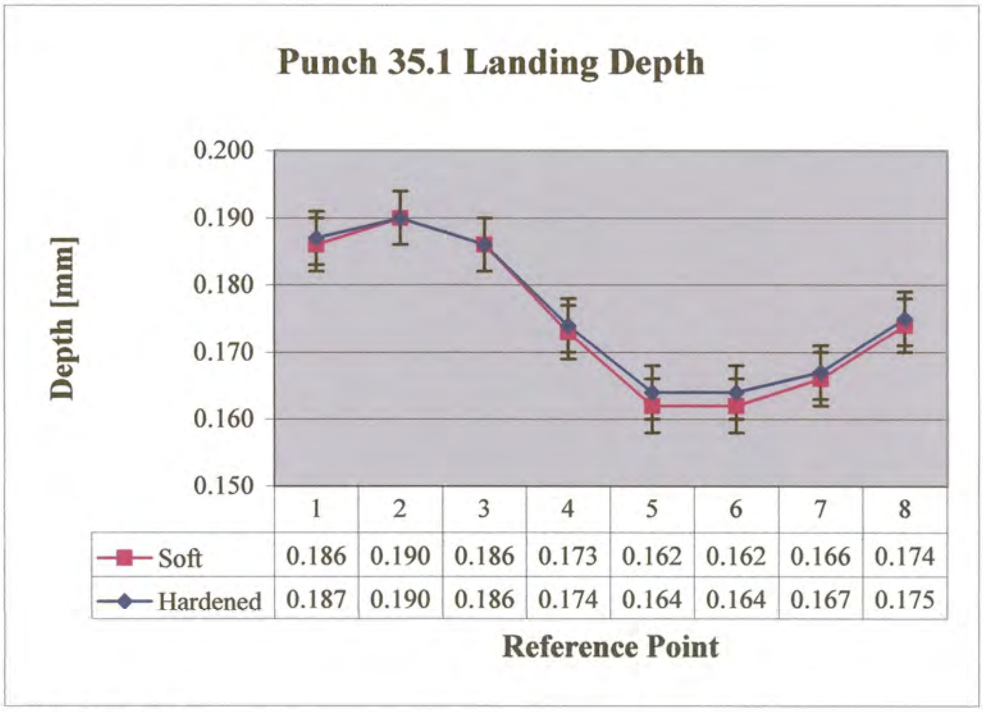
	1	2	3	4	5	6	7	8
Soft	61.548	61.544	61.542	61.539	61.541	61.545	61.547	61.549
Hardened	61.543	61.538	61.535	61.532	61.533	61.539	61.542	61.545

FIGURE F 62



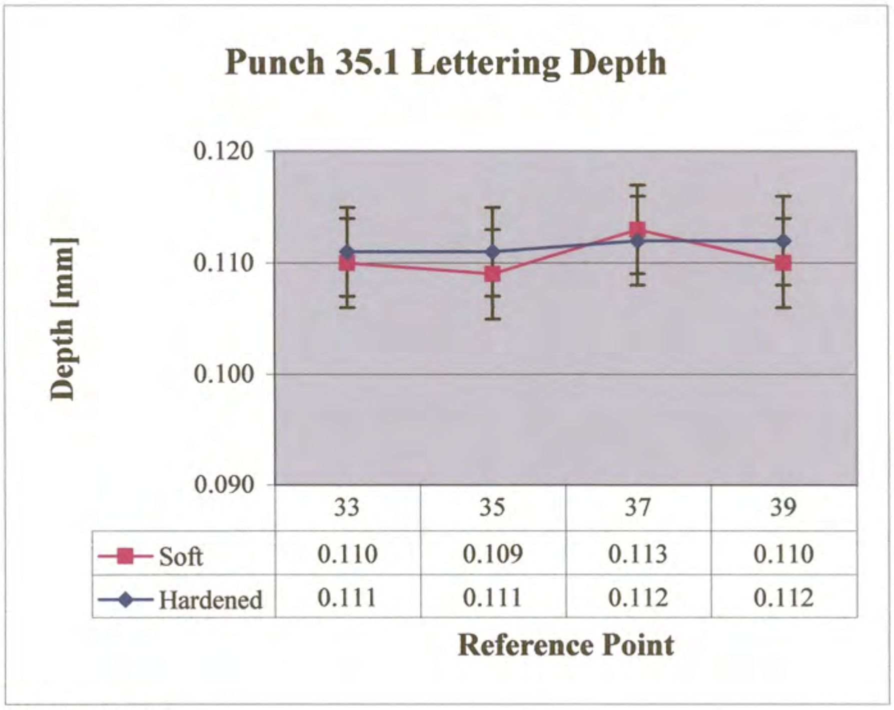
Reference Point	17	19	21	23	25	27	29	31
Soft	0.133	0.138	0.138	0.136	0.136	0.138	0.136	0.133
Hardened	0.133	0.139	0.139	0.137	0.137	0.139	0.139	0.133

FIGURE F 63



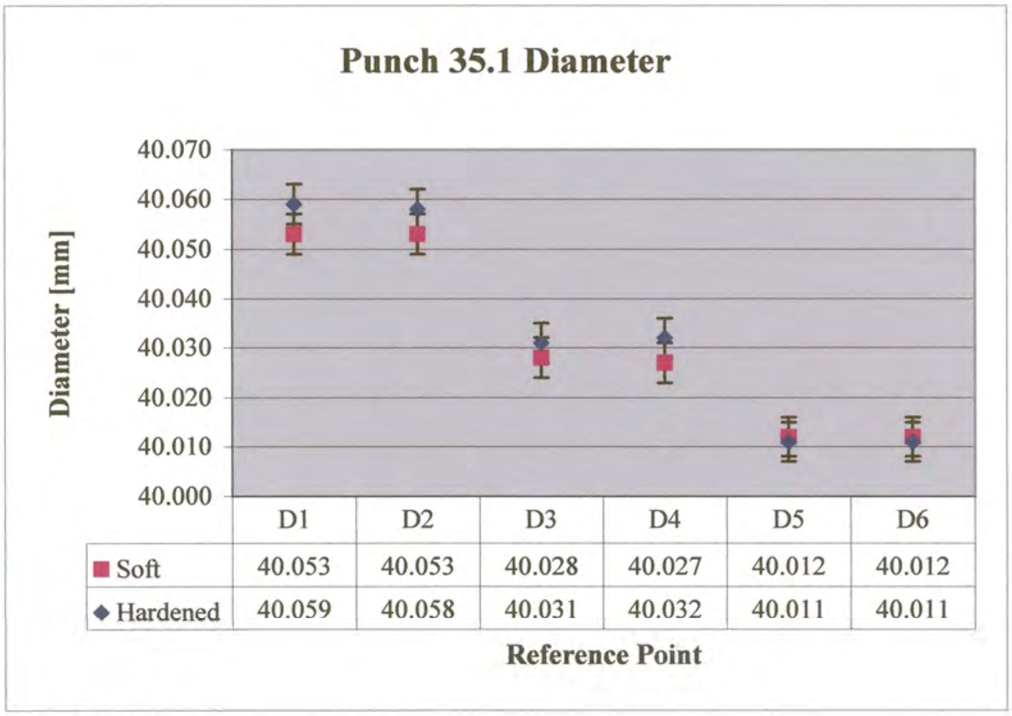
Reference Point	1	2	3	4	5	6	7	8
Soft	0.186	0.190	0.186	0.173	0.162	0.162	0.166	0.174
Hardened	0.187	0.190	0.186	0.174	0.164	0.164	0.167	0.175

FIGURE F 64



	33	35	37	39
Soft	0.110	0.109	0.113	0.110
Hardened	0.111	0.111	0.112	0.112

FIGURE F 65



	D1	D2	D3	D4	D5	D6
Soft	40.053	40.053	40.028	40.027	40.012	40.012
Hardened	40.059	40.058	40.031	40.032	40.011	40.011

FIGURE F 66

Master Punch 35.2 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	61.390	**26**	61.390
2	61.392	**27**	61.254
3	61.397	**28**	61.390
4	61.397	**29**	61.252
5	61.394	**30**	61.388
6	61.391	**31**	61.251
7	61.389	**32**	61.382
8	61.389	**33**	61.215
9	61.205	**34**	61.323
10	61.205	**35**	61.217
11	61.213	**36**	61.328
12	61.222	**37**	61.233
13	61.229	**38**	61.343
14	61.228	**39**	61.227
15	61.223	**40**	61.337
16	61.215	**41**	20.537
17	61.245	**42**	20.538
18	61.378	**43**	13.159
19	61.242	**44**	13.160
20	61.379	**45**	61.395
21	61.244	**46**	61.212
22	61.383	**47**	61.227
23	61.252	**48**	61.231
24	61.387	**49**	61.222
25	61.255		

