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Wear and surface characteristics on tool performance with CVD coating of Al_2O_3/TiCN inserts during machining of Inconel 718 alloys

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The Inconel 718 alloys, which are primarily temperature resistant, are widely used in aviation, aerospace and nuclear industries. The study on dry cutting processes for this alloy becomes difficult due to its high hardness and low thermal conductivity, wherein, most of the heat transfers due to friction are accumulated over the tool surface. Further, several challenges like increased cutting force, developing high temperature and rapid tool wear are observed during its machining process. To overcome these, the coated tool inserts are used for machining the superalloys. In the present work, the cemented carbide tool is coated with chemical vapor deposition multi-layering Al_2O_3/TiCN under the dry cutting environment. The machining processes are carried out with varying cutting speeds: 65, 81, 95, and 106 m/min, feed rate 0.1 mm/rev, and depth of cut 0.2 mm. The variation in the cutting speeds can attain high temperatures, which may activate built-up-edge development which leads to extensive tool wear. In this context, the detailed chip morphology and its detailed analysis are carried out initially to understand the machining performance. Simultaneously, the surface roughness of the machined surface is studied for a clear understanding of the machining process. The potential tool wear mechanism in terms of abrasion, adhesion, tool chip off, delaminating of coating, flank wear, and crater wear is extensively identified during the processes. From the results, it is observed that the machining process at 81 m/min corresponds to a better machining process in terms of lesser cutting force, lower cutting temperature, better surface finish, and reduced tool wear than the other machining processes.

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1. Introduction

The tremendous growth of the aviation industry extends an exceptional edge to the manufacturing sectors. Inconel 718 is one of the superalloys that are widely used in aircraft engines, due to its high strength, capability to withstand high temperature and outstanding resistance to corrosion [1]. Due to its high hardness value and low thermal conductivity, the machining of the Inconel 718 faces serious challenges [2, 3]. During a machining process, a high temperature and pressure are developed at the tool-workpiece interface. This leads to the reduction in the tool life and undergoes rapid tool wear. The carbide particles present in the workpiece and its ineffective heat dissipation low to its low thermal conductivity leads to abrasive wear [4]. Micro-welding over the tool surface, severe notching on the tool edge are the common phenomena of tool wear during the machining of the Inconel 718 alloys.

The cutting fluids are used in the machining process to reduce the friction, temperature and impart lubrication between the tool-work piece interfaces. To some extent, it protects the machined surface from oxidation and improves tool life. During turning of the Inconel 718, a sufficient lubrication needs to be provided to reduce the cutting temperatures and developed forces. The mineral, synthetic and animal-based alloys are used as lubricating fluids in the cutting process due to their desirable lubricating properties. Apart from this traditional cooling strategy, alternative methods, such as Minimum Quality of Lubrication [5, 6], High Pressure Cooling [7], Cryogenic cooling and others were also studied. Marques [8] demonstrated that the addition of a solid lubricant in vegetable oil, during turning of the Inconel 718, showed an improvement in the tool life. Suarez [9] studied the variation in the tool wear pattern during the high pressure cooling (pressure of 8 MPa) on the turning inserts. The flank wear and cutting force was reduced by 30% and 10%, respectively, during machining the Inconel 718. Polvorosa [10] varied the coolant pressures and analysed the tool wear at different faces of the tool morphology. Sharman [11] showed an improvement in the tool life when the cutting fluid pressure was enhanced from 70 to 150 MPa. With the further increase in the fluid pressure, no change in the tool life was observed. Pereira [12] evaluated the surface characteristics with varying cutting parameters during turning of the Inconel 718 under cryogenic conditions (medium: liquid nitrogen). Recently, Gonzalez [13] observed an improvement in the tool life when cryoMQL method of lubrication is used.

On the other direction, the tool profile and its material properties play a predominant role in arriving at acceptable machining performance. In this context, uncoated ceramic carbide tools are used, but their usage is restricted to low cutting speeds [14]. Using cutting fluids will lead to health hazards to the technicians [15]. In the present scenario, a coated tool with a dry turning process has received much attention, since it is economical and environmentally friendly [16]. The coating of the insert results in a low coefficient of friction and also improves wear resistance on the tool. The coating exhibits exceptional wear resistance and chemical stability when machining with high cutting speeds [17]. The selection of the coated tool for machining depends on its hardness, wear properties, stability at high temperature, lubricity, and others.

