A study on effect of tool tip temperature on wear of ceramic cutting tools

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Abstract. This work reflects the effects of tool tip temperature on flank wear of ceramic cutting tools during the turning of nickel alloy 718 (HRC 45). Two types of ceramic cutting inserts were used Al oxide (620) and mixed oxide (6050), during the turning operation under dry environmental conditions at various cutting speeds of 145 m/min, 230 m/min and 360 m/min respectively. The Al oxide inserts showed better results at cutting speed of 145 m/min and 230 m/min than mixed oxide. The worn out edges of inserts and micro structural properties were obtained by using SEM and tool makers microscope. The results were obtained after analyzing each test. The wear resistance of cutting inserts were affected by the tool tip temperature at the cutting zone.
Keywords: Alumina-based ceramic tools; mixed oxide ceramic tool, Flank wear; nickel alloy - 718, dry machining, tool temperature

1. Introduction
Flank wear is one of the main difficulties in machining of Nickel alloy-718 and therefore, it is imperative to understand and describe a possible future event of tool wear [1]. The use of ceramics as cutting tool in hard turning is having benefits of low cost than 14% of cubic boron nitride cutting tools. Moreover, ceramic cutting tools can be utilized at variety of cutting speeds [2]. The main issues during machining of Nickel alloy are short tool life and surface quality problems that must be examined [3]. To maintain the temperature during the machining, a proper tool chip contact length is to be maintained. Flank wear occurs due to abrasion of plastic deformation which depends on tool chip contact condition [4]. Generally ceramic cutting tools are used in dry environmental conditions to protect the tool edge from thermal shocks [5]. During turning of hard materials the combination of dry cutting and high speed is still an issue for researchers in view of economic, environmental and health aspects. For estimating the tool life, it is important to understand mechanism of wear such as abrasive, adhesive and chemical tool wear [6]. The ceramic cutting tools have shown good performance when compared with carbides. On the basis of hot hardness and chemical wear resistance it has been observed that mixed Al-oxide ceramic tools have shown better performance than Polycrystalline Cubic Boron Nitride (PCBN) tools during turning operation [7]. Further, alumina oxide inserts are also one of the basic cutting tools in category of ceramics. ZrO₂ is added to one of the category of alumina oxide to hardened the material and to maintain its growth of grain size which plays important role in cutting of hard materials [8]. It is known fact that during any machining process the heat is generated by mechanical work. However, in cutting zone rise of temperature influences tool life, surface integrity, chip formation mechanism and also the edge of the cutting tool by plastic deformation [9].
The increase of cutting speed in turning, the process tends to become highly adiabatic and as a result, the heat developed will be mainly concentrated in the primary deformation zone due to sharing action by the cutting tool [10]. The selection of process parameters during plain turning of nickel alloy-718 also influence the machining temperature, three dimensional forces of cutting, wear of tool and surface quality [11]. The micro structure of the work piece is also highly affected by rise of cutting temperature which in turn leads several issues in turning process [12]. It is also important to measure the temperature rise during the process of machining. Rise of temperature in basic metal cutting plays vital role as it adversely affects the various important parameters such as hardness, wear resistance and strength of cutting tool. Excess heat rises the temperature of cutting edge which badly effects the tool life [13].

The aim of this experimental investigation is to study the effects of temperature on tool wear using cutting inserts during turning operation of Nickel alloy-718. Figure 1 highlights the schematic of basic turning operation.

![Figure 1. Representation of basic turning operation.](image)

2. Experimental Details

2.1. Work-piece material

A round job of nickel based alloy-718 of specifications of 50 mm diameter and length of 400 mm hardness of 45 HRC has been selected as the work piece in these experiments. The chemical composition is given in Table 1. The microstructure and EDX of test sample used for experimental work of nickel alloy 718 is highlighted in Figure 2 (a) and (b) respectively.

