Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 55
ISSUE 2
December
2012

Evaluating the machinability of AISI 304 stainless steel using alumina inserts

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Received 24.10.2012; published in revised form 01.12.2012

Manufacturing and processing

ABSTRACT

AISI 304 austenitic stainless steel is generally regarded as difficult to machine steels on account of their high strength, high work hardening tendency and poor thermal conductivity. The machinability of AISI 304 was investigated by some researchers using uncoated and coated carbide inserts, but its machinability using advanced cutting inserts like alumina was not explored adequately. Therefore, in this paper the machinability of AISI 304 is being evaluated by machining (CNC turning process) the work material using alumina inserts. The machinability is evaluated in terms of surface finish achieved on the work piece, tool wear encountered and tool life achieved by the inserts for various machining time and the cutting zone temperature generated during the process.

Keywords: Machinability; AISI 304; Alumina

Reference to this paper should be given in the following way:
M.A. Xavior, Evaluating the machinability of AISI 304 stainless steel using alumina inserts, Journal of Achievements in Materials and Manufacturing Engineering 55/2 (2012) 841-847.

1. Introduction

Anthony and Adithan had investigated the performance of carbide inserts on machining of AISI 304 austenitic steel to determine the influencing factors of surface roughness and tool wear. It was reported that cutting speed and feed rate had remarkable influence on surface roughness and tool wear [1]. Zafer and Sezgin determined the best suitable cutting condition and cutting parameters for machining of AISI 304 stainless steels by considering the acoustic emission [2]. The best cutting speed and feed rate were determined based on flank wear, Built Up Edge, chip form, surface roughness of the machined samples and machine tool power consumption. Apart from classical methods, it was also reported that the acoustic emission generated during machining could be used to evaluate the machinability. It was found that, the lowest flank wear was observed at a feed rate of 0.25 mm/rev for all the cutting speeds. So, if the surface roughness quality is important, feed rate should not be higher than 0.25 mm/rev. As cutting speed increased, built up edge decreased; however as feed rate increased, built up edge also increased. Akasawa et al. reported that Austenitic stainless steels are difficult to machine [3]. Qi HS and Mills made many attempts to improve the machinability of Austenitic stainless steels [4]. Kopac and Sali had reported that the machinability of AISI 304 is more difficult than the other alloy steels due to reasons such as having low heat conductivity, high built-up edge tendency and high deformation hardening [5].

Ibrahim conducted turning tests on two grades of Austenitic stainless steels (AISI 304 and AISI 316) [6]. The researcher concentrated on the influences of cutting tool coating, cutting speed and workpiece materials on surface roughness and cutting forces. Findings were presented as below

- Cutting speed was found to have a significant effect on the machined surface roughness values. With increasing cutting speed, surface roughness values decreased until a minimum value was reached, beyond which they increased.
- Higher surface roughness values at lower cutting speeds were attributed to the high BUE formation tendency.

Ihsan et al., carried out turning tests on AISI 304 Austenitic stainless steel to determine the optimum machining parameters [7]. Metal cutting involves the generation of large amount of heat and in the machining of AISI 304 stainless steel it is not dissipated rapidly due to the thermal conductivity of this material. Determination of the optimum cutting speed had been aimed when turning AISI 304 Austenitic stainless steel using cemented carbide-cutting tools. A decrease in tool wear was observed with increasing the cutting speed. The criterion for the tool life was 0.3 mm width flank wear and the optimum cutting speed and feed rate was found to be 180 m/min and 0.24 mm/rev respectively for the flank wear criterion.

Trent reported that austenitic stainless steels are characterized by a high work hardening rate and low thermal conductivity [8]. When machining this material, cutting force variation is also much more obvious than those when machining unalloyed steel. Jiang et al., reported that austenitic stainless steel is generally regarded as more difficult to machine than carbon and low alloy steels on account of their high tensile strength, high work hardening tendency and poor thermal conductivity [9]. Work hardening is recognized to be responsible for the poor machinability of Austenitic stainless steels, in addition, they bond very strongly to the cutting tool during cutting and when chip is broken away, it may take with it a few fragments of the tool, particularly when cutting with cemented carbide tools.