The researchers have used different approaches in improving the machinability of superalloys. Thandra [18] mentioned that the tool life, material removal rate, and reduction in the cutting force are observed by heating the specimen through a gas-flame heating method. Lopez [19] studied the tool wear and machining properties under the influence of plasma-assisted heating over the workpiece surface. With this method, he found an improvement during the machining process. Studies on similar heating methods on the specimen and improving machinability were carried out by several researchers. The equation for finding the energy consumption during the machining operation is seen in the literature [20]. When the machining process is carried out at high temperatures, the form of energy is converted from mechanical to thermal phenomena. The thermal energies induce high temperatures at the chip tool interface. Moreover, significant heat is generated between the tool rake face and the chip rear edge, and the flank surface and the machined surface region, which leads to the tool wear. All these heat transfer mechanisms depend on the thermal conductivity, properties of the tool/work materials, and cutting conditions.

Due to the low thermal conductivity, the Inconel turns out to be difficult in the machining process. There exists peak temperature at the chip tool interface, which aids in transferring the heat to the tool, resulting in the diffusion of the tool over the workpiece. Ezugwu [21] mentioned the formation of a hardened layer over the machined surface due to the rise in the temperature at the interface and low thermal conductivity of the material. The formation of high temperatures leads to the formation of irregularities on the machined surfaces. The high temperatures may also generate thermal cracks, alter the microstructure, and develop residual stresses, which causes an increase in its hardness [22]. Sugihara [23] performed machining trials and demonstrated lower flank wear with textured inserts than that with the non-textured ones.

Ibrahim [24] observed the increase in the tool wear with the increase in the tool depth, when machining the Inconel 718 with PVD-TiAlN coated carbide tool. Hao [25] reported the influence of variation in the cutting speeds during machining the Inconel 718 with coated ceramic tools. Zhang [26] reported the improvement in the tool life with negative inserts during machining the Inconel 718. Zemzemi [27] determined the heat generation for the CBN and coated carbide tools during turning the Inconel 718. He finally concluded in the difficulty in predicting the heat generation during the machining process. Grzesik [28] conducted the tool wear studies for TiAlN coated carbide against a titanium alloy using a pin on disc method. A severe abrasive wear is observed during the machining. Recently, PcBN tool are successfully used in machining nickel-based alloys [29]. Oliveria [30] conducted the tool wear studies for cemented carbide tools over the Inconel and found a relationship between the tool wear and the residual stress formation.

The formation of chips and shear bands helps in analyzing the machinability during the turning process. The chip morphology depends on the cutting parameters, heating conditions at the chip-tool interface, and thermo-mechanical loading. The formation of serration due to the variation in the cutting speed, feed rate and depth of cut was investigated by Amin [31]. The chip formation and its analysis for super alloys were studied by few researchers. The studies on titanium alloys [32], the Inconel [33], and others aimed at understanding the chip serration are seen in a few works of literature.

The heat formation at the tool tip causes a severe tool wear which decreases the tool life and material removal rate. The variation in the chip formation also affects machinability [34]. High temperature develops build-up edges over the tool tip, leads to diffusion and finally enhances the tool wear. The high temperature also promotes crack formation; and infuses residual stress over the machined surface. Hence, a detailed insight into the machining process during turning of the Inconel 718 needs wider studies. Recently, an improvement in the machinability studies is observed as the researches on the atomised spray cutting fluid [35], ultrasonic vibration cutting [36] and other methods are started. Also, proceeding further in this direction, the present work focuses on detailed machinability studies in terms of chip analysis, tool wear, and surface characteristics of the machined surface. In the present work, Al_2O_3/TiCN with a coating thickness of 1 µm of each layer was fabricated using the CVD coating techniques. The effect of the cutting speeds on the chip formation and its morphology during machining the Inconel 718 are studied in detail. Further, the studies on the effect of cutting force and surface characteristics over cutting speed are carried out. The detailed tool wear characteristics for each of the machining processes are discussed in detail finally.

2. Materials and methods

A workpiece (round bar with φ21 mm diameter) of the superalloy Inconel 718 was used as a work material in the present work. The turning tests were carried out with a CNC precision turning centre. The tungsten carbide (ANSI designation: TNMG 120412) was used as a cutting tool. The tool is then coated with TiCN/Al_2O_3, which consists of 2 layers and each layer thickness is maintained at 1 µm. The first top layer TiCN resists the tool wear due to abrasion and Al2O3, which has a low thermal coefficient, protects the tool at high temperature. The machining processes were carried out with four different cutting speeds (65, 81, 95, and 106 m/min), a uniform feed rate of 0.1 mm/rev, and the depth of cut of 0.2 mm, respectively. The chip thickness is measured using digital vernier calliper having a 0.01 mm least count. Digital lathe tool dynamometers with 0.01 N accuracy are used for measuring the cutting force during machining. A Talysurf (Mitutoyo make) are used for the surface measurement over the machined area. The configuration of the insert is shown in the Table 1.

