CHAPTER 4

Experimental setup

In this chapter the experimental procedure will be explained and the equipment setup will be shown. The technique for wear measurement will also be explained.

4.1 The procedure

In order to take a tool insert through its natural life cycle a cutting experiment was set up. Cutting parameters were selected and were kept constant as much as possible. The experiment consisted of a number of cylindrical workpieces which were cut repetitively on a lathe with the depth of the cut being kept constant. A cool-down time of approximately 2 minutes was allowed for between each cut. The tool inserts were removed during certain intervals to measure tool wear.

4.2 The setup

The experiments were conducted on a Graziana Tortona SAG14 lathe. This was a "manual" lathe meaning that the machine is not of the CNC type. Operator experience therefore plays a role in the consistency of the data and should be kept in mind when the results are shown.

The type of cut is a very important consideration. During interrupted cutting, the shock impulses excite all the natural frequencies of the system. These natural frequencies are very strong indicators of tool wear. In the case of a continuous cut, the excitation of natural frequencies are not as prominent. This fact also complicates the matter of recognition for a TCM system and also influences the quality of the data.

Cutting was done using a boring bar. Boring bars are used to machine on the inside of a component. A boring bar usually has a more slender shape than a normal tool holder.

For this project the boring bar was not used for boring but for normal cutting. Boring bars are less rigid that normal tool holders for lathes, but it can still be used for normal cutting operations. (The availability of the bar also made it a very good choice.)

The boring bar was instrumented with strain gauges on one side. Figure 4.1 shows a schematic of the front end of the tool holder. This figure shows the approximate location of the strain gauge rosette. HBM 1.5/120XY91 strain gauges were used for the experiments. These strain gauges measure $1,5mm$ by $1,5mm$ with the complete padding and packaging measuring $3mm$ by $3mm$. Each strain gauge rosette contained two strain gauges orientated in perpendicular directions. The two strain gauges were connected in a half bridge configuration into strain gauge amplifiers. A Clip AE 101 strain gauge amplifier was used for this. The fact that the signals of two strain gauges measuring in two perpendicular directions were combined implies that sensor fusion was implemented. (see also figure 4.6)

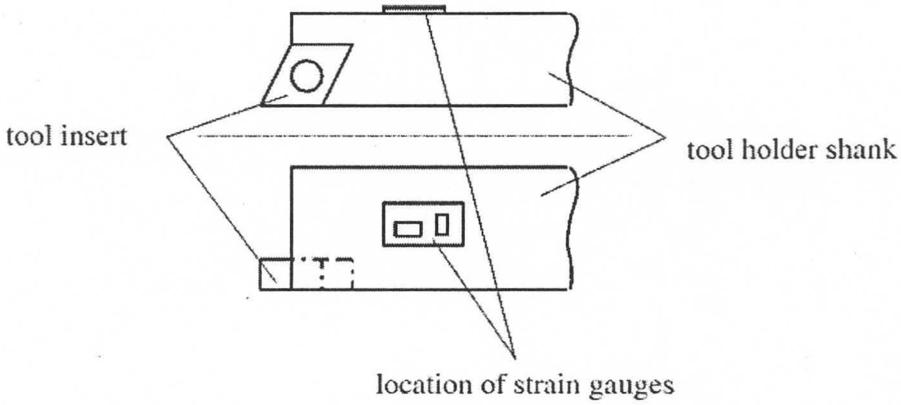

Figure 4.1: The approximate location of the strain gauges.

Low-pass filtering was done on the signal to prevent aliasing. The filter design was that of a $4th$ order Chebyshev type which had a roll off of $-3dB$ at $4350Hz$. The filter was built in-house and designed with the FilterLab Low Pass program[1]. The filtered signal was then captured on a personal computer in a MATLAB environment using the Data Acquisition Toolbox (DAQ toolbox). The DAQ toolbox allows for the easy creation of rather elaborate monitoring systems.

To automate the data processing as much as possible the data had to have a uniform structure. This means that all the recorded signals had to have the same length. In order to achieve this a triggering mechanism is needed. This trigger mechanism was created so that recording was started when the signal crossed a certain threshold. Recording was then allowed for a set amount of time before it was stopped. This recording time as set to be longer that than the cutting time of the each experiment run.

The experiment went as follows. The tool was set at the correct depth for the cut,

---

[1] Available from Microchip Corporation at http://www.microchip.com

but just "outside" the workpiece so that when the lathe is started and the autofeed is engaged, the tool will enter the workpiece within approximately 1 second. When the tool touches the workpiece, the recording is triggered and continued until the set time is exhausted. The signal is then stored on the computer. This is shown schematically in figure 4.2.

