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# ***SECTION A***

## **DIE DEVELOPMENT**

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## INTRODUCTION

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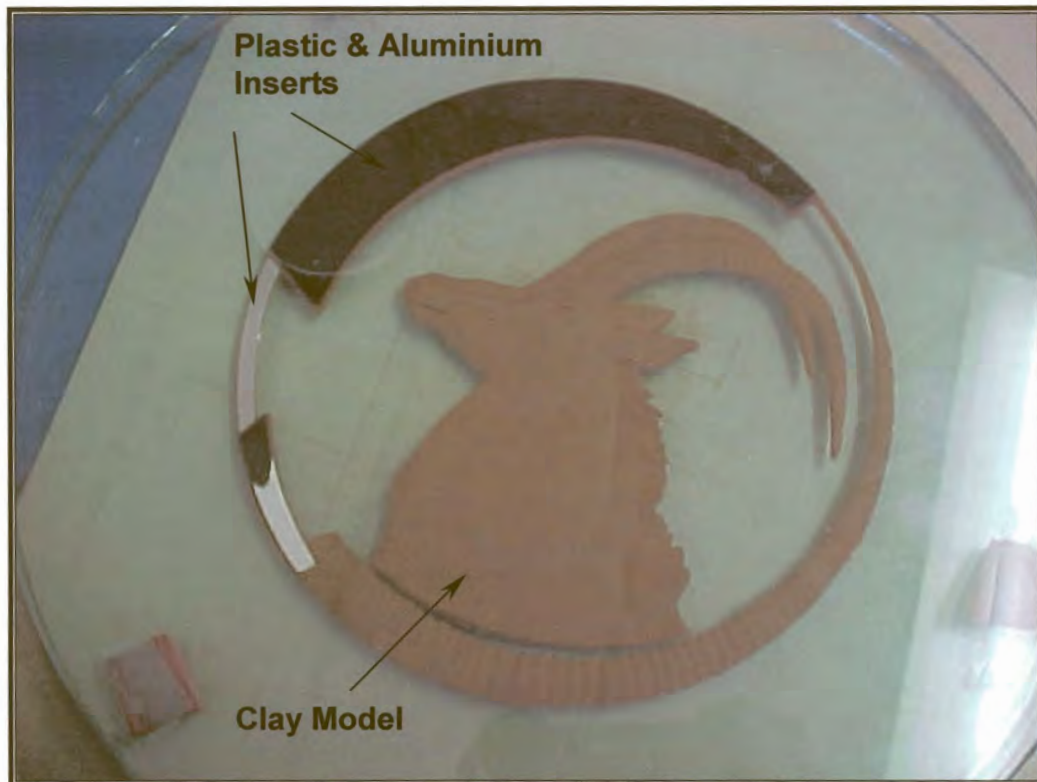
This section will provide an overview of the die development process. The details of the die development process will be discussed in the relevant sections of the report.

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.

- 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.

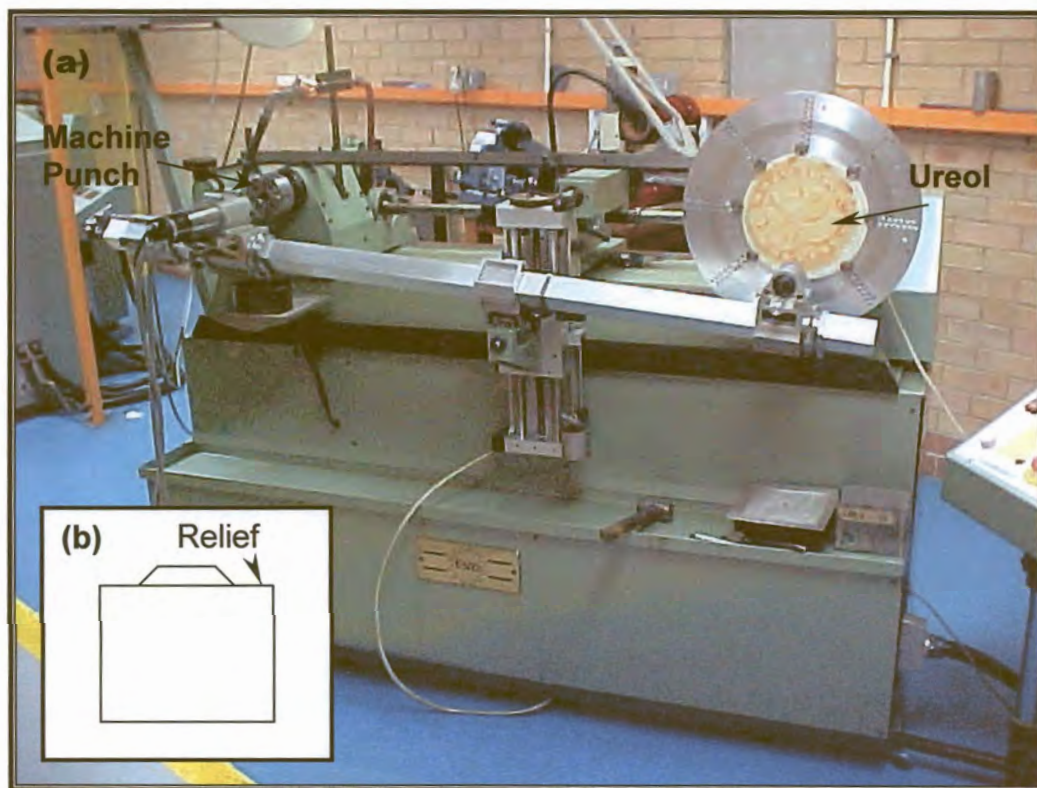


FIGURE 4 (a) Reduction machine (b) Relief cut into Machine Punch



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.

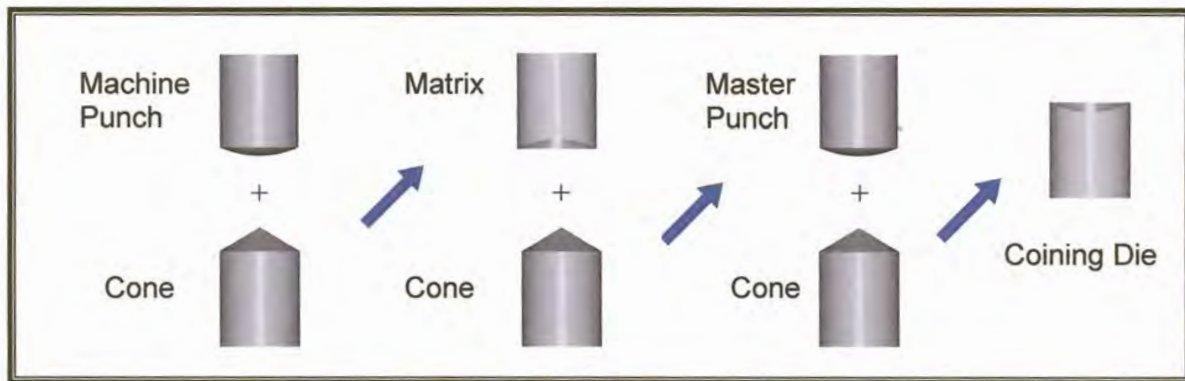


**FIGURE 5 Die blanks**

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).

