Chapter 5
Investigations and Discussion on Flank Wear of Coated Carbide Tool Inserts on EN24, EN31 and EN8

After the experiments conducted to investigate and analyze data using the uncoated carbide tool, it was proposed to carry out experiments using coated carbide tool inserts (CCMT060204-TN2000). Four experiments have been conducted in three different sets namely Set 21 Experiments 13-16 using EN24, Set 22 Experiments 17-20 using EN31 & Set 23 Experiments 21-24 using EN8 material. The experiments have been conducted with cutting speeds $S_1 = 94$ m/min (500 rpm) and $S_2 = 188$ m/min (1000 rpm), 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 the Tables below.

Table 5.1: Experimental Set 2

<table>
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<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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Table 5.2: Experimental Sets - Categories

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<td>Category -S22</td>
<td>Flank Wear Analysis of Coated Carbide inserts on En31 - Experiments 17-20</td>
</tr>
<tr>
<td>Category -S23</td>
<td>Flank Wear Analysis of Coated Carbide inserts on En8 - Experiments 21-24</td>
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Table – 5.3 Experiments for Tool 2 on three materials

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

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

5.1 Flank Wear Analysis with Cutting Forces

Figure 5.1 (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 5.1 a shows Trend line for machining of steel specimens at a cutting speed of 94 m/min and for a feed of 0.07 mm/revolution. This indicates a gradual change moving upwards and increasing in the initial very low wear regions. Highest wear in the tool was recorded from EN8 and was 0.31 mm compared to the other two materials for the same trial which are 0.29 mm and 0.2 mm respectively for both EN24 and EN31 materials. The flank wear values are slightly of lesser magnitude compared to uncoated carbide tools. The initial wear in the tool in all the specimens are almost same for the first 2-3 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.

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 and uniform from the first trial and has been recorded as maximum as 0.31 mm in the last trial for EN8 material. Cutting force Fz
corresponding to this wear is 370 N; however cutting force $F_z$ in case of EN24 and EN31 are 330 N and 380 N for the last trials. The machining showed coiled chips in all the three materials at this speed and feed and did not coil around the tool post. There were sparking during the machining of EN24, EN31 and EN8.

Figure 5.1 b shows the graphs drawn between cutting force $F_z$ and Flank 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 from the two materials EN24 and EN31 are identical from the first trial to the last trial. The highest value of wear was found to be from machining of EN8 (0.36 mm) as against 0.31 mm wear obtained from EN24 and EN31 materials.

The cutting force component $F_z$ has been recorded as 60 N, 90 N and 70 N respectively for the first trial in each of the materials and subsequently it has consistently increased in magnitude and corresponding to the maximum wear of 0.36 mm of wear the force component $F_z$ was recorded 400 N. One significant feature is that all the three trend lines seem to go upwards showing similarity in each of the cases.

From the figure 5.1 c, it is clear that the highest value of flank wear recorded was when EN8 material was machined. Machining of EN8 initially releases continuous chips and like in the first case of 94 m/min and 0.07 mm/revolution of feed the chips coil around the tool post. Initial wear was more from EN31 material and subsequently the flank wear recorded was highest form EN8 and the maximum force component $F_z$ corresponding to this wear magnitude of 0.35 mm was found to be 390 N. EN31 has recorded a value of 420 N for the wear of 0.25 mm and the same parameters are 360 N and 0.31 mm respectively from EN24. There seems a change in the cutting force components with change in cutting conditions. However, the cutting force $F_z$ seems to change differently with the materials and cutting conditions than mere materials used in machining. The trend lines’ slopes have gradually scaled up as shown.

Flank wear of tool and corresponding changes in force $F_z$ for the machining condition of maximum speed and feed for the coated carbide tool on three materials is
graphically represented in figure 5.1 d. Here the Maximum flank wear of 0.40 mm was recorded from the machining of EN8 material. Corresponding value of cutting force Fz is also almost identical. Complete wear obtained from the machining of EN24 and EN31 are identical and this is the second time the experiments have shown similarity in the wear from two different materials. This speed generates higher chip flow rate and the chips would coil at this stage and whips abrade the tool and the holder. 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. 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 0.37 mm. The other two materials EN24 and EN8 have recorded 420 N for a wear of 0.37 mm and 0.4 mm respectively. The data for these experiments are as given in the Appendix IV, V and VI.
Figure 5.1: 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
5.2 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 cutting condition of 94 m/min cutting speed and 0.07 mm/revolution feed. This is shown in Figure 5.2 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 part and this is attributed to the fact that the tool is relatively hard as the same is coated very hard and has a better tool life compared to the uncoated carbide tool inserts used in the earlier sets of experiments. The magnitude of wear obtained from the machining of EN24, EN31 and EN8 are 0.29 mm, 0.20 mm and 0.31 mm respectively. The graph also eventually indicates the effect of EN8 on carbide tool inserts in that there is a slightly higher wear obtained in machining EN8 compared to the other two materials.

Figure 5.2 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 0.36 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 shows 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 5.2 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 (0.35 mm). However, the wear values resulted from other two materials EN24 and EN31 material are 0.31 mm and 0.25 mm. The other two materials have shown a change in the slope at around 0.16 mm.

