Micro Structure and Wear Analysis of Carbide Tool in SS316 Material

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Abstract: In this research, austenitic stainless steel SS316 was machined utilizing textured carbide cutting tools under dry conditions. Wire spark erosion machining was used to create micro-textures on the tool rake's face. Machinability (MRR, average roughness, and tool wear) of stainless steel 304 (SS304) has been investigated using three major machining process parameters, specifically cutting speed, depth of cut, and feed rate. Using a scanning electron microscope, this study investigated the surface morphology of a Tungsten Carbide (WC) coating on austenitic stainless steel (SS316). For austenitic stainless steels coated with Tungsten Carbide (WC) as well as those without WC coating, wear and corrosion tests have been carried out. Research shows that coated Tungsten carbide (WC) over Austenitic Stainless Steel (SS316) provides longer corrosion life and superior surface material erosion resistance to high velocity air combined with Al2O3 abrasive particles than Austenitic Stainless Steel (SS316). Analysis of Scanning Electron Microscope pictures reveals that coated materials have improved surface behavior over un-coated materials.

Key words: Tool Wear analysis, Micro-machining, Micro-structures,

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INTRODUCTION

In the manufacturing industry, cutting costs are reduced, machine quality is improved, and more rigid materials are fabricated. High-speed machining improves machining efficiency by cutting down on machining time. High carbon content makes machining steels, cast irons, and super alloys harder. Limiting factors for cutting speed include temperature softening and the chemical stability of the tool material itself [1]. As manufacturing processes become more productive, the development and evolution of improved cutting tools are enhanced to obtain better tribological performance and wear resistance. Because of the cutting's severe nonlinearity and the nuanced interactions between deformation and temperature fields, there is a significant knowledge gap in metal cutting mechanics today [2]. Mechanical engineers' primary focus has long been on high-speed manufacturing. As production increases, so do the number of cutting tools available, both in terms of materials and designs. Instead of increasing productivity and improving surface smoothness, high-speed machining causes significant amounts of heat to be generated during the cutting process. When a lot of cutting force is used, the power need goes up [3]. By using Finish Hard Turning, producers may produce finished parts with high-quality finishes on hardened materials without the use of grinding. To reduce costs, boost productivity, and improve material qualities, Grinding is more time consuming than hard turning with a multilayer coated carbide tool because of the wear on the tool. Manufacturing companies result in increased product quality and efficiency while incurring lower costs. Manufacturers prefer hard turning because it eliminates the need for lubricants such as cutting fluids

Theory of metal cutting:

Every modern consumer product uses some form of metal cutting as it's the backbone of engineering and manufacturing. An effective metal-cutting operation depends heavily on the cutting tool. As economic competition has increased, so has research into metal cutting tool materials, resulting in the development of novel materials with exceptional performance and future scope for productivity growth that is simply incredible [4]. Using cutting tools designed to process new materials at maximum efficiency, manufacturers are always on the lookout for new materials and applying them to advanced composite solutions. The following are the primary features that each cutting material must have in order to fulfil its necessary functions:

- To overcome wearing action, it is necessary
- The ability to withstand high temperatures
- A high level of resistance to vibration

As hardness increases, so do the tensile properties of many materials. When heavy cuts are made on work pieces with holes or pockets, materials in the list's more incredible hardness section will shatter

LITERATURE REVIEW

When producers' performance is negatively affected by poor abrasive wear behavior, the entire process of agriculture becomes economically unviable [5]. This leads to higher agricultural costs. Rotavator blades have been coated, nitrided and carbonitrided, borided and shot peened to increase their working life by scientists and researchers. In the short term, these strategies have demonstrated encouraging outcomes in terms of enhancing wear resistance, but there is a lack of data regarding their long-term success [6]. Chipping away this small layer of surface material results in significant wear due to the improvements provided by these methods. As a consequence, it is necessary to investigate material processing procedures for increasing the rotavator blade material's abrasion resistance. When reviewing CVD diamond deposition on steel using different interlayers, [7.] also address the influence of deterministic microstructures on adhesion. That's because of significant thermally induced residual tensions that are generated in the film and cause spontaneous delamination on flat substrates [8]. This is why they tested a laser-etched substrate surface and found that spontaneous deformation can be prevented provided proper intermediary layers are applied. The mechanical interlocking was mostly responsible for this, whereas no conclusions were drawn the about micro structure's influence on residual stresses in the diamond layer. The design of the microstructure was also left uninformative. A number of studies were compared as a result of this in [9]. which used the substrate's surface microstructure as a partial solution and discovered that roughness had a favorable impact on layer adhesion This study found that most substrate microstructures were stochastic, and only a few surfaces with geometrically defined microstructures were examined in depth [10]. As a result, certain guidelines for recording and deriving specific attributes of particle-blasted surfaces were utilized for this study.