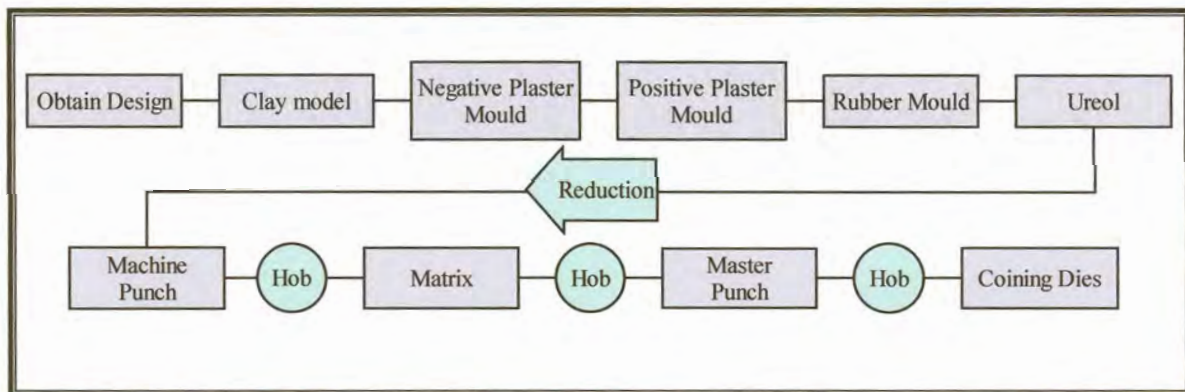
The master punch is the deliverable product that is the responsibility of the development department. Since this project concentrates on the development process most of the project time will be devoted to the process discussed above.

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

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## MATERIAL SELECTION

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### 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.

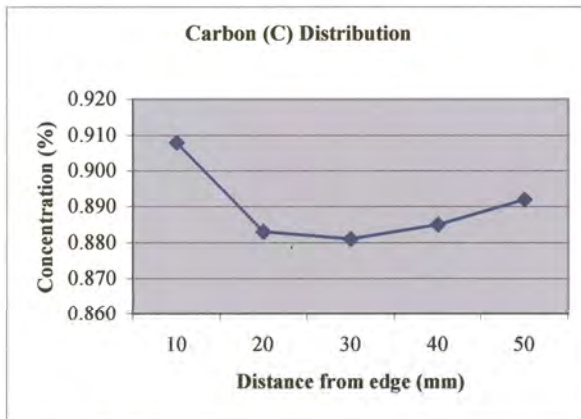
The distribution of the elements is a factor, which influences the response of the material to deformation. The results of the test are shown in Table 1.2. The distance column refers to the location of the sample point from the side of the billet. The results of Table 1.2 are presented graphically in 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**

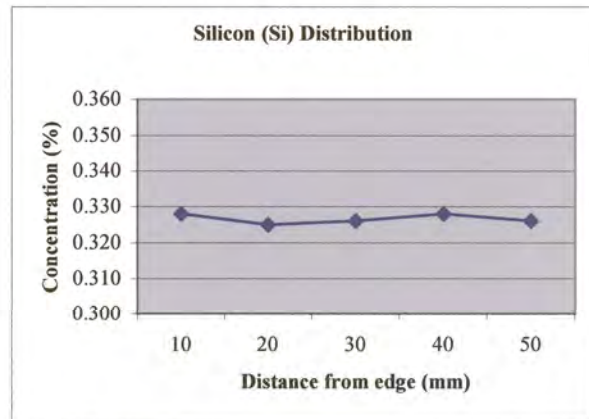
Distance (mm)	Element (%)						
	C	Si	Mn	P	S	Cr	Mo
10	0.908	0.328	0.436	0.0251	0.0266	4.91	0.963
20	0.883	0.325	0.433	0.0252	0.0266	4.91	0.939
30	0.881	0.326	0.433	0.0251	0.0266	4.89	0.944
40	0.885	0.328	0.433	0.0252	0.0266	4.90	0.940
50	0.892	0.326	0.435	0.0251	0.0266	4.91	0.951
<b>Average</b>	<b>0.890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

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
<b>Average</b>	<b>0.200</b>	<b>0.0159</b>	<b>0.0272</b>	<b>0.0591</b>	<b>0.140</b>	<b>0.0100</b>