Landing

Ref. Point	*Depth*
1	0.185
2	0.187
3	0.184
4	0.175
5	0.165
6	0.163
7	0.166
8	0.174
Average	**0.175**

Design

Ref. Point	*Depth*
17	0.133
19	0.137
21	0.139
23	0.135
25	0.135
27	0.136
29	0.136
31	0.131
Average	**0.135**

Lettering

Ref. Point	*Depth*
33	0.108
35	0.111
37	0.110
39	0.110
Average	**0.110**

Dome

0.042

Diameter

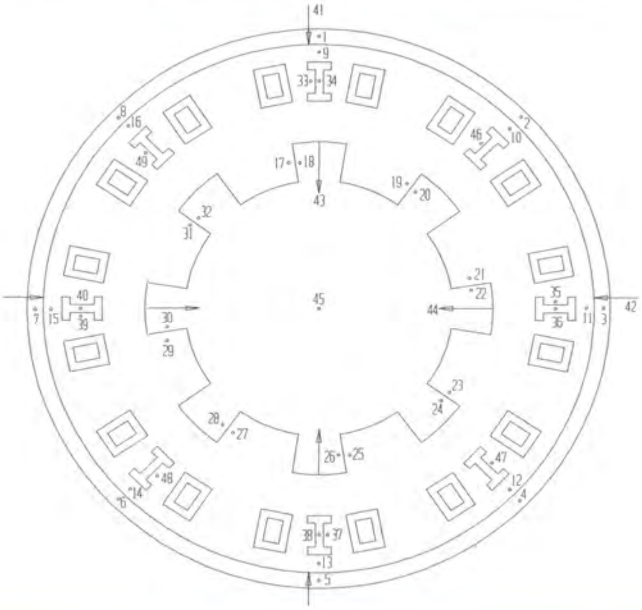
Ref. Point	*Diameter*
D1	40.064
D2	40.066
D3	40.048
D4	40.049
D5	40.039
D6	40.038

Master Punch 35.2 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	61.386	**26**	61.381
2	61.386	**27**	61.247
3	61.387	**28**	61.385
4	61.383	**29**	61.246
5	61.380	**30**	61.383
6	61.380	**31**	61.245
7	61.381	**32**	61.378
8	61.384	**33**	61.210
9	61.199	**34**	61.318
10	61.196	**35**	61.209
11	61.202	**36**	61.319
12	61.209	**37**	61.222
13	61.216	**38**	61.331
14	61.217	**39**	61.222
15	61.215	**40**	61.332
16	61.209	**41**	20.540
17	61.241	**42**	20.544
18	61.375	**43**	13.157
19	61.237	**44**	13.161
20	61.375	**45**	61.386
21	61.238	**46**	61.204
22	61.376	**47**	61.215
23	61.241	**48**	61.224
24	61.379	**49**	61.218
25	61.246		



Landing

Ref. Point	*Depth*
1	0.187
2	0.190
3	0.185
4	0.174
5	0.164
6	0.163
7	0.166
8	0.175
Average	**0.176**

Design

Ref. Point	*Depth*
17	0.134
19	0.138
21	0.138
23	0.138
25	0.135
27	0.138
29	0.137
31	0.133
Average	**0.136**

Lettering

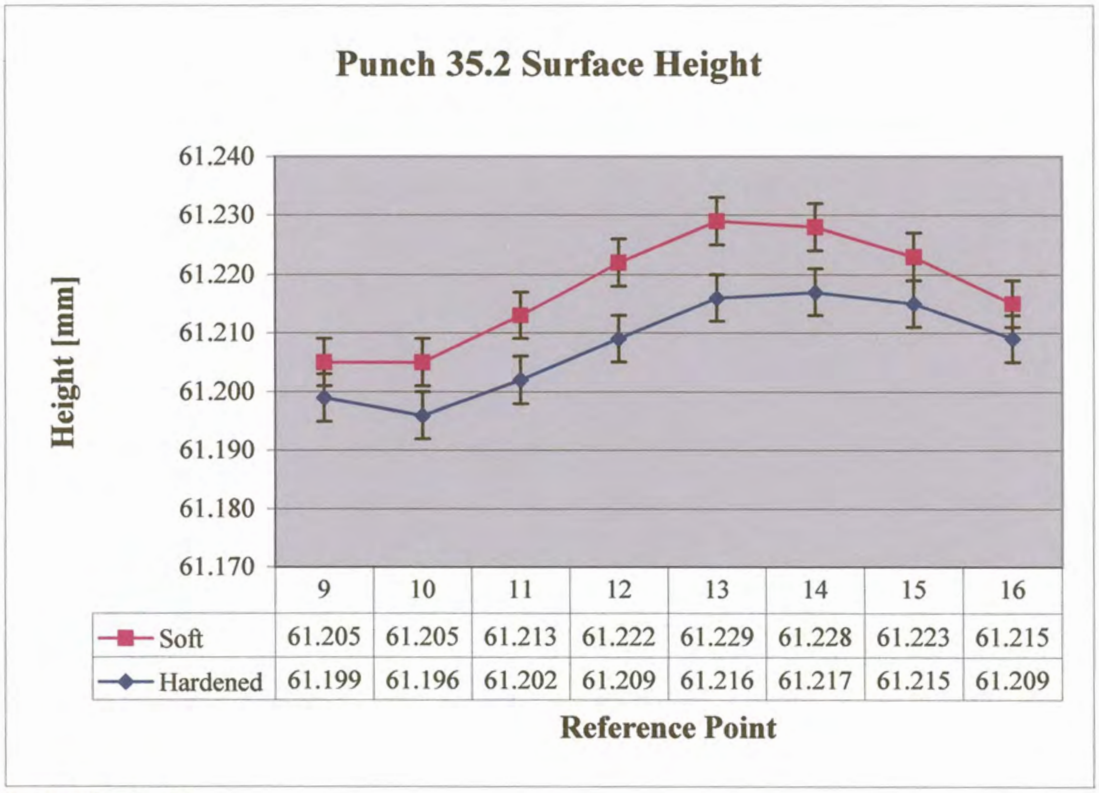
Ref. Point	*Depth*
33	0.108
35	0.110
37	0.109
39	0.110
Average	**0.109**

