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Effect of Cutting Parameters on Tool Wear, Tool Life and Cutting Temperature During Dry Turning of Dss2205

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Abstract

It has been demonstrated that duplex stainless steels (DSS), which include an equal amount of ferrite and austenite, are better than single-phase steels such austenitic stainless steels (ASS). Improved features are linked to higher DSS performance, however these same qualities also make DSS more difficult to machine. Moreover, machining becomes more challenging due to the formation of Builtup Layers. In this work, 2205 Duplex Stainless Steel (DSS2205) was CNC dry turned, and the impact of machining parameters on tool wear, tool life, and cutting temperature was assessed. By changing the feed rate and cutting speed, experiments were carried out. For the DSS2205 machine in dry conditions, cutting settings were chosen to include a depth of cut of 0.7 mm, a cutting speed of 140 m/min, 180 m/min, and 220 m/min, and a feed rate of 0.14 mm/rev, 0.18 mm/rev, and 0.22 mm/rev. Dry turning was performed using an uncoated cemented carbide tool, a TiAlSiN-coated tool produced by the High Power Impulse Magnetron Sputtering (HiPIMS) coating technique, and a TiSiN-coated tool produced by the Scalable Pulse Power Plasma (S3p) coating technique. As a means of comparison, tool wear, tool life, and cutting temperature were measured. The tool life obtained with TiSiN (S3p) and TiAlSiN (HiPIMS) tools was four and three times higher, respectively than that of uncoated tools. The higher cutting temperatures that the coated tools demonstrated had no bearing on the machining performance because PVD coatings held up even at higher machining temperatures.

Keywords: - Coatings, HiPIMS, S3p, DSS2205, Wear.

I.Introduction:

DSS2205 offers superior strength, toughness, and resistance to corrosion, making it an ideal choice for a wide array of industrial applications, particularly in aggressive environments such as marine, chemical, and offshore [1].

Although DSS2205 has several favorable properties, machinability issues may arise when compared to traditional austenitic stainless steels. DSS2205's distinct microstructure and chemical makeup make machining operations more difficult. In order to overcome these challenges, it is crucial to choose the best cutting settings and machining environment for duplex steels [2-6].

For the amount of tool wear, the temperature produced during machining is a major consideration. Higher thermal conductivity of tool materials, in general, allows this generated temperature to enter the tool and as a result, causes faster tool wear and shorter tool life. The tool's surface needs to be less thermally conductive and more wear resistant so that heat generated during machining doesn't transfer to the workpiece or chips. No tool material can simultaneously satisfy the needs for surface and core characteristics. This is done by utilising cutting tools that have hard coatings applied to their surfaces. Surface coatings can enhance the tribological characteristics of cutting tools [7].

The temperature that is created during machining has a significant impact on the quantity of tool wear. Generally speaking, higher thermal conductivity of tool materials permits this generated temperature to enter the tool, leading to accelerated tool wear and a reduced tool life. The surface of the tool must be more wear-resistant and less thermally conductive to prevent heat from being transferred to the workpiece or chips during machining. No tool material can meet the requirements for both core and surface qualities at the same time. To do this, cutting tools with hard coatings applied to their surfaces are employed. The tribological characteristics of the cutting tools can be enhanced by surface coatings.

PVD HiPIMS technology is chosen over Chemical Vapor Deposition (CVD) because of its benefits, which include low deposition temperatures and environmentally friendly features.

The majority of research has focused on either developing mathematical models to estimate cutting temperature, tool wear, and tool life during DSS2205 machining, or on employing lubricants for DSS machining. Traditional machining techniques still offer a lot of room for cutting parameter adjustment. The application of recently created coating methods for carbide tools for DSS dry machining is the main topic of this study. Analysis is done on cutting temperature, tool life, and tool wear as optimization criteria.

II.Research Methodology:

Tool Wear and tool life Measurement

Figure 2.1 depicts the many types of tool wear like Tool face wear, Flank Wear, Nose bleed. The wear is counted three-times within wear region, and the average is used to evaluate performance [1].