RESEARCH METHODOLOGY

A three-jaw centre lathe was used for the experiment, which was done in dry conditions. Using a tool that can feed deep work while traversing the work, a lathe eliminates unwanted material such as chips from a revolving work piece. This work piece has a hole drilled in the face so that it can be supported by the tailstock while it is being machined.

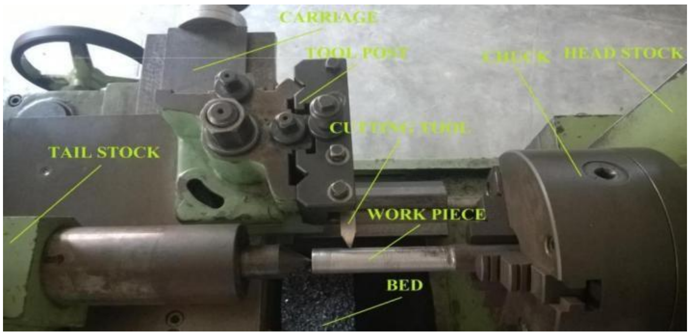

Figure 1: Experimental setup

Cylindrical SS304 rod (23*63.7 mm) used in the project. Carbide Tip Tool cutting tool (13*101.98 mm). It is done at various speeds and depths of cut. Feeding can be maintained at a steady rate. A quick look at the most important machining parameter setting is provided in Table.

Table 1: Main machining parameters of the experiment

Parameters	Value
Feed (mm/rev)	0.2,0.4,0.6
Speed (rpm)	800,1000,1200
Depth of cut (mm)	0.2, 0.4,0.5

During machining, the tool chip contact reaches its highest temperature. In other words, we use a Thermal imager, which is a non-contact temperature monitoring device, to get the information we need. These devices use infrared light (at temperatures above absolute zero) to see through objects and measure the amount of heat radiated. The energy radiated is converted into a temperature readout, which is known as a thermo gram. Thermo grams are images of objects in the infrared spectrum that have been captured by a camera and shown as a thermal image. As the cutting tool is being machined, the temperature on the imager (which measures from -20 degrees Celsius to +600 degrees Celsius) is being used to determine how hot it should be. When machining, a stop watch is used to keep track of how much time has passed

Measurement of Tool Wear

Each run used a different cutting edge. They made use of a fresh cutting edge. Using a Toolmaker's Microscope and a digital readout device, the tool wear was calculated See Fig. for an eye-level view of the tool insert.

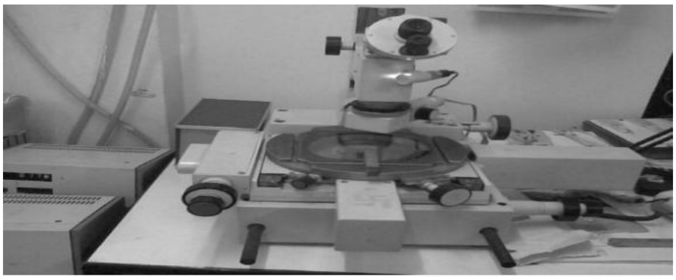

Figure 2: Tool makers' Microscope

Figure 3: View of the insert through the eyepiece

Surface Micromachining

In surface micromachining, thin film layers are deposited on a substrate's surface and used to build structural MEMS components. Instead of building components inside a substrate as is the case with bulk micromachining, Surface micromachining removes material by removing a thin layer from the top. A scanning electron microscope was used to make micro gears via surface micromachining (SEM).

Stainless Steel 304:

There are many different grades and finishes of stainless steel available, but most people prefer to buy it annealed or cold wrought. Portion of stainless steel 304 with chromium (Cr) and nickel (18/8 stainless steel) (Ni). When it comes to low temperature strength and mechanical qualities, Type 304 excels. It also welds beautifully. Type 304 does not undergo heat treatment hardening, making stamping and bending possible. A wide range of industries, such as furniture, food processing, and pharmaceuticals, rely on the versatility of SS304.

Table 2: Physical Properties of Stainless Steel 304

Property	Value
Density	8.00 g/cm^3
Melting Point	1450 °C
Modulus of Elasticity	193 GPa
Electrical Resistivity	0.42 x 10^{-6} Ω.m
Thermal Conductivity	16.2 W/m.K
Thermal Expansion	17.2 x 10^{-6}/K

Heat Resistance of Stainless Steel 304

Because of its high oxidation resistance, stainless steel 304 can be used intermittently up to 870°C and continuously for up to 925°C. But if corrosion resistance in water is a concern, don't use it continuously at temperatures between 425-860°C. Carbide precipitation resistance makes 304L the best choice in this case. Grade 304H is ideal for applications requiring high strength at temperatures up to and including 800°C. When exposed to water, this substance will not corrode.

