Experimental Investigations to Study the Effect of Carbide Insert Shapes on Machining of AISI 4140

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Abstract—*Machining is characterized by many process parameters. One of the important process parameter is the shape of the cutting tool. In this study, the performance of three different shapes of carbide inserts (triangular, round and square shapes) were investigated when turning AISI 4140. Cutting speed, feed and depth of cut have been selected as the machining parameters for this study. Full factorial design was used for experimentation. It has been observed that cutting tool shape has a great role in controlling the surface quality along with the other machining parameters.*

Keywords: *Surface roughness, speed, feed, depth of cut, tool shape*

Introduction

Machining is a process in which material is removed from the work piece in the form of chips with the cutting tool. The output of the machining is measured in terms of surface quality, cutting forces and metallurgical properties. However; the surface quality is an important parameter to evaluate the productivity of machine tools as well as machined components. Hence, achieving the desired surface quality is of great importance for the functional behavior of the mechanical products. The surface roughness of machined parts is known to have considerable effect on mechanical properties such as wear resistance and fatigue strength. So, it is necessary to improve the surface quality of the product.

There are large numbers of machining parameters controlling the quality of the product. Much attention has been given to the other parameters such as cutting conditions, tool coatings, coolant etc. However the tool shape has also effect on the surface roughness of the workpiece. Therefore in the present study, an attempt has been made to investigate the effect of three different shaped carbide inserts (triangular, round and square inserts) during turning of AISI 4140 at different machining conditions.

Literature Review

Characterization of surface topography is important in applications involving friction, lubrication, and wear. In general, it has been found that friction increases with average roughness. Roughness parameters are therefore, important in applications of machining. Some researchers have studied the effect of different tool shapes on the surface roughness and cutting forces.

G. Petros and Petropoulos studied the influence of feed rate and tool nose radius on surface roughness in oblique finish turning of carbon steel for both sharp and worn cutting tools. A comparison between the experimentally determined values of surface roughness and the theoretical values were computed and further they established the law to predict surface roughness [1]. I.S. Jawahir, *et al.*, presented result of an experimental study on finish turning of steels with cermet chip forming tool inserts. They investigated the chip breakability, surface roughness, and specific cutting pressure. The interrelationships among these parameters were established with a view to develop methodologies for optimum solutions in finish turning operations [2].

W.H. Yang and Y.S. Tarang used orthogonal array, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) to investigate the cutting characteristics of S 45C steel bars using carbide cutting tools and found the optimal cutting parameters [3]. Jeffrey D. Thiele and Shreyes N. Melkote investigated the effects of tool cutting edge geometry and workpiece hardness on the surface roughness and cutting forces in the finish hard turning of AISI 52100 steel. Cubic boron nitride inserts with various representative cutting edge preparations and through-hardened AISI 52100 steel bars were used as the cutting tools and workpiece material, respectively. This study showed that the effect of edge geometry on the surface roughness and cutting forces is statistically significant. Specifically, large edge hones result in higher average surface roughness values than small edge hones, due to increase in the extent of ploughing compared to shearing [4].

S.M. Darwish presented the work in which the effect of the tool material and the cutting parameters on surface roughness of 718 nickel-base superalloy under dry cutting conditions and a constant nose radius was studied. The tool materials used were ceramic and CBN inserts. These variables were investigated using a 2^k factorial design. The presented work demonstrated a favorable effect for ceramic inserts on surface roughness, when compared with CBN inserts. The work also showed that the feed-rate has the dominant effect on surface roughness amongst the parameters studied, irrespective of the tool material used [5]. M.Y. Noordin et.al. studied the performance of a multilayer tungsten carbide tool using response surface methodology (RSM) when turning AISI 1045 steel. The experimental results indicate that the proposed mathematical models suggested could adequately describe the performance indicators within the limits of the factors that are being investigated. The feed was the most significant factor that influences the surface roughness and the tangential force [6].

Y. Sahin and AR Motorcu developed a surface roughness model for turning of mild steel with coated carbide tools. The model was developed in terms of cutting speed, feed rate and depth of cut, using response surface methodology. Machining tests were carried out with TiN-coated carbide cutting tools under various cutting conditions. The established equation shows that the feed rate was main influencing factor on the surface roughness [7]. J.G. lima *et al*. studied the machinability of hardened AISI 4340 high strength low alloy steel and AISI D2 cold work tool steel. The test involving the AISI 4340 steel was performed using two hardness values. The results indicated that when turning AISI 4340 steel using low feed rates and depths of cut, the forces were higher when machining the softer steel and that surface roughness of the machined part was improved as cutting speed was elevated and deteriorated with feed rate [8].