Figure 5.2 d shows trend lines which show some degree of similarity such that the flank wear produced by the them are The significant feature of this is the shift in the slope is seen in all the cases. Wear rate is gradual in all the cases and highest wear is recorded in EN8, the next higher wear is in EN24 0.37 mm and EN31 has the lowest value of 0.3 mm 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.
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Figure 5.2: Flank Wear versus time

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

Figure 5.3 a, b, c and d shows various graphs between AE (RDC) and flank wear. In the first figure 5.3 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 EN8. In turning three materials using coated carbide 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 EN31 machining using coated carbide tool inserts. The highest value of flank wear in ceramic tool inserts was obtained in machining EN8 and the corresponding value is 0.31 mm for which AE (RDC) is 3014. 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, machining carried out using coated carbide tool inserts on EN24 has shown a flank wear of 0.29 mm for AE (RDC) of 3012, on EN31 has shown AE (RDC) of 3121 for a wear of 0.2 mm and on EN8 has shown a value of AE (RDC) of 3014 for a wear of 0.31 mm.

Figure 5.3 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 0.31 mm, 0.31 mm and 0.36 mm in each of these materials. Flank wear from EN24 and EN31 recorded wear of 0.31 mm and from EN8 recorded maximum of 0.36 mm. The highest value of flank wear obtained during machining of EN8 in these experiments was 0.36 mm and AE (RDC) corresponding to this was 3898. AE (RDC) for EN24 has varied from 213 to 3232, whereas the same value recorded for EN31 and EN8 varied between 119-3686 and 765-3898 respectively.

Figure 5.3 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 0.31 mm, 0.25 mm and 0.35 mm for the three materials. AE (RDC) values corresponding to the recorded values of flank wear in these inserts are recorded as 149-3454 for EN24, 489-3745 for En31 and 1010-4012 for EN8 for these steel specimens.

Figure 5.3 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 0.37 mm, 0.37 mm and 0.4 mm respectively. Actual wear in ceramic tool inserts from EN8 material was the highest, but the AE (RDC) for EN31 seem to show higher value. This behavior was seen in the other two results as well. The wear rate for ceramic tool inserts with EN 24, EN31 and EN8 are almost similar and very small in magnitude. AE (RDC) values corresponding to the recorded values of flank wear in these inserts are recorded as 313-3789 for EN24, 599-3701 for EN31 and 1412-7689 for EN8 for these steel specimens.
Figure 5.3: AE (RDC) versus Flank wear

(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) $S=188 \text{ m/min}, F=0.08 \text{ mm/rev}, D=0.5\text{mm}$
5.4 Flank Wear Analysis with Acoustic Emission – AE (EG)

Figure 5.4 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 5.3 a shows that the flank wear values recorded for the first set of experiments were 0.29 mm, 0.2 mm and 0.31 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 for these values. The wear has increased steadily in each of these cases and the trend lines drawn for these cases are also similar.

Figure 5.4 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. EN8 has influenced highest flank wear (0.36 mm) in the coated carbide tool inserts. The magnitude of wear influenced by the other materials was same and has been recorded as 0.31 mm. These produced lesser coils while machining the same materials and the effect of coiling around the tool post was also marginal. This is an interesting feature as the wear resulting from both EN24 and EN31 has been the same. Also, the coated carbide tool inserts have shown almost similar wear rates under the same cutting conditions irrespective of material change.

Figure 5.4 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 0.35 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. Flank wear resulted in machining other steel specimens of EN24 and EN8 was 0.31 mm and 0.25 mm.

As per the figure 5.4 d, the wear recorded while machining EN24, EN31 and EN8 were 0.37 mm, 0.37 mm and 0.4 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. This indicates that the increase in speed and feed has influence on increasing the flank wear in coated carbide tool inserts in turning steel specimens and also has shown a considerable change in the AE parameters.
Figure 5.4: AE (EG) 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
5.5 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 5.5 a, b and c and 5.6 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.

Cutting force Fz increased systematically in each of the cases and in most of the cases cutting force Fz 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. The both the AE parameters showed gradual rise in their values indicating that the acoustic emission is sensitive to flank wear as well.

The second three sets (S21, S22 and S23) comprising of 12 experiments (Experiment Numbers 13-24) showed that EN8 influences more wear in coated carbide tool inserts compared to EN24 and EN8. The magnitude of wear in each of them is in the same range with a slight change in the values. The experiments were also conducted up to the sets of experiments which could have been possible in one specimen when operated for the same cutting condition without being disturbed.

The wear pattern has followed almost the same way. Right from the first operating speed and feed combination to the last combination there is consistent increase in the flank wear. Relatively similar changes in the flank wear values were obtained from
the experiments with EN24 and EN8. This signifies that higher cutting speed and feeds have direct impact on the wear. Also, in the present case of the specimens used, flank wear in coated carbide inserts were recorded more in machining EN8 at higher operating speeds and feeds.

Although wear rate remained different in each of the experiments, the wear values are more in EN8. The investigation also shows that flank wear of coated carbide cutting tool inserts on EN24 is found to be in the range of 0.31 mm – 0.4 mm. Thus the inference that can be drawn from this investigation is that the coated carbide tool has a consistent and higher wear rate with EN8 material for the cutting conditions used.
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Comparative Wear in Coated Carbide inserts - EN24

![Graph (a)]

Comparative Wear in Coated Carbide inserts - EN31

![Graph (b)]

Comparative Wear in Coated Carbide inserts - EN8

![Graph (c)]

Figure 5.5: Comparative Flank Wear in Coated carbide Inserts
Figure 5.6: Comparative Flank Wear in Coated Carbide Inserts