Alumina tools are widely used in the manufacturing industry for the machining of various hard materials. Interest in ceramics as a high speed cutting tool material is based primarily on favorable material properties. As a class of materials, ceramics possess high melting point, excellent hardness and good wear resistance. Unlike most metals, hardness levels in ceramics generally remain high at elevated temperature, which means that cutting tip integrity is relatively unaffected at high cutting speeds [10]. The presence of TiC in alumina inserts increased the resistance to thermal and mechanical shocks, and improved the resistance to crack initiation and propagation [11]. These characteristics enable alumina tools to satisfactorily machine such steels, especially when finish and continuous cutting.

2. Experimentation

Literature reveals that feed rate have more influence on surface roughness followed by nose radius of the tool when compared to other machining parameters. Likewise, cutting speed influences tool life and cutting zone temperature than any other cutting parameters. In order to understand the trend of variations of these parameters experiments are conducted by choosing a range of values of cutting parameters and the output parameters are recorded. The experimental conditions are mentioned in Table 1. The cutting tools (alumina inserts) used for experimentation are TNGA 160404, TNGA 160408 and TNGA 160412 and the tool holder is TTJNR2525. The machine tool used for experimentation is a Jobber XL CNC machine from ACE designer with Fanuc control system; variable speed motor 50-4000 rpm and 7.5 kW rating. Fig. 1 shows the machine tool with an integrated computer screen display where programming can be done and the operating parameters for each trial can be easily fed. It also shows the workpiece loaded in the chuck and clamped between centers. The sensor cable for measuring the tool-shim interface temperature from the tool holder to the display unit is also shown. Further, the machining time display and the temperature display units are shown in the Fig. 1. During the machining process i.e. for each experimental trial appropriate cutting fluid is applied through nozzles fixed in the tool holder (turret). After each trial the flank wear on the tool was measured using CARL ZIESS Optical Microscope having 50 X to 1500 X magnification, equipped with Clemex Vision Professional Edition Image Analysis Software. The surface roughness on the workpiece was measured using Mitutoyo Surface Roughness tester. The cutting zone temperature developed during the machining process was measured by a thermocouple, Iron - Constantan (J-Type) Tool Tip type with a temperature range of 30-400ºC, with sensitivity of ± 0.1ºC. The Iron - Constantan (J-Type) thermocouple used was a base metal system using a positive arm of Iron wire and a negative arm of Constantan wire. A thin thermocouple of diameter 0.5 mm was mounted in a shallow groove on the silver steel shim, so that, it could detect the average temperature developed at the interface of the insert and the shim. Fig. 2 indicates the actual temperature measurement system which shows the tool holder, the cutting insert, the shim and the thermocouple cable placed between the insert and the shim. Before each test, the system was calibrated in the laboratory. The reliability of the technique had been checked in the preliminary tests by repeating the same cutting condition (including the types of cutting fluids) and thermocouple conditions several times using the workpiece material, the results were consistent and satisfactory. Once the consistent and satisfactory results were observed, the actual data collection was performed and recorded.

Table 1.
Experimental conditions

1	Work Material	AISI 304 Austenitic Steel (diameter 50 mm)
2	Tool Material	Alumina inserts (70% Al_2O_3 & 30% TiC)
3	Cutting speed	80, 100, 120, 140, 160 & 180 m/min
4	Feed rate	0.06, 0.1, 0.14, 0.18, 0.22 mm/rev
5	Depth of cut	0.2, 0.3 & 0.4 mm
6	Nose radius	0.4, 0.8 & 1.2 mm
7	Cutting Fluid	Soluble oil, St. cutting oil & Coconut oil