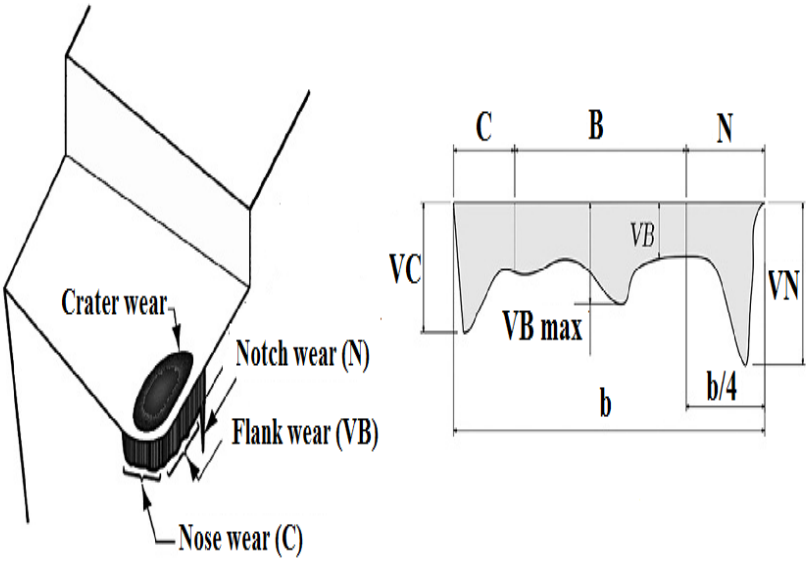


Figure 1. Types of wear in a cutting tool [1]

Figure 1 depicts a photographic perspective of tool wear measuring setup. In the current investigation, flank wear was measured using a Nikon measuring microscope equipped with a digital colour camera and measurement software.

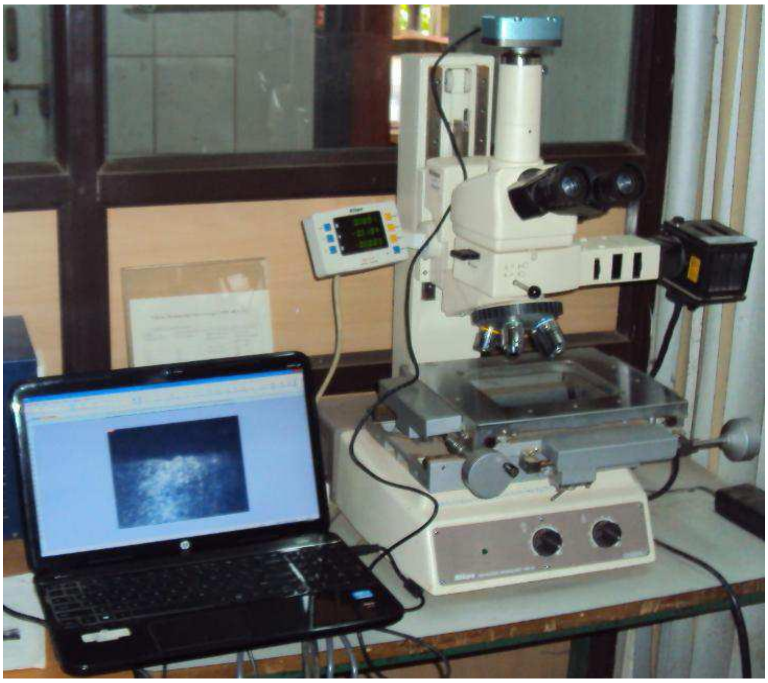


Figure 2. Photographic view of Nikon Measuring Microscope

The most popular piece of equipment for measuring chip thickness, crater wear, nose wear, and flank wear is the Nikon measuring microscope. When compared to flank and crater wear, nose wear was shown to be the most common type of wear in the current study. Tool life was estimated by measuring the mean nose wear.

