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An Investigation of the Number of Inserts Effect on the Machining Time and Metal Removal Rate During the Milling of AISI D3 Steel at High Cutting Speeds

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In this study, the effect of the number of milling cutter inserts on the metal removal and the machining time in milling of AISI D3 cold work tool steel has been investigated. A CNC machining centre was used for cutting operations. The machinability tests were carried out in dry cutting conditions at various cutting speeds, feed rates and with different number of inserts. The flank wear was measured by using an optical microscope in order to determine the tool life. The machining time decreased when the cutting speed, the number of inserts and feed rate increased. On the contrary, the flank wear increased when the same parameters increased. The flank wear increased gradually until the first 0.2 mm, but the wear rate increased significantly when above this point under different cutting conditions and with different numbers of inserts. This condition following the first 0.2 mm wear value was constant due to the high cutting speed rates based on the notch wear which emerged from fast wear.

Keywords: machining time, flank wear, metal removal rate in milling

0 INTRODUCTION

In machining practices, the high-speed rates have become more important in that they increase productivity. The scientists doing machinability experiments regard the high-speed rates as one of the most important issues. In parallel with the advancing technology, productivity has increased and the more precise surfaces have been obtained due to the development of cutting tools that are resistant to high temperatures. In the related literature, the correlation between the number of inserts and the tool life has been investigated. According to investigations, the tool life reduces as the number of insert increases, while the metal removal rate increases. This decrease in tool life is attributed to the high cutting speed rates when the process is conducted by multi inserted tools [1] and [2]. Linear correlation has not been found between the decreasing of number of insert and tool life. Due to the different deformation behaviour of the inserts on milling cutter, the single insert has been used in the experiments [1]. Kuljanic [2] has stated that the impact of the number of inserts on tool life depends on the adjustment of cutting speed, feed per tooth and workpiece-tool-machine combination.

According to the results of the machining experiments, the tool life extends with increasing cutting speed and feed rate. The effect of cutting speed on tool life is more effective than the feed rate [3] and [4]. Hossein and Yahya [5] have studied the possible failure modes of tool wear and the effect of cutting speed and feed rate variation on tool life and tool wear modes. They found that an increase in tool wear was noticed with increasing the cutting speed, while at the same time, a decrease in tool wear was observed with increasing the cutting feed.

Camuşcu and Aslan [6] have studied tool wear in high speed end milling of AISI D3 cold-work tool steel using coated carbide, coated cermet, alumina (Al_2O_3) based mixed ceramic and cubic boron nitride (CBN) cutting tools. The cutting tools' performance was compared in terms of tool life and surface finish of the work piece. The best cutting performance was obtained with CBN tool [6]. Ghani et al. [7] have carried out an investigation into the wear mechanism of TiN-coated carbide and uncoated cermets tools at various combinations of cutting speed, feed rate and depth of cut for end milling of AISI H13 tool steel. It has been observed that the time taken for the cutting edge of TiN-coated carbide tools to

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initiate cracking and fracturing is longer than that of uncoated cermets tools.

The implementation of single or multi layer coatings on cutting tools improves their performance to the maximum level. In the study conducted using single tip, maximum deformation resistance was obtained with TiAlN coated cutting tool [3]. In a similar study, have investigated the deformation mechanism using two types of coatings on tools, PVD-TiN and CVD-TiCN+Al_2O_3, in milling Ti6Al4V titanium alloy [4]. This study has revealed that the performance of the CVD coated tool is better than that of PVD coated tool. In the outcomes provided at the end of the study conducted by milling of Inconel 718 alloy, the performance of the uncoated tool was found to be better than those of the coated tools at low cutting speeds, while the coated tools exhibited slightly better performance at high cutting speeds [8].

The tool life experiments have been conducted in various cutting environments. As a result of a study conducted in dry, water-cooling and in pressurized-air cooling environments, the pressurized-air cooling was found to have changed the tool life into a better condition when compared to dry and water-cooling environment conditions [9].