**TABLE 1.2 Distribution of elements through 2363 Tool Steel**



**FIGURE 1.1**



**FIGURE 1.2**



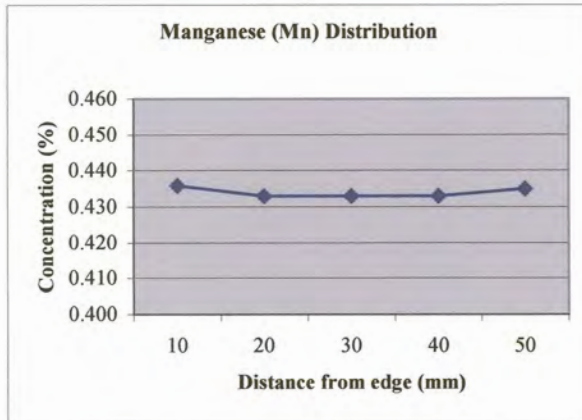


FIGURE 1.3

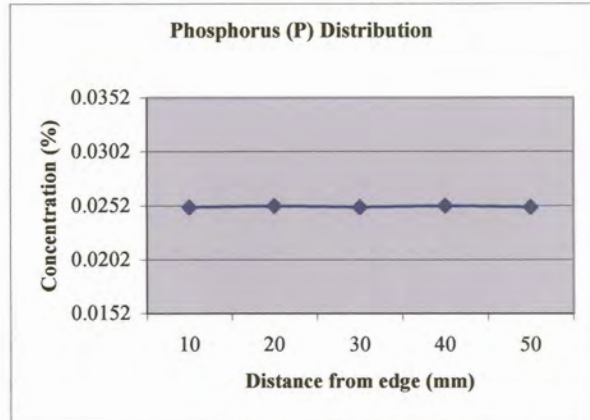


FIGURE 1.4

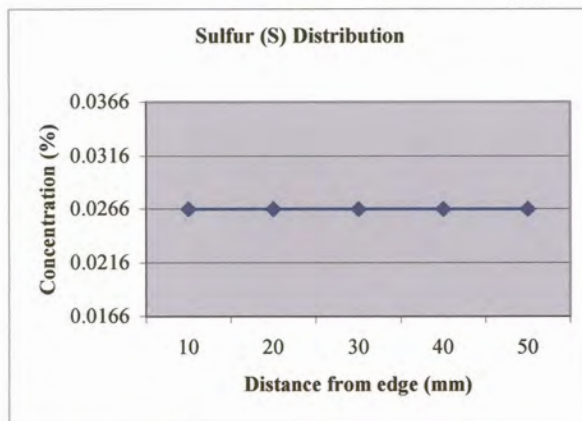


FIGURE 1.5

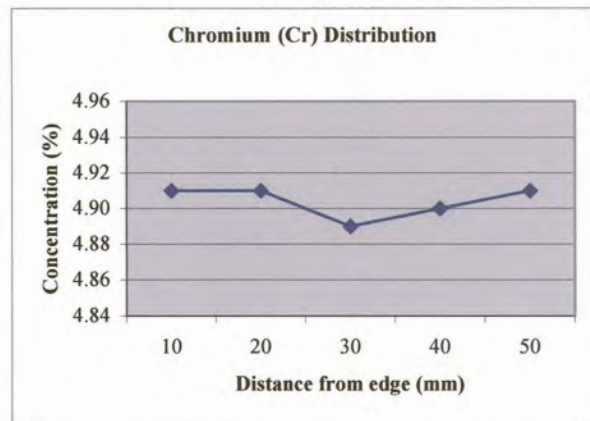


FIGURE 1.6

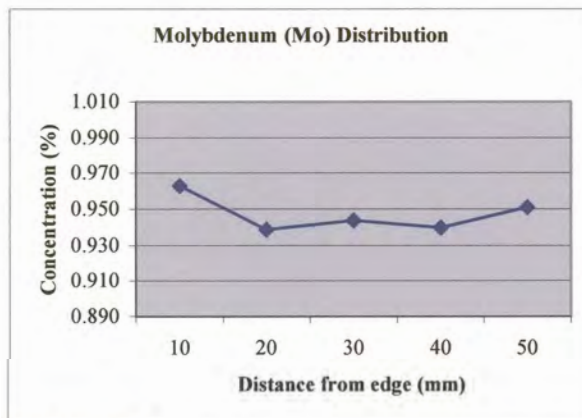


FIGURE 1.7

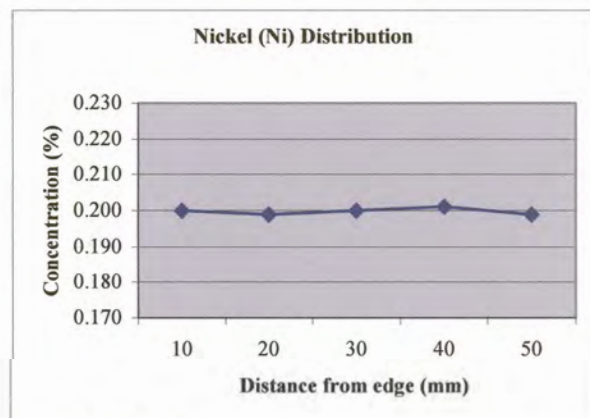


FIGURE 1.8

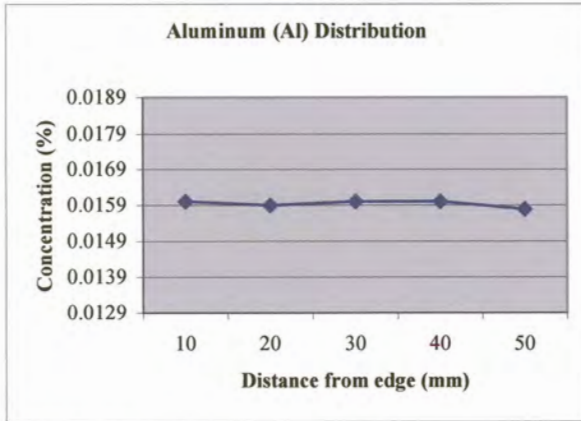


FIGURE 1.9

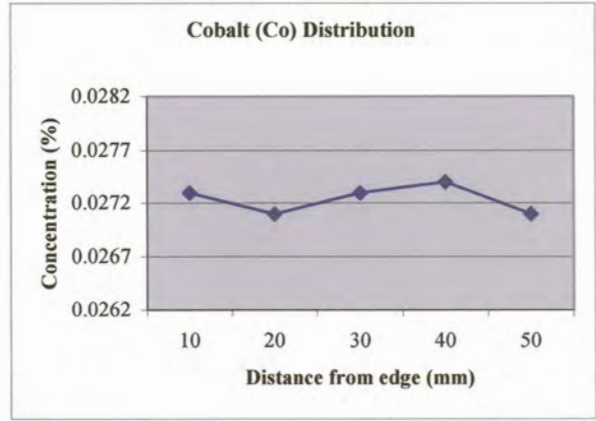


FIGURE 1.10

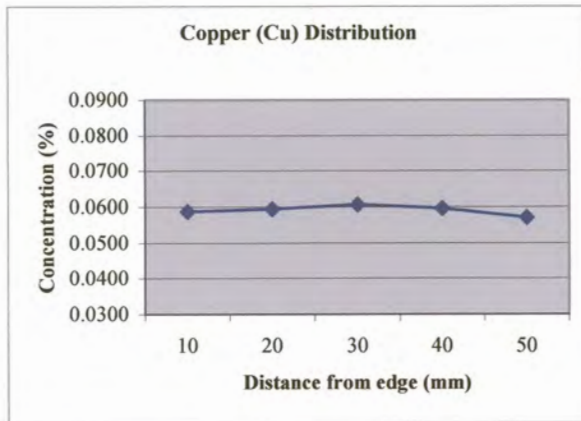


FIGURE 1.11

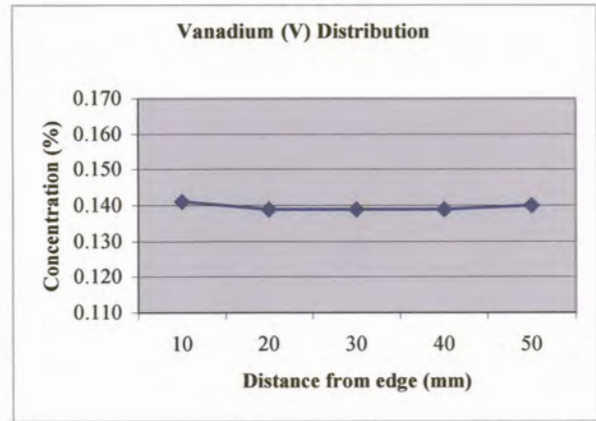


FIGURE 1.12

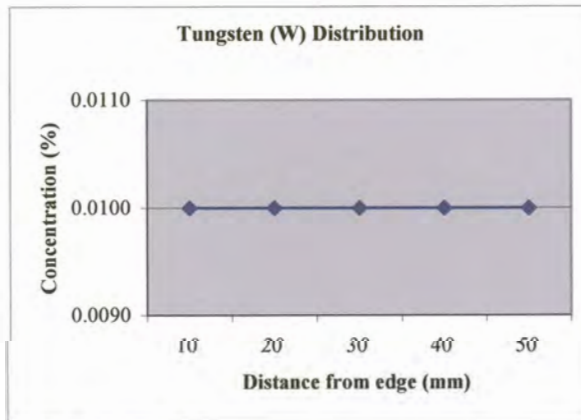
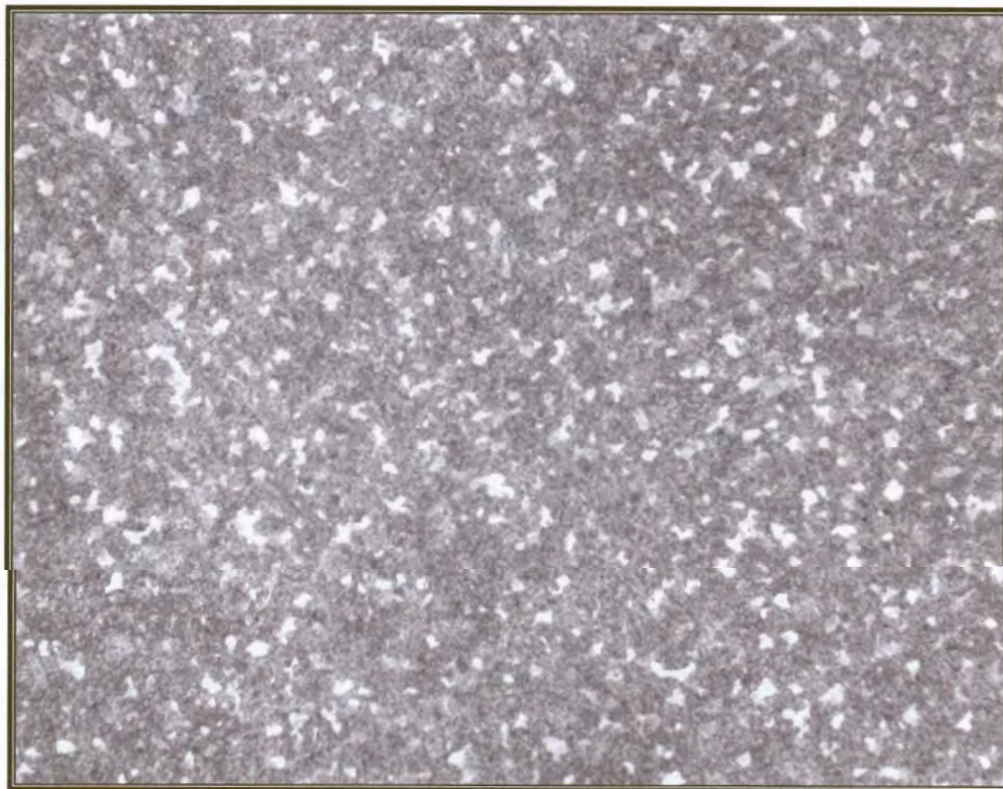


FIGURE 1.13

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 spheroidised 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).



**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  $65 \pm 1.0$  HR<sub>b</sub> calibration block. The reading on the block was 64.9 HR<sub>b</sub>. 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.

*Summary of results:*

