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The economic Impact of Using Negative Rake Angle in High Speed Hard Turning

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Abstract

In high speed hard turning the cutting tool edge is under high pressure and the cutting forces are concentrating on the edge of the tool causing a breakage in the early stage of the tool life. Thus, by using a negative rake angle, the cutting forces will shift from the edge of the cutting tool to the flank face. The present work studies the economic factors of high speed hard turning (HSHT) by using negative rake angle. The influence of negative rake angle on tool life and power consumption has been discussed. AISI 4340 was used as work piece material; this steel is hardened to 60 HRC, machined by a mixed ceramic tool (Al_2O_3-TiC). Totally 100 experiments were performed in order to measure the flank wear length, current, voltage, and power factor. The experiments were obtained with constant cutting depth (0.15 mm), constant feed rate (0.075 mm), constant cutting speed (250 m/min) and five different tool rake angles (0^o ,-3, -6, -9 and -12^0).

Keywords: high speed hard turning, negative rake angle, tool life, power consumption.

1. Introduction

Hardened steels are machined by grinding process, but grinding is actually are time consuming. The developments of new cutting tools such as ceramics and CBN have led to the use of higher cutting speeds compare with conventional machining. In recent years, High Speed Hard Turning (HSHT) has emerged as a very advantageous machining process for cutting hardened steels. Among the advantages of this modern turning operation are final product quality, reduced machining time, and lower machining cost (Mamalis et al., 2008).

Recent researchers found that by increasing the cutting speed in turning hard materials the cutting forces reduced (Lin et al., 2008; Yalles et al., 2009) and that may cause an improvement in tool life and also reduce the power consumption.

Al Hazza et al. (2013) found that the cutting speed is the most significant factor on the flank wear length. Sahin (2009) claimed that in high speed cutting, the machining costs decreased due to the increasing production rate. Benga and Abrao (2003) said that the ability to turn hardened steels without the use of cutting fluids is considered to be of significant importance because this will reduce the machining cost by approximately 15% .

In contrast, high speed cutting leads to the rapid wear of cutting tools, which is caused by the high temperatures generated at the cutting zone and as a result tool life decreases (Diniz and Oliveria, 2008). Thus, the tooling cost increases. As result, the traditional cutting tools are not effective, so the hard tools such as CBN and ceramics tools are most suitable. Because of economical and suitability reasons the ceramic tools may be a good decision based on the following observations from previous researches:

1. For finishing cuts the ceramic insert has less than half the flank wear of CBN after 30 minutes cutting time and ten times cheaper than CBN for the same size and geometry insert (Stier, 1990).
2. Ceramics are considered to be one of the most suitable tool materials for machining hardened steels because of their high hot hardness, wear resistance and chemical inertness (Dewes and Aspinwall, 1997).
3. Cakan (2010) said that interest in ceramics as a cutting tool material is owing to such favorable material properties as high melting point, excellent hardness, and good wear resistance.

However, using ceramics tools may lead to an early breakage because of hardness of the work piece and the lack of the toughness of this type of cutting tool. Therefore, a negative rake angle may strength the cutting edge by shifting the pressure from the edge of the cutting tool to the flank face. Figure 1 concluded the reasons for using negative rake angle in HSHT when using ceramic tools.

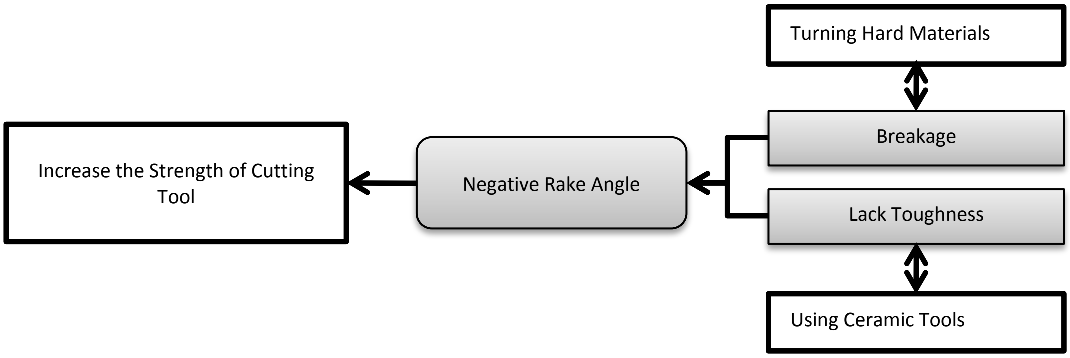

Figure 1: Using negative rake angle reasons

2. Negative rake angle

Trent and Wright (2000) claimed that the strongest tool edge is achieved with negative rake angle tools, and these are frequently used for the harder grades of carbide and for ceramic tools which lack toughness.