Table 1. Configuration of the insert

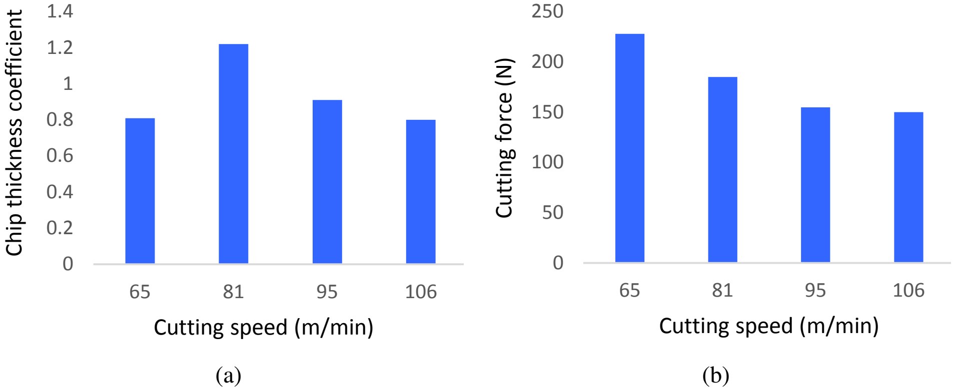
Corner radius	0.8 mm
Clearance angle	0°
Substrate	HC
Rake angle	6°
Edge length	13 mm

3. Results and discussions

The formation of chips for varying cutting speeds is shown in Fig. 1. The mechanism of chip formation in the Inconel is entirely different from other materials such as steel, aluminium, and copper [37]. In the case of aluminium having high thermal conductivity, the heat generated at the chip tool interface is easily absorbed by the workpiece [38]. Hence, the thermal conductivity of the tool plays a predominant role in the transfer of heat that is formed at the tooltip. At a lower cutting speed, 65 m/min, the increased temperature at the rear side of the chip causes the chip to form a curved shape. Loosely coiled chips are formed finally. With the increase in the cutting speed to 81 m/min, continuous-long chips are formed during the process. The decreased friction at the chip-tool interface and improved machinability aids in uniform machining processes. The frictional force again increases with the increase in the cutting speed, where a huge amount of heat evolves in cutting. During the process, more heat is transferred to the chip, which increases the curl diameter. Brittle and discontinuous chips are formed beyond 95 m/min cutting speed. The chip formation for the increasing cutting speeds is shown in Fig. 2.

Fig. 1. Chip formation for the cutting speeds65, 81, 95, and 106m/min (from left to right)

The chip thickness coefficient for the various cutting speeds is shown in Fig. 2a. It is observed that that the chip thickness coefficient increases initially and then decreases with the increase in the cutting speeds. At the lowest cutting speed of 50 m/min, chip thickness is found to be high. This is mainly due to the low chip velocity and increased frictional force. With the increase in the cutting speed to

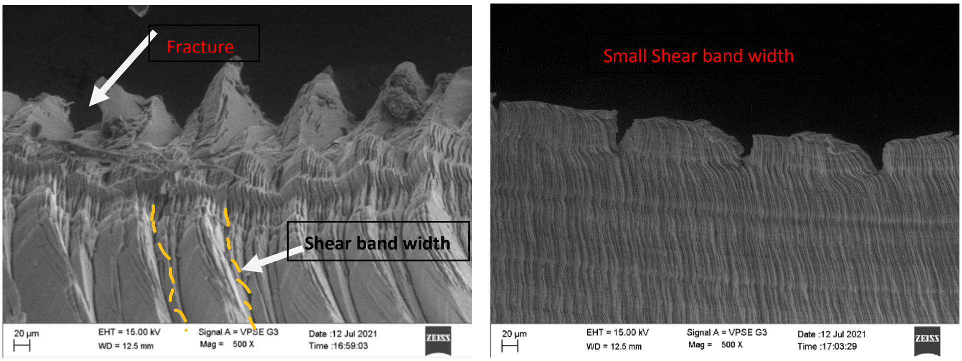


(a) (b)

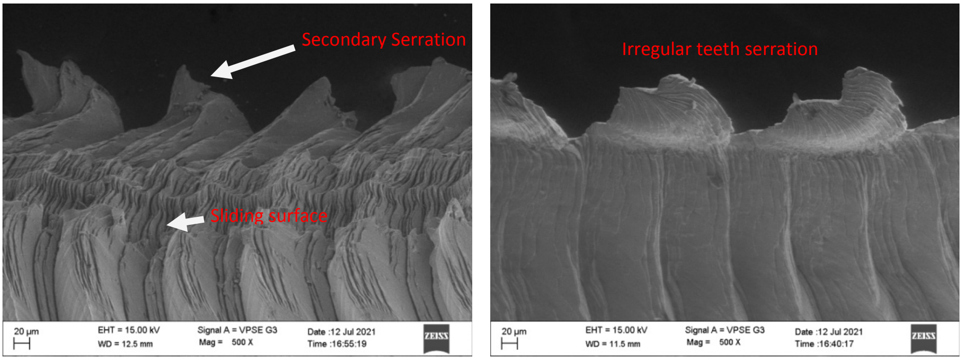
Fig. 2. Chip thickness ratio and cutting force with the increase in cutting speed during machining Inconel 718