| Element Line | Weight % | Atom% | Formula |
|--------------|----------|-------|---------|
| Al K         | 0.16     | 0.34  | Al      |
| Ti K         | 0.57     | 0.69  | Ti      |
| Cr K         | 16.14    | 17.96 | Cr      |
| Mn K         | 0.24     | 0.25  | Mn      |
| Fe K         | 17.68    | 18.31 | Fe      |
| Ni K         | 60.69    | 59.80 | Ni      |
| Nb L         | 2.49     | 1.55  | Nb      |
| Mo L         | 1.57     | 0.94  | Mo      |
| Ta L         | 0.46     | 0.15  | Ta      |
| Total        | 100.00   | 100.00| Al      |
2.2. Cutting Inserts material and Tool Holder

Al–oxide (620) and mixed oxide (6050) were used as cutting inserts for machining of Nickel alloy-718. The ceramic cutting inserts have been chosen because nickel alloy-718 has poor machinability at higher cutting speeds with conventional cutting tools. Both the tools were installed on triangular holder and with same geometrical aspects. Table 2 presents the overall metaphors of the materials of cutting tool and tool holder used as shown in Figure 3 and Figure 4 respectively.

| Work specimen | Inconel-718 | Tool holder | Multiple lock Negative tool holder |
|---------------|-------------|-------------|-----------------------------------|
| Hardness      | 45HRC       | Shape of inserts | Triangular |
| Density       | 8.19 g/cm³ | Rake angle | -10° |
| Young’s modulus | 206GPa | Clearance angle | 0° |
|               |             | Plan approach angle | 30° |
|               |             | Nose radius | 0.8mm |

**Figure 2.** (a) Microstructure and (b) EDX of Nickel Alloy-718.

**Figure 3.** Triangular shaped tool holder.

**Figure 4.** Shape of ceramic cutting inserts.

**Table 2.** Work material Inconel 718 properties, tool geometry and tool holder nomenclature.
Three cutting speeds namely 145, 230, 360 m/min were used with constant feed of 0.3mm and depth of cut of 0.19 mm/rev. High cutting speeds were employed to study its effect on tool tip temperature and tool wear. The radius of cutting insert nose was 0.8 mm. The turning experiments were performed on Machine Tool Kirloskar Center Lathe 1550 having specifications: Centers height 165mm, Range of spindle speed from 45 to 2000 RPM, feed range 0.4-0.08 mm/rev. Constant machining time approach was employed for conducting experiments. The Lieca dm 6000 advanced microscope was available to measure the flank wear of both the inserts of ceramics using various three cutting speeds. The cutting insert tool temperature was measured with Pt 100 thermocouple with an accuracy of 1°C installed with computerized lathe tool dynamometer through a computer connected to the machine. The thermo couple was inserted in the groove provided on the shim and same is seated on the holder of the cutting tool as shown in Figure 5.

![Image](image_url)

Figure 5. A typical assembly of Thermocouple inserted in the shim of the cutting inserts.

3. Results and Discussion

3.1. Analysis of tool tip temperature

It has been observed that the turning operation of Inconel 718 becomes difficult, as in the cutting zone area heat gets concentrated. As such, measurement of tool tip temperature becomes important issue as it affects flank wear during the turning operation of nickel alloy 718.

Figure 6 highlights gradual increase of tool tip temperature at various three cutting speeds of 145 m/min, 230 m/min and 360m/min respectively with constant feed 0.19mm/rev and depth of cut 0.3mm using of Al-Oxide cutting insert. Initially, with increasing speed the temperature of tool tip increases. Accordingly the tool temperature rises from 45 °C to 130 °C at cutting speed 360 m/min with passage of machining time span of 180 sec. Similarly at 230m/min the temperature of tool rises from 45 °C to 85 °C which is 35% lower than at the cutting speed 360m/min.
Figure 6. Effect of cutting speed on temperature of Al-Oxide cutting insert.

Figure 7. Effect of cutting speed on temperature of Mixed-Oxide cutting insert.
Accordingly, the turning at cutting speed of 145m/min the temp rises maximum up to 70 °C from 35 °C during 180 seconds machining time which shows lowest tool tip temperature using Al-oxide ceramic cutting insert during machining.