Generally, researchers have focused on toll deformation, the effects of cutting tool coating and environmental conditions using single insert. The costs of cutting tools are important to manufacturers. The cost factor causes lowering to the minimum level of implementation with the least number of inserts. In contrast, the increase in the duration of the process is also a well-known factor. The aim of this study is to find out the effect of the number of inserts on the amount of the material removal rate and on the length of process time at high cutting speeds.

To explore this objective, AISI D3 cold work tool steel has been machined on a vertical CNC machining centre under intense cutting speed rates using the coated carbide inserts. The milling process was carried out in a dry condition by applying 1, 3 and 6 inserts mounted on a milling cutter at various cutting conditions. In order to have an accurate measurement, the flank wear of the cutting tools was measured using an optical microscope.

1 EXPERIMENTAL PROCEDURE

1.1 Workpiece Material

In this study, AISI D3 cold work tool steel was chosen as the work piece material. This steel type is used in many manufacturing industries such as the manufacture of cold extrusion and drilling moulds, mould plates, powder metallurgy kits, ceramic shaping moulds and cold punch. The work piece material is rectangular and is of 100 x48 x 300 mm, which is by ISO 8688-1. The chemical composition of the work piece is shown in Table 1.

Table1. *Chemical composition of AISI D3 cold work tool steel*

C	Si	Mn	Cr	Ni	V	W	Cu	Fe
1.938	0.37	0.22	10.66	0.22	0.135	0.062	0.07	85.82

1.2 Cutting Tools and Tool Geometry

In milling experiments, the coated carbide inserts manufactured by Mitsubishi Carbide were used. Based on ISO description, it possesses SEMT 13T3AGSN tool geometry and JM chip breaker form. In the experiments, a milling cutter (ASX445-080A06R) 80 mm in diameter was used. In Fig. 1, the position of the cutting tool with respect to the workpiece is given. The cutting tool and the workpiece are in a symmetric location and move in opposite directions with respect to each other.

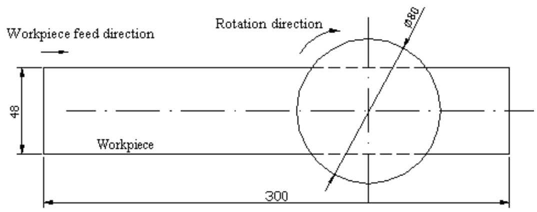

Fig. 1. *Workpiece and tool position during machining*

1.3 Cutting Parameters

Table 2. *Cutting parameters*

Paremeters	Values
Cutting speed, m/min (V)	416, 500, 600
Feedrate, mm/tooth (f)	0.08, 0.1, 0.125
Number of insert (ts)	1, 3, 6

The cutting parameters implemented in milling of AISI D3 cold work tool steel are shown in Table 2. In all experiments, the depth of cut is determined as 1 mm. The experiments were carried out under dry cutting conditions.

1.4 Machining Tests

The machining experiments were conducted on a vertical CNC machining centre. A total number of 27 experiments were carried out at various cutting parameters. Tool deformations were measured and investigated using a Mitutoyo optic microscope with 0.001 mm sensitivity and a capability of magnifying 5 to 10 folds. The experiments revealed that notch wear was observed when machining at high cutting speeds. Determination of machining time was based on ISO 2688-1. In determining the machining time, VB_{max} was taken as 1 mm. The flank wear at the inserts was measured and recorded at specific intervals.

2 EXPERIMENTAL RESULTS

2.1 The Correlation between Machining Time and Flank Wear

The cutting tool flank wear variation depending on the machining time during the milling of AISI D3 cold work tool steel is given in the Figs. 2 to 6. The process time/flank wear curves were drawn for various numbers of inserts and cutting conditions. When flank wear curves drawn in Fig. 2 are examined, a slow wear rate until VB_{max} = 0.2 mm is seen. However, wear rate above this point is significantly higher.