Y. Sahin and A.R. Motorcu developed a surface roughness model in terms of main cutting parameters such as cutting speed, feed rate and depth of cut using response surface methodology. Machining tests were carried out in turning AISI 1050 hardened steel by cubic boron nitride (CBN) cutting tools under different conditions. The results indicated that the feed rate was dominant factor on the surface roughness [9]. D.l. Lalwani et.al. presented the effect of cutting parameters on cutting forces and surface roughness in finish hard turning of MDN 250 steel using coated ceramic tool. They found that the feed rate was found dominant factor on the surface roughness [10].

Sulleyman Neseli *et al.* investigated the influence of tool geometry on the surface finish obtained in turning of AISI 1040 steel. The results indicated that the tool nose radius was the dominant factor on the surface roughness [11]. R. Suresh et.al. made an attempt to analyze the influence of cutting speed, feed rate, depth of cut and machining time on machinability characteristics such as machining force, surface roughness and tool wear using response surface methodology (RSM) based upon second order mathematical models during turning of AISI 4340 high strength low alloy steel using coated carbide inserts. From the parametric analysis, it was revealed that, the combination of low feed rate, low depth of cut and low machining time with high cutting speed is beneficial for minimizing the machining force and surface roughness [12].

Hamdi Aquici *et al.* experimentally studied the heat treated AISI H11 steel when machined with cubic boron nitride which is essentially made of TiCN. Results showed that the cutting force components were influenced principally by the depth of cut and workpiece hardness, on the other hand both feed rate and workpiece hardness have statistical significance on surface roughness [13].

It is clear from above mentioned literature that much work have been conducted on the surface roughness and cutting forces during turning, but few studies have been conducted to see the effect of shape of the tool geometry during machining. Therefore, in this research work, the effect of tool shape on the surface roughness will be investigated during machining of AISI 4140 steel.

Experimentation

Experiments have been conducted to determine the effect of different tool shapes on the surface roughness produced during machining of AISI 4140 steel. Three types of tool shapes were taken for experimentation keeping different cutting conditions and comparison is made between three tool inserts (round, triangular and square). Turning tests were performed on LB-17 model HMT lathe machine. The workpiece material AISI 4140 was heat treated to 25-30 HRC. The diameter and length of workpiece are 80 mm and 600 mm respectively. This material has wide applications in manufacturing of axles, conveyor parts, sprockets etc. The chemical composition of the AISI 4140 is shown in Table 1.

Table 1: Chemical Composition of AISI 4140 (%)

C	Si	Mn	P	S	Cr	Mo	Ni
0.425	0.269	0.644	0.14	0.18	1.31	0.251	0.050

The cutting tools used in the present study were round insert (RNMA160408S01225), triangular insert (TNMA160408S1525) and square insert (TNMA1608S01525). The tool holders (Widax, 9B, PBGCR) were used in the study. In this study, the cutting speed was varied from 35 to 88 m/min; feed was kept as 0.1 to 0.15 mm/rev and depth of cut was 0.5 to 2.5 mm. Five levels of each machining conditions were taken and full factorial design methodology was used for experimentation. The surface roughness of workpiece was measured with Surface Roughness Tester (Mutitoyo) at three different locations and an average value of surface roughness was taken. The experimental set up is shown in Fig. 1.

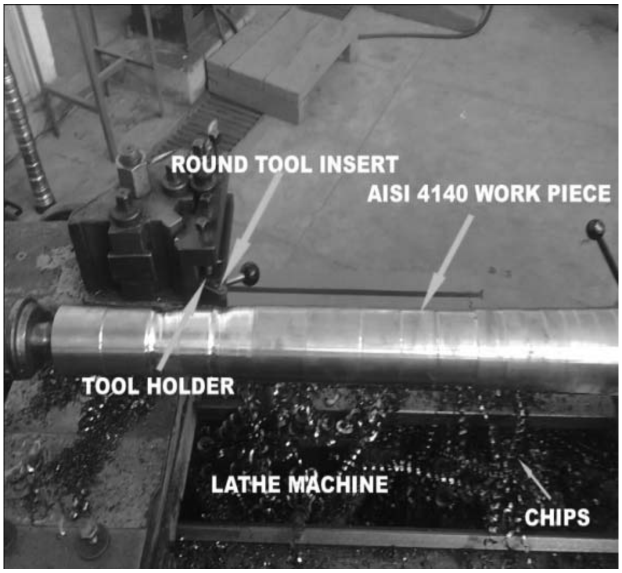

Fig. 1: Experimental Setup

Results and Discussion

The purpose of this study was to investigate the effect of different tool shapes on the surface roughness during machining of AISI 4140 material along with other machining conditions.