The negative rake angles strengthen the cutting edges enabling them to sustain heavier cutting loads (Trent and Wright, 2000); there is also an economical reason for advantage in favor of using indexable inserts because the cutting edge in both bottom and top of the insert can be used.

Al Hazza and Adesta (2011) said that the rake angle is one of the cost drivers in high speed hard turning process. Using negative rake angle transfers the initial shock from the edge of the cutting tool to the face of the tool. This prolongs the life of the tool and higher cutting speeds can be employed.

Adesta et al. (2009) found out that by increasing negative rake angles the higher wear occurred shorter duration of tool life and poor surface finish. Adesta and AL Hazza (2011) said that using the negative rake angle will increase the cutting forces but these forces will shift to the tool face and that will reduce the load on the edge of the tool.

The objective of this research is to study and concentrate on the economical factors when using negative rake angle in high speed turning and high lighting its relation with the surface quality. These factors are tool life and power consumption. These factors have been analyzed through an experimental work.

3. Research methodology

In order to achieve the research objectives, the following steps have been applied:

1. Extensive literature review in areas of: high speed hard turning and cost techniques.
2. Studying the process theoretically and experimentally.
3. Experimental work.
4. Measurement
5. Analyzing

Figure 1 shows the research flow chart in details.

4. Experimental work

The cutting variables were as the following; five different rake angles (0, -3, -6, -9 and -12) at 250 m/min as a cutting speed, 0.15mm as depth of cut and 0.0.75 mm/rev as a feed rate. During the experiment the following variables were measured; flank wear rate, cutting force and energy consumption. The work piece material was AISI 4340 which is hardened to 60 HRC. The instruments that have been used in the experiment as following;

1. CNC turning machine (Romi- Bridgeport 2).
2. Force meter (tool holder load cell)
3. Microscope picture (Motic digital microscope)
4. Microscope wear rate(Hisomet-DH2)
5. Digital clamp meters (3) (current).
6. Cos meter.
7. Voltmeter (voltage).

The experiment set up is concluded in figure 3.