Dome

0.042

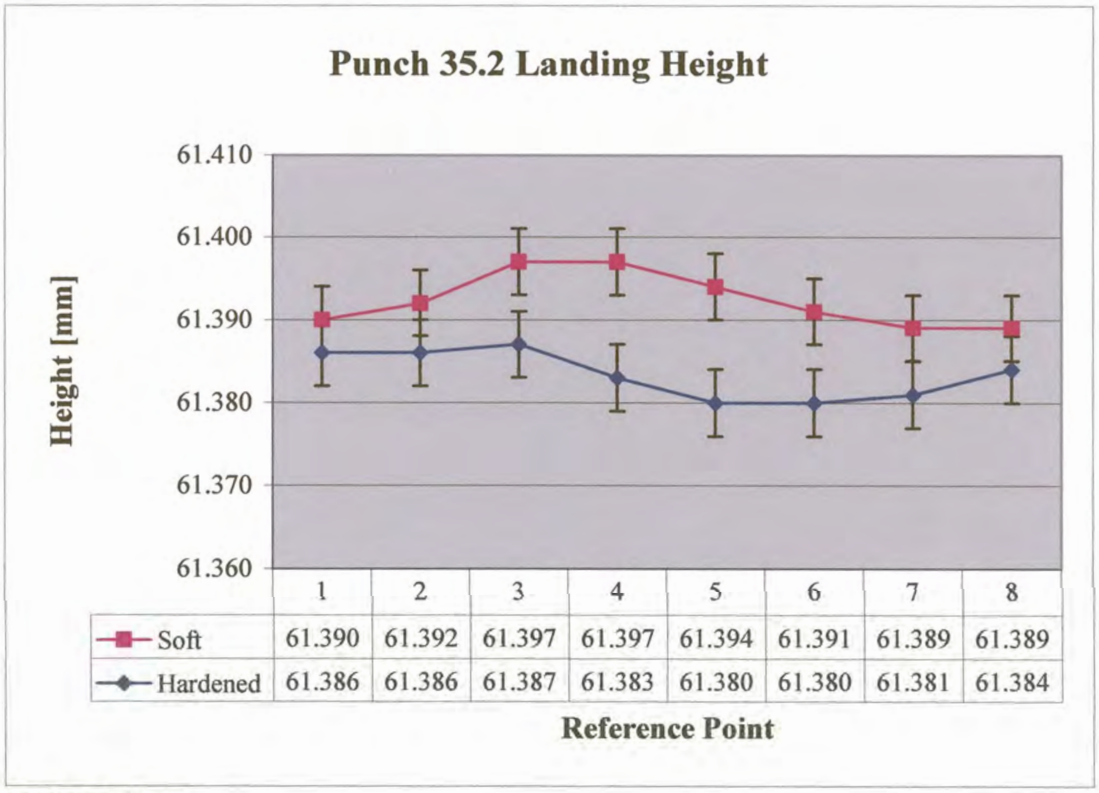
Diameter

Ref. Point	*Diameter*
D1	40.072
D2	40.073
D3	40.050
D4	40.053
D5	40.041
D6	40.042



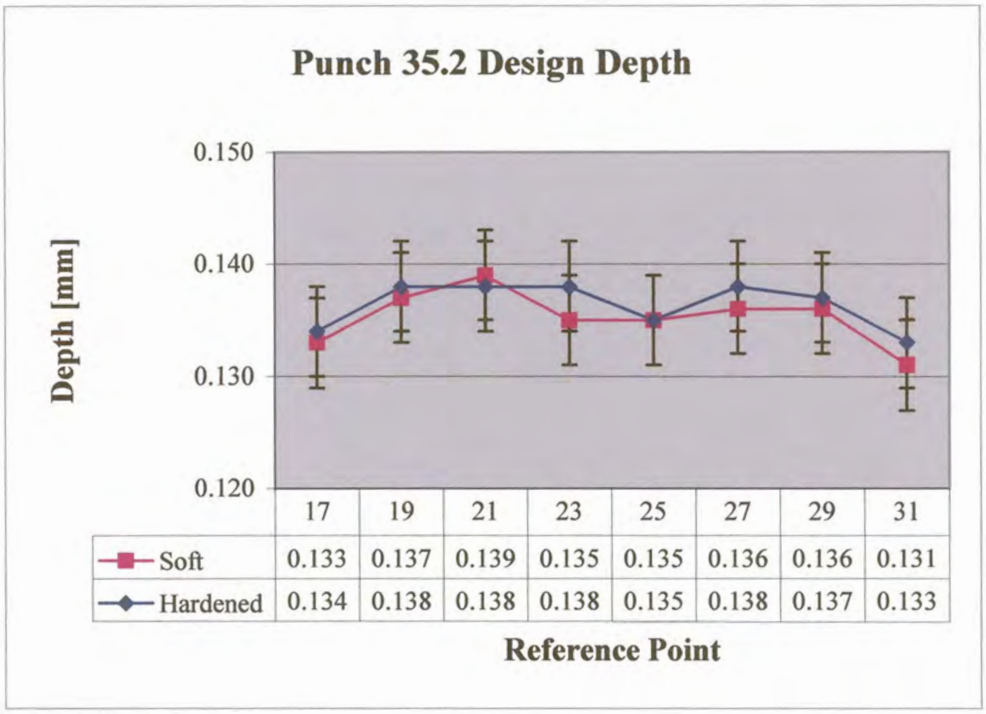
	9	10	11	12	13	14	15	16
■ Soft	61.205	61.205	61.213	61.222	61.229	61.228	61.223	61.215
◆ Hardened	61.199	61.196	61.202	61.209	61.216	61.217	61.215	61.209

FIGURE F 67



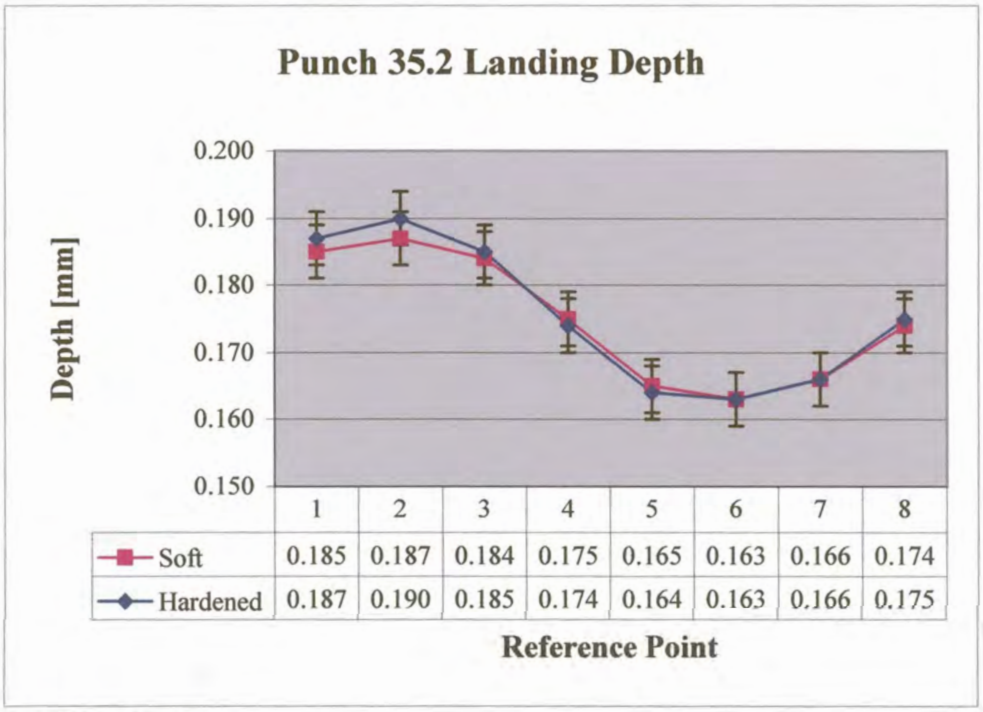
	1	2	3	4	5	6	7	8
■ Soft	61.390	61.392	61.397	61.397	61.394	61.391	61.389	61.389
◆ Hardened	61.386	61.386	61.387	61.383	61.380	61.380	61.381	61.384

FIGURE F 68



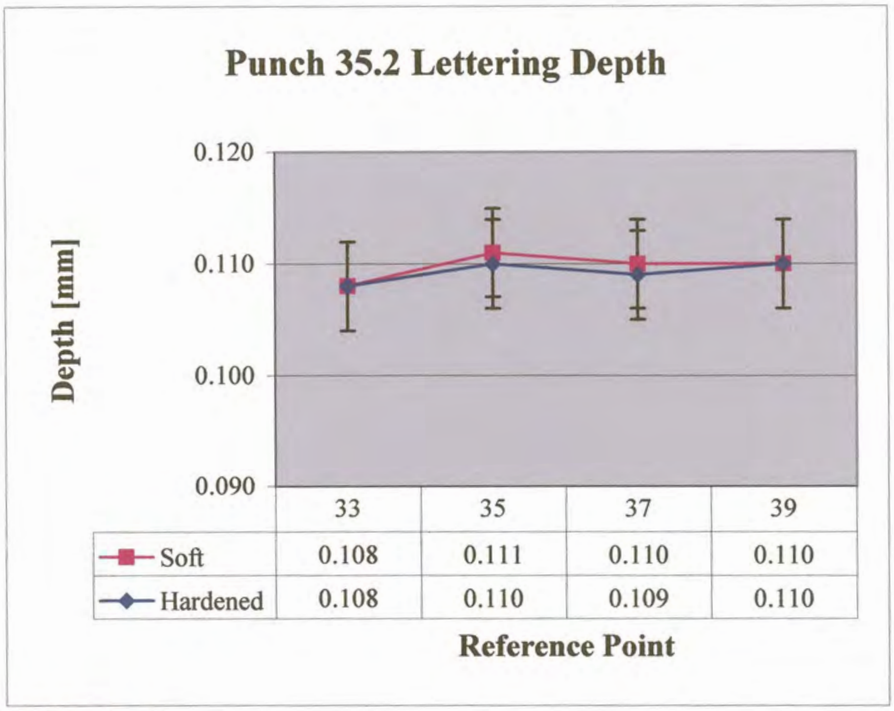
	17	19	21	23	25	27	29	31
Soft	0.133	0.137	0.139	0.135	0.135	0.136	0.136	0.131
Hardened	0.134	0.138	0.138	0.138	0.135	0.138	0.137	0.133