Average hardness of the 50 mm billets,

= 94.7 HR<sub>b</sub> = 210 Brinell

Average hardness of the 40mm billets,

= 98.1 HR<sub>b</sub> = 228 Brinell



**FIGURE 1.17 Leco RT 2100**

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.

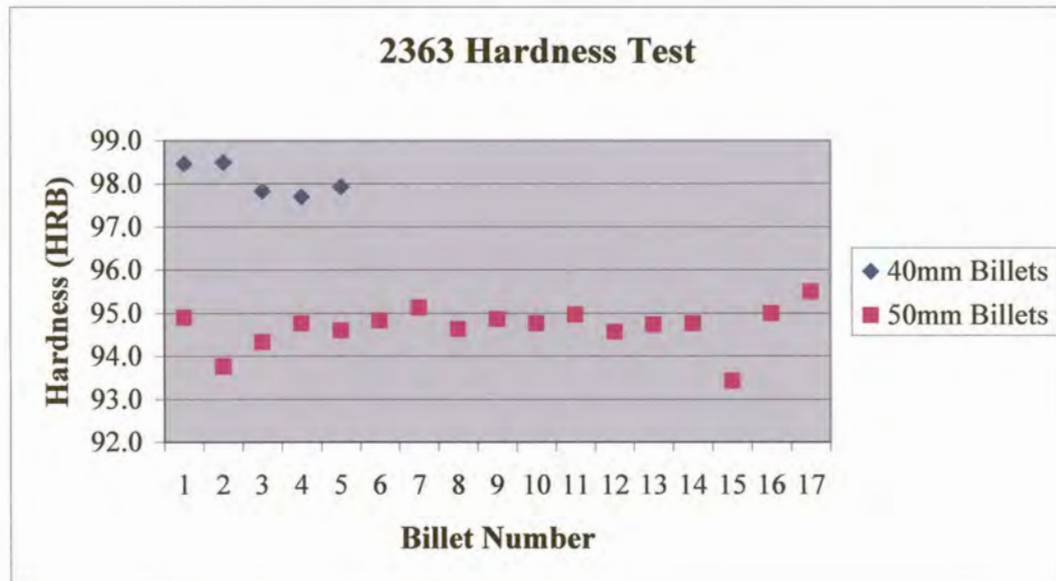
<b>40 mm Billets</b>		Reading in HR <sub>b</sub>			
Reading		1	2	3	Average
Billet No.	1	98.1	98.7	98.6	98.5
	2	98.1	98.5	98.9	98.5
	3	97.8	97.7	98.0	97.8
	4	97.5	97.5	98.1	97.7
	5	97.5	97.9	98.4	97.9

<b>50 mm Billets</b>		Reading in HR <sub>b</sub>			
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.

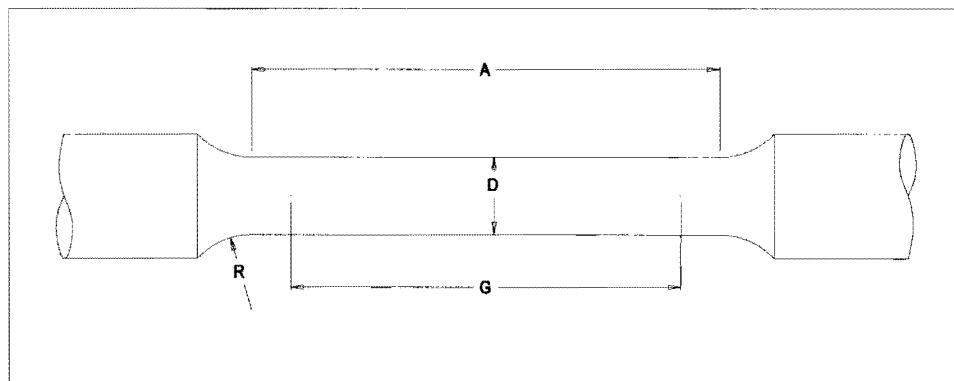
To evaluate the elastic and plastic deformation characteristics of the material tensile tests were done on the material by ISCOR. The candidate made eight specimens for the tensile tests. The first three specimens were made in the longitudinal (casting) direction of the material. The Specimens were made 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