81 m/min, there is a reduction in the friction force due to the increased chip flow velocity. Beyond an increase in the cutting speed from 95 m/min, again excessive tool coating wear starts at the tooltip junction resulting in increased friction between the rake and the chip rear surfaces. From the chip's appearance, an increase in its thickness is observed. The variation of the cutting force with the increase in the cutting speeds is shown in Fig. 2b. There is truncation in the magnitude of the cutting force with an increase in the cutting speeds. At the lower cutting speed, an increase in the friction between the chip rear surface and rake surface resulted in a higher cutting force. At the higher cutting speed, beyond 95 m/min, the thermal softening of the workpiece resulted in a lower cutting force. The bond energy in the crystal lattice reduces, with an increase in the cutting force, and hence the strength of the material decreases. Similar observations are also made by Pawade [39]. The poor heat dissipation of the workpiece due to its poor thermal conductivity resulted in a huge heat generation and thermal softening on the workpiece surface. Hence, a reduction in the cutting force is observed [40, 41].

The analysis of chip morphology is one of the useful methods to identify the machining processes during turning the Inconel 718. Sawtooth chips with different appearances are observed during its SEM analysis, Fig. 3. The serrated chips are formed mainly due to the heat conjunction at the chip-tool interface during machining at a higher temperature [42]. The formation and propagation of cracks that takes place at the primary shear zone, results in thermoplastic instability and forms saw-tooth edges on the chips [42]. At the chip-tool junction, when the tool moves forward, it uplifts the material from the workpiece surface and forms serration at the chip rear end and the next segment processes. Here, the chip rear end sticks and slips periodically and generates heat upon the working conditions. When working with high cutting speeds, a high temperature evolves, which thermally softens the workpiece surface. Further, the serration tooth also extends its length, due to the thermal expansion induced in it during the machining process.



(a) 65 m/min (b) 81 m/min

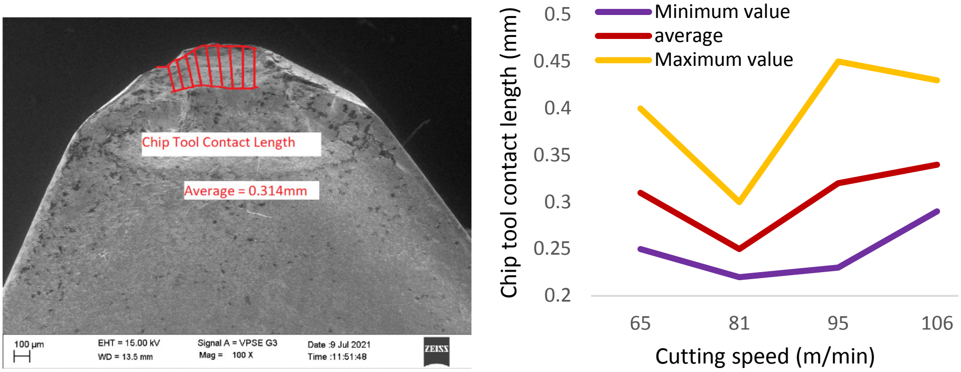


(c) 95 m/min (d) 106 m/min

Fig. 3. Chip obtained during the increase in various cutting speeds for machining Inconel 718

In the case of low cutting speed, i.e., 65 m/min, more heat is generated due to the increased friction needed for uplifting the chip from the workpiece and more friction is generated between the tool rear end and tool rake surface. Due to this, some fracture is observed at the corner of the chip serrations, Fig. 3a. More sliding surfaces, which are observed, indicate the difficulties in upsetting the material from the workpiece and form serrated portions over the chip. With a further cutting speed increase to 81 m/min, the sliding surface, the fracture, or the serration length are tremendously reduced. This is mainly because of improved machinability in terms of improved upsetting of materials, improved chip flow velocity, and reduced friction, Fig. 3b. Moreover, serrated chips with their increased teeth length, shear bands, and poor chip morphology are formed with the speed increased beyond 95 m/min, as shown in Figs. 3c, 3d.