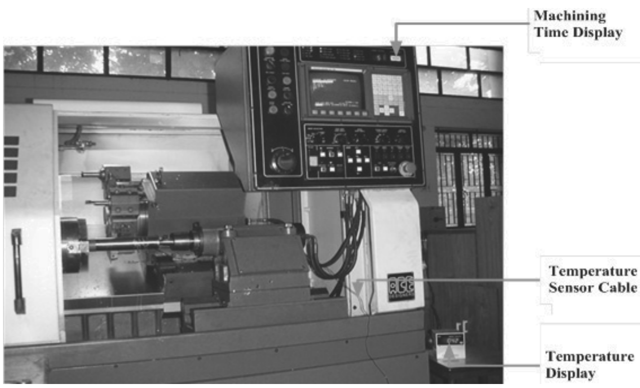

Fig. 1. CNC Machine tool used for experimentation

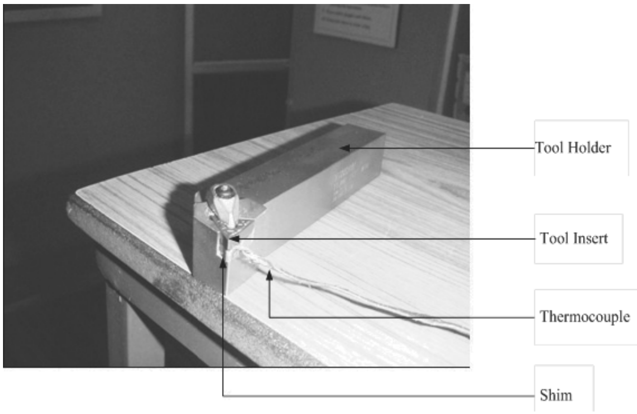

Fig. 2. Cutting zone temperature measuring system

3. Results and discussion

Fig. 3 illustrate the evolution of flank wear of alumina inserts as a function of cutting time for the cutting speeds considered while machining. The Fig. 3 shows the wear pattern during the machining of AISI 304 using alumina inserts. A tool life of 25.2 min., 30.8 min. and 36.2 min is observed for the cutting speeds 180, 140 and 100 m/min respectively. A maximum tool life of 36.2 min was observed while machining AISI 304 with alumina inserts.

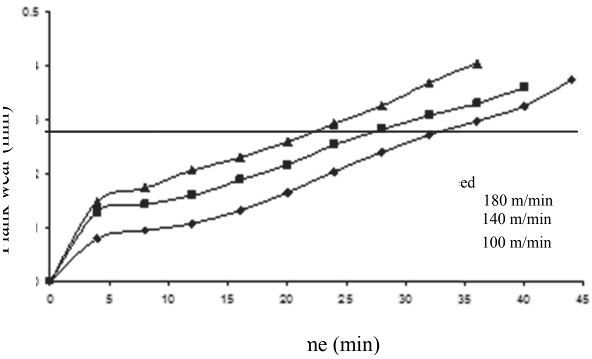

Fig. 3. Flank Wear Vs Machining time for different cutting speeds (Tool: Alumina, Work: AISI 304)

Fig. 4 (a-g) shows the morphology of flank wear in an alumina insert as a function of cutting time. Fig. 4 (a) shows the fresh cutting edge of an alumina insert. Fig. 4 (b) shows a small amount of wear after six minutes of machining. The width of the flank wear is gradually widens over a period of time. Fig. 4 (c) shows a wear of about 40 microns and it is uniform throughout the cutting edge. Further widening of flank wear is observed in Fig. 4 (d and e). As the wear increases chattering marks were observed on the work piece during machining after 20 minutes. More heat was developed at the machining zone and the chip was almost red hot condition as it get sheared from the work piece, which confirms that two third of the heat is carried away by the chip. Steady wearing of cutting edge is observed in Fig. 4 (f). In Fig. 4 (g) it is evident that the width of wear in enlarged such that wear band in destroyed indicating the rapid wear rate after 30 minutes.

