Further need for a comprehensive analysis of flank wear was conceived and another tool material was selected for experiments. Ceramic single point turning tool inserts (CCMT060204-TT115) was used to carry out experiments. Four experiments have been conducted in three different sets namely Set 31 Experiments 25-28 using EN24, Set 32 Experiments 29-32 using EN31 & Set 33 Experiments 33-36 using EN8 material. The experiments have been conducted with cutting speeds $S_1 = 94$ m/min (500 rpm) and $S_2 = 188$ m/min (1000rpm), Feeds $F_1 = 0.07$ mm/rev and $F_2 = 0.08$ mm/rev and constant depth of cut $D = 0.5$ mm at different cutting parameters as shown in Tables below.

Table 6.1: Experimental Set 3

<table>
<thead>
<tr>
<th>Experiment Number</th>
<th>Work Material</th>
<th>Tool Material</th>
<th>Speed rpm</th>
<th>Feed mm/rev</th>
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<tr>
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<td>T3</td>
<td>S1</td>
<td>F1</td>
</tr>
<tr>
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<td>T3</td>
<td>S1</td>
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<td>T3</td>
<td>S2</td>
<td>F1</td>
</tr>
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<td>S2</td>
<td>F2</td>
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<td>T3</td>
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Table 6.2: Experimental Sets - Categories

<table>
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<tr>
<td>Category -S31</td>
<td>Flank Wear Analysis of Ceramic inserts on En24 – Experiments 25-28</td>
</tr>
<tr>
<td>Category -S32</td>
<td>Flank Wear Analysis of Ceramic inserts on En31 – Experiments 29-32</td>
</tr>
<tr>
<td>Category -S33</td>
<td>Flank Wear Analysis of Carbide inserts on En8 – Experiments 33-36</td>
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Table – 6.3 Experiments for Tool 3 on three materials

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<td>S-1</td>
</tr>
<tr>
<td>F-2</td>
<td>S-2</td>
</tr>
</tbody>
</table>

M1- EN24 M2- EN31, M3-EN8
S1-500 rpm, S2-1000rpm, F1-0.07 mm/rev, F2-0.08 mm/rev

6.1 Flank Wear Analysis with Cutting Forces

Figure 6.1 (a, b, c & d) show four graphs of cutting forces (Fz) versus flank wear for all the three materials using the above cutting parameters. Figure 6.1 a shows Trend line for machining of steel specimens at a cutting speed of 94m/min and for a feed of 0.07mm/revolution. This indicates a gradual change moving upwards and increasing in the initial very low wear regions. Highest wear recorded from EN8 was 0.2 mm compared to the other two materials for the same trial which are 0.18 mm respectively for both EN24 and EN31 materials. The flank wear values are typically small compared to uncoated and coated carbide tools. The initial wear in the tool in all the specimens are almost same for the first 5-6 trials. This indicated that the initial wear in all the materials are similar for similar cutting conditions although the materials are different. The slope of the curve is almost similar as well as the magnitude of cutting force Fz. The trend lines drawn for the three materials show that the flank wear is almost same. Very small wear was recorded in all the experiments.

The cutting forces Fz for the highest wear value in the experiment in three materials are 330 N, 380 N and 370 N for EN24, EN31 and EN8 respectively. The table points to the increase in the cutting force values for each trial and for each change in the wear. The wear rate is consistent uniform from the first trail and is recorded maximum value of 0.2 mm in the last trail for EN8 material. Cutting force Fz corresponding to this wear is 370 N; however cutting force Fz in case of EN24 and EN31 are 330 N and 380 N for the last trials.
Figure 6.1 b shows the graphs drawn between cutting force Fz and Flak wear represented for the three materials for the increased feed of 0.08 mm/revolution (change in feed) and for the same cutting speed of 94 m/min (500 rpm). Flank wear in all the three materials are almost similar from the first trial to the last trial. The highest value of wear was found to be from machining of EN31 and EN8 (0.22 mm) as against 0.2 mm wear using EN24 material.

The cutting force component Fz has shown higher trend in ENS with the maximum wear recorded from the same material is 0.22 mm and the relative cutting force of 400 N. One significant feature is that all the three trend lines seem to go upwards showing similarity in each of the cases.