FIGURE F 69



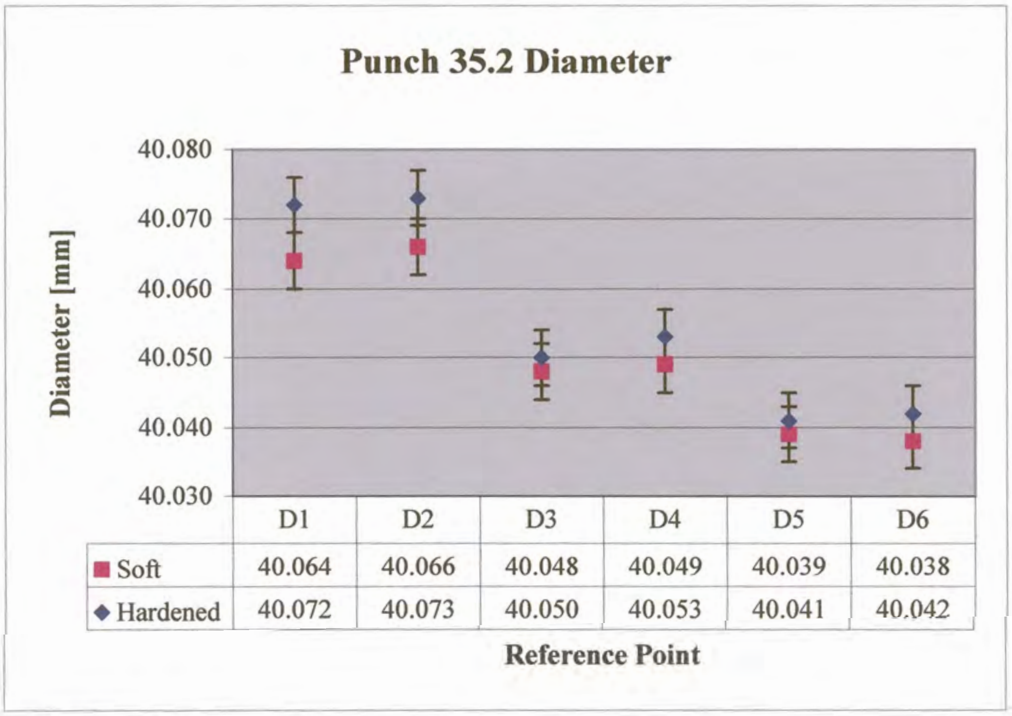
	1	2	3	4	5	6	7	8
Soft	0.185	0.187	0.184	0.175	0.165	0.163	0.166	0.174
Hardened	0.187	0.190	0.185	0.174	0.164	0.163	0.166	0.175

FIGURE F 70



	33	35	37	39
Soft	0.108	0.111	0.110	0.110
Hardened	0.108	0.110	0.109	0.110

FIGURE F 71



	D1	D2	D3	D4	D5	D6
Soft	40.064	40.066	40.048	40.049	40.039	40.038
Hardened	40.072	40.073	40.050	40.053	40.041	40.042

FIGURE F 72

Master Punch 40.1 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	59.520	**26**	59.498
2	59.517	**27**	59.364
3	59.511	**28**	59.502
4	59.505	**29**	59.367
5	59.503	**30**	59.504
6	59.505	**31**	59.369
7	59.509	**32**	59.501
8	59.516	**33**	59.341
9	59.332	**34**	59.449
10	59.327	**35**	59.332
11	59.326	**36**	59.443
12	59.331	**37**	59.340
13	59.338	**38**	59.450
14	59.342	**39**	59.346
15	59.342	**40**	59.456
16	59.341	**41**	20.543
17	59.366	**42**	20.546
18	59.499	**43**	13.162
19	59.360	**44**	13.160
20	59.497	**45**	59.507
21	59.358	**46**	59.333
22	59.496	**47**	59.335
23	59.359	**48**	59.343
24	59.496	**49**	59.345
25	59.361		

Landing

Ref. Point	*Depth*
1	0.188
2	0.190
3	0.185
4	0.174
5	0.165
6	0.163
7	0.167
8	0.175
Average	**0.176**

Design

Ref. Point	*Depth*
17	0.133
19	0.137
21	0.138
23	0.137
25	0.137
27	0.138
29	0.137
31	0.132
Average	**0.136**

Lettering

Ref. Point	*Depth*
33	0.108
35	0.111
37	0.110
39	0.110
Average	**0.110**

Dome

0.036

Diameter

Ref. Point	*Diameter*
D1	40.075
D2	40.074
D3	40.055
D4	40.054
D5	40.045
D6	40.044

Master Punch 40.1 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	59.509	**26**	59.496
2	59.509	**27**	59.359
3	59.507	**28**	59.499
4	59.500	**29**	59.361
5	59.495	**30**	59.499
6	59.495	**31**	59.362
7	59.499	**32**	59.497
8	59.505	**33**	59.333
9	59.322	**34**	59.443
10	59.320	**35**	59.328
11	59.320	**36**	59.439
12	59.324	**37**	59.334
13	59.329	**38**	59.445
14	59.331	**39**	59.337
15	59.330	**40**	59.448
16	59.330	**41**	20.539
17	59.361	**42**	20.540
18	59.495	**43**	13.152
19	59.356	**44**	13.154
20	59.496	**45**	59.504
21	59.354	**46**	59.328
22	59.492	**47**	59.331
23	59.357	**48**	59.336
24	59.494	**49**	59.337
25	59.359		

Landing

Ref. Point	*Depth*
1	0.187
2	0.189
3	0.187
4	0.176
5	0.166
6	0.164
7	0.169
8	0.175
Average	**0.177**

Design

Ref. Point	*Depth*
17	0.134
19	0.140
21	0.138
23	0.137
25	0.137
27	0.140
29	0.138
31	0.135
Average	**0.137**

Lettering

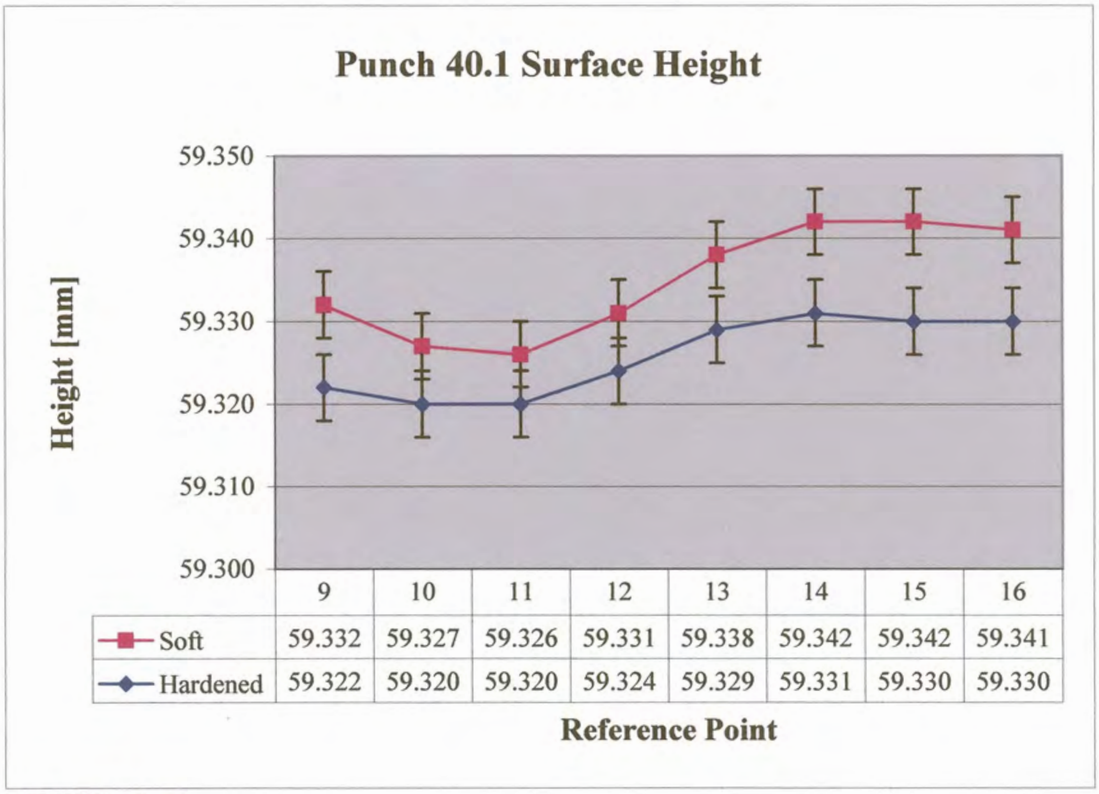
Ref. Point	*Depth*
33	0.110
35	0.111
37	0.111
39	0.111
Average	**0.111**