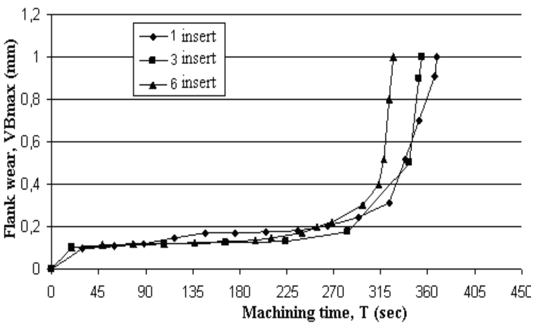

Fig. 2. *Relationship between flank wear and machining time (V = 416 m/min, f = 0.125 mm/tooth)*

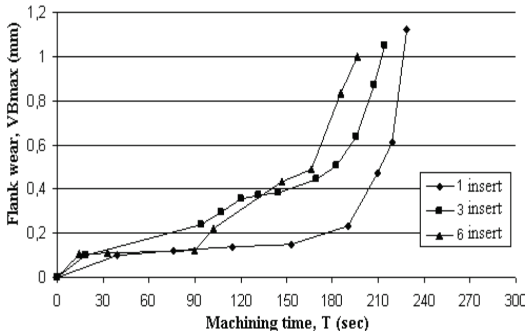

Fig. 3. *Relationship between flank wear and machining time (V = 500 m/min, f = 0.08 mm/tooth)*

This condition following from 0.2 mm wear value keeps its resistance due to high cutting speed rates based on the provided notch wear, which is exhibited by quick wear. At the same time, increasing the number of insert prolongs machining time. The same can be seen in Figs. 3 and 4. This can be attributed to high heat emerging due to increasing the number of insert.

The 0.125 mm/tooth feed rate and cutting speeds of 416, 500 and 600 m/min were used for the experiments carried out in order to find out the effect of cutting speed on tool wear. As seen in Fig. 4, at each cutting speed, slow progressing wear was experienced up to 0.2 mm flank. At this point, the cutting tools wore more rapidly. This situation may be attributed to the emergence of high heat caused by the presence of those high cutting speeds. When cutting speed is increasing, the machining time decreases [3] and [4].

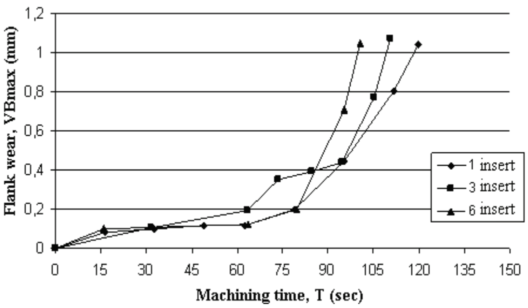

Fig. 4. *Relationship between flank wear and machining time (V = 600 m/min, f = 0.08 mm/tooth)*

In order to find out the effect of feed rate, the tests were carried out at 600 m/min cutting speed and with a single insert. The flank wear curves depending on the machining time at different cutting speeds are given in Fig. 5. It is seen that the inserts wore rapidly at 416 m/min cutting speed after 325 second. When the cutting speed was 500 m/min, the rapid wear began after 180 second. Then, the cutting speed increased up to 600 m/min, and at that cutting speed, the rapid insert wear began after 60 second.

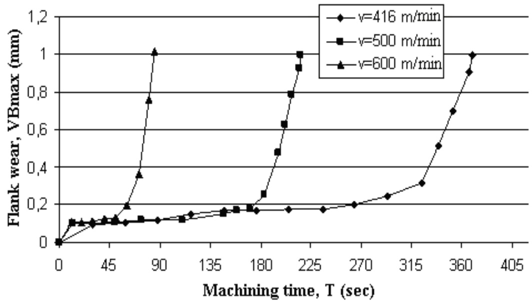

Fig. 5. *Relationship between flank wear and machining time (f = 0.125 mm/tooth, a = 1.0 mm, ts = 1)*

In Fig. 6, flank wear curves against machining time at various cutting speeds are shown. In each curve, slow flank wear up to 0.15 mm can be seen. However, from that value on, the emerging notch wear accelerated the flank wear. The increasing feed rate shortens the machining time [3] and [4]. When both Figs. 5 and 6 are examined, it is seen that the feed rate has a lower effect on machining time than the cutting speed [9]. In Figs. 7 (a) and (b), the notch wear on flank surface of the cutting tool is shown.