The analog to digital conversion was done with a National Instruments PCI-6024E analog to digital card. A schematic of the data acquisition system can be seen in figure 4.3. The signals were sampled at a rate of $f_s = 20kHz$.

In appendix D some photos are shown of the equipment.

4.2.1 Machining parameters

The purpose of the experiment was to monitor the progression of wear for a tool during a normal life cycle. Parameters were chosen so that they were to fall for the "medium" range for most tool inserts. As with some design situations some of the parameters were chosen arbitrarily for a first iteration. The machining parameters that were decided on are shown in table 4.1.

Table 4.1: The machining parameters for the experiment.

Machining Parameter	value	unit
feed	2	mm/rev
depth of cut	0.5	mm
cutting speed	120	m/min

By the nature of a cutting process, there is a fundamental problem with keeping experimental conditions constant. Each time a cut is made the workpiece looses $0,5mm$ from the circumference. This changes the circumferential velocity for the next cut. If experiments were to be kept 100% constant, cutting could only have been done on workpieces of exactly the right circumference. A lot of workpieces would therefore be needed for the experiments. This would have been a very expensive experiment. To counteract this problem it was decided to introduce a tolerance band of about 8% around the cutting speed. This means that for a certain rotational speed on the lathe, a certain amount of cuts could be made that all lie within the cutting speed band.

Tool wear is renowned for its dependence and sensitivity to machining conditions. It is therefore desirable to have cutting conditions that are not always exactly the same so that a classification algorithm that proves its effectiveness on those signals will also have proved its robustness a priori.

Typical shavings can be seen in figure 4.4. This shows a long continuous chip of about $1m$ length. The chip has a bright blue metallic colour, which is indicative of martensite

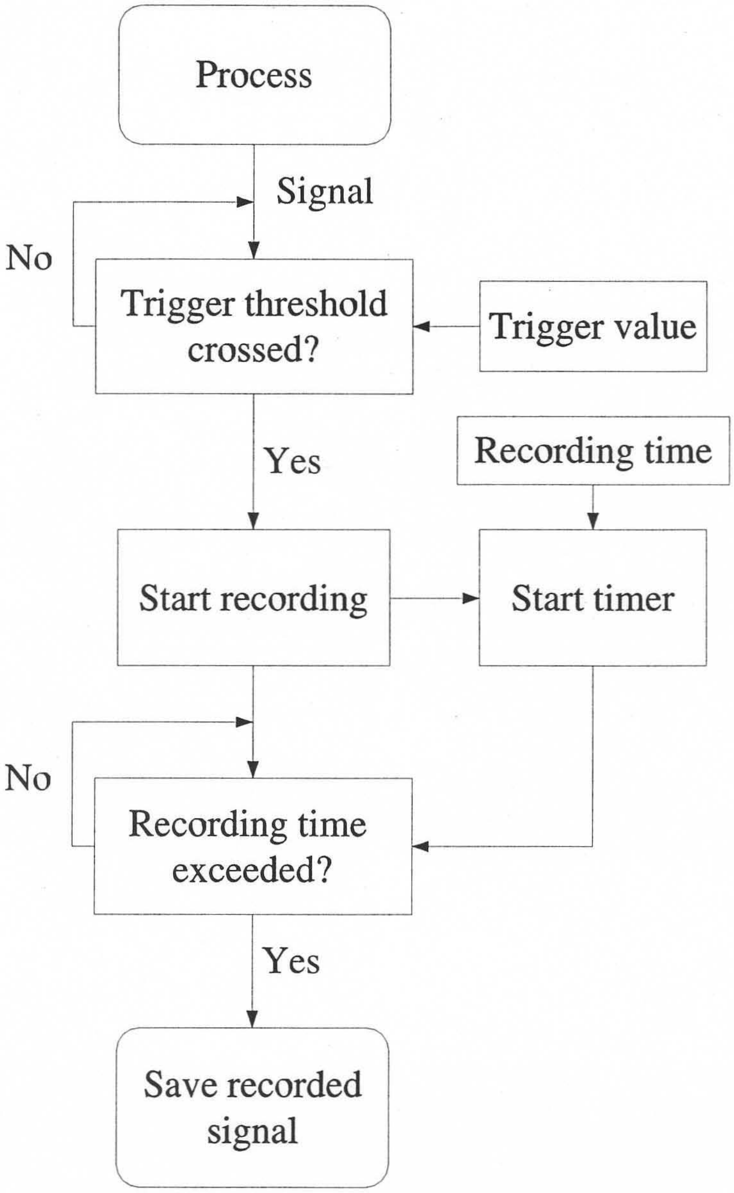

Figure 4.2: A schematic of the data acquisition program.