The chip tool contact over the rake surface is calculated and depicted in Fig. 4a. It is reported that at a lower cutting speed, a high value of chip-tool contact is obtained due to increased friction between the chip and the tool surface [43]. This value gradually decreases with the increase in cutting speed due to the lower



(a) (b)

Fig. 4. Image of variation of chip tool contact length for low cutting speed 65 m/min (a) and variation of chip tool contact length with variation in cutting speeds (b)

rubbing during the machining process. With a further increase in the cutting speed, the increased friction and tool wear facilitates the increase in its value. At a lower cutting speed, 65m/min, a high cutting force is induced over the rake surface, which causes the removal of layers on its surface. This increases the value of the chip-tool contact length. With a further increase in the cutting speed to 81 m/min, the low friction between the surfaces results in decreasing the chip-tool contact length value. But at the higher cutting speed, and increased tool wears progression, the chip-tool contact length again starts increasing and reaches a larger value. At a cutting speed of 105 m/min, the variation in the chip-tool contact length is minimal, with an increase in its value, when compared with lower cutting speeds. This minimal variation in its value is mainly due to the thermal softening of the work material, which causes uniform delamination of coating and the tool wear over its rake surface, Fig. 4b.

During the machining of the Inconel 718, saw tooth chips are formed in all the cutting processes. During the cutting mechanism, firstly, when the tooltip comes in contact with the material, the normal line (towards upright direction) from the shear plane, experiences a compressive stress. During the uplifting of a chip material, the shear plane experiences a higher heat due to the greater amount of inelastic work transformed into heat [44]. This leads to thermal softening over the primary shear zone, which reduces the shear strength in this region. This leads to the initiation of crack at the lower cutting speed. Here, the cracks are formed periodically over the free chip surfaces. Also, the uneven series of shear bands, the uneven height of the teeth, and the series of sliding surfaces are observed during the machining process. Similar observations are made, when the cutting speed is increased to a certain value, i.e., 95 m/min. But at a higher cutting speed, 106 m/min, a larger serrated tooth pitch is observed due to the increased tool wear and the larger material deformation [45].

The surface roughness on the machined surface is shown in Fig. 5. From the results, as not quite apparent, higher surface roughness is observed at lower cutting speed (65 m/min) due to the larger friction force and crater wear formed over the rake surface. The surface roughness decreases with the increase in cutting speed to 81 m/min due to some stability formed during the machining process. The increase in the surface roughness is again observed with the increase in the cutting speed. The thermal softening of the material and detrimental crater wear lead to an increase in its value.

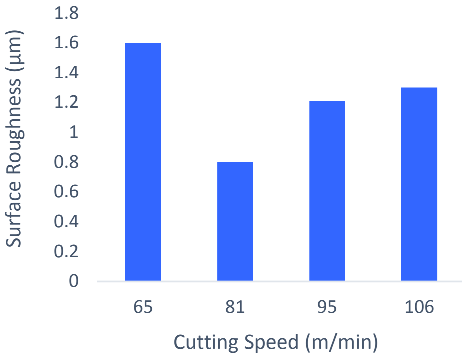
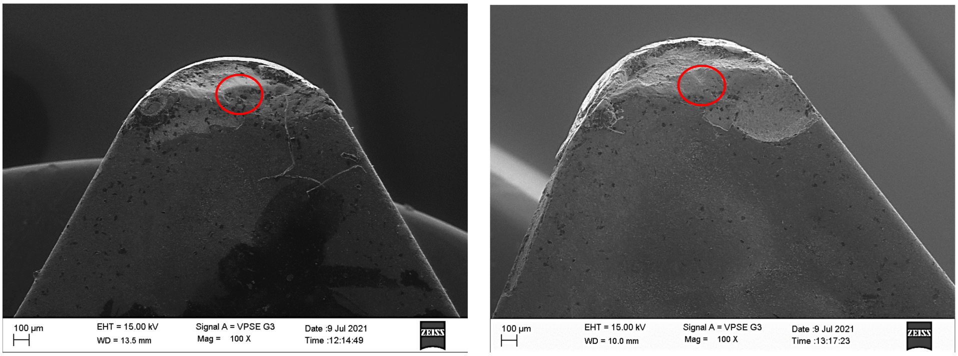
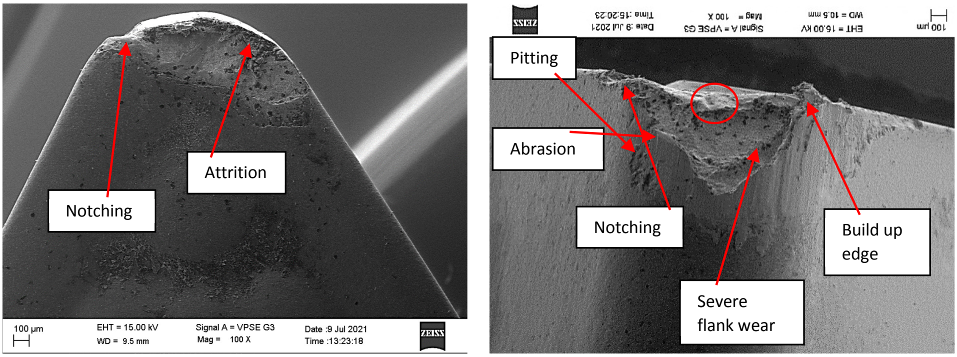