Further experiments were conducted to understand the trend of variation in surface roughness and cutting zone temperature for the variation of certain cutting parameters. Accordingly, Fig. 5 shows the plot between feed rate and surface roughness for different cutting speeds. Different feed rates (0.06, 0.1, 0.14, 0.18 and 0.22 mm/rev.) were used for the machining process. Three different cutting speeds (100, 140 and 180 m/min) were maintained for each combination of feed rates and the trails were conducted. All other parameters such as depth of cut, rake angle, clearance angle and nose radius were kept constant. Soluble oil was the cutting fluid used for the experimentation. It was observed that the surface roughness on the specimen gradually increase as the feed rate is increased for any cutting speed considered. As the cutting speed is increased from 100 to 180 m/min, less difference in surface roughness is observed for a lower feed rate of 0.06 and 0.14 mm/rev. and as the feed rate increased difference in surface roughness also increases. Higher surface roughness value in AISI 304 can be explained by the highly ductile nature of austenitic stainless steels which increases the tendency to form a large and unstable built up edge (BUE). The presence of the large and unstable BUE causes poor surface finish. BUE and wear / chipping are closely associated with each other in the case of machining ductile materials. Both of them lead to increased surface roughness values.

Fig. 6 shows the plot between feed rate and surface roughness for different nose radius. Different feed rates (0.06, 0.1, 0.14, 0.18 and 0.22 mm/rev.) three different nose radius (0.4, 0.8 and 1.2 min) were maintained for each combination of feed rates and the trails were conducted. From the graph it is evident that surface roughness increases as the feed rate increases and the surface roughness decreases as the nose radius is increased. Minimum surface roughness is obtained at lower feed rate because at lower feed rates, the distance from peak to valleys on the machined surface is smaller resulting in better surface finish. The finding is agreeable with Liu and Mittal who had reported that a surface comparable with a ground surface was realized using a tool with a large nose radius during turning process [12].

Fig. 7 shows the plot between cutting speed and the cutting zone temperature for different cutting fluids. Different cutting speeds (80, 100, 120, 140 and 160 m/min) were used for performing the machining trail with three different cutting fluids (soluble oil, coconut oil and straight cutting oil). The viscosity of the cutting fluids was considered as the discriminating parameter in this research work. From the Fig. 7, it is evident that the temperature gradually increases with increase in cutting speed irrespective of the cutting fluid used. The temperature observed while machining in the presence of soluble oil is considerably less when compared to the temperature observed while machining in the presence of the other two cutting fluids for the entire range of cutting speeds considered. This is due to the presence of water content in soluble oil which would increase the rate of cooling. Further the cooling ability of coconut oil is in between the soluble oil and straight cutting oil because the viscosity of it lies between the viscosities of two cutting fluids.