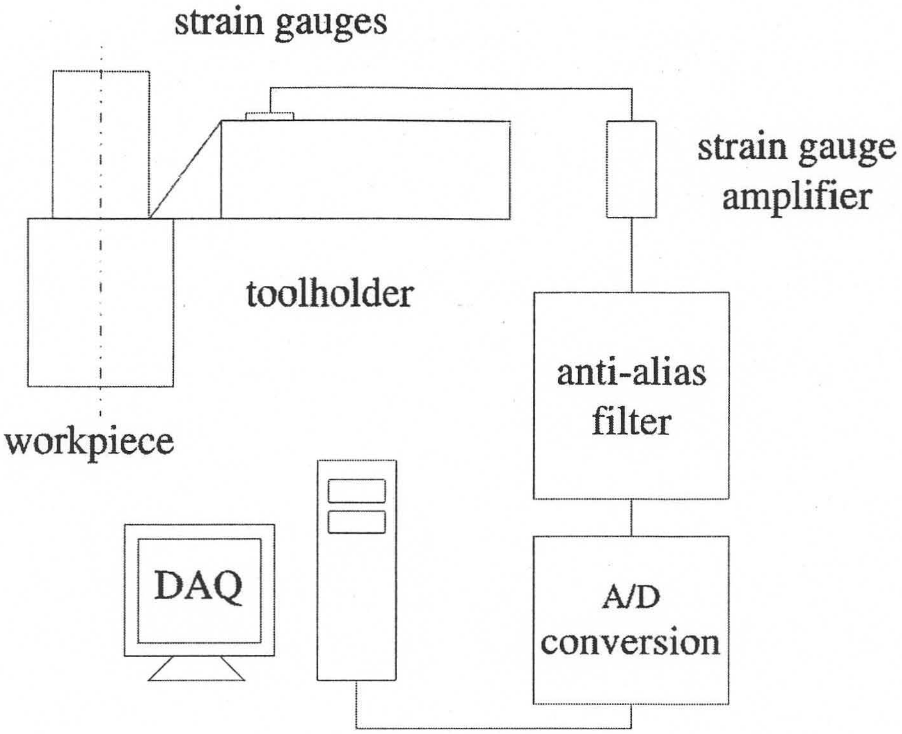

Figure 4.3: The schematic overview of the data acquisition system used for the experiments.

and subsequently a very high cutting temperature. This may also be because of the high carbon content of the workpiece material. This continuous chip is actually undesirable in real life situations according to (Cho et al., 1999). Continuous chips usually have an adverse affect and surface roughness and may cause tangling problems around the tool.

It is interesting to note that if the depth of cut was increased to $1mm$, the cutting chips would break up into small curls with lengths of about $25mm$. The colour of these chips were also the bright metallic blue. If the depth of the cut was however slightly decreased, the chips continued to be long but the colour turned silvery and bright. This silver colour is an indication that the tool is being utilised to its capacity.

As was previously mentioned, because the machine is operator driven, the quality of the data is dependant on the experience of the operator. The depth of each cut was measured directly after each cut with normal vernier callipers. This is shown in figure 4.5 in the form of a histogram of the depth of cut during the experiment. There is quite a large variance around the mean. This large variance has the same effect on tool wear as the cutting speed tolerance band.

The last machining parameter to take into account is that of cooling fluid. On recommendations from technical personnel it was decided to cut the material dry. No cooling fluid was used since dimensional stability was not an important issue. Also, the cooldown period and the continuous chip that transports the heat away from the workpiece, provided a steady experimental temperature.