Fig. 5. Surface roughness during the increase in cutting speed for machining Inconel 718

The detailed tool wear studies are performed for all the tools used in the machining process. Here, for the Inconel 718, the temperature formed at the chip tool interface plays a predominant role in the tool wear. An elevated temperature at the tooltip results in tool distortion that affects the integrity of the machined work part. The rake surface of the cutting tool during the variation in the cutting speed is shown in Fig. 6. A severe cut and abrasion are observed during the cutting speed at 65 m/min. Here, due to severe rubbing of the chip over the rake surface develops a huge cutting force, resulting in coating delamination and a significant crater wear. Also, some thermal micro-cracks are observed over the tool surface. The outer coating TiCN, which has a lower coefficient of friction, reduces the friction between the chip rear surface and the tool rake face. The penultimate coating, Al_2O_3, helps in reducing the crater wear on the tool [46]. These two layers protected the tool coating layer at a cutting speed of 81 m/min. The minimal delamination of coating is also observed during the process. With the further increase in the cutting speed beyond 95 m/min, an extensive detrimental crater wear is observed. The huge temperature develops, resulting in the removal of coating completely, wherein the substrate is exposed in machining the workpiece. Usually, this type of wear pattern is due to the overload condition of the tool over the machined surface. An increase in the flank wear is also observed, especially, when the cutting speed is 106 m/min. The detrimental crater wear, thermal softening and substantial flank wear cause the poor surface finish on the machined part, as seen from Fig. 6.



(a) 65 m/min (b) 81 m/min

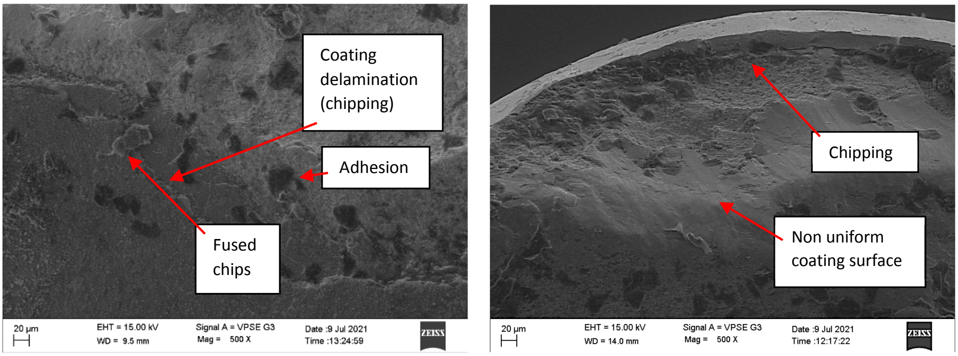


(c) 95 m/min (d) 106 m/min

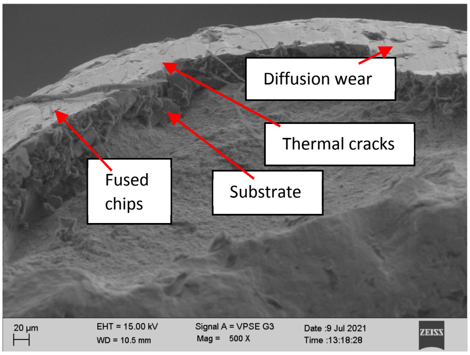
Fig. 6. Tool wear during the increase in various cutting speeds for machining Inconel 718

One of the general sources of information in predicting the tool wear is flank wear measurement, which is done over the flank surfaces. At the cutting speeds from 65 to 95 m/min, the depth of the flank wear was found to be between the range 0.1 to 0.25 mm, which is well within the limit, as specified in ISO 8688-2(1989). But at these cutting speeds, the flank wear depth progressively increased, so at the higher cutting speed, 106 m/min, a severe flank wear was observed. This is mainly due to the higher temperature induced over the flank surface at a higher cutting speed. The increased thermal/mechanical loads over the cutting surface also contributes to increasing flank wear. The CVD coating tool experienced lesser flank wear and $Al_2O{-}3$ restricted the heat flow from reaching the substrate, so the thermal softening of the work materials led to the formation of build-up edges over the tool edge.