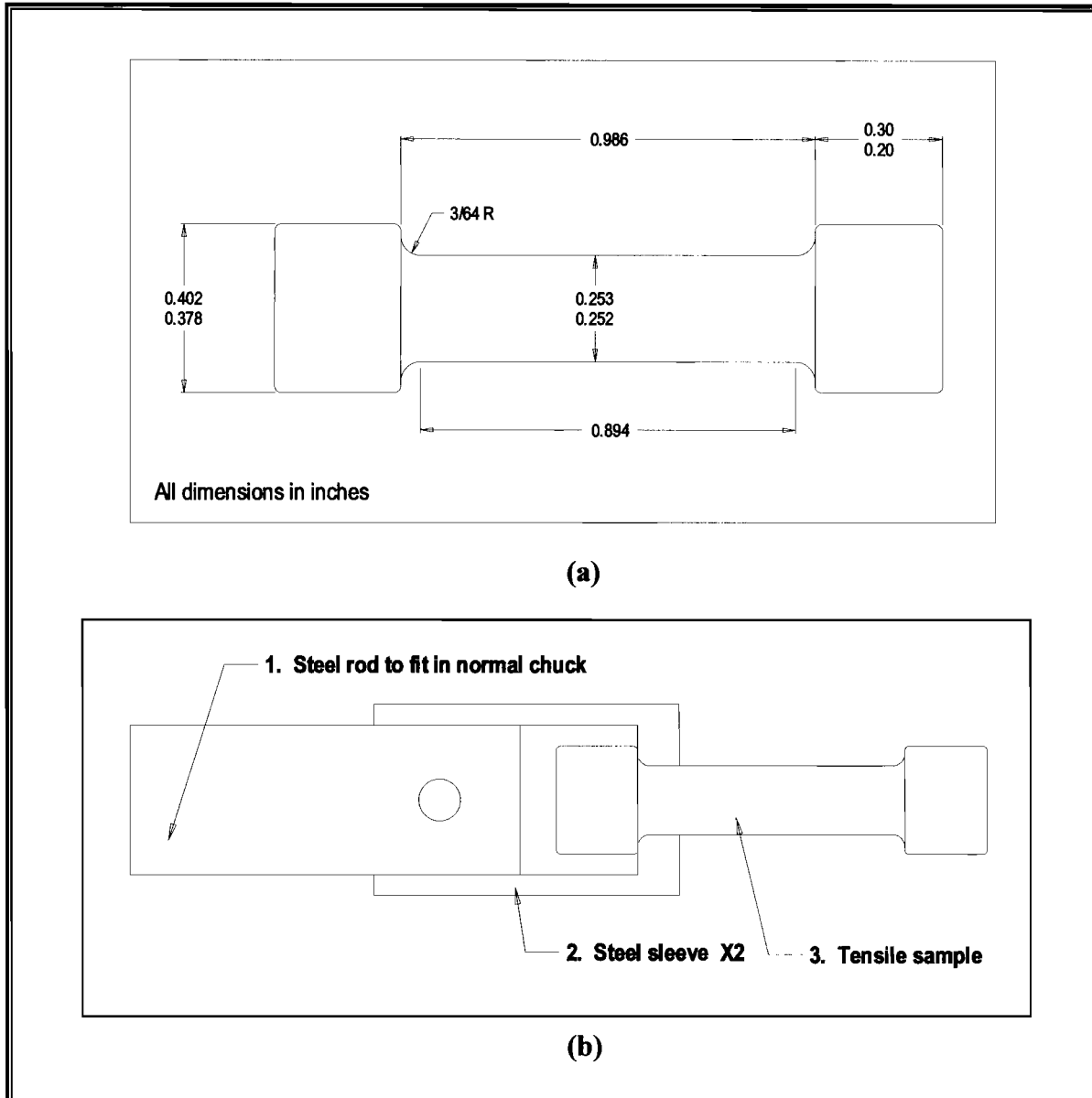
significant amounts of deformation occur in both directions during the hobbing process. It would be inaccurate to only assume response characteristics from the longitudinal direction.

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	$62.5 \pm 0.1$ mm
D – Diameter	$12.5 \pm 0.2$ mm
R – Radius of fillet, min	10 mm
A – Length of reduced section, min	75 mm

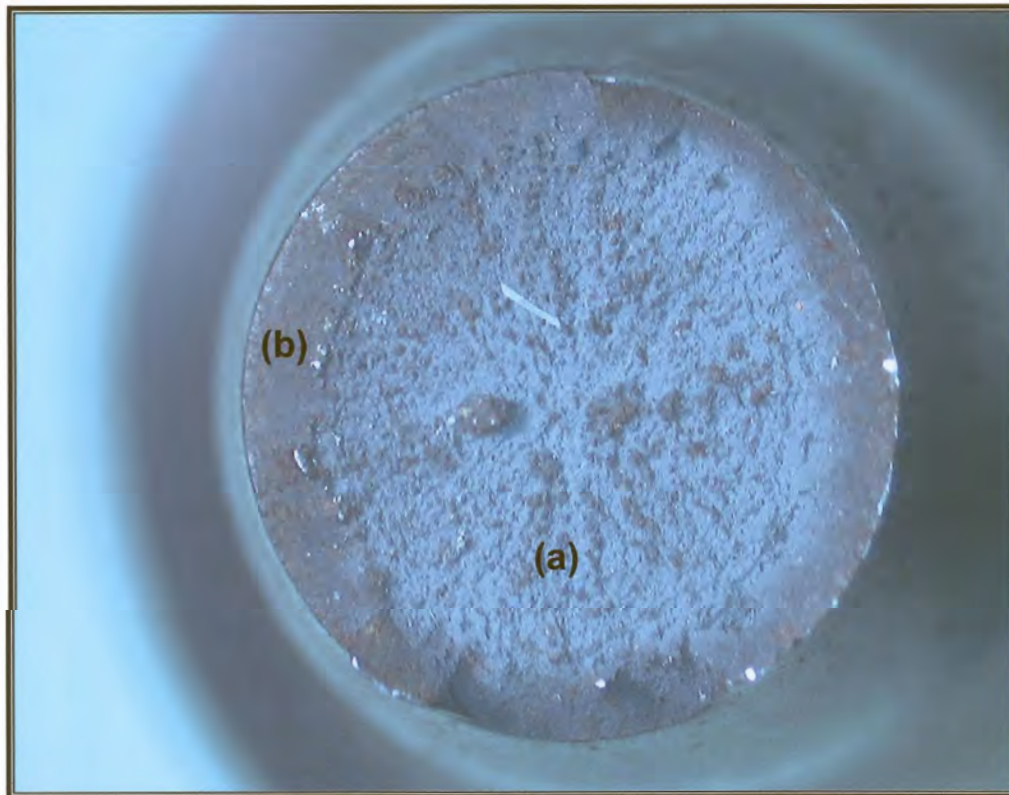
**FIGURE 1.19 Round Tensile Samples (ASTM E8 Spec.)**