Dome

0.041

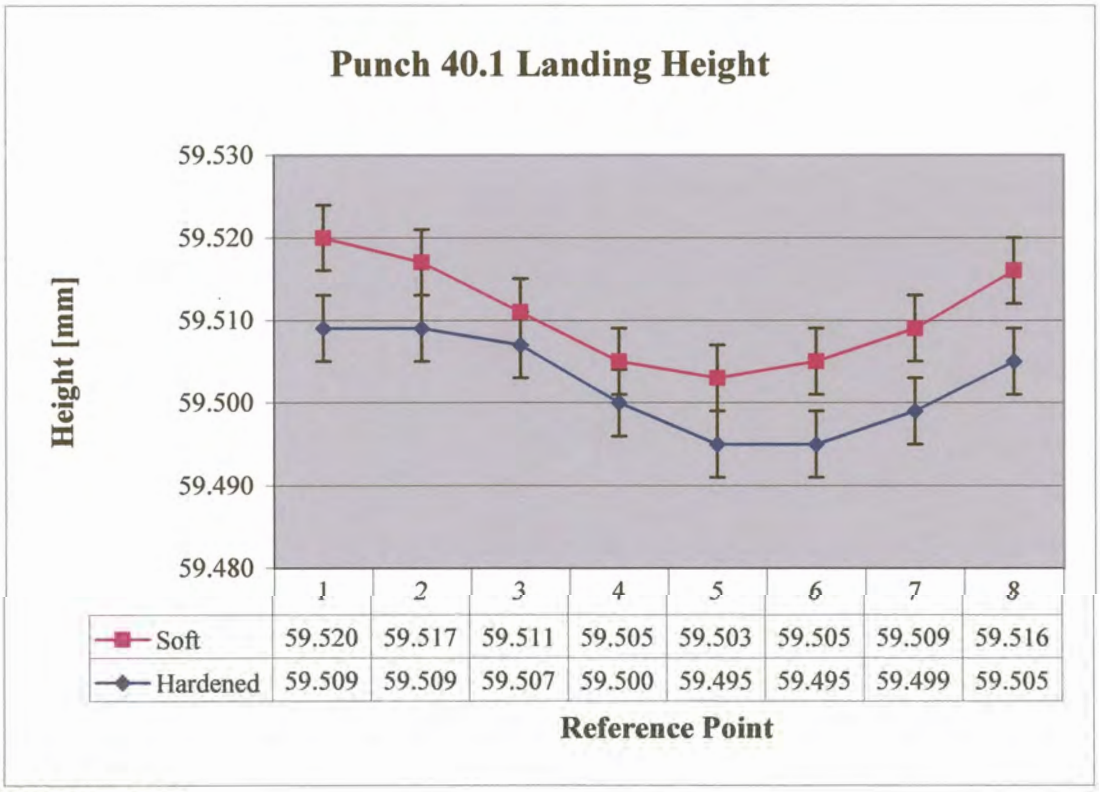
Diameter

Ref. Point	*Diameter*
D1	40.077
D2	40.078
D3	40.057
D4	40.055
D5	40.046
D6	40.044



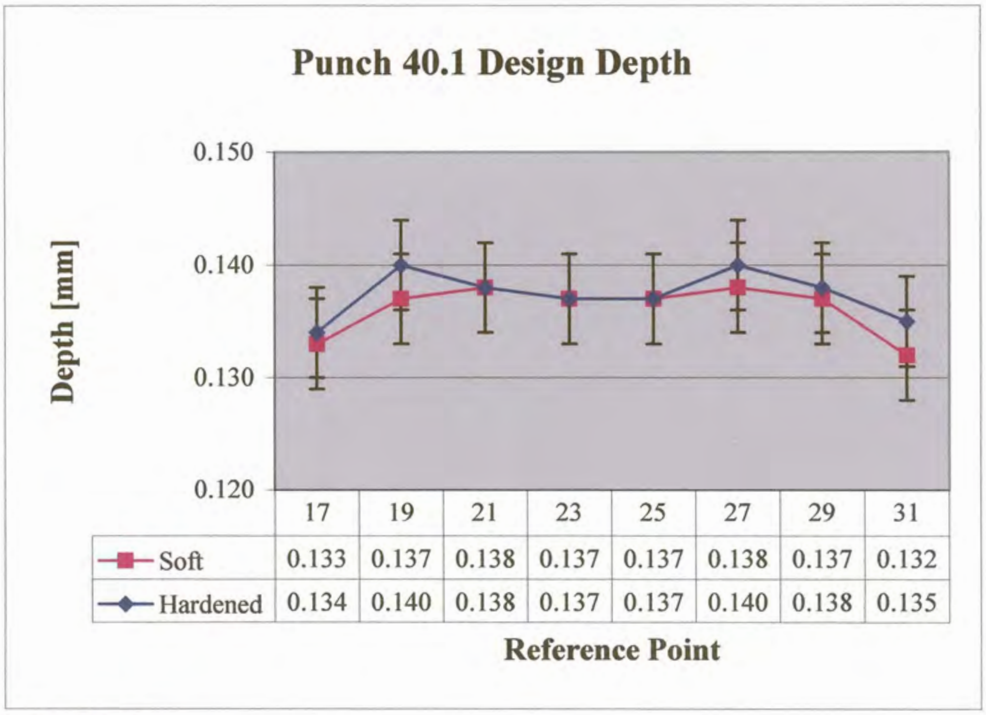
	9	10	11	12	13	14	15	16
Soft	59.332	59.327	59.326	59.331	59.338	59.342	59.342	59.341
Hardened	59.322	59.320	59.320	59.324	59.329	59.331	59.330	59.330

FIGURE F 73



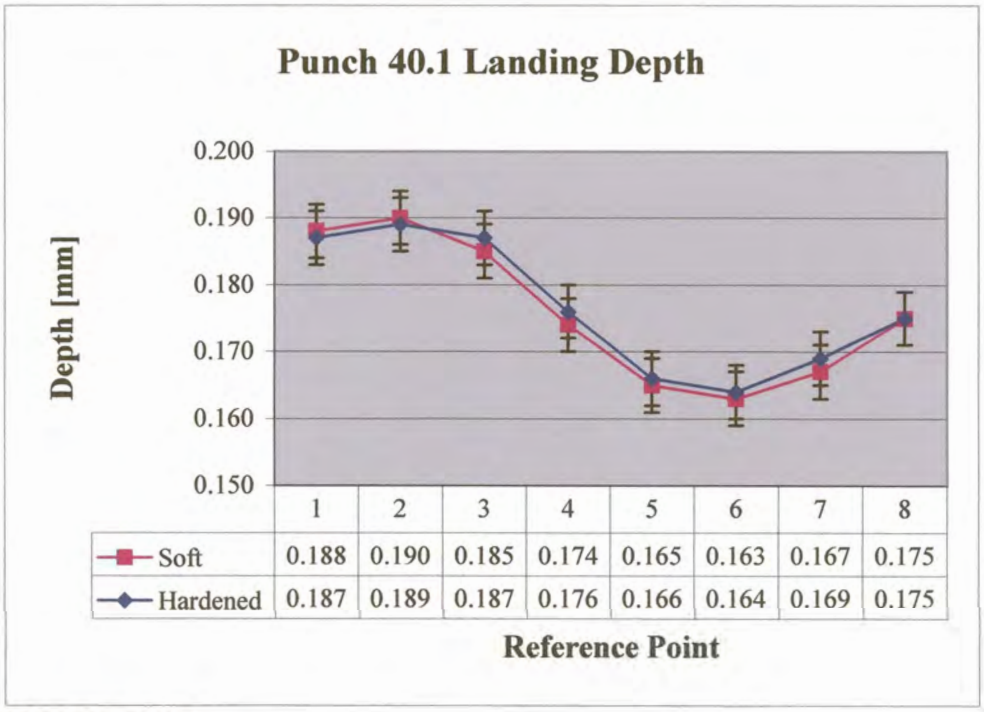
	1	2	3	4	5	6	7	8
Soft	59.520	59.517	59.511	59.505	59.503	59.505	59.509	59.516
Hardened	59.509	59.509	59.507	59.500	59.495	59.495	59.499	59.505