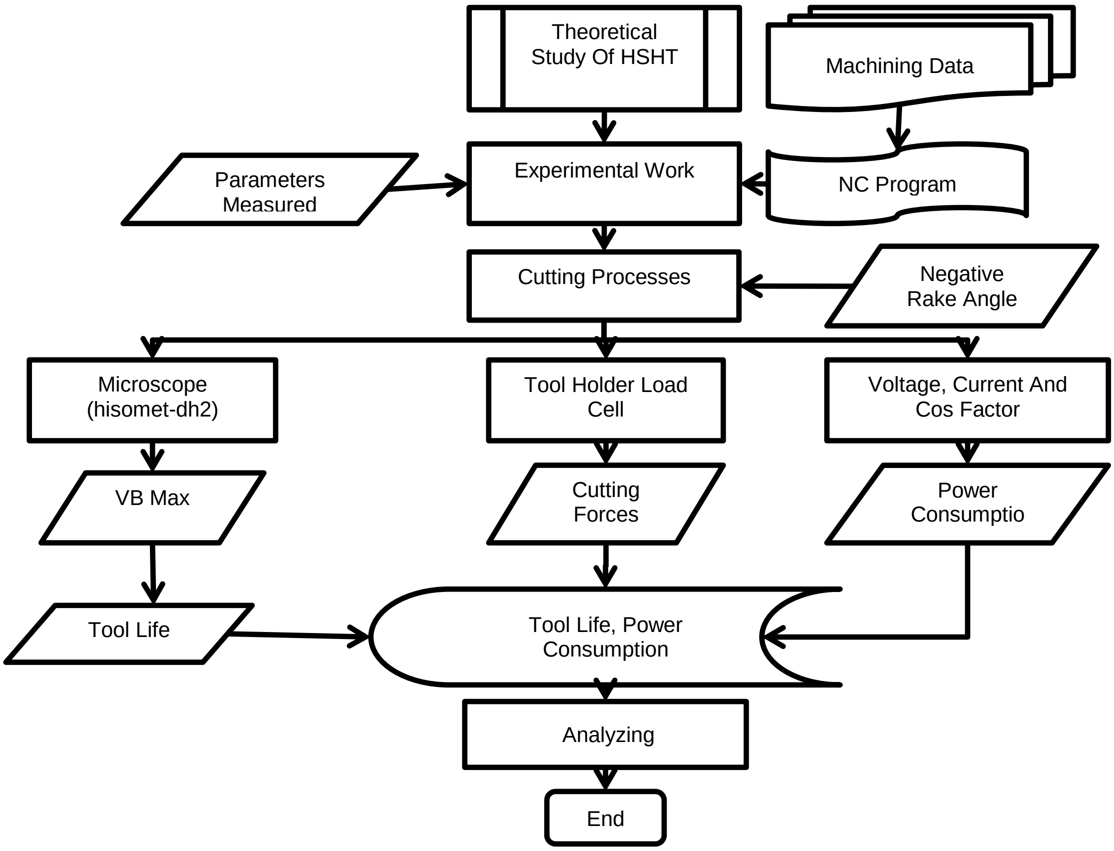

Figure 2: Research methodology

5. Economic factors

5.1 Tool Life

The useful life of a tool can be defined in terms of the progressive wear that occurs on the tool rake face (crater wear) and/or clearance face (flank wear). Of these two, flank wear is often used to define the end of effective tool life (Arsecularatne, 2006). In this research tool life was estimated by using the flank wear maximum = 0.3 for the different rake angle.

The flank wear was measured after each pass so the total was ten values during each rake angle. Figure 3 shows the flank wear progress for the cutting tool in five different rake angles.

The figure shows that by using zero rake angles the flank wear progress gave high values. After 400 mm of machining it reaches the maximum value allowed. Davim (2008) claimed that when the flank angle equal to (0°) then the flank surface of the cutting tool is in full contact with the work piece and due to the spring-back of the work piece material, there is a significant friction force in such a contact that usually leads to tool breakage. This means that the tool life may decrease to the half of the tool life.

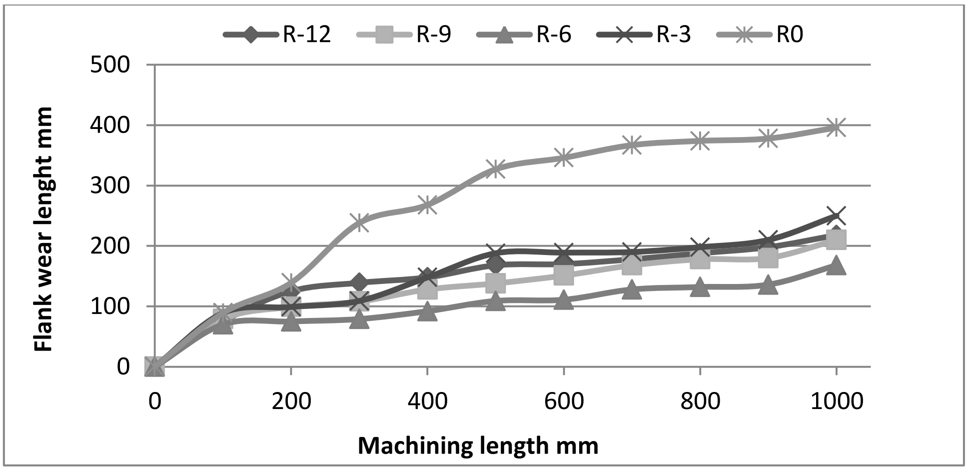

Fig.3: Flank wear length during the machining time

The total flank wear length after 1000 mm of machining have been concluded in Figure 4.