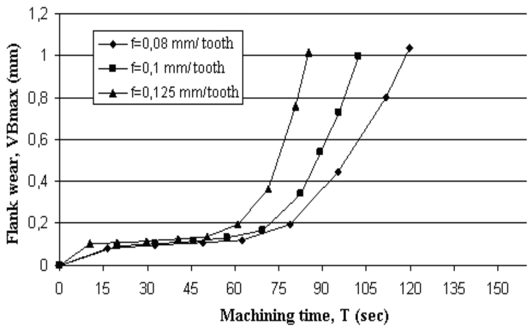

Fig. 6. *Relationship between flank wear and machining time (V=600 m/min, ts = 1)*

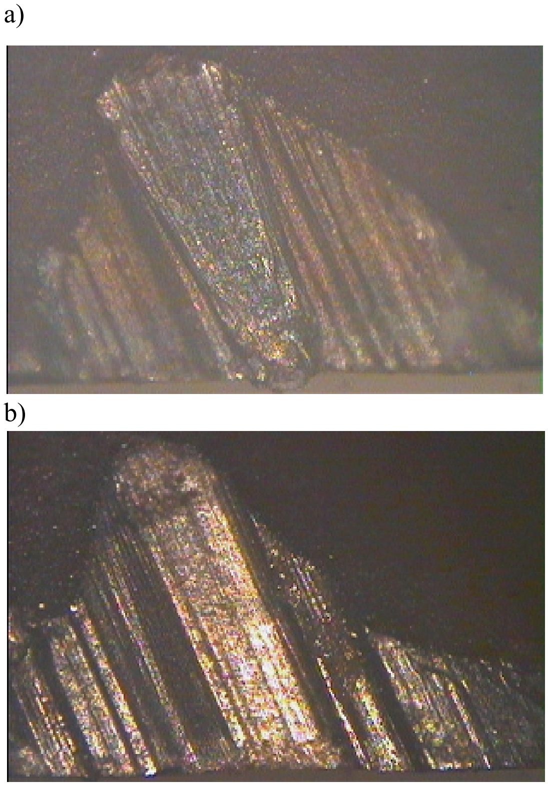

Fig. 7. *Notch wear on the flank surface (a) V = 500 m/min, f = 0.1 mm/tooth, ts = 1, (b) V = 416 m/min, f = 0.1 mm/tooth, ts = 3*

2.2 Relation between Metal Removal Rate and Flank Wear

The variation of flank wear depending on material removal rate during the milling of AISI D3 cold work tool steel is shown in Fig. 8. When the given figures are examined, pertaining to all cutting condition, the material removal rate increased due to increasing the number of insert [1].

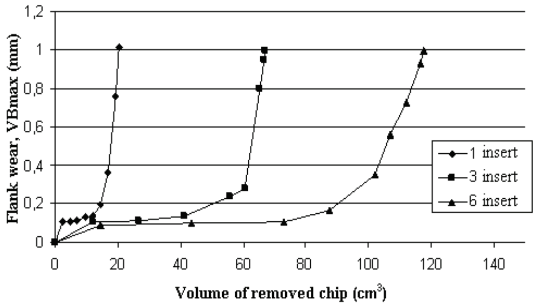

Fig. 8. *Flank wear variations depending on metal removal rate at V = 600 m/min and f = 0.125 mm/tooth.*