FIGURE F 74



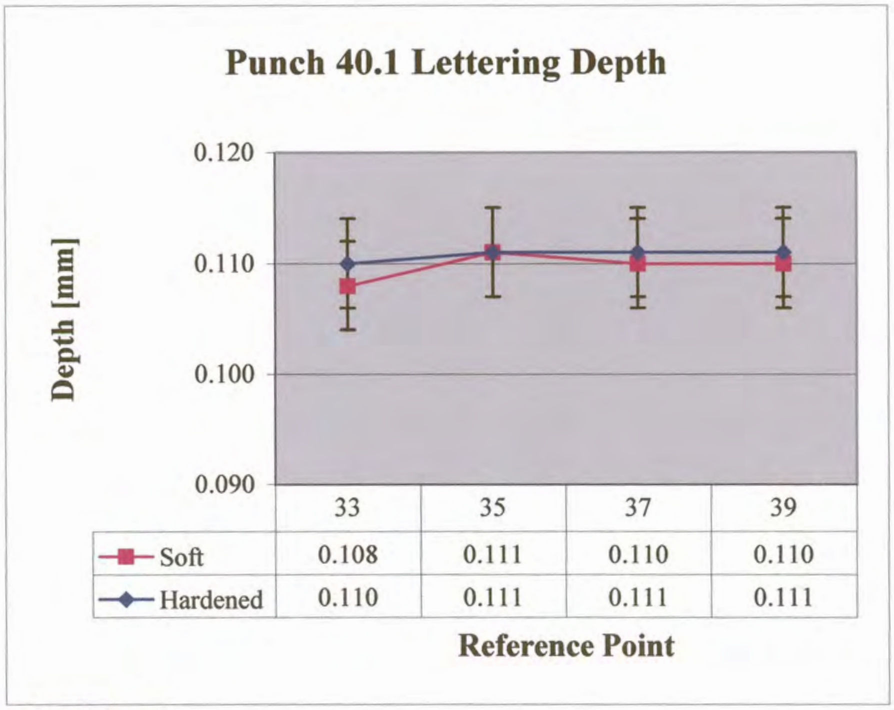
	17	19	21	23	25	27	29	31
Soft	0.133	0.137	0.138	0.137	0.137	0.138	0.137	0.132
Hardened	0.134	0.140	0.138	0.137	0.137	0.140	0.138	0.135

FIGURE F 75



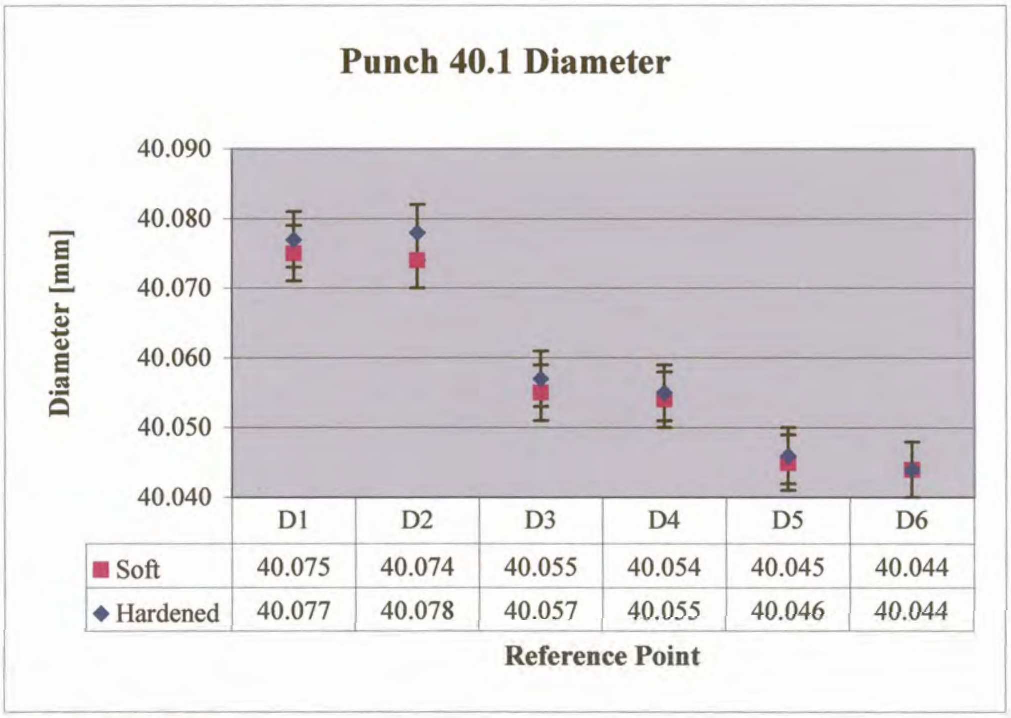
	1	2	3	4	5	6	7	8
Soft	0.188	0.190	0.185	0.174	0.165	0.163	0.167	0.175
Hardened	0.187	0.189	0.187	0.176	0.166	0.164	0.169	0.175

FIGURE F 76



	33	35	37	39
Soft	0.108	0.111	0.110	0.110
Hardened	0.110	0.111	0.111	0.111

FIGURE F 77



	D1	D2	D3	D4	D5	D6
■ Soft	40.075	40.074	40.055	40.054	40.045	40.044
◆ Hardened	40.077	40.078	40.057	40.055	40.046	40.044

FIGURE F 78

Master Punch 40.2 Soft

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	59.679	**26**	59.659
2	59.677	**27**	59.523
3	59.674	**28**	59.661
4	59.668	**29**	59.526
5	59.664	**30**	59.662
6	59.666	**31**	59.528
7	59.670	**32**	59.660
8	59.676	**33**	59.500
9	59.491	**34**	59.609
10	59.486	**35**	59.492
11	59.488	**36**	59.603
12	59.493	**37**	59.499
13	59.498	**38**	59.611
14	59.502	**39**	59.505
15	59.501	**40**	59.617
16	59.499	**41**	20.542
17	59.526	**42**	20.547
18	59.658	**43**	13.162
19	59.519	**44**	16.155
20	59.659	**45**	59.665
21	59.518	**46**	59.492
22	59.657	**47**	59.497
23	59.521	**48**	59.504
24	59.657	**49**	59.505
25	59.522		

Landing

Ref. Point	*Depth*
1	0.188
2	0.191
3	0.186
4	0.175
5	0.166
6	0.164
7	0.169
8	0.177
Average	**0.177**

Design

Ref. Point	*Depth*
17	0.132
19	0.140
21	0.139
23	0.136
25	0.137
27	0.138
29	0.136
31	0.132
Average	**0.136**

Lettering

Ref. Point	*Depth*
33	0.109
35	0.111
37	0.112
39	0.112
Average	**0.111**

Dome

0.034

Diameter

Ref. Point	*Diameter*
D1	40.060
D2	40.060
D3	40.038
D4	40.039
D5	40.029
D6	40.028

Master Punch 40.2 Hardened

* All measurements are in millimeters

Measurements

Ref. Point	*Height*	*Ref. Point*	*Height*
1	59.654	**26**	59.643
2	59.654	**27**	59.507
3	59.651	**28**	59.646
4	59.645	**29**	59.510
5	59.642	**30**	59.646
6	59.643	**31**	59.510
7	59.648	**32**	59.645
8	59.653	**33**	59.479
9	59.469	**34**	59.590
10	59.466	**35**	59.474
11	59.466	**36**	59.585
12	59.471	**37**	59.482
13	59.475	**38**	59.592
14	59.479	**39**	59.487
15	59.480	**40**	59.597
16	59.477	**41**	20.533
17	59.509	**42**	20.537
18	59.642	**43**	13.152
19	59.503	**44**	13.156
20	59.641	**45**	59.649
21	59.502	**46**	59.474
22	59.641	**47**	59.477
23	59.503	**48**	59.482
24	59.641	**49**	59.485
25	59.506		