Table 2, Table 3 and Table 4 show the surface roughness obtained after machining with triangular, square and round insert respectively. In the Table 4, only 13 experimental runs have been performed because the round insert was not performing well at high depth of cuts of 2.0 mm and 2.5 mm due to vibration and chattering problems keeping other machining parameters same. The variation of surface roughness with feed, speed and depth of cut is shown in Fig. 2, Fig. 3 and Fig. 4 respectively. From the Fig. 2, it is clear that by using the round insert, the surface roughness decreases from 2.25 µm to 1.89 µm with increase of feed by keeping the speed (55m/min) and depth of cut (1.5 mm) constant. The surface roughness increases from 1.22 µm to 1.57 µm by using square insert. The surface roughness increases from 0.98 µm to 1.92 µm in case of triangular insert. It is also clear that triangular insert perform much better as compared with the square and round inserts at low feeds. However, at higher feeds, square insert performs well. This may be due to the higher stability of the square insert at higher feeds.

Table 2: Machining of AISI 4140 with Triangular Insert

Run No.	Cutting Speed (v) m/min	Depth of Cut (d) mm	Feed (f) (mm/rev)	R_a (µm)
1.	55	1.5	0.1	0.98
2.	55	1.5	0.113	1.03
3.	55	1.5	0.125	1.16
4.	55	1.5	0.138	1.47
5.	55	1.5	0.15	1.92
6.	55	0.5	0.125	1.56
7.	55	1.0	0.125	1.48
8.	55	1.5	0.125	1.11
9.	55	2.0	0.125	1.07
10.	55	2.5	0.125	1.15
11.	35	1.5	0.125	1.89
12.	44	1.5	0.125	1.95
13.	55	1.5	0.125	2.01
14.	70	1.5	0.125	2.04
15.	88	1.5	0.125	2.14

Table 3: Machining of AISI 4140 with Square Insert

Run No.	Cutting Speed (v) m/min	Depth of cut (d) mm	Feed (f) (mm/rev)	R_a (µm)
1.	55	1.5	0.1	1.22
2.	55	1.5	0.113	1.38
3.	55	1.5	0.125	1.35
4.	55	1.5	0.138	1.44
5.	55	1.5	0.15	1.57
6.	55	0.5	0.125	2.45
7.	55	1.0	0.125	1.64
8.	55	1.5	0.125	1.16
9.	55	2.0	0.125	1.09
10.	55	2.5	0.125	1.22
11.	35	1.5	0.125	5.15
12.	44	1.5	0.125	4.01
13.	55	1.5	0.125	3.68
14.	70	1.5	0.125	1.49
15.	88	1.5	0.125	1.16

Table 4: Machining of AISI 4140 with Round Insert

Run No.	Cutting Speed (v) m/min	Depth of Cut (d) mm	Feed (f) (mm/rev)	R_a (µm)
1.	55	1.5	0.1	2.25
2.	55	1.5	0.113	1.93
3.	55	1.5	0.125	1.81
4.	55	1.5	0.138	1.75
5.	55	1.5	0.15	1.89
6.	55	0.5	0.125	3.28
7.	55	1.0	0.125	1.89
8.	55	1.5	0.125	1.38
9.	35	1.5	0.125	3.76
10.	44	1.5	0.125	3.5
11.	55	1.5	0.125	3.45
12.	70	1.5	0.125	1.78
13.	88	1.5	0.125	1.03

The results plotted in Fig. 3 show that by using the round insert, the surface roughness decreases from 3.76 µm to 1.03 µm with increase of speed by keeping the feed (0.125 mm/rev) and depth of cut (1.5 mm) constant whereas surface roughness decreases with triangular insert from 1.89 µm to 2.14 µm. The investigated surface roughness for square insert varies from 5.15 µm to 1.16 µm. It is clear that square insert performs better than the round and triangular insert.