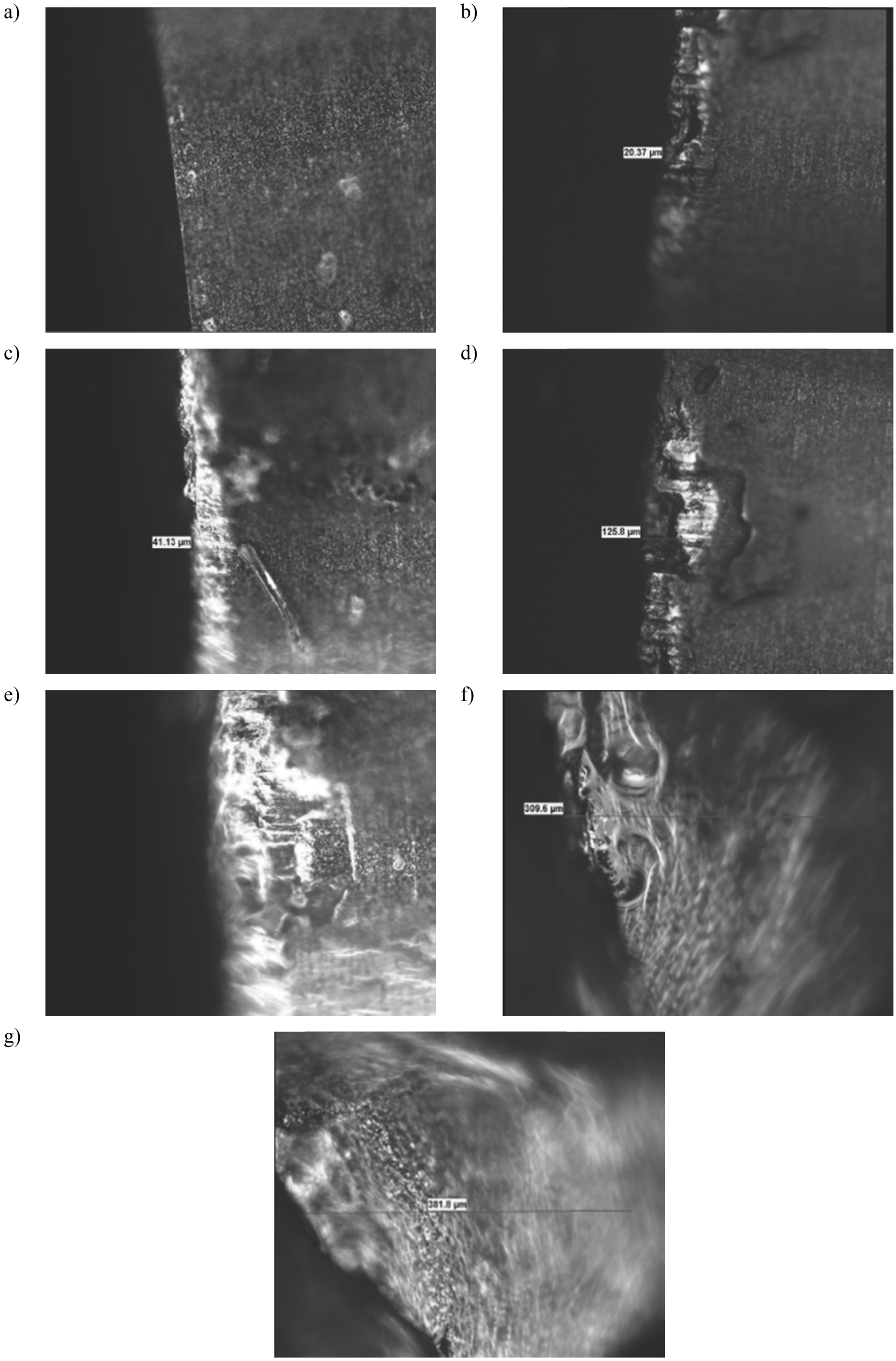

Fig. 4. Flank Wear propagation in alumina inserts at interval of 6 minutes

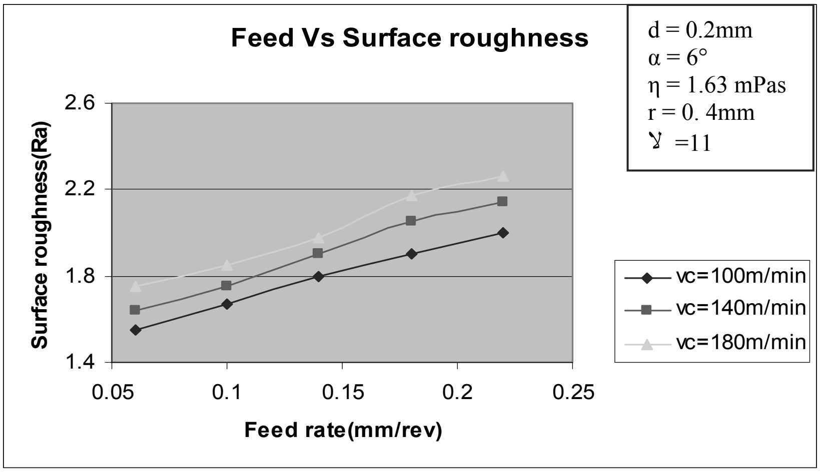

Fig. 5. Feed rate Vs Surface roughness for different Cutting speed

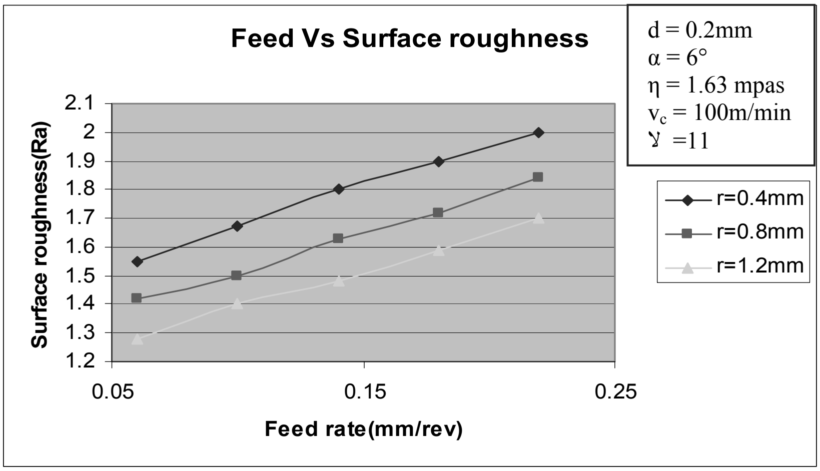

Fig. 6. Feed rate Vs Surface roughness for different Nose radius

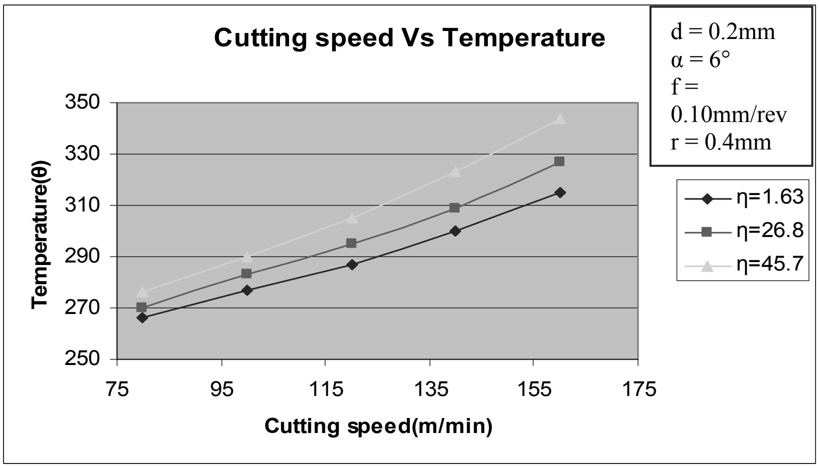

Fig. 7. Cutting Speed Vs Temperature for different Cutting fluid

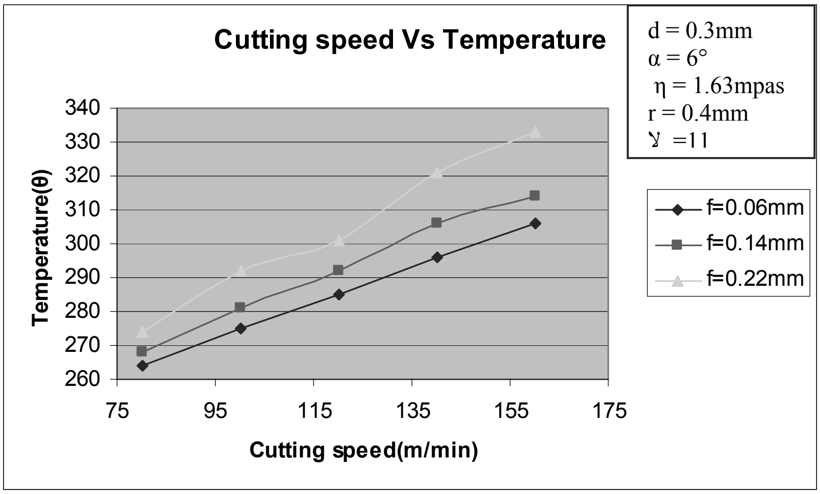

Fig. 8. Cutting Speed Vs Temperature for different Feed rates

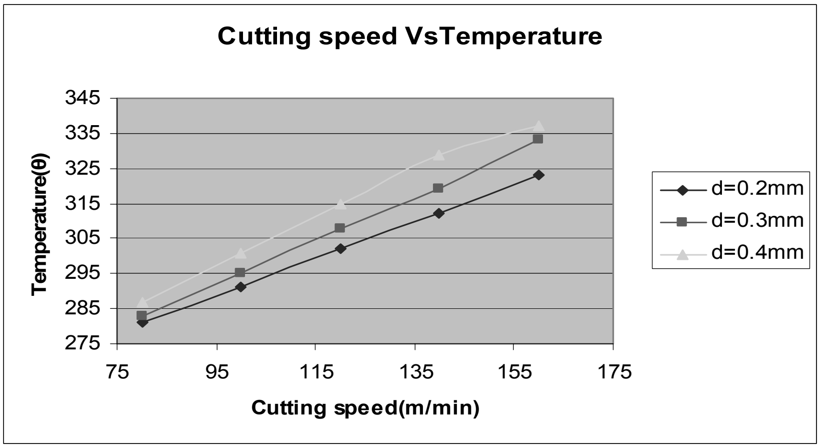

Fig. 9. Cutting Speed Vs Temperature for different Depth of cut

Fig. 8 shows the plot between cutting speed and the cutting zone temperature for different feed rates. Different cutting speeds (80, 100, 120, 140 and 160 m/min) three different feed rates (0.06, 0.14 and 0.22 mm/rev.) were maintained for each combination of cutting speeds and the trails were conducted. From the Fig. 8, it is evident that for the