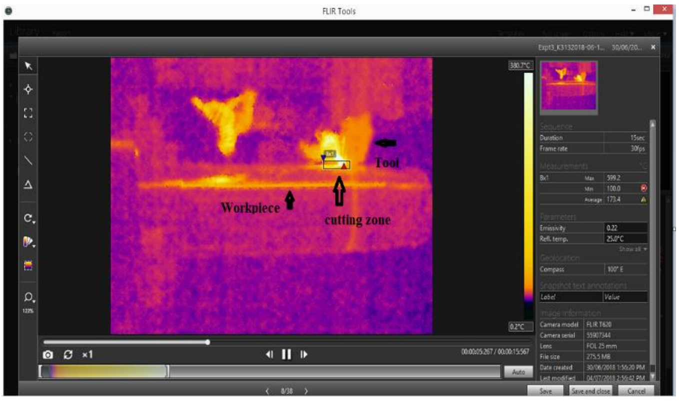
According to ISO a nose wear 0.3 mm for uniform wear and 0.6 mm for non-uniform wear is the criterion for deciding tool life. Accordingly, a nose wear of 0.6 mm was selected as a tool life criterion for deciding the tool life. Some of the researchers have quoted that surface roughness can be an indicator for tool to reach its life. Deterioration of the surface after machining is also considered while calculating the tool life.

Cutting Temperature Measurement

FLIR T620 thermal camera was used to count the temperature. 90 mm was selected as the cutting pass length for the purpose of determining the cutting temperature. Despite their high cost, thermal cameras are still among the most promising solutions for measuring temperature because they provide broad and non-contact temperature monitoring. Thus, the heat flow perturbation issue with the instrument is avoided. The camera can record immediate modifications in addition to the stages of chip formation and the area surrounding the work piece, tool holder, as well as tool posts because of its fast response, which enables high cutting speeds in machining experiments.

Figure 3. Set-up of FLIR T620 Thermal Camera

In order to record the formation of the chip and measure its temperature, FLIR's T620 excellent quality thermographic camera was used in this project. An example of a thermal image captured during machining is shown on the program's screen in Figure 4. The average temperature at the interface between the tool and the chip was found by analysing the movies captured throughout the experiment using the FLIR programme. The temperature analysis was conducted using a typical cutting zone.



Expt3_K3132018-06-1... 30/06/20...

Sequence

Duration	15sec
Frame rate	30fps

Measurements °C

Bx1	Max	599.2
	Min	100.0
	Average	173.4

Parameters

Emissivity	0.22
Refl. temp.	25.0°C

Geolocation

Compass	100° E

Snapshot text annotations

Label	Value

Image information

Camera model	FLIR T620
Camera serial	55907344
Lens	FOL 25 mm
File size	275.5 MB
Date created	30/06/2018 1:56:20 PM
Last modified	04/07/2018 2:56:42 PM

Figure 4. Thermal image during the machining

Table 1. Details of the cutting parameters for machining with uncoated, HiPIMS and S3p deposited single-layer coated tools

Cutting Tools	T1 (S3p TiSiN)
	T2 (HiPIMS TiAlSiN)
	T3 (Uncoated)
Input Parameters	Cutting Speed (Vc) = 140, 180 and 220 m/min
	Feed (f) = 0.14, 0.18, and 0.22 mm/rev
	Depth of cut = 0.7 mm
Response parameters	Tool Wear and Life
	Machined Surface Roughness
	Cutting Temperature