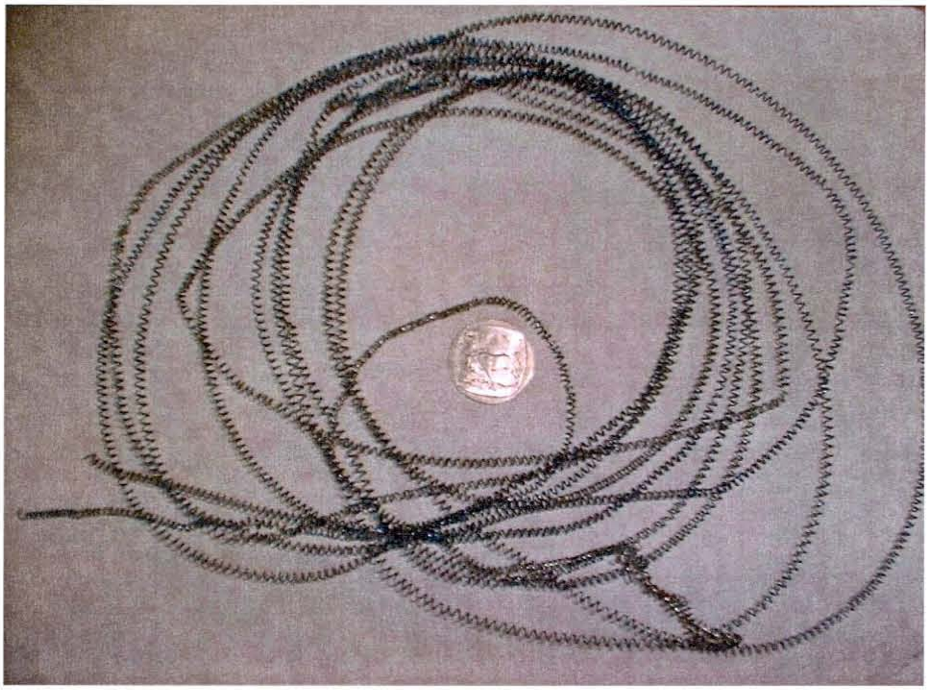

Figure 4.4: A typical shaving from a cut.

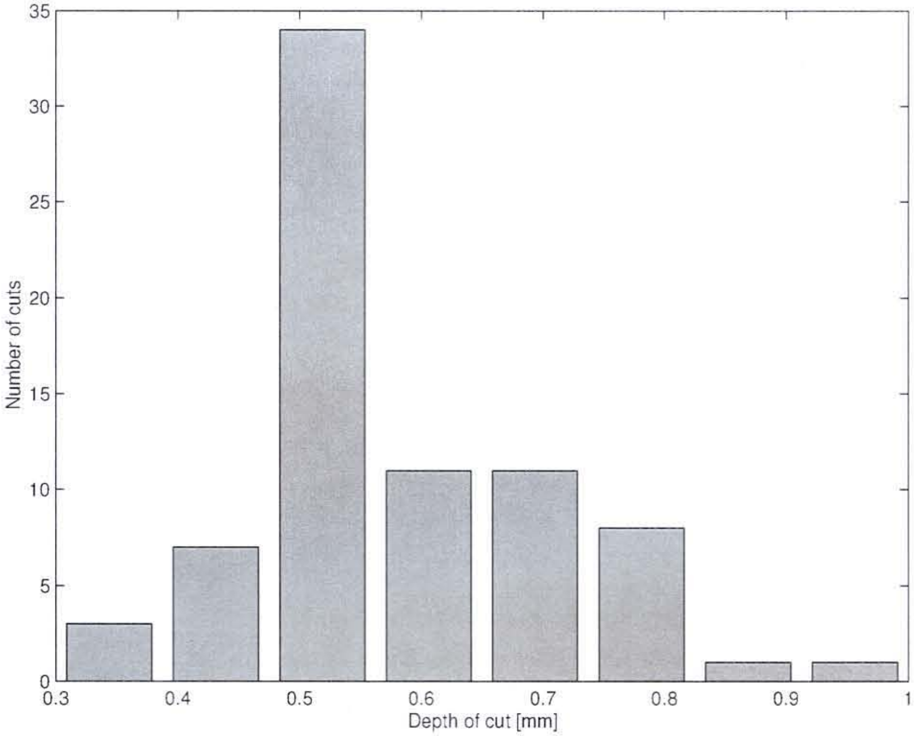

Figure 4.5: A histogram for the depth of cut.

4.2.2 The tool holder

Previously it was mentioned that a boring bar was used. This was a Mitsubishi S160 SCI PR09[2]. The boring bar was machined on the side and top so that there would be space for the stain gauges. The stain gauges were covered with an epoxy mixture to protect them from the machining environment. It will be assumed that the epoxy does not change the modal properties of the bar in any significant way.

In the setup the bar was given an overhang of $30mm$. This is almost the minimum amount that the geometry of the bar and the epoxy coating allows for.