From figure 6.1 c, it is clear that the highest value of flank wear recorded was when the ceramic tool insert was used for machining ENS specimen. Flank wear recorded was 0.25 mm and the force component Fz for this was found to be 390 N. Ceramic tool inserts measured a flank wear of 0.21 mm and 0.22 mm when used for turning EN24 and EN31 specimens and magnitude of cutting force Fz for these values of wear were 360 N and 420 N respectively. There seems a change in the cutting force components with change in the cutting conditions. The trend lines' slopes have gradually moved up beyond after the third trial and for a wear of 0.1 mm.

Flank wear of tool and corresponding changes in force Fz for the machining condition of maximum speed of 188 m/min and feed of 0.08 mm/revolution for the ceramic tool on three materials is graphically represented in figure 6.1 d. The data for these experiments are as given in the Appendix VII, VIII and IX. Here the Maximum flank wear was recorded from the machining of EN8 material.

The initial wear of tool in machining the three materials in the first three trials is almost identical. There is a marginal change in the value of Fz in the machining of three materials. Corresponding value of cutting force Fz is also almost identical. The slopes of the curve for all the three materials seem to change gradually as shown. Although the maximum wear obtained from three materials for the 20 trials are almost very close, the Fz component for EN31 shows 20 N more than the other force component recorded for machining other two materials.
Flank wear in all the cases has crossed 0.2 mm mark and the cutting force component has crossed 400 N mark in each of the three cases. Trend line for all the materials has been distinctly indicating the change in the slope and two of the curves (EN24 and EN31) seem to be identical compared to the curve for EN8. Highest Fz recorded was 440 N for EN31 for a wear of 0.26 mm. The other two materials EN24 and EN8 have recorded 420 N for a wear of 0.25 mm and 0.27 mm respectively.
Figure 6.1: Cutting force $F_z$ versus Flank Wear

(a) $S=94$ m/min, $F=0.07$ mm/rev, $D=0.5$mm
(b) $S=94$ m/min, $F=0.08$ mm/rev, $D=0.5$mm
(c) $S=188$ m/min, $F=0.07$ mm/rev, $D=0.5$mm
(d) $S=188$ m/min, $F=0.08$ mm/rev, $D=0.5$mm
6.2 Flank Wear Analysis with Time

One significant feature of the graphs drawn between flank wear and time for all the materials for the cutting conditions is that the tool material has very small wear for the first machining condition of 94 m/min cutting speed and 0.07 mm/revolution feed. This is shown in Figure 6.2 a. The figure also shows the trends which are almost identical in the first 6 trials in EN31 and EN8 materials. The wear seems to be still in the initial wear and this is attributed to the fact that the tool is considerably very hard and has a better tool life. Magnitude of wear in EN24, EN31 and EN8 are 0.18 mm, 0.18 mm and 0.20 mm respectively. The graph also eventually indicates the effect of EN8 on ceramic tool inserts in that there is slightly higher wear obtained in machining EN8 compared to the other two materials.

Figure 6.2 b has shows a strange change in that the effect of tool wear in machining the three materials is almost converging to a maximum flank wear of 0.22 mm in two of the three cases. Although the initial wear occurred in the first few trials in each of the cases seem to diverge a little, towards the last trials there seems to be having no change in the flank wear values. Trend lines drawn for the points generated for the three materials show this change with three separate and distinct lines in the initial wear region and later on diverging to arrive at a common point. The wear rate in all these three cases is gradual and almost similar.

Figure 6.2 c shows the flank wear versus time curve for all the three cases. EN31 induces lesser flank wear than the other two. Further, the flank wear effect is seen more from the machining of EN8 for this cutting condition. The three curves are identical showing the similarity in the characteristic of the tool for wear in machining three different materials. Highest value of flank wear recorded was from EN8 (0.25 mm). However, the wear values resulted from other two materials EN24 and EN31 material are 0.21mm and 0.22 mm.

Figure 6.2 d shows trend lines which look identical but with slightly varying slopes. The significant feature of this is the shift in the slope is seen around 0.12 mm after 7th minute in the first two cases and the third at around 0.13 mm in the third case. Wear rate is gradual in all the cases and highest wear is recorded in EN8, the next higher
wear is in EN31 and EN24 has the lowest value of flank wear corresponding to the same trial.