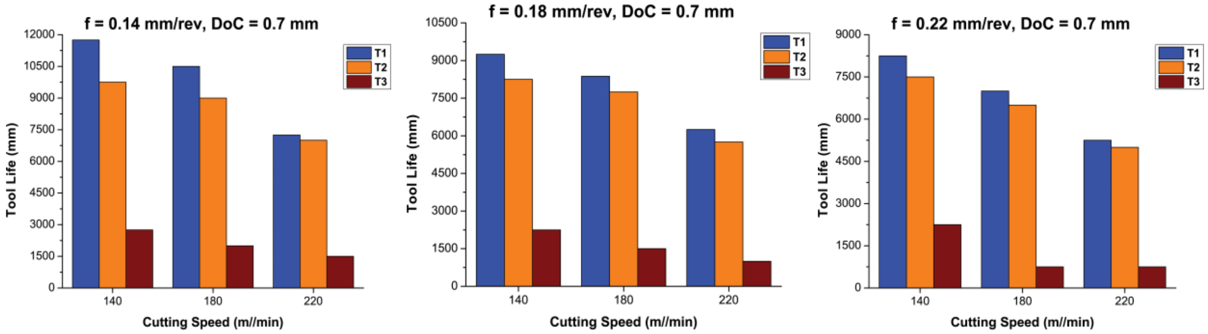
III.Result & Discussion

Effect of Cutting parameters on Tool Life

Figure 5 illustrates how cutting parameters like feed and speed affect tool life. It has been noted that when cutting speed as well as feed increase, tool life reduces. Uncoated tools (T3) showed least tool life followed by PVD S3p TiSiN (T1) and HiPIMS TiAlSiN (T2) tools.

As cutting speed increases temperature in cutting zone also increases and here thermal conductivity of coating plays an important role. Uncoated tools due to higher thermal conductivity, experiences higher cutting temperature which as a outcome gives faster wear in the initial stage of machining only.

A rise in feed value results in a decrease in tool life. This is because using larger feed values results in increased friction. Increased cutting temperature at the cutting zone cause faster tool wear as a result. On other hand even though, thermal conductivity increases with temperature, for coated tools the effect is very less. This is because of PVD method used for depositing the coatings. After some machining time when coating is delaminated, carbide tool is exposed to the actual cutting temperature and then tool wear out. At all the machining speeds similar results are observed.



(a) (b) (c)

Figure 5. Effect of cutting speed on tool life at (a) f = 0.14 mm/rev, (b) f = 0.18 mm/rev, (c) f = 0.22 mm/rev , depth of cut = 0.7 mm for T1, T2 and T3 tools

In the chosen parameters of the speed of cutting (140-220 m/min) with feeds (0.14-0.22 mm/rev), the tool life (machining length) of the uncoated tools ranged from 750 to 2750 mm. The T2 tools had the longest tool life, ranging from 5250 through 11750 mm, while the T1 tools showed a tool life around 5000 and 9750 mm. Comparing T1 tools to uncoated tools, the former had four times longer tool life at lower cutting rates of 140 m/min. The longest tool life, 11750 mm, was shown by T1 coated tools. T2 and T3 tools had tool lives of 9750 mm as well as 2750 mm, respectively. Tools showed reduced life at increased feed rates such as 0.22 mm/rev as opposed to 0.12 mm/rev. However, when all cutting characteristics were combined, the S3p TiSiN coated tool outperformed the other tools. The outstanding qualities of the S3p TiSiN coated tool are the reason for its performance. TiAlSiN coated tools have double the tool life than uncoated tools due to their exceptionally low stresses and excellent adhesion. Uncoated tools are subjected to considerable thermo-mechanical strain during dry turning. This results in excessive tool wear and reduces the tool's lifespan. When the speed of cutting increased by 140 to 220 m/min at a rate of feed of 0.14 mm/rev, it was found that the tool life for uncoated tools decreased from 2750 to 1500 mm. For T1 tools, the tool life decreased from 9750 to 7000 minutes, and for T2 tools, it decreased between 11750 to 7250 millimetres.