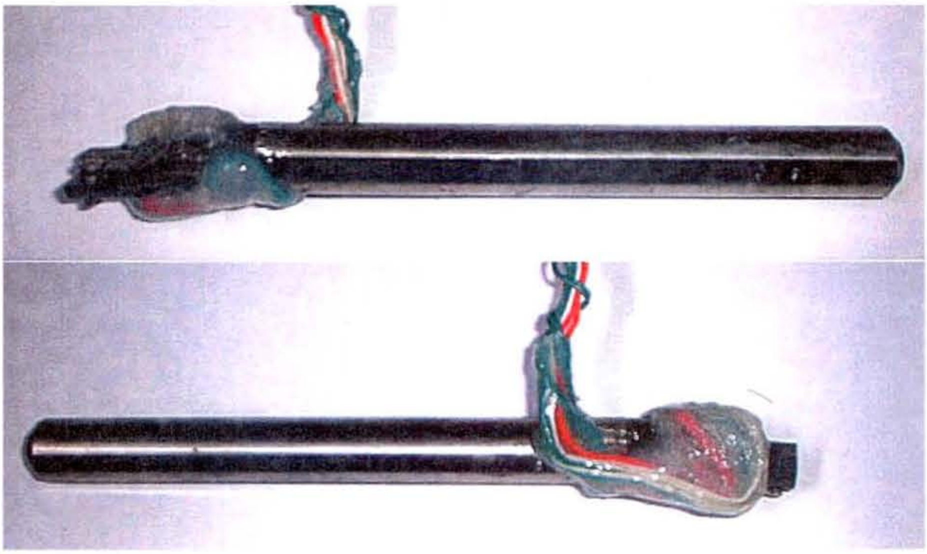

Figure 4.6: The boring bar was instrumented with strain gauges on one side.

4.2.3 The insert and measurement of tool wear

With the machining parameters listed on page 34, Mitsubishi suggests a medium finishing tool insert. It was decided from references from the Mitsubishi website to select a *US7020 MV* tool insert.

In order to measure tool wear during the life of the tool it was necessary to remove the tool for inspection during certain time increments. This was adjusted as experience was gained with the tool inserts. In the end, wear was measured after every $10 - 15$ minutes of cutting time.

The measurement of tool wear was done on an optical microscope. Since the machining parameters were chosen to be in the "mid range", efforts under the microscope were focused on finding traces of flank wear. Flank wear and nose wear are the most common forms of wear to be found on tools.

---

[2] Information on this boring bar can be downloaded in pdf format from: http://wwww.mitsubishicarbide.com

It was found from the measurements under the microscope that nose wear is the dominant wear mode for the machining parameters and workpiece combination. Nose wear is commonly found at low cutting speed and the mechanism of wear is caused by abrasion wear on the cutting tool´s major edges. Tool sharpness is caused by plastic or elastic deformation of the cutting edge. A built-up edge may also be formed at low cutting speeds. In figure 4.7 a plan view the worn nose of the tool is shown. In contrast with this, figure 4.8 shows a new tool insert (this is however at a lower magnification).