Landing

Ref. Point	*Depth*
1	0.185
2	0.188
3	0.185
4	0.174
5	0.167
6	0.164
7	0.168
8	0.176
Average	**0.176**

Design

Ref. Point	*Depth*
17	0.133
19	0.138
21	0.139
23	0.138
25	0.137
27	0.139
29	0.136
31	0.135
Average	**0.137**

Lettering

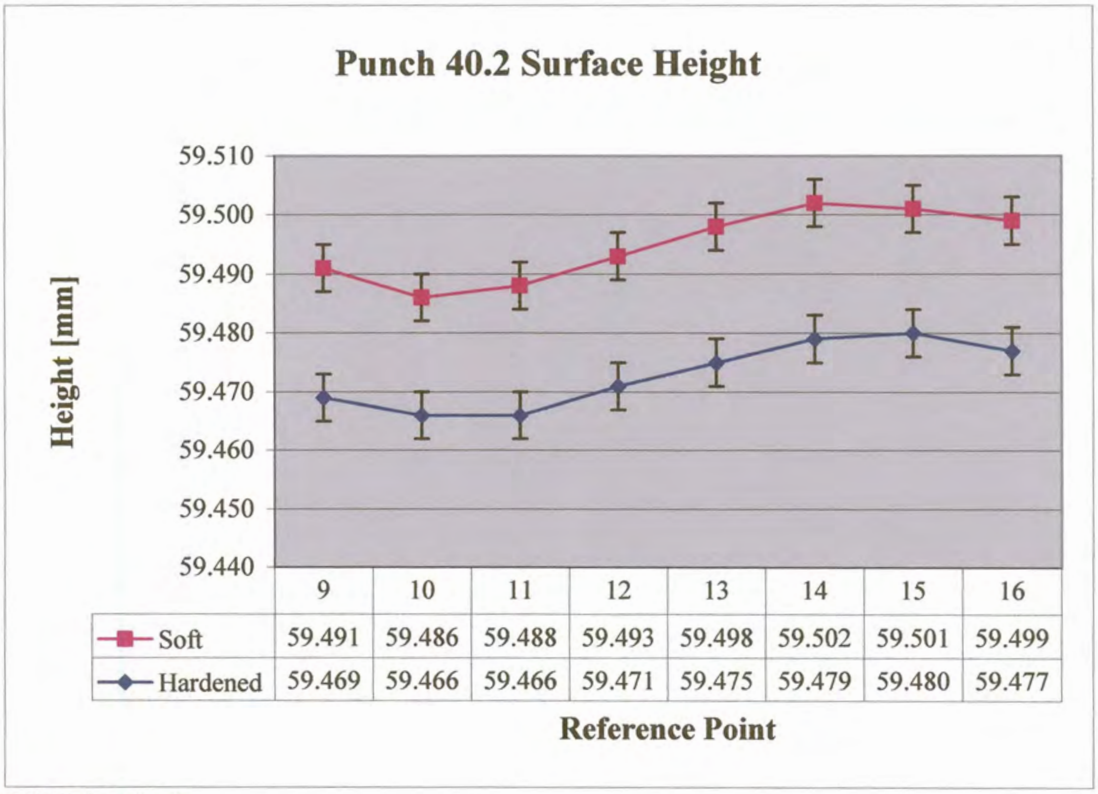
Ref. Point	*Depth*
33	0.111
35	0.111
37	0.110
39	0.110
Average	**0.111**

Dome

0.039

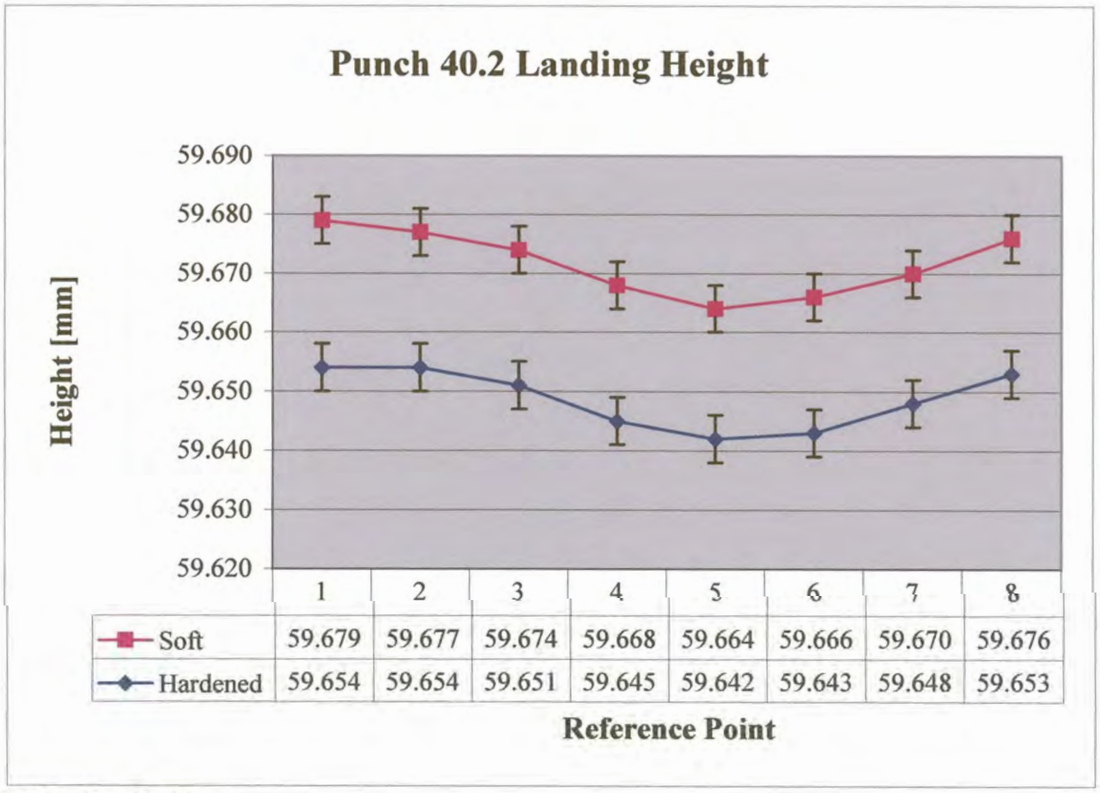
Diameter

Ref. Point	*Diameter*
D1	40.055
D2	40.054
D3	40.034
D4	40.031
D5	40.021
D6	40.021



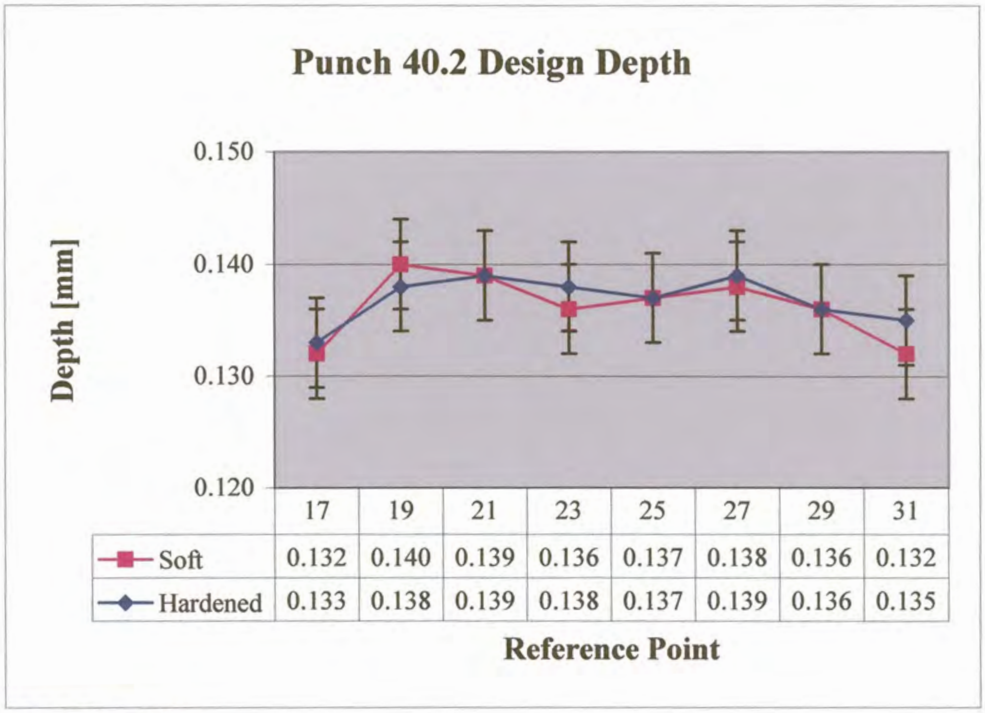
	9	10	11	12	13	14	15	16
Soft	59.491	59.486	59.488	59.493	59.498	59.502	59.501	59.499
Hardened	59.469	59.466	59.466	59.471	59.475	59.479	59.480	59.477