Figures 5(b) and 5(c) show a similar pattern of decreased tool life as we increase cutting speed, using a feed of 0.18 mm/rev and 0.22 mm/rev, correspondingly. When the cutting speed went up from 140 to 220 m/min at a feed of 0.18 mm/rev, the tool life for uncoated tools dropped from 2250 to 1000 mm. Tool life dropped from 9250 to 6250 mm for T1 tools and from 8250 to 5750 mm for T2 tools. Uncoated tools exhibited a drop in tool life about 2250 to 750 mm when the cutting speed was raised from 140 to 220 m/min at a feed of 0.18 mm/rev. In addition, the tool lives of the T1 and T2 tools decreased to 8250 to 5250 mm as well as from 7500 to 5000 mm, accordingly. With coated tools, the rate of tool life reduction is higher. This is due to the fact that tool wear advances more quickly when the coating delaminates. On the other hand, uncoated tools exhibit a constant decrease in tool life starting with the initial cutting pass. An intriguing finding is that, at a cutting speed of 220 m/min, there is less variation in the tool values of life for T1 and T2 tools at a feed of 0.14 mm/rev. However, there is a greater difference when cutting at 140 and 180 m/min, with the T1 tool outperforming the T2 tool due to its longer tool life. This demonstrates that at faster cutting speeds of 220 m/min, both coated tools are operating similarly. However, the T1 tool performed better at a reduced rate between 140 and 180 m/min since it combined sputtering and evaporation technologies for coating deposit. This will make it easier to choose the coated tool under specific cutting conditions. Generally speaking, it appears that the 140 and 180 m/min speeds for cutting are the most practical and cost-effective in terms of tool life among the chosen cutting conditions.

Effect of feed on tool life

Figure 6 illustrates the effect of feed on tool life. Tool life was shown to drop when the feed was raised between 0.14 to 0.22 mm/rev. For every combination of cutting settings, T1 tools performed better than other tools. When the feed rate was adjusted from 0.14 mm/rev to 0.18 mm/rev, the tool life of T1 tools decreased between 11750 mm to 9250 mm at a speed of cutting of 140 m/min. When the feed rate was increased to 0.18 mm/rev, the tool life decreased between 9250 mm to 8250 mm. With a rise in feed, the T2 and T3 tools both displayed a comparable decline in tool life. Because of an increase in the chip-tool interaction length as well as contact surface area, this occurs as feed increases. As a result, more thermal energy is generated. Furthermore, the additional feed causes the friction area in the subsequent deformation zone to rise, which ultimately raises the temperature. Higher cutting temperatures cause the tool's material to deteriorate and accelerate tool wear at the cutting zone. As a result, the tool lasts less time. However, excellent machining performance is made possible by the incredibly low stresses and high adhesion of coated tools.

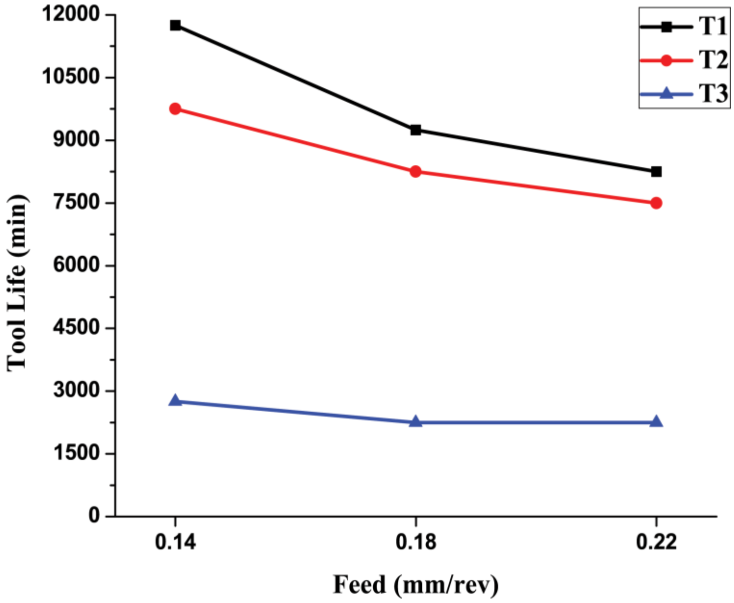
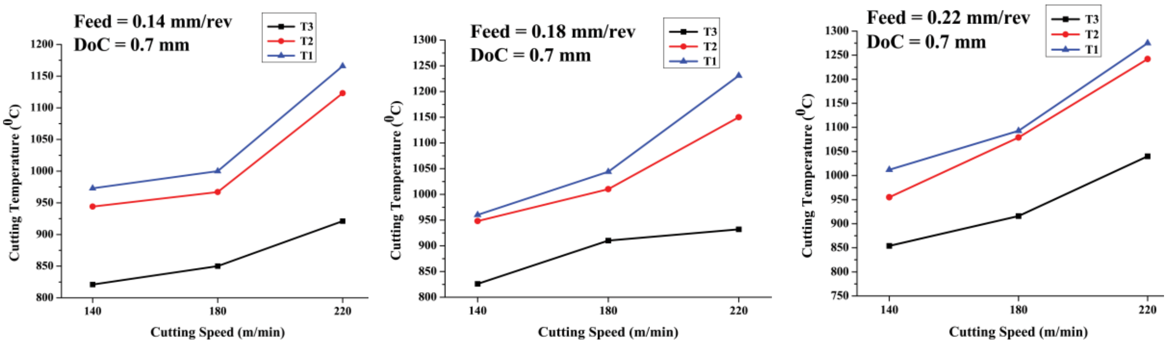