Effect of increasing speed to a maximum value of 188 m/min (1000 rpm) and corresponding feed of 0.08 mm/revolution shows almost identical behaviour of tool. The three curves are showing the values and the trend.
Figure 6.2: Flank Wear versus time

(a) \( S=94 \text{ m/min}, F=0.07 \text{ mm/rev}, D=0.5\text{ mm} \)  
(b) \( S=94 \text{ m/min}, F=0.08 \text{ mm/rev}, D=0.5\text{ mm} \)  
(c) \( S=188 \text{ m/min}, F=0.07 \text{ mm/rev}, D=0.5\text{ mm} \)  
(d) \( S=188 \text{ m/min}, F=0.08 \text{ mm/rev}, D=0.5\text{ mm} \)
6.3 Flank Wear Analysis with Acoustic Emission – AE (RDC)

Figure 6.3 a, b, c and d shows various graphs between AE (RDC) and flank wear. In the first figure 6.3 a, the three graphs of AE (RDC) versus Flank wear drawn from the experimental data of three materials shows almost similar pattern of curve for two materials EN24 and ENS. In turning three materials using ceramic turning tool inserts for an operating speed of 94 m/min and feed value of 0.07 mm/revolution.

The AE (RDC) values have increased steadily for the initial wear values in all the cases. However, the AE (RDC) values seem to be showing higher values in EN8 machining using ceramic tool inserts. The highest value of flank wear in ceramic tool inserts was obtained in machining EN8 and the corresponding value is 0.2 mm for which AE (RDC) is 2378. Another feature that can be extracted here is that the value of AE (RDC) has significantly changed and reduced when the wear recorded for different materials lowered. Thus, EN31 has shown AE (RDC) of 2787 and ENS has shown a value of AE (RDC) of 1589 for a wear of 0.18 mm in both the cases.

Figure 6.3 b shows graphs drawn for the same materials with higher speed, feed and for the same depth of cut. This has certainly produced slightly increased wear by a magnitude of 0.02 mm, 0.04 mm and 0.02 mm in each of the materials. Flank wear from EN24 recorded wear of 0.2 mm, from EN31 recorded 0.22 mm and from EN8 recorded 0.22 mm. Although highest value of flank wear obtained during machining in these experiments showed as 0.22 mm in two materials, machining of EN31 using ceramic tool inserts have recorded higher AE (RDC) value of 4696. AE (RDC) for EN24 has varied from 413 to 1989, whereas the same value recorded for EN31 and EN8 vary between 619-4696 and 802-2989 respectively.

Figure 6.3 c shows the relationship of Flank wear and AE (RDC) for next higher speed of 188 m/min (1000 rpm) and minimum feed (0.07 mm/revolution). In the experiment machining using EN31 showed higher AE (RDC) values although the flank wear developed is not highest for the same. However, the experiment seems to show different trend in the EN24 and EN8 samples for the same operating conditions.
However, the wear pattern is similar but the AE (RDC) values are lesser. Shape of the exponential curve is almost the same.

The wear rate has significantly changed with change in the operating conditions and the maximum wear values actually measured in these cases were 0.21 mm, 0.22 mm and 0.25 mm for the three materials. The AE (RDC) values for the three cases are in the range 601-3876 for EN24, 725-4837 for EN31 and 889-4198 for EN8 materials. AE (RDC) for a flank wear of 0.22 mm (EN31) was the highest in this experiment.

Figure 6.3 d signifies the highest speed and feed for the experiments. Like in the other set of experiments, the flank wear actually obtained from the experiments were 0.25 mm, 0.26 mm and 0.27 mm respectively. Actual wear in ceramic tool inserts from turning EN8 material was the highest, but the AE (RDC) for EN31 seem to show higher value. This behaviour was seen in the other two results as well. The wear rate for ceramic tool inserts with EN24, EN31 and EN8 are almost similar and very small in magnitude. Although the flank tool wear showed 0.26 mm from turning EN31 specimen, the AE (RDC) recorded for the same is the highest 5417 compared to the maximum wear obtained from turning EN8 specimens for which the E (RDC) recorded was 4675.
Figure 6.3: AE (RDC) versus Flank wear

(a) S=94 m/min, F=0.07 mm/rev, D=0.5mm
(b) S=94 m/min, F=0.08 mm/rev, D=0.5mm
(c) S=188 m/min, F=0.07 mm/rev, D=0.5mm
(d) S=188 m/min, F=0.08 mm/rev, D=0.5mm
6.4 Flank Wear Analysis with Acoustic Emission – AE (EG)

Figure 6.4 a, b, c and d shows various graphs between AE (EG) and flank wear. It is seen that AE (EG) values increase with tool wear. Figure 6.3 a shows that the flank wear values recorded for the first set of experiments were 0.18 mm, 0.18 mm and 0.2 mm respectively in machining EN24, EN31 and EN8. A careful observation of data also shows that the AE (EG) values are also recorded as 62417, 61987 and 63456 respectively. The wear has increased steadily in each of the cases and the trend lines drawn for these cases are also similar.