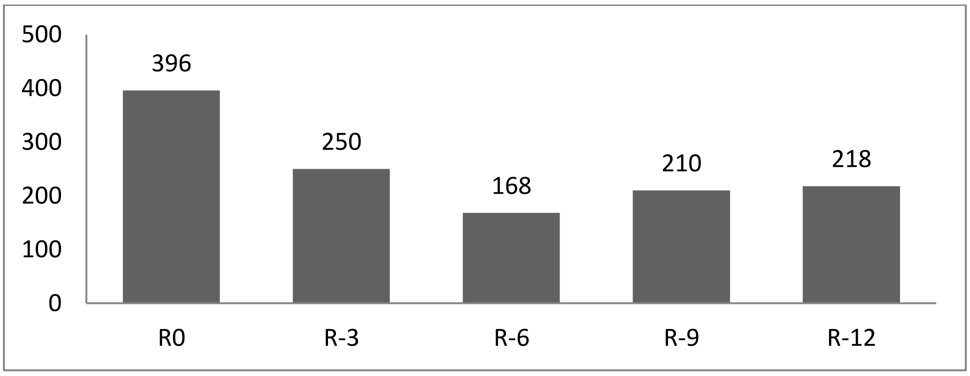

Fig.4: Flank wear length in different negative rake angle after 1000 mm of machining

The tool life is estimated in accordance to ISO 3685 (1993) using tool life criteria of average flank wear: 0.3 mm. The flanks wear increases normally with the time of cutting. Figure 5 shows the tool life for different rake angle.

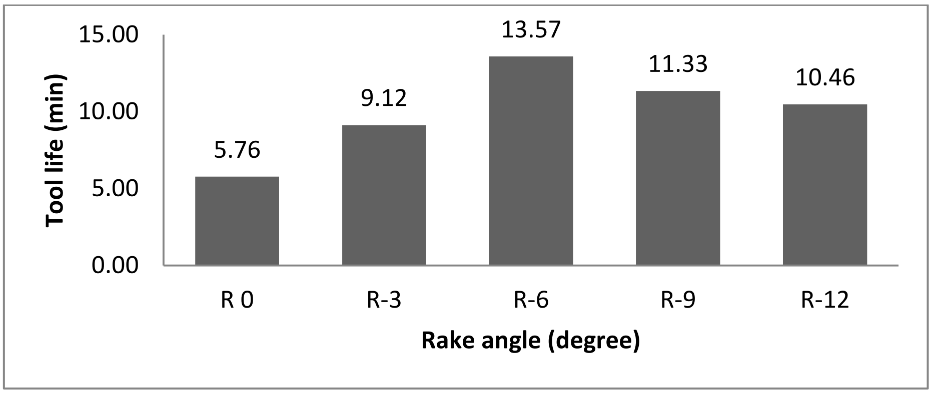

Fig.5: Tool life in different rake angle

The figure shows that the best tool life was when using -6 degree. After -6 the tool life decreases slightly.

5.2 Cutting forces

The cutting forces measured by using tool holder load cell as shown in Figure 6. This dynamometer consists of a typical commercial tool holder (approaching angle 90^o) type (PTGNR 2020 k16 Sandvick), two strain gauges type (fla-10-11) were mounted at the maximum strain determined area for each force component as shown in Figure 7, which were also electrical connected in a half-bridge Wheatstone circuit.

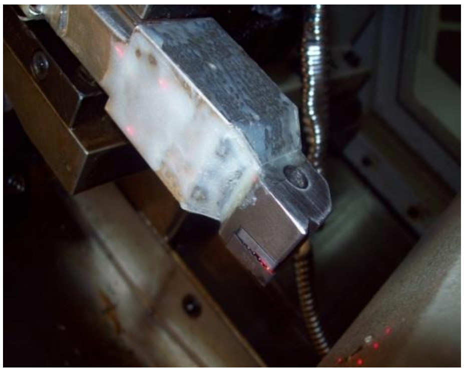

Fig. 6. Too holder load cell

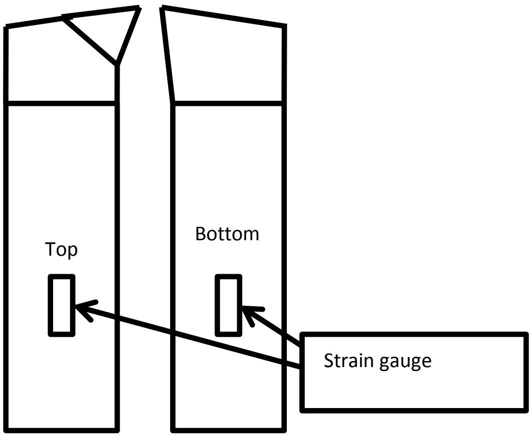

Fig.7. Strain gauge position on the tool holder to measure the cutting forces

Figure 8 shows the cutting force in high speed hard turning. The cutting forces increased with the increase of the negative rake angle.