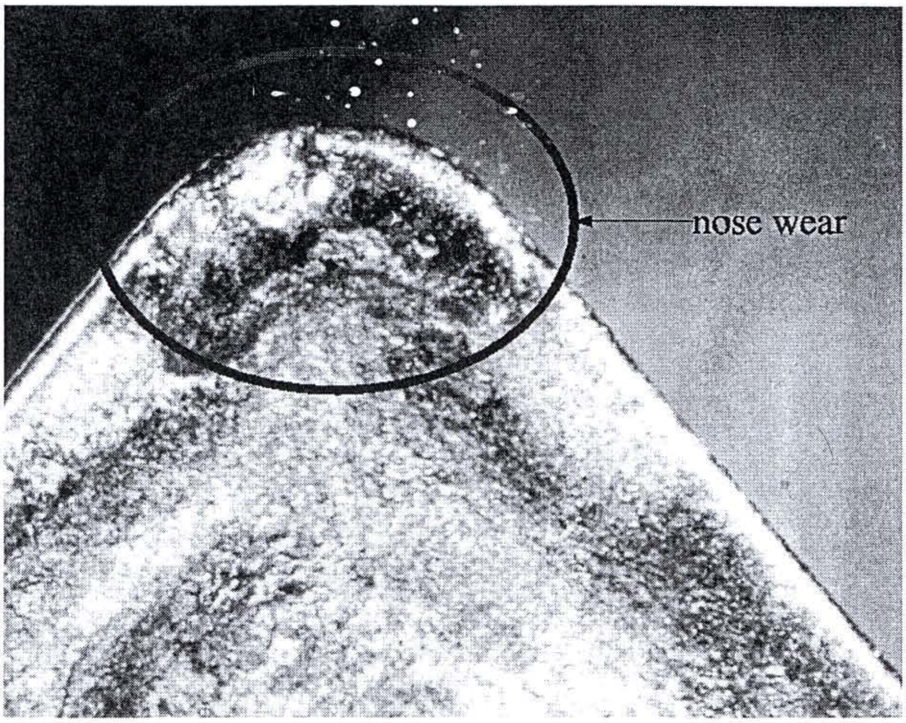

Figure 4.7: The nose of an insert under a microscope. Nose wear is shown on this photo.

In a similar situation to the dilemma of the changing cutting speed for each experiment, was that of the removal of the tool insert. The removal and re-insertion of the insert changes the dynamic characteristics of boring bar and insert system. This change is caused by the difference in clamping conditions at each "iteration" of the wear measurements. This again is once again not necessarily a bad thing, since it offers a chance to, at least in a qualitative manner, to prove the robustness of the recognition system which is to be implemented.

4.2.4 Machining material

The experiments were conducted on EN 19 alloy steel. This is a tough steel which is mostly used for shafts and gears. Because of its high carbon content this steel is ideal for hardening. This can sometimes present a problem for machining. If the material

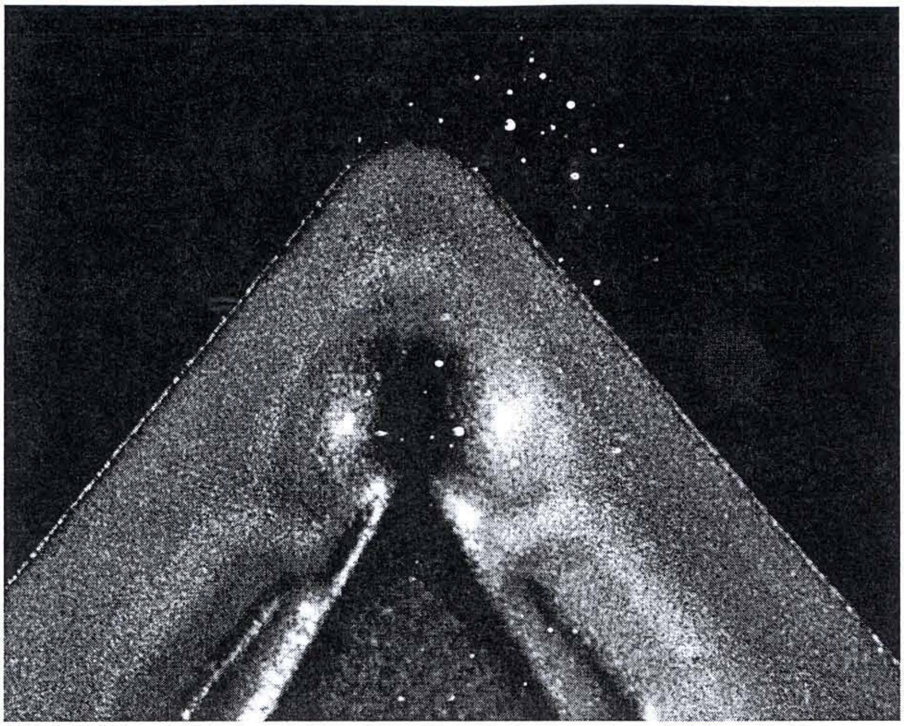

Figure 4.8: The nose of a new tool insert.

is not cold cut, it hardens and become almost unusable. This can also happen on the surface during cutting if the machining parameters are not correctly set. The mechanical properties can be seen in table 4.2.

Table 4.2: The mechanical properties of EN 19 steel.

Property	Limit	Elongation
Ultimate tension stress	1089 MPa	12 %
Yield stress	955 MPa	18 %

The steel was also oil quenched and tempered to the so-called T-condition, which had a Bernell hardness between $262 - 296BHN$. EN19 is a tough steel alloy and was chosen so that the "natural" life of the tool, in which we are interested would not be to long.

Workpieces were $300mm$, "roundbar" shafts with a $80mm$ diameter. The shafts were covered with a uncut material crust which had to be removed before the experiments could begin. After the removal of this crust the shaft had a diameter of approximately $75mm$.