The detailed SEM images for variation in cutting speed (except for 95 m/min – since it gives a similar results as 106 m/min) are shown in Fig. 7. During the material removal process at low cutting speeds, 65 m/min, the plastically deformed chips over the rear side start rolling over the rake surface, here the soft thin layers, experiencing high temperatures, sticks over the rake surface. These layers act as the



(a) 65 m/min (b) 81 m/min



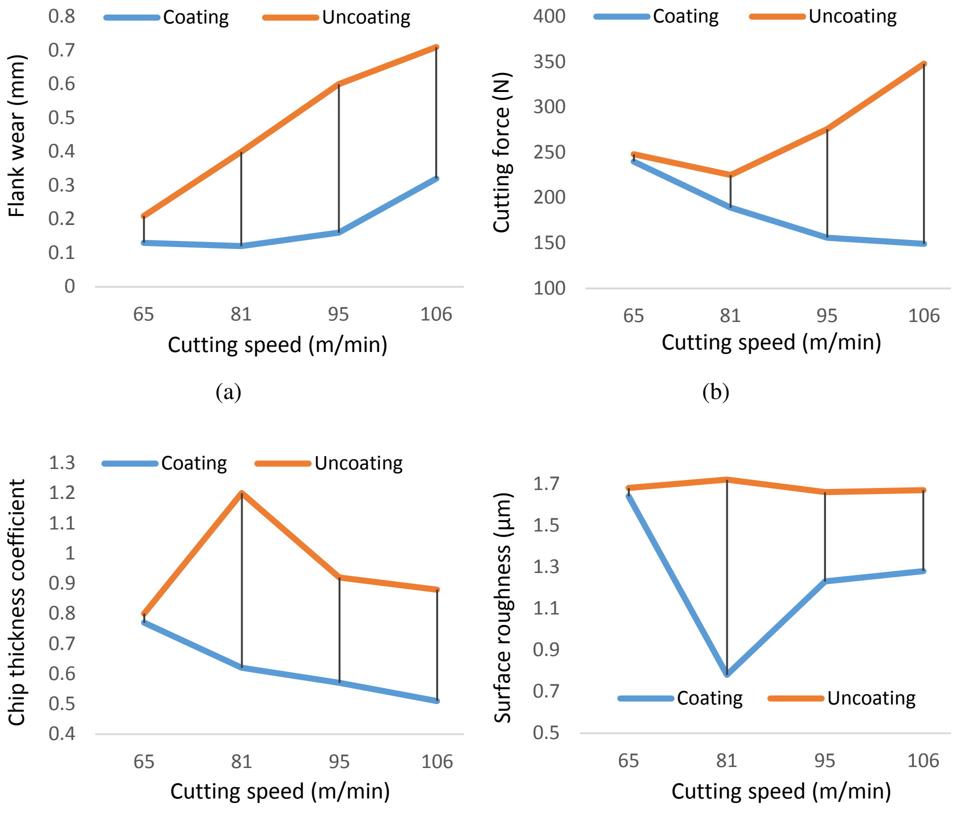
(c) 106 m/min

Fig. 7. Detailed tool wear during the increase in various cutting speeds for machining Inconel 718

secondary cutting edge of the tool and lead to forming some scratches or parallel grooves over the work material. This leads to increasing the surface roughness of the work material. At the higher cutting speeds, these scratches or parallel grooves lead to the formation of abrasion wear. The plastically deformed chips will act as hard inclusions (due to the work hardening of the work material on the constant interface over the tool surface) formed over the tool surface and will create abrasion wear on the workpiece. The abrasion wear is observed for 95 and 106 m/min in our analysis. With the increase in the abrasion wear, some portions of the tool, including micro-weld workpiece particles are removed from the tool surface and form pitting over the flank surface or notching over the tool edge. The notching may also be formed due to the sudden impact point load acting over the tool edge, as seen from Fig. 6d. Also, the continuous attachment of the chip over the tool surface, leads to chip fragmentation. These chips get stuck over the tool rake surface and get burnt due to the excessive heat developed during the machining process. These burnt chips are observed during machining at 65, 95 and 106 m/min cutting speeds. The burnt chips are generally formed due to the high temperature and atmospheric oxygen [47]. In the high-temperature machining process, the tool material tries to bond with the work material and vice versa, due to the high chemical affinity of the work material. This leads to diffusion during the process, where a smooth worn-our surface is observed over the rake surface. Apart from diffusion, thermal cracks are also observed at high temperatures. The elevated heat during the process aids in the formation of thermal cracks over the tool surface.