Applications

- Chemicals, petroleum, metallurgical machinery, aircraft, and food processing equipment all use it. Also, AISI 304 stainless steel is utilized when creating home furnishings and accessories for the family.
- Stainless steel 304 is used to make a variety of steel products, including sheet, plate, tube, and pipe.

RESULTS AND DISCUSSIONS

The microstructure effects of the workpiece material are crucial in micro-machining. Micro scale tool dimensions or features are of the same order as grain size and cannot presume that the work piece material's microstructure is uniform in macro scale. The work piece material is considered to be isotropic and homogeneous in macro scale because of this. Because the cutting depth is only a few micro meters, chips occur frequently inside the grain. Surface roughness varies from grain to grain due to crystallographic orientation and elastic recovery during in the material phase. They recommend cutting at a depth 10 times greater than the grain size of the particular material in order to prevent crystallographic grain effect and get a high-quality finish. Shimada et al. investigate the relationship between the tool edge and the material of the work piece. In molecular dynamics simulations, cutting speeds of 2000 m/s resulted in kinetic energy transferred to the work piece that was significantly more than cohesive energy.

Operating with a constant grain size ensures consistent results. The impact of micro structure on surface formation and cutting force in a micro-end milling operation on single- and multi-phase materials should also be investigated. In single phase materials, the edge radius effect has a considerable impact on surface generation due to the thinness of the chips. This case study found that as silicon was machining, surface roughness altered as a result of three unique effects: a geometric effect, an influence of the minimum chip thickness, and an impact of burr formation on grain boundaries on surface roughness.

A micro-machining experiment carried out on a variety of materials by Furukawa has shown that the cutting mechanism varies substantially for single crystal, polycrystalline, amorphous materials, and materials that are either brittle or ductile. Unreformed chip thickness (feed per tooth) and tool engagement duration were shown to be substantially correlated with cutting force, with cutting force increases exponentially as cut depth decreased below 3 meters for all materials tested. Amorphous acrylic resin or single-crystal fluorite has a more significant fluctuation in cutting power, resulting in greater cut depth. When surface fractures vanished, machining had reached a ductile condition. When ductile cuts were compared to shallow cracks, shallow cracks were found to depend on silicon's crystallographic orientation

Analysis of Adhesive Wear Process:

When adhesive wear occurs, a series of events occur: adhesive chips form, cutting ability diminishes, and so on. Analysing microcosmic and macroscopic processes allows for a straightforward classification of adhesive-induced wear into four stages

Micro structures of the experimental study for SS316 micro machining coated carbide tool