Figure 6. Effect of feed rate on the tool life of T1, T2 and T3 tools at a cutting speed of 140 m/min

Effect of cutting speed on cutting temperature

When turning DSS2205 under dry conditions, Figure 7 illustrate how cutting speed affects cutting temperatures for feed rates of 0.14, 0.18, and 0.22, respectively. On cutting temperatures, cutting speed had a greater impact than feed rate. The temperature of the cutting surface rose as a result of the increased cutting speed. The cutting temperature were observed to rise from 140 to 220 mm/rev at a rate of feed of 0.14 mm/rev, as shown in Figure 7(a).



(a) (b) (c)

Figure 7. Effect of cutting speed on cutting temperature at (a) f = 0.14 mm/rev, (b) f = 0.18 mm/rev, (c) f = 0.22 mm/rev, DoC= 0.7 mm for T1, T2 and T3 tools

This trend of increasing the cutting temperatures with the cutting speed was seen for all the tools used including coated and un-coated tools. This can be due to the strain rate and the specific energy that increases with the cutting speed. The precise cutting energy rises with cutting speed does. Shear energy and friction energy are the two categories into which the specific cutting energy is separated. The relationships between chip and shear velocity are called friction and shear energy, respectively. Consequently, arise in cutting speed causes a rise in specific energy, which raises the temperatures during cutting. Moreover, straining rate is equally responsible for rise in cutting temperatures.

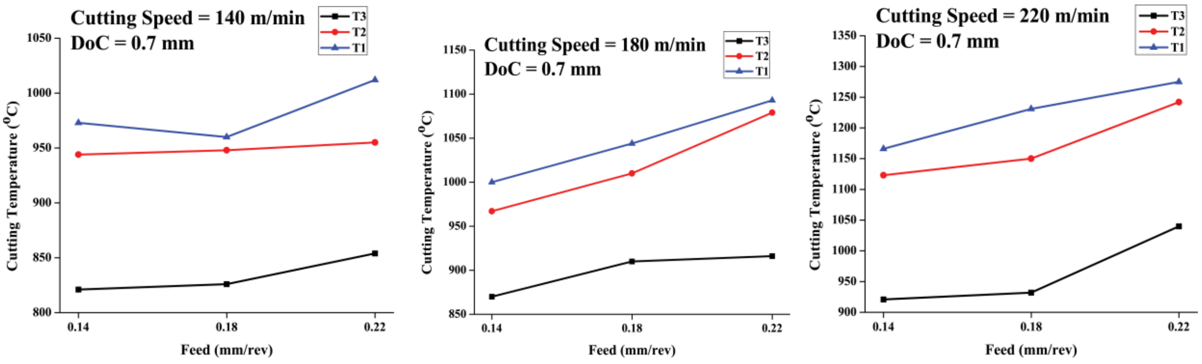
The temperatures during cutting for T3 tools rose from 821 to 921° C at a feed rate of 0.14 mm/rev as the cutting speed was raised from 142 to 220 m/min. The temperatures during cutting for T1 tools amplified from 973 to 1166° C, while the temperature for T2 tools raised from 944 to 1123° C.