Similarly, as shown in Figure 7, it is clear that with the increase in cutting speed from 145m/min to 360m/min the tool temperature increases using mixed oxide ceramic cutting insert (with machining time of 180 seconds). However, it starts to decreasing abruptly at completion of machining time length (approximately 120 seconds at cutting speed 360m/min and 230m/min) due to the complete wear of cutting insert. Its temperature remains constant approximately at 100 °C after rises the temp from 20 °C at 145m/min) almost after machining time 67 seconds, because of good wear resistance as compare at higher cutting speeds. Comparing the Figures 6 and 7, it is observed that mixed oxide cutting insert shows decreasing trends of temperature after completion of 120 seconds of machining time whereas, Al-oxide cutting insert shows marginal increasing trend of rise of temperature throughout the machining time at higher cutting speeds. This is attributed to excess wear of the mixed oxide cutting insert than Al-oxide cutting insert. In view of the increasing wear of the mixed oxide insert, the temperature of tool tip falls down due to the decrease of cutting forces.

3.2. Microscopic Analysis of Flank Wear
The micrograph of worn cutting edge of Al-oxide and Mixed-oxide ceramic cutting inserts at the cutting speeds 145, 230 and 360 m/min feed rate of 0.19 mm/rev and depth of cut 0.3 mm are demonstrated in Figures 8 and 9 respectively. Flank wear of worn out cutting inserts were recorded using Lieca dm 6000 advanced microscope. Each test was carried out for virgin insert, for which machine was stopped. Investigation of Flank wear tests was carried out for both the Al and mixed ceramic cutting inserts for different cutting speeds. From Figure 8 the results show that with the increase in cutting speed from 145 to 230 and 360m/min respectively, the flank wear gradually increases which indicates the values of wear. Similarly Figure 9 also demonstrates that flank wear also increases with increase of cutting speeds at 230m/min but it gradually decreases at 360m/min. However, when comparing the flank wear of Al Oxide and mixed oxide ceramic cutting inserts it concludes that Al oxide provides superior wear reissuance at 145 and 230 m/min. whereas at high speed 360m/min it was observed better wear resistance in case of mixed oxide cutting insert.
Figure 8. (a) Al-Oxide cutting insert (before machining) and flank wear of Al-Oxide cutting inserts at speeds (b) 145 (c) 230 (d) 360 m/min (after machining).

Figure 9. (a) Mixed-Oxide cutting insert (before machining) and flank wear of Mixed-Oxide cutting inserts at speeds (b) 145 (c) 230 (d) 360 m/min (after machining).
4. Conclusion
These results help to understand flank wear of Al-oxide and mixed oxide cutting tools during turning process. In this study main focus was to investigate the effect of cutting insert temperature on gradual failure of cutting tool. It has been observed that the flank wear rate of cutting insert is maximum where intense temperature area is present. This is evident from excessive flank wear at cutting speed of 360 m/min due to rise of temperature up to 200 °C. It is observed that Al-oxide cutting inserts have better wear resistance than mixed oxide ceramic cutting inserts as is reflected in the results pertaining to cutting speeds of 145 m/min and 230 m/min. At the cutting speed of 145 m/min, the mixed oxide tool showed quite good tool wear results. Increasing the speed to 360 m/min in case of Al-oxide during machining, resulted in remarkable temperature rise which affected the cutting edge causing higher tool wear. Moreover, at cutting speeds of 145 and 230 m/min it shows better wear resistance as compared to cutting speed of 360 m/min. In case of mixed oxide at speeds of 230 and 360 m/min, temperature (within the machining time span of 120 seconds) got decreased abruptly because of complete wear of cutting tool edges and as a consequence, the temperature falls down abruptly. The results at the speed of 145 m/min show better wear resistance, the temperature rises initially and it remains constant after the 120 seconds of total machining time and thereafter remained constant at 100°C.

In view of the above, it has been concluded that Al-oxide cutting insert shows better wear resistance at cutting speeds of 145 and 230 m/min as compared to the higher cutting speed of 360 m/min. Similarly, mixed oxide cutting insert shows better wear results at 145 m/min as compared to the higher cutting speed due to rise in temperature because of the heat concentrated in the primary cutting zone and also more friction due to high cutting speed. In general, it has been seen that with the increase of a cutting speed, the cutting temperature increases which effects the cutting edge of tool.

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