**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

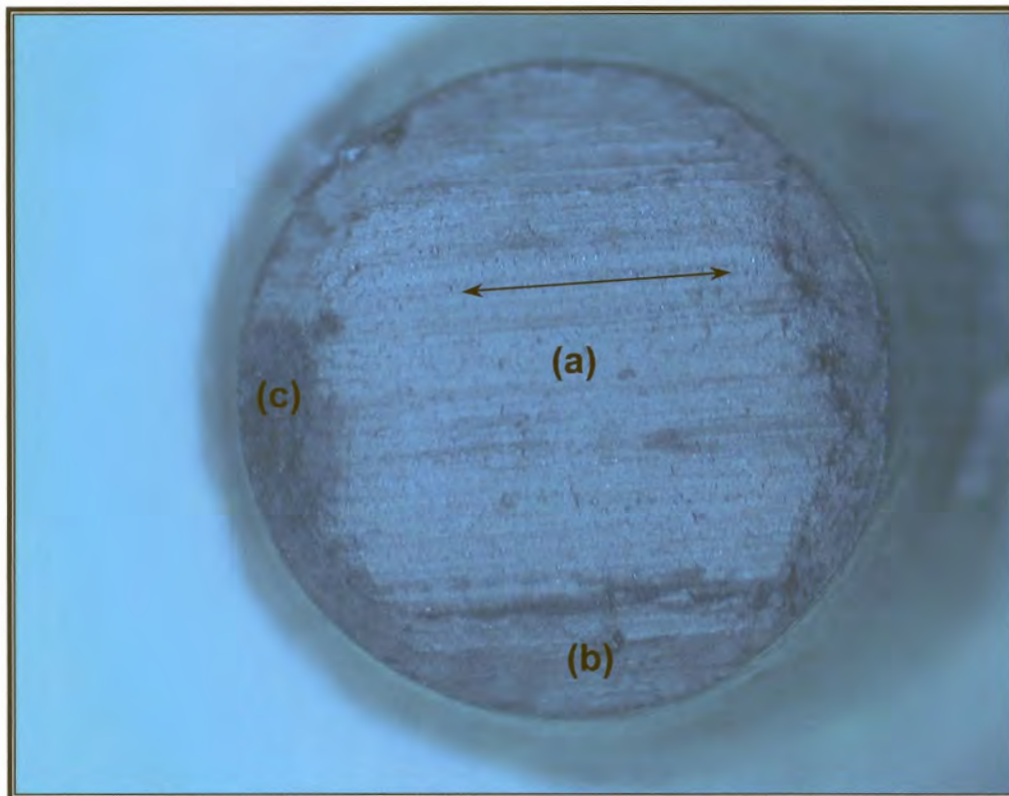
zone is formed by stable crack propagation resulting from the coalescence of microvoids that are formed in the centre due to the high stress state present in the material. Region (b) indicates the shear lip that is formed at final fracture. This lip is formed by a shearing process along a surface that is oriented  $45^\circ$  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.

$$\sigma_{y \text{ long}} = 430 \text{ MPa}, \quad \epsilon_{\text{max long}} = 23 \%$$

$$\sigma_{y \text{ trans}} = 390 \text{ MPa}, \quad \epsilon_{\text{max trans}} = 18 \%$$

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<sub>v</sub>. 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<sub>v</sub>.

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.

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

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

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

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## COIN DESIGN

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### 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.



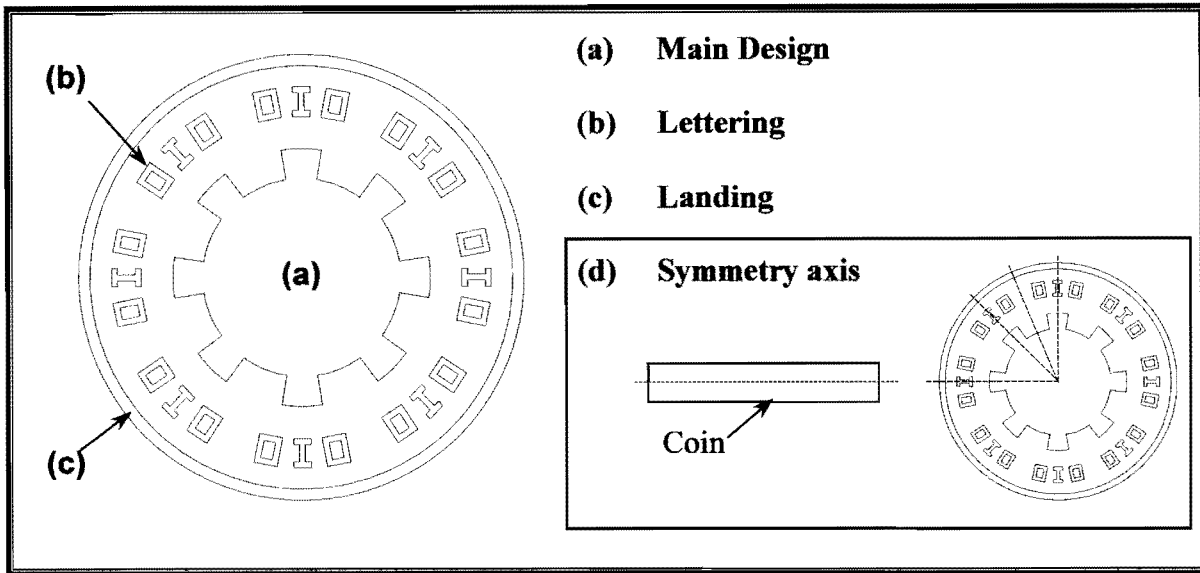
The major factors considered during the selection process were:

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.



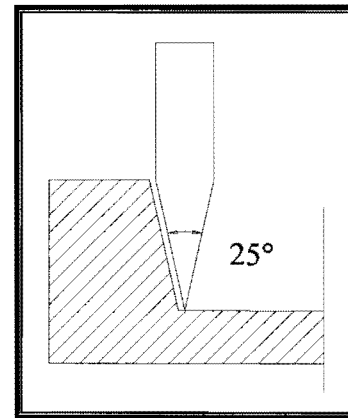
**FIGURE 2.1 Coin design**

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  $25^\circ$  will be used to engrave the design and the lettering. This means that the design and lettering will slope at an angle of  $12.5^\circ$  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

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## BLANK DESIGN

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### 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:  $1.575 \pm 20 \mu\text{m}$   
min: 1.555 mm  
max: 1.595 mm

**2) Diameter of Blanks**

size:  $21.740 \pm 50 \mu\text{m}$   
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:  $1.960 \pm 100 \mu\text{m}$   
min: 1.860 mm  
max: 2.060 mm

**4) Diameter (Rimmed)**

size:  $21.490 \pm 50 \mu\text{m}$   
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:  $2.050 \pm 100 \mu\text{m}$   
min: 1.950 mm  
max: 2.150 mm



### 6) Diameter (Plated)

size:  $21.700 \pm 80 \mu\text{m}$   
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  
=  $21.780 + 0.1$   
=  $21.880 \text{ mm}$



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  
=  $21.780 \text{ mm}$

### 9) Coin

Diameter = Collar size +  $50 \mu\text{m}$   
=  $21.930 \text{ mm}$  (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  $1.575 \pm 0.02$  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 burrs 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.