Tools without coatings, T3 tools, had the minimum temperatures during cutting. Most of the heat created was transferred to the tool due to their higher thermal conductivity, whilst the cutting region had a lesser cutting temperature. However, the T3 tools' increased temperature made them weaker and caused quicker tool wear to be seen. The cutting region temperature for tools with coatings is significantly influenced by the coating's thermal conductivity. The decreased thermal conduction of all coated tools prevents heat from entering the tool. However, the heat either moves with the chips created during the machining or is transmitted to the workpiece. As an effect, coated tools are seen to have greater cutting temperatures.

Figure 7(a) shows that the rate of rise in cutting temperature was linear at feed rate of 0.14 mm/rev when the cutting speed amplified from 140 to 180 m/min. The rise rate of temperatures during cutting for T3 tools was only 5% when the cutting speed was raised from 180 m/min to 220 m/min. Furthermore, temperatures rose by 16% and 19%, respectively, for T1 and T2 tools. Faster cutting speeds' increased friction force and strain rates provide justification for this. T2 tools have been observed to have higher cutting temperatures than T1 tools. This happened as a result of T1 tool coating's stronger thermal stability and lower thermal conductivity (11 W/m.K) than T2 tool coating.

At feed rates of 0.18 and 0.22 mm/rev, respectively, the same trend of an increase in cutting temperature correlating with an upsurge in cutting speed was seen as showed in Figure 7(b) and 7(c) respectively. When the cutting speed amplified from 140 to 220 m/min, at a feed rate of 0.18 mm/rev, the cutting temperature for T1 tools amplified from 826 to 932° C. Temperatures during cutting for T1 tools increased from 960 to 1231° C, while those for T2 tools amplified from 948 to 1150° C. When cutting speed was amplified from 140 to 220 m/min at a higher feed of 0.22 mm/rev, a rise in cutting temperature from 854 to 1040° C was seen for T3 tools. The temperatures during cutting for T1 & T2 tools increased from 1012 to 127 ° C and from 955 to 1242° C, respectively.

Effect of fed rate on cutting temperature



(a) (b) (c)

Figure 8. Effect of feed rate on cutting temperature at (a) V_c = 140 m/min, (b) V_c = 140 m/min, (c) V_c = 140 m/min, DoC= 0.7 mm for T1, T2 and T3 tools

The effect of increasing feed rate from 0.14 to 0.22 mm/rev upon cutting temperatures at 140 m/min is shown in Figure 8(a). On the other hand, Figures 8(b) and 8(c) show how feed rate affects cutting temperatures while cutting at 180 and 220 m/min, respectively. Figure 5.21 makes it evident that all of the tools employed, including T1, T2, and T3, experienced an increase in cutting temperatures at a cutting speed at 140 m/min while the feed rate was raised from 0.14 to 0.22 mm/rev. The rate of material removal (MRR) or the quantity of material eliminated per unit of time, increases as the feed rate increases. To remove the material, more shearing energy was needed in this case. The quantity of heat produced in the area being cut zone grows with increased shear energy application, and eventually the cutting zone's temperature rises as well. The cutting temperatures with uncoated or T3, tools increased from 821 to 826° C at a cutting speed of 140 m/min when the feed rate rose from 0.14 to 0.18 mm/rev. Next, the cutting temperatures rose from 826 to 854° C as the feed speed rose from 0.18 to 0.22 mm/rev. Furthermore, for the T1 and T2 tools, the initial cutting temperatures went up from 973 to 960° C and from 944 to 948° C, respectively, for an increase feed rate from 0.14 to 0.18 mm/rev under the same cutting conditions. Furthermore, for T1 and T2 tools, the cutting temperatures went up from 960 to 1012° C as well as from 948 to 955° C, respectively, when the feed rate went up from 0.18 to 0.22 mm/rev.

