Assessment of machinability of super alloy inconel 718 using aluminium oxide and mixed oxide ceramic cutting tools

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Abstract. The current study, attempts to be have made for the assessment of influence of cutting speeds with constant feed of 0.19mm/rev with 0.3mm depth of cut on tool wear during dry turning of Inconel 718. Comparative study was conducted using Al -oxide and Mixed Oxide cutting inserts (commercially available with similar geometry) for experimental trials. This exploratory investigation focuses on the tool life deterioration of various ceramic materials associated with the machinability of Inconel 718 under selected process parameters. Also, significant parameters were identified that effect and control flank wear. The flank wear was assessed on the inserts for every trial through measurements using advanced Optical Microscope. Further observations were made on Hitachi Scanning Electron Microscope (SEM) to understand the wear pattern encountered by selected tool materials.

Keywords: Alumina-based ceramic tools; mixed oxide ceramic tool, Flank wear; nickel alloy -718, dry machining, tool temperature

1. Introduction
Nickel based super alloys present a challenge regarding machinability (although they posses excellent mechanical engineering properties) in plethora of applications which includes nuclear power, industry, aerospace, marine and allied fields[1]. Nickel alloys have nickel as then major component in its composition (more than 50%). Nickel based super alloys have poor machinability owing to tendency of galling and welding especially on rake face of tool. At low cutting speeds built up edge formation has also been reported[2]. In particular machining of Inconel 718 involves work hardening and other deleterious effects on tool materials leading to their inability to work satisfactory for sustained durations. Due to ultra super properties as corrosion resistance, resistance of elevated temperature, creep resistance, adequate nil-ductility transition temperature (NDT), Nickel 718 alloy has wider engineering applications[3]. Traditional machining of Inconel 718 is full of challenge due to continues work hardening experienced in a long duration sustained machining operation[4]. Continues work hardening results in plastic deformation of cutting tool which limits the tool speed as a control on aggressive for restricting damage to tool and work piece. However, work hardening results in deterioration to tool through galling or welding and consequently results in rapid replacement of the tool[5]. Recent research has focused on new materials for tools which includes development of carbide (with and without coatings). The ceramic tools in particular have shown potential to work in high temperature environment at high cutting speeds without corresponding on strength or toughness[6]. To obtain good surface finish on work piece of 718 Inconel both cutting tool material and its geometry play a very important role. Therefore, conventional cutting tool materials are now getting replaced by ceramics tools[7]. Tool wear on 718 Inconel is a complicated phenomena which is interwoven by thermo-chemical/metallurgical reaction under action of high forces encountered during high speed cutting process manifested in the form of work hardening (plastic deformation). This may also involve galling/welding and adhesion and some limited abrasion[8]. For machining at higher speeds of cutting ceramic cutting tools are capable ten times better than the conventional tools [9].
some applications coated carbides, ceramics and CBN have been used for high speed machining of nickel based super alloys. Effect of process parameters on wear resistance of ceramic tools has been reported by[10]. Extra ordinary tool wear is associated with machining of Nickel based super alloys due to absorvent of heat production in confined volume causing abrupt rise in temperature resulting in plastic deformation and other adverse properties which limits cutting speed[11]. In a study on wear of inserts for machining of alloys, speed of cutting has been found one of the important parameter [12]. In that study it was found that tool life was inversely proportional to the cutting speed [13]. In another study it has been found that cutting speed of 300m/min was optimum ceramic and PCBN tools have been used in super alloy-718 with focus on cutting temperature, cutting forces, frequency of interruption on tool life and other related issues involving tool wear[14]. The cutting tool may be deteriorated on account of adhesion, abrasion or fracture depending upon duration of cutting and cutting speed [15,16]. Some tri-biological affects related to adhesive, fracture and plastic flow under ultra thermal condition of machining of 718 have been reported[17]. The present study address the feasibility of used aluminum oxide, mixed oxide basis ceramic cutting tools to assist the machinability of Nickel Alloy-718 by varying cutting parameters that significantly affected the tool wear.