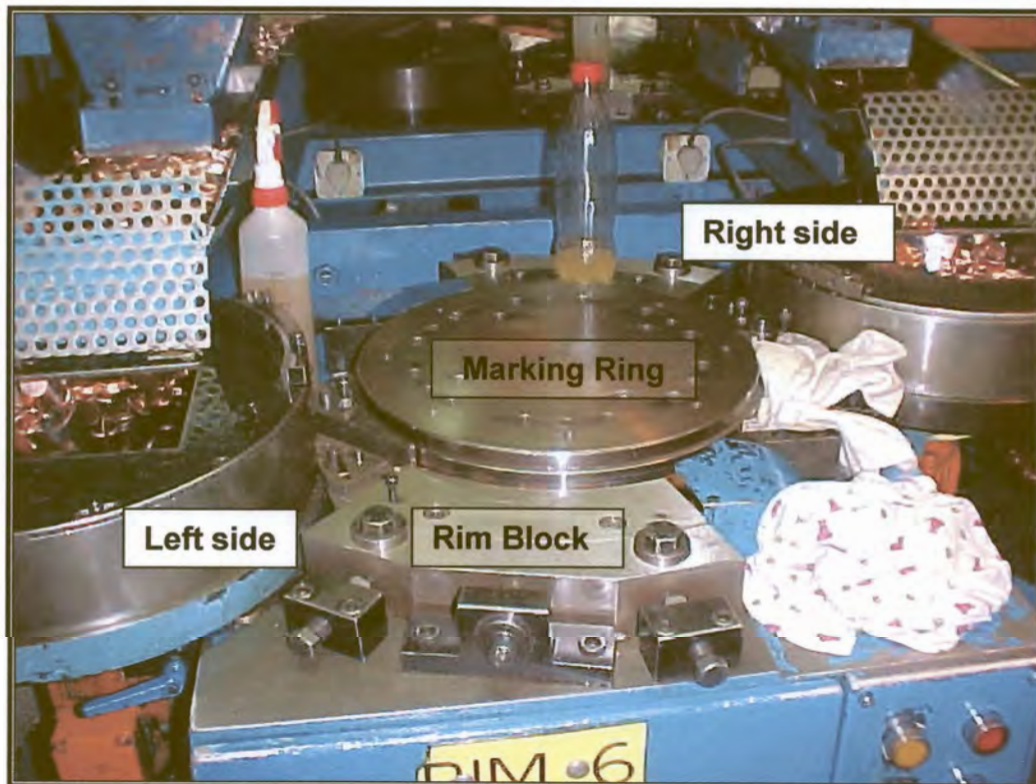
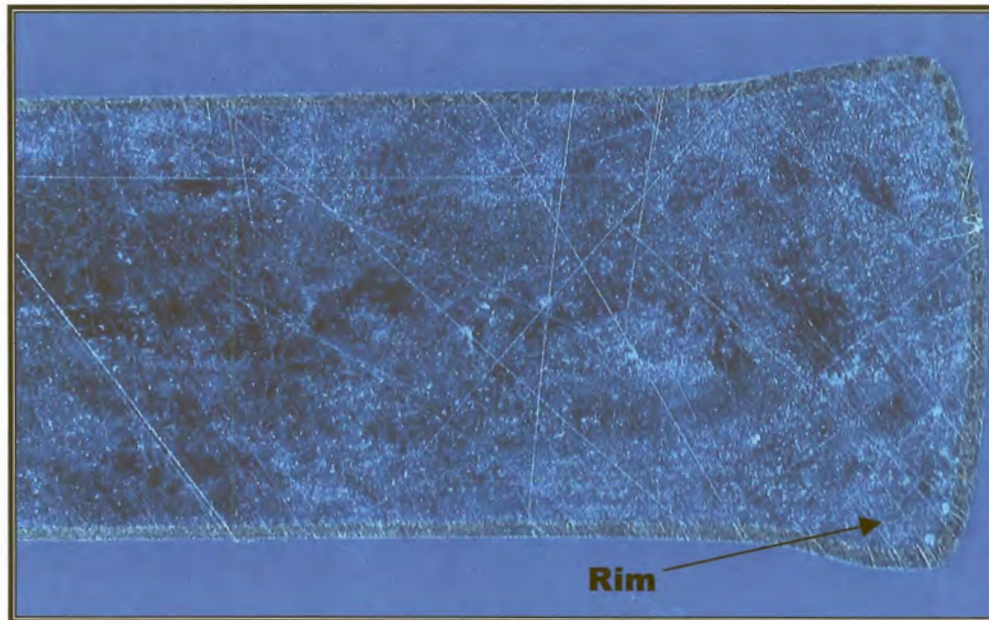


FIGURE 3.2 Upsetting Mill



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:

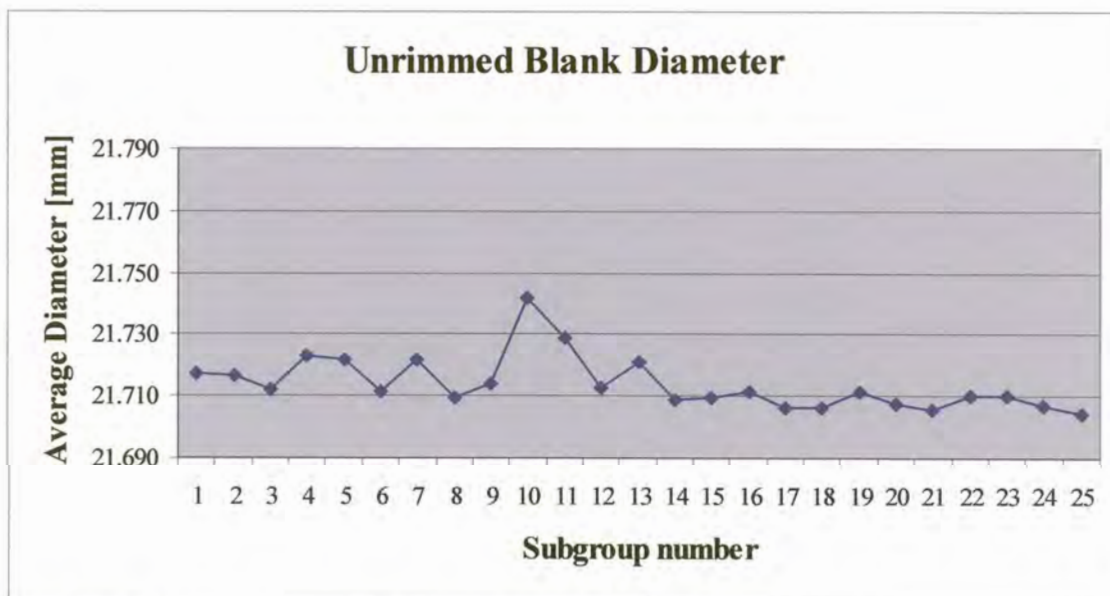
1. The diameter was measured before and after rimming
2. The mass of the blanks was measured
3. The thickness of the blanks before rimming was measured.

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.