In Fig. 8, the tool life and the material removal rate based on VB_{max} = 1 mm wear value for all the experiments are drawn. When Fig. 8 is examined, it is possible to observe that the increase in the insert number leads to a decrease in tool life. As shown in Table 3, the longest machining time (435 seconds) was obtained when machining at 416 m/min cutting speed and 0.08 mm/tooth feed rate with a single insert. However, the shortest machining time (82 seconds) was obtained when machining at 600 m/min cutting speed and 0.125 mm/tooth feed rate with six inserts. According to these values, the longest machining time was obtained when the cutting speed and the feed rate and the number of inserts were at their lowest values.

On the other hand, the lowest tool life was obtained when the cutting speed and the feed rate and the number of inserts were at their highest values. Regarding the material removal rate, the highest value was obtained at cutting speed of 416 m/min and the feed rate of 0.125 mm/tooth using six inserts, and the lowest value was obtained at 600 m/min cutting speed and 0.08 mm/tooth feed rate using a single insert. While the size of the metal removed was rising up at the highest feed rate level and the insert number, at the highest cutting speed rate decreased. It was because of the fact that the impact of the cutting speed on the machining time was much more influential when compared to the feed rate and insert numbers.

Due to the high cutting speeds, machining times were very short in all experiments. However, when evaluated based on the material removal rate, the results were quite satisfactory.

That refers to the fact that in order to provide 416 m/min cutting speed, 0.08 mm/tooth feed rate, and in order to reach to 46 cm³ splitter volumes at the end of single insert use, the same cutting parameters and 30 minutes process time is required at 100 m/min cutting speed. That time variation must never be underestimated by the firms, as the machining time is a crucial factor.

3 CONCLUSIONS

Milling experiments on AISI D3 cold work steel at high cutting speeds were carried out in order to find out insert numbers, material removal rate and the machining time. The obtained results are given as follows:

1. Increasing the number of cutting insert reduces the machining time. This fact is attributed to the high cutting heat at the high cutting speeds.
2. The flank wear increases slowly up to 0.2 mm. However, the wear rate increases rapidly above this point and VB_{max} = 1 mm is reached within a short time.
3. Under same cutting conditions, the machining time decreases with increasing the cutting speed.
4. The machining time decreases with increasing the feed rates. However, its effect is lower than that of the cutting speed.
5. The material removal rate increases with increasing the cutting speed and the number of inserts, and it decreases with increasing the feed rate.

Finally, regarding the process time 416 m/min cutting speed, the 0.08 mm/tooth feed rate and 1 insert must be chosen, and regarding the volume of the removed metal 416 m/min cutting rate, the 0.125 m/min rate and 6 pieces

Table 3. *Machining time and metal removal rate*

Cutting conditions			Machinig time (sn), (for metal removal rate (cm^3)), VB=1 mm					
	V_c (m/min)	f_z (mm/tooth)	1 insert		2 insert		3 insert	
1	416	(0.080)	435.68	(46.0)	426.24	(135.4)	402.74	(255.8)
2	416	(0.100)	344.50	(45.7)	365.31	(145.2)	338.00	(268.5)
3	416	(0.125)	369.13	(61.1)	354.38	(176.1)	327.58	(325.7)
4	500	(0.080)	226.46	(28.8)	212.14	(81.1)	196.22	(150.1)
5	500	(0.100)	200.70	(31.9)	198.04	(94.6)	195.34	(186.6)
6	500	(0.125)	216.03	(43.0)	210.18	(125.4)	168.88	(201.7)
7	600	(0.080)	118.48	(18.1)	109.45	(50.2)	99.94	(91.6)
8	600	(0.100)	102.30	(19.6)	97.15	(55.7)	102.86	(117.5)
9	600	(0.125)	85.00	(20.3)	93.34	(66.9)	82.13	(117.7)

inserts must be chosen. The effect of the number of insert on the surface quality should be analyzed in prospective research.

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