During the machining process, the formed burrs fix to the tool surface due to the pressure force acting on the burr and the welds over the rake surface. This adhered material then gets detached from the rake surface and thus promotes chipping off the coating from the tool surface. This results in the initiation of cracks in the coating surface and subsequently peeling it off during the machining process [48]. Hence, coating delamination is observed at the low cutting speed. Similar effects are also seen at higher cutting speeds (106 m/min), where the coating delamination develops a bumpy surface over the machined surface, which increases the surface roughness of the machined part. The fusion of chips formed at high temperatures is visible over the rake surface.

As discussed earlier, the attrition, abrasion, adhesion, and tool chipping are the major concerns for the tool wear in the case of uncoated tool inserts. In the case of the coated tool, apart from the above, the delamination of coating and chip fusion are the additional reasons for the tool wear. The abrasion is due to the fact that micro-welded hard particles rub over the tool surface and erode the rake and flank surfaces. Attrition is the reduction in the tool strength through a sustained attack or pressure. The delamination of the coating from the tool surface is due to adhesion, attrition, and others. Further, to understand the effect of coating substrate, the uncoated carbide tools are used to investigate the variation in the machining process and tool failure. In the case of cemented carbide tool, the flank wear is mostly dominant and deep with the increase in the cutting speeds. The abrasion of the tool over the hard workpiece surface leads to a rapid tool wear. At the minimum cutting speed, 50m/min, minimum flank wear of 0.21 mm, and at the highest cutting speed maximum flank wear of 0.71 mm is recorded. It is noticed that at the lowest cutting speed, 65 m/min, the flank wear was within the allowable limit ($\leqslant$ 0.3 mm). In the case of the coated carbide tool, the flank that wears up to 95 m/min was well within the limit, Fig. 8a. The cutting force was drastically reduced in the case of the coated tool, when compared with the uncoated tool inserts. This is mainly due to the presence of coating layers, TiCN and Al_2O_3. The TiCN coating aids in obtaining high fracture toughness and reduces abrasive wear. The Al2O3 coating imparts good oxidation resistance. The multiple layered coating aids in imparting high hardness on the tool surface and enables prolonged machining duration. The tool wear decreases during the process and hence reduces the cutting force, as is recorded in Fig. 8b. From the comparison of the chip thickness coefficients, it follows that an increased chip thickness is formed during the machining of uncoated tool inserts. Increased chip thickness attributes a larger work done during the material removal process. Overall, lower cutting force and increased chip thickness ratio aid reducing the coefficient of friction and the frictional resistance. These effects are seen with



(a) (b)

(c) (d)

Fig. 8. The effect of flank wear, cutting force, chip thickness coefficient and surface roughness with the increase in cutting speed during machining Inconel 718

the coated thickness when compared with the uncoated chip thickness. Surface roughness rises with the increase in the cutting speed and similar observations are noted with the uncoated tool insert machining. Surface finish is found to be improved in the case of a coated tool compared to the uncoated one. The coating of the tool protects the tools from deformation, abrasion, and oxidation, Figs.8c, 8d.

4. Conclusions

In the present work, the machining studies of the Inconel 718 were carried out in detail for a multi-layered carbide tool (TiCN/Al_2O_3). The detailed chip analysis, in terms of chip morphology, chip thickness ratio, cutting force, and chip tool contact length was performed. The tool wear was examined and its analysis was then carried out. A clear comparison between a coated and an uncoated tool in terms of various performance characteristics was made. The following conclusions were drawn from the work.

1. Continuous coiled chips, with an initially decreasing and then increasing chip length, are observed with the increase in the cutting speeds.
2. The chip thickness coefficient increases and then decreases with an increase in the cutting speed. At a cutting speed of 81 m/min, its maximum value is obtained due to the formation of a lower chip thickness. This is mainly due to an increase in the chip flow velocity.
3. The cutting force decreases with the increase in the cutting speed. At a higher speed, the thermal softening of the material facilitates decreasing the cutting force.
4. The chip tool contact length increases with the increase in the cutting speeds. A large variation in these values due to the dynamic nature of machining is observed. At the highest speed, the variation in the value is reduced due to the thermal softening of the material and uniform tool wear.
5. A large flank wear, coating delamination, thermal cracks, BUE, chipping off a tool, and chip fusion over the tool surface are observed at the larger cutting speeds
6. The attrition, abrasion, and delamination are the major concerns for the tool wear. The abrasion is due to the fact that micro-welded hard particles rub over the tool surface and erode the rake and flank surfaces. Attrition is the reduction in the tool strength through sustained attack or pressure. The delamination of the coating from the tool surface is due to adhesion, attrition, and others. All these phenomena are seen in both coated and uncoated chip thickness.
7. From the comparison between the coated and uncoated tool inserts one concludes that a lower cutting force, an improved surface finish, and better other parameters are observed in the coated inserts.

The data that support the findings of this study are available from the corresponding author upon reasonable request. The authors confirm that the data supporting the findings of this study are available within the article.

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