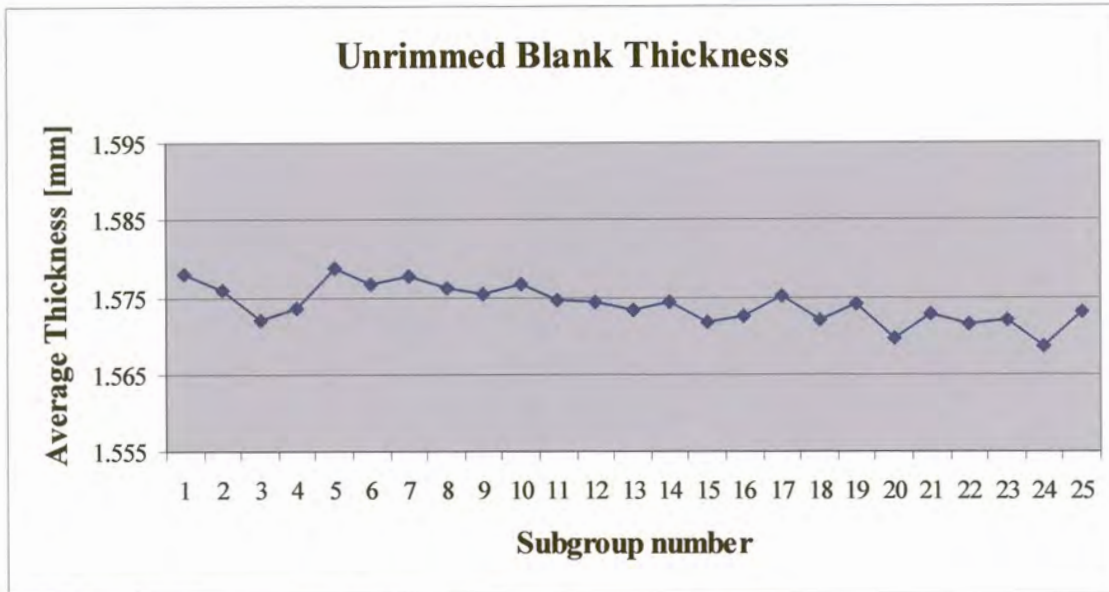


One hundred and twenty five samples were taken from the un-rimmed blanks in subgroups of five. The samples were taken in evenly spaced intervals throughout the coil. The second sample set consisted of one hundred and fifty rimmed blanks in subgroups of five. The blanks are fed from both sides of the 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

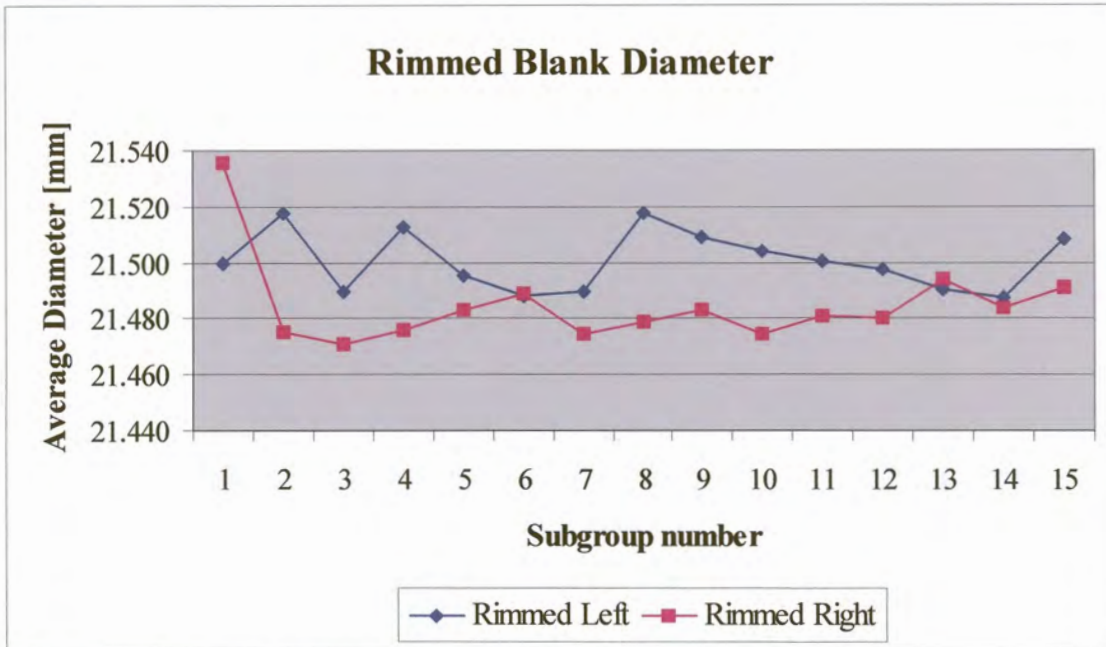


FIGURE 3.7 Average diameter of the rimmed blanks.

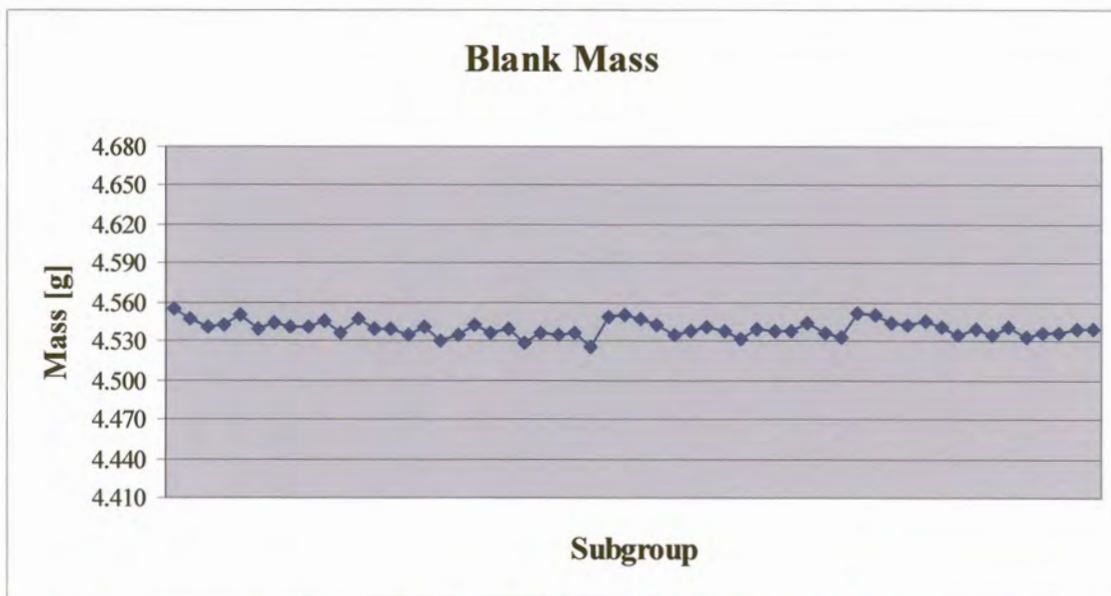


FIGURE 3.8 Blank mass for all subgroups. (Un-rimmed and rimmed blanks)

### 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.