Figure 6.4 b shows that a small change in the feed in the experiments has indicated change in the wear values in each of the three cases of materials. EN31 and EN8 have influenced highest flank wear (0.22 mm) in the ceramic tool inserts. The magnitude of wear influenced by the other material is also very marginal thereby indicating the property of the tool which has greater resistance to wear. Ceramic tool inserts have shown almost similar wear rates under the same cutting conditions irrespective of material change.

Figure 6.4 c shows change in the AE (EG) values with flank wear in three materials. Each trial from all the materials have indicated rise in the wear values initially, and steady values in between and consistent rise thereon towards the end. AE (EG) for the maximum wear 0.25 mm was recorded as 88876 in machining EN8. However, the interesting fact is that the AE (EG) values also showed a consistent change irrespective of the material used.

As per the figure 6.4 d, the wear recorded while machining EN24, EN31 and EN8 were 0.25 mm, 0.26 mm and 0.27 mm respectively. AE (EG) for all the three cases show that there is a small variation in the AE (EG) values corresponding to the flank wear developed in machining.
Figure 6.4: AE (EG) versus Flank Wear

(a) $S=94$ m/min, $F=0.07$ mm/rev, $D=0.5$mm  
(b) $S=94$ m/min, $F=0.08$ mm/rev, $D=0.5$mm  
(c) $S=188$m/min, $F=0.07$ mm/rev, $D=0.5$mm  
(d) $S=188$m/min, $F=0.08$ mm/rev, $D=0.5$mm
6.5 Discussion

Machining of the three materials developed long coils of continuous chips in all the cutting conditions used. These chips would coil and get cut during the course of action of the machining process. However, these coils would get clogged during machining. The effect of such a cogging of the chips has not been considered.

The graphs 6.5 a, b and c and 6.6 a, b and c are drawn for showing the comparative wear of coated carbide inserts in turning EN24, EN31 and EN8 materials. The graphs show the effect of speed and feed in all the cases. Two important features extracted from the graphs are – flank wear in each of the experiments follow the typical wear curve (figure 1.5) and secondly the increase in the value of flank wear in each of the cases when the speed and feed were increased.

Machining of the three materials developed short coils of continuous chips in all the cutting conditions used. However, these coils would have lesser influence in the flank wear when the coils abrade on the tool surface. Also, sometimes may also get clogged during high speed and high feed machining. From the above discussions it was seen that in most of the cases cutting forces show an upward trend with the increase in the tool wear rate. The tangential component – main cutting force (Fz) is more sensitive to tool wear as compared to axial component feed force (Fx) and radial component (Fy).

During experimentation it was observed that the Acoustic Emissions parameters AE (RDC) and AE (EG) show a significant increase with tool wear. Both the AE parameters showed gradual rise in their values for all cases. This indicates that the acoustic emission is sensitive to flank wear.

The final three sets (S31, S32 and S33) comprising of yet another 12 experiments (experiment numbers 25-26) showed that EN8 influences more amount of flank wear in ceramic tool inserts compared to EN24 and EN31. The difference in the magnitude of flank wear is very marginal in all the three sets each set having four experiments. Also the wear pattern has followed almost the same way which was seen in the other
two cases of tools. Right from the first operating speed and feed combination to the last combination there is a consistent increase in the flank wear. Relatively similar changes in the flank wear values were obtained from the experiments with EN24 and EN31. This signifies that higher cutting speed and feeds have direct impact on the wear. Also, in uncoated inserts wear faster at higher operating speeds and feeds.

The experiments also show that the turning EN8 material using ceramic inserts influenced higher flank wear in the experiments with varied cutting conditions. Although wear rate remained different in each of the experiments, the highest wear values are recorded in machining EN8. The investigation also shows that maximum flank wear of ceramic single point tool inserts when operated on EN24, EN31 and EN8 material was found to be in the range of 0.05 mm – 0.25 mm, 0.05 mm - 0.26 mm and 0.05 mm – 0.27 mm respectively. Also, the same tool has shown higher wear rate with higher feed in EN8 than in other two materials. Thus the inference that can be drawn from this investigation is that the uncoated carbide tool has a consistent and higher wear rate with EN8 material for the cutting conditions used.
Figure 6.5: Comparative Flank Wear in Ceramic Inserts
Chapter 6
Investigations and Analysis of Ceramic Inserts

Figure 6.6: Comparative Flank Wear in Ceramic Inserts