combination of low feed rate and lesser cutting speed, the cutting zone temperature is very low. The difference in temperature value for the three feed rates is very meager, but as the cutting speed increases for the same feed rates the difference in temperature value observed is considerably increasing. This shows that cutting speed has more influence on the temperature developed during the machining process.

Fig. 9 shows the plot between cutting speed and the cutting zone temperature for different depths of cut. Different cutting speeds (80, 100, 120, 140 and 160 m/min) three different depths of cut (0.2, 0.3 and 0.4 mm) were maintained for each combination of cutting speeds and the trails were conducted. From the Fig. 9 it is evident that the temperature gradually increases with increase in cutting speed. For any cutting speed, lower temperature value is observed for a lesser depth of cut and as the depth of cut is increased the temperature also increases accordingly. This indicates that as the depth of cut is increased, area of contact surface increases and more friction is induced between the tool and workpiece which results in increase in temperature.

4. Conclusions

The machinability of AISI 304 was evaluated by machining the work material using alumina inserts. The machinability was evaluated in terms of surface finish achieved on the work piece, tool wear encountered and tool life achieved by the inserts for various machining time and the cutting zone temperature generated during the process. The tool life achieved by alumina insert while machining AISI 304 was determined and it was found that a maximum of 36.2 min is possible at a cutting speed of 100 m/min (for a flank wear of 0.3 mm threshold value). Further experimentation was carried out to understand the variation of surface roughness and cutting zone temperature for the variation of certain cutting parameters while keeping the other parameters constant.

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