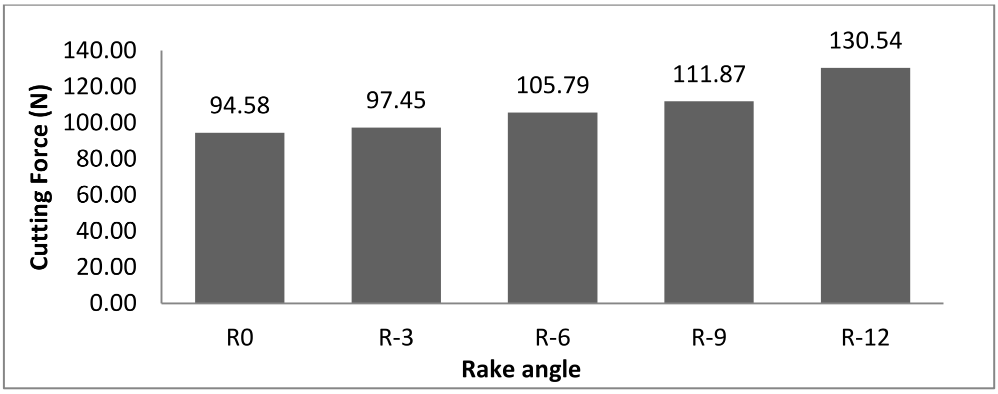

Fig.8: cutting forces with different negative rake angle

5.3 Voltage, current and power factor measurement

Energy used in machining can be estimated by different techniques. It is estimated either by direct or indirect measurement. Direct method is the method that needs to measure directly the current, voltage and the power factor during all the machining stages. Direct method can give the exact energy consumed during the process and can be used also to validate the results when using other methods.

Indirect methods can be divided into two main methods according to the basic thermodynamics (Gutowski et al., 2006; Gutowski et al., 2007; Gutowski et al., 2009) or estimating the power based on the forces and velocities relationship (Acosta et al., 1997; Campatelli, 2009).

Al Hazza et al. (developed a new model to estimate the energy cost in high speed hard turning using a negative rake angle.

In this research, the energy is measured directly by using three digital clamp meters to measure the current, digital voltmeter for measuring the voltage and load factor for measuring the power factor. These instruments are connected to the main electricity source for the CNC turning machine as shown in Figure 9. The energy is measured in two different situations: movement without cut and movement with cutting (the cutting tool in touch with the work piece).

Fig.9: Instruments used for measuring the power

The average power consumed during machining are concluded in figure 10.

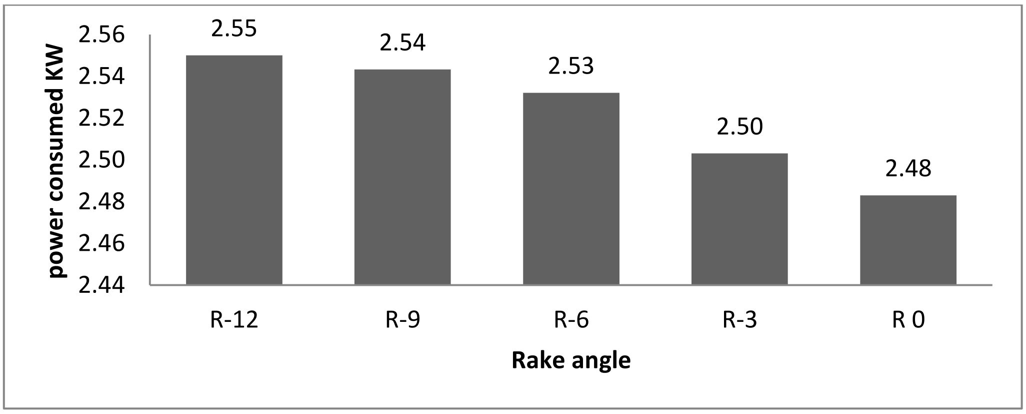

Figure 10: power consumption

6. Conclusion

As a conclusion, rake angle has a high influence on the economic factors in high speed turning. It was found that the best tool life when using -6 degree, after -6 the tool life decreases slightly. It was found also that the cutting forces and the power consumption increased with the increase of the negative rake angle. However, the percentages of the energy cost to the tooling cost are very low. Thus, using a -6 degree in high speed hard turning may reduce the total machining cost

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