Cutting temperatures of T3 tools have been shown to be lower than those of T1 and T2, or coated tools. This is explained by the fact that uncoated tools have a high thermal conductivity, which enables heat produced during manufacturing to enter the cutting tool rather than the cutting zone. When using uncoated tools, this lowers the cutting temperatures in the cutting zone. As a result, when compared to coated tools, the bare tools displayed lower temperatures. Additionally, this results in a decrease in T3 tool strength and an acceleration of tool wear rate. T3 tools eventually have a shorter tool life over coated tools.

When cutting at 180 and 220 m/min, a similar trend of rising cutting temperature with feed rate was seen. Cutting temperatures increased by 5% for T3 tools while the feed rate increased form 0.14 to 0.22 mm/rev with a cutting speed of 180 m/min. In contrast, it was 9% and 10% for T1 and T2 tools. This demonstrates unequivocally that coated tools are capable of having reduced thermal conductivity, even at greater cutting temperatures up to 1000° C. Additionally, the T3 tools exhibited a rise in cutting temperatures between 921 to 1040° C (12%), the T2 tools showed an improvement from 1123 to 1242° C (10%), and the T1 tools showed an increase from 1166 to 1275° C (9%), while maintaining a cutting speed for 220 m/min with an upsurge in feed rate between 0.14 to 0.22 mm/rev.

IV.Conclusions:

Using both coated and un-coated tungsten carbide tools, DSS 2205 was dry turned in the current research. Single-layer coatings applied utilizing a variety of sophisticated deposition methods, including HiPIMS and S3p, were utilized. The machining effectiveness of these tools was calculated using several cutting conditions and parameters. During the dry turning DSS 2205, it was observed that coating material produced using radical PVD coating deposition processes demonstrated improved machining efficiency when used with tungsten carbide tools. The following are some of the key conclusions reached from the current study:

- An increase in tool wear rate was noted with machining length. The uncoated tools only had a 750 mm tool life because of the significant friction and ultimately high cutting temperatures. The SEM image clearly demonstrated the chipping of the uncoated tools, which is the cause of their subpar performance.

- In the chosen parameters of cutting speed (140-220 m/min) with feed (0.14-0.22 mm/rev), the tool life (machining length) of the uncoated tools ranged from 750 to 2750 mm. The T2 tools had the longest tool life, ranging from 5250 to 11750 mm, while the T1 tools showed a tool life between 5000 and 9750 mm.
- Comparing T1 tools with TiSiN deposited by S3p and T2 tools with TiAlSiN deposited by HiPIMS to T3 (uncoated) tools, the former demonstrated a tool life that was 4.2 times greater.
- Increased feed values as well as cutting speed led to higher cutting temperatures. Uncoated tools showed reduced cutting temperatures in the area where they were cutting due to their higher heat conductivity. However, because more heat was carried into the uncoated tools, they showed signs of wear faster and had a shorter tool life.
- It was found that the cutting temperatures in the cutting zones rose in tandem with increases in feed and cutting speed. Coated tools demonstrated higher cutting temperatures because there are less heat conductivity. For T1, T2 and T3 tools, the corresponding cutting temperatures were 973, 944 and 821 at a feed rate of 0.14 mm/rev and a cutting speed of 140 m/min. It was found that the thermal conductivity of the coatings used was directly connected to the temperatures generated during the cutting operation.
- Cutting temperatures increased by 5% for T3 tools when the feed rate was raised from 0.14 to 0.22 mm/rev at a speed of cutting of 180 m/min. In contrast, it was 9% and 10% for T1 and T2 tools. This demonstrates unequivocally how coated equipment can have reduced heat conductivity.

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