2. Experimental Details
In this exploratory investigation lathe was operational with variable speed options :45 RPM-2000 RPM with a 5 HP motor drive rating have been used for turning of diameter 50x400mm long work piece of 718 nickel alloy. Cutting inserts both ceramic based aluminum oxide, mixed oxide (triangular shaped) were used. The input parameters for experimentation were (i) Cutting speed 145m/min, 230 m/min and 360 m/min. (ii) Constant feed rate 0.19mm/rev. (iii) Constant depth ofcut 0.3mm. One of the objectives of the present work was to analyze the effect of cutting speed on tool wear during operation of Nickel alloy 718.

| Elements | Ni  | Cr  | Mo  | Fe  | Mn  | Al  | Ti  | Nb  | Ta  |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| % Weight | 60.69 | 16.14 | 1.57 | 17.68 | 0.24 | 0.16 | 0.57 | 2.49 | 0.46 |

The lathe was having availability of variable speed 45RPM TO 2000RPM and a 5HP electrical motor drive . The turning inserts of ceramic based Al Oxide and mixed oxide cutting inserts of triangular shape. The main input parameters on which experiments were carried out were selected various high cutting speeds, constant feed, depth of cut respectively. Table 2 shows the properties of work material and tool geometry used in the experimental work.

Figure 1. Experimental Setup Kirloskar center lathe machine Tool - 1550.
Table 2. Detail of tool geometry and turning tool holder.

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

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 Liecadm 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.

3. Results and Discussion

In this experimental work, assessment of flank wear of cutting inserts of ceramic materials were studied with using of Lieca DM 2500M optical microscope and on similar grounds to understand pattern of wear occurred during outside turning process. Subsequently analysis of tool wear were also examined independently on Scanned Electron Microscope (SEM). It is observed that from Figure 2(a) that VB (max) increases with increase of speed of cutting 145m/min to 230m/min within the range of 69% to 71%. Further, it again decreases with increase of speed with a margin of 71% to 69%. Furthermore, on similar conditions of experimental analysis as given in graphical figure 2(b) that mixed oxide inserts have performed the machining with increase of value of wear of VB (max) very high when comparing with Al oxide inserts, there is increase of tool wear by 50% more as seen in microscopic Figure 2(b).

3.1. Microscopic Analysis of Tool Wear

In view of the experiments of turning of Inconel alloy 718 for assessment of flank wear of tools were studied with help of Lieca DM 2500M optical Microscope and to understand mode of the wear occurred in used Inserts of ceramics further analysis of flank wear were investigated independently on measuring equipment Scanned Electron Microscope (SEM). It is observed that from Figure 2(a), that
VB (max) gradually increases with increase of cutting speed 145m/min to 230m/min within the range of 69% to 71%. But at the same time, it decreases with increase of cutting speed of 360m/min within the range of 69%. With the result it has been seen that with the increase of higher cutting speed the flank wear decreases. Furthermore, on similar conditions of experimental analysis as shown in graphical Figure 2(b) that mixed oxide cutting inserts have shown tendency of flank wear 50% higher than as compare to Al oxide, but independently it also shows less wear at higher cutting speeds.

3.2. SEM Analysis for Tool Wear

The catastrophic breakage, built-up edge and chipping of the cutting tool edges as highlighted in figure 5(a), 5(b) and 5(c) respectively have been observed under SEM. A flank face of cutting insert shows more chipping and tool fracture when the machining speed increases from 145 to 230 m/min the main wear mechanism observed is abrasive wear with deeper grooves with the parallel marks on the flank wear face of the aluminum oxide cutting tool.

Similarly, in case of mixed oxide ceramic cutting inserts similar factors affecting flank wear which is influenced by high cutting speed and temperatures. Typical wear is observed by machining hard materials using ceramic tools. Also, deeper grooves and depth of wear can be seen on fig. 6(a) & 6(b) due to the excessive wear.
Figure 5. SEM image for Al-Oxide insert. (a). Vc - 145m/min, d = 0.3mm and f = 0.19mm/rev. (b). Vc - 230m/min, d = 0.3mm and f = 0.19mm/rev. (c). Vc - 360m/min, d = 0.3mm and f = 0.19mm/rev.

Figure 6. SEM image for Mixed-Oxide insert. (a). Vc - 145m/min, d = 0.3mm and f = 0.19mm/rev. (b). Vc - 230m/min, d = 0.3mm and f = 0.19mm/rev. (c). Vc - 360m/min, d = 0.3mm and f = 0.19mm/rev.

4. Conclusion

In machining of Inconel-718 Ni-base super alloy the tool wear is greatly influenced by factors such as thermal softening, adhesion, diffusion, notching and thermal cracking. Mixed Oxide tool has shown severe wear pattern and higher wear values when compared to Al oxide ceramic tool. For mixed oxide ceramic cutting condition higher flank wear values are observed as compare to Al oxide ceramic cutting inserts.

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