FIGURE F 79



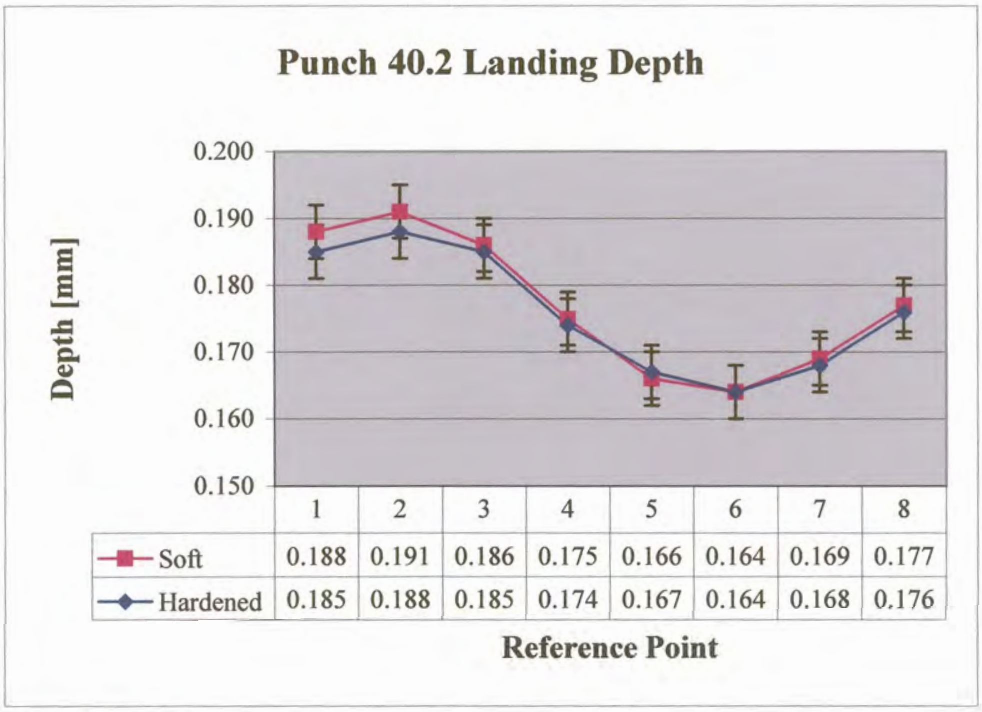
	1	2	3	4	5	6	7	8
Soft	59.679	59.677	59.674	59.668	59.664	59.666	59.670	59.676
Hardened	59.654	59.654	59.651	59.645	59.642	59.643	59.648	59.653

FIGURE F 80



Reference Point	17	19	21	23	25	27	29	31
Soft	0.132	0.140	0.139	0.136	0.137	0.138	0.136	0.132
Hardened	0.133	0.138	0.139	0.138	0.137	0.139	0.136	0.135

FIGURE F 81



Reference Point	1	2	3	4	5	6	7	8
Soft	0.188	0.191	0.186	0.175	0.166	0.164	0.169	0.177
Hardened	0.185	0.188	0.185	0.174	0.167	0.164	0.168	0.176

FIGURE F 82

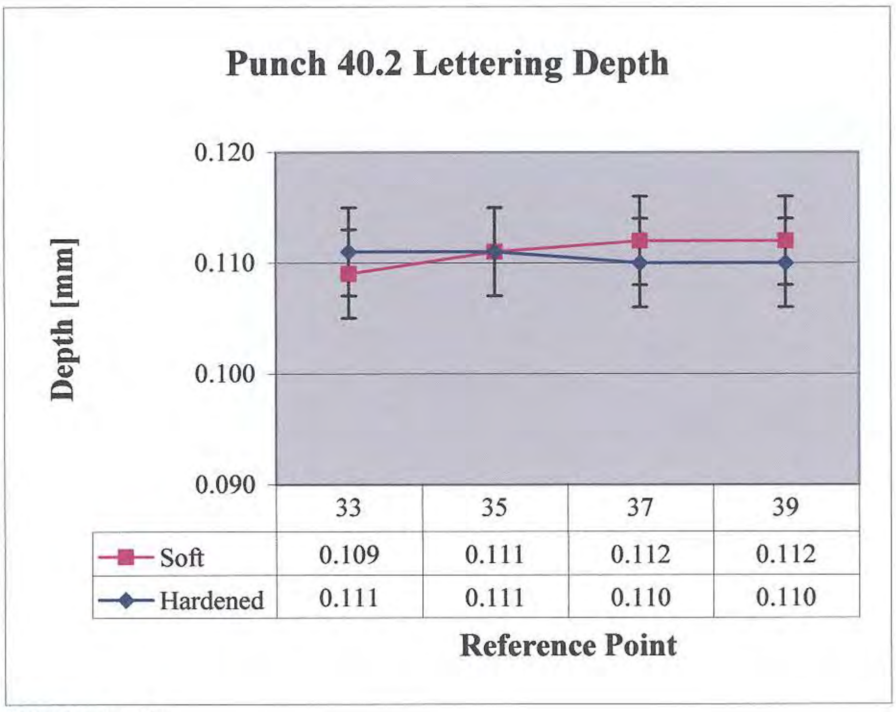


FIGURE F 83

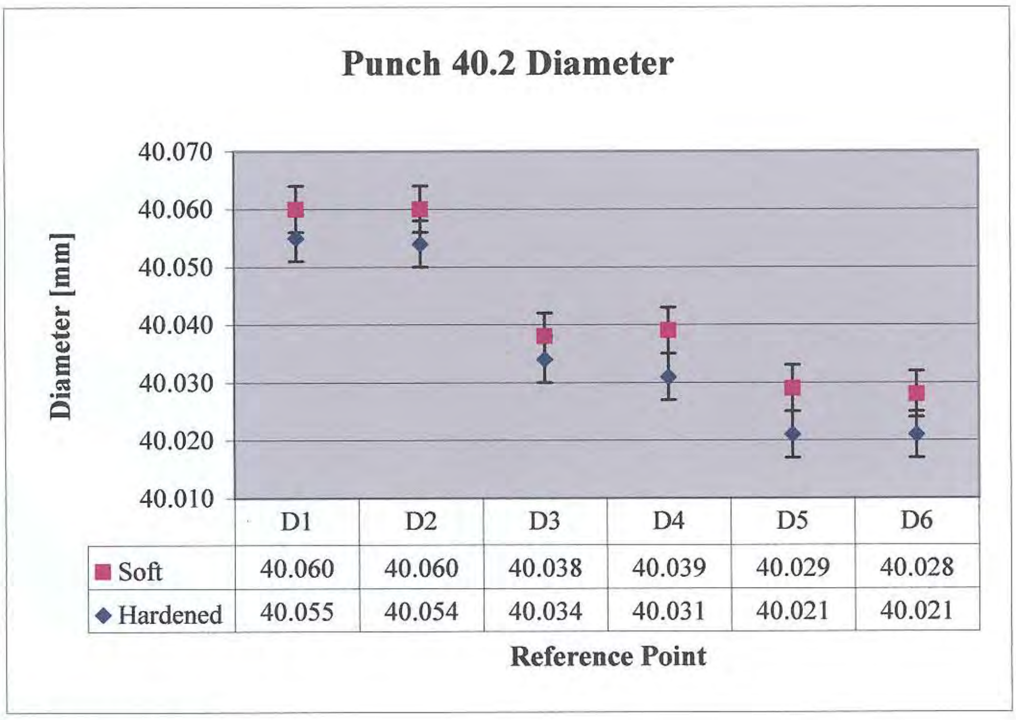


FIGURE F 84