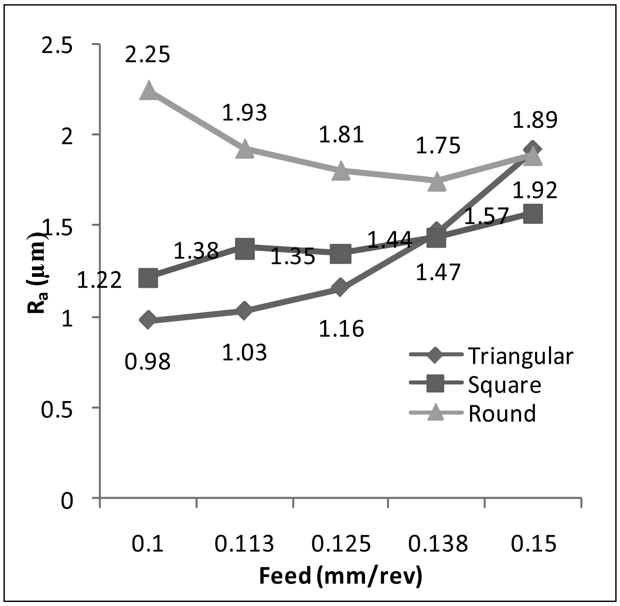

Fig. 2. Variation of Surface Roughness with Feed

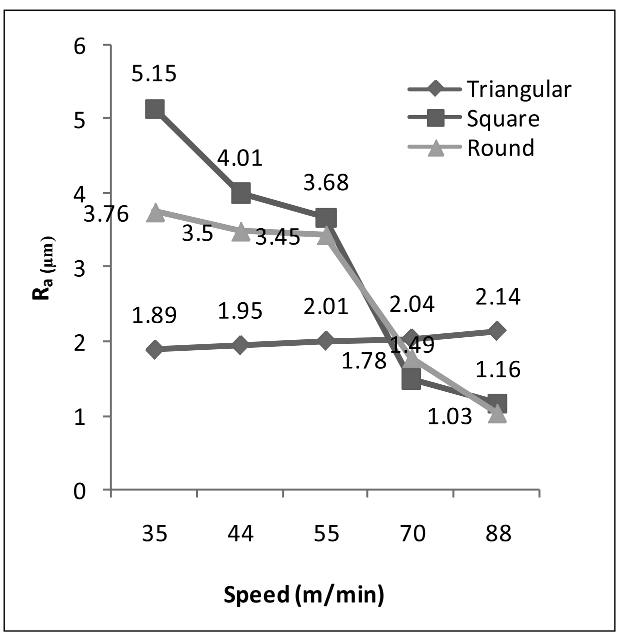

Fig. 3. Variation of Surface Roughness with Speed

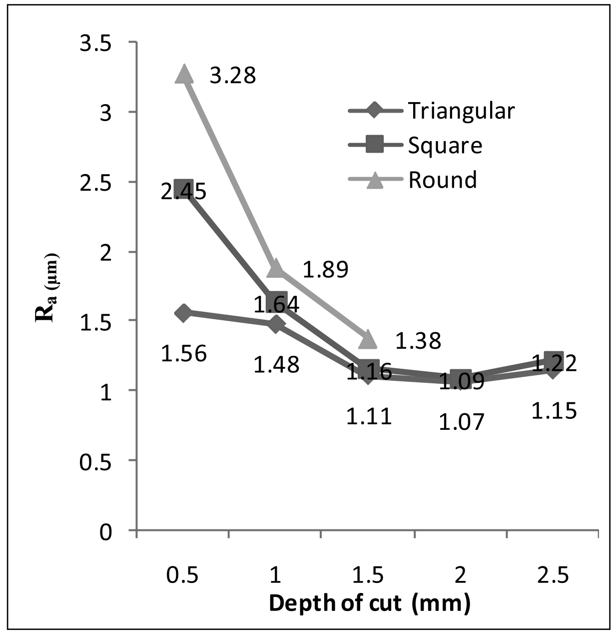

Fig. 4. Variation of Surface Roughness with Depth of Cut

The results plotted in Fig. 4 show that by using the round insert, the surface roughness decreases from 3.28 µm to 1.38 µm with increase of depth of cut by keeping the feed (0.125 mm/rev) and speed (55m/min) constant whereas surface roughness also decrease with triangular and square insert. Hence it is concluded that triangular insert is performing better as compared to other inserts under the similar machining conditions.

Conclusion

In this study, effect of tool shape on the surface quality has been investigated during machining of AISI 4140 steel. Following conclusions are obtained:

1. Surface roughness increases with increase of feed in all the insert shapes. Triangular insert produces lower values of surface roughness as compared to square and round inserts.
2. Surface quality improves with increase of speed in case of square and round inserts as compared triangular insert.
3. Surface quality also improves with the increase of depth of cut. However, round insert does not perform at higher depth of cuts due to chattering. Triangular insert shows superior performance.

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