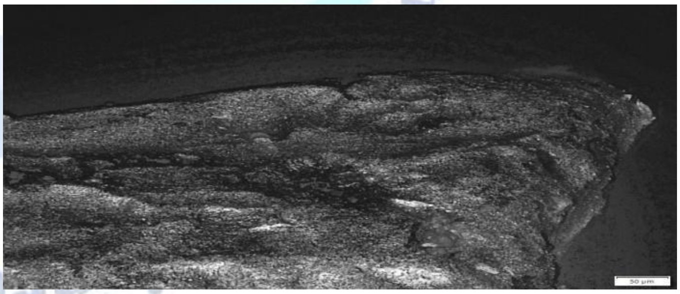

Figure 4: Feed: 600, Speed: 1500, Depth of cut: 0.1 Microstructure 200x

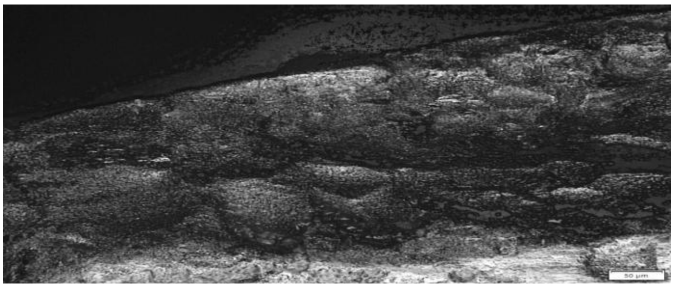

Figure 5: Feed: 600, Speed: 2000, Depth of cut: 0.2 Microstructure 200x

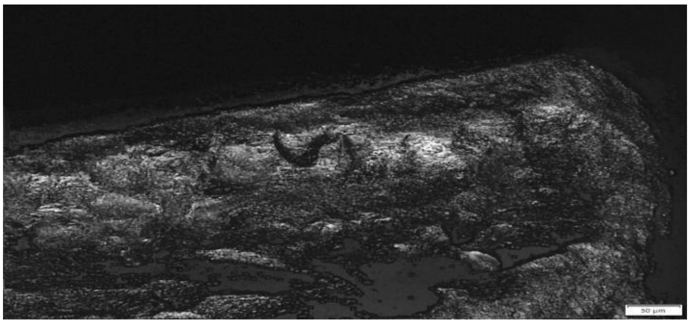

Figure 6: Feed: 600, Speed: 2500, Depth of cut: 0.3 Microstructure 200x

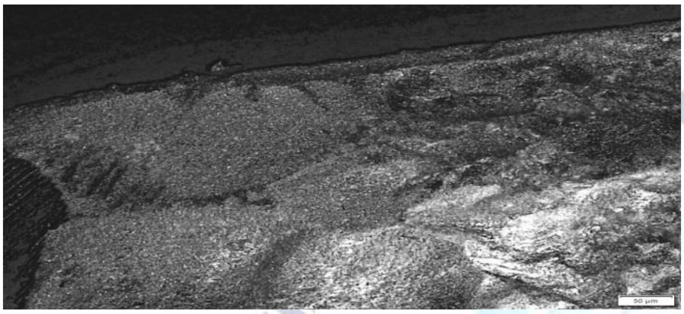

Figure 7: Feed: 600, Speed: 3000, Depth of cut: 0.4 Microstructure 200x

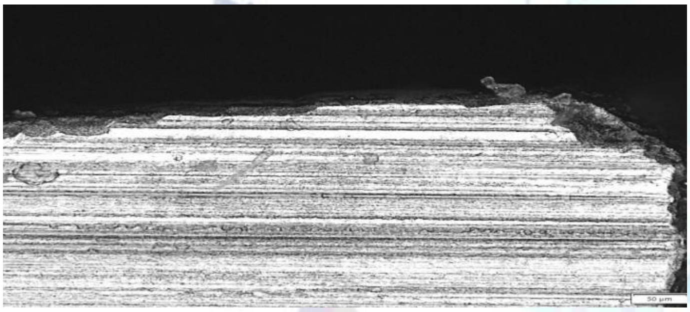

Figure 8: Feed: 800, Speed: 1500, Depth of cut: 0.2 Microstructure 200x

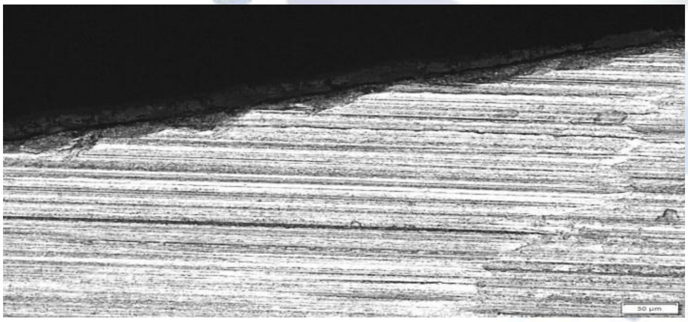

Figure 9: Feed: 800, Speed: 2000, Depth of cut: 0.3 Microstructure 200x

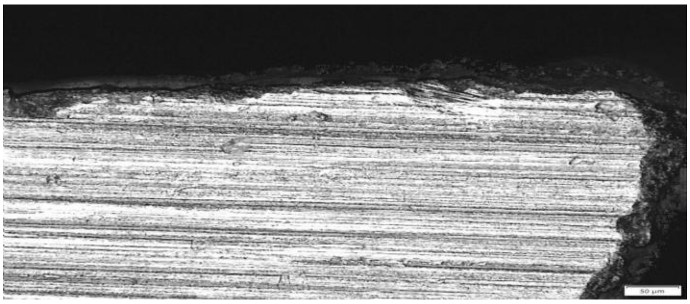

Figure 10: Feed: 800, Speed: 2500, Depth of cut: 0.4 Microstructure 200x

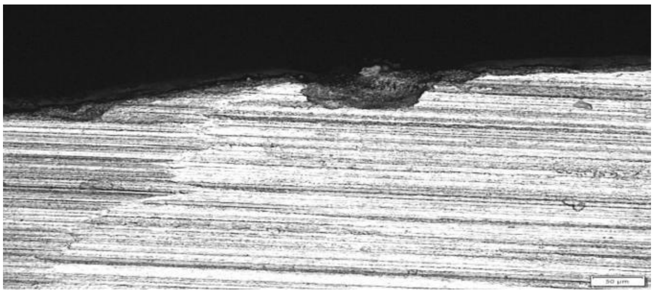

Figure 11: Feed: 800, Speed: 3000, Depth of cut: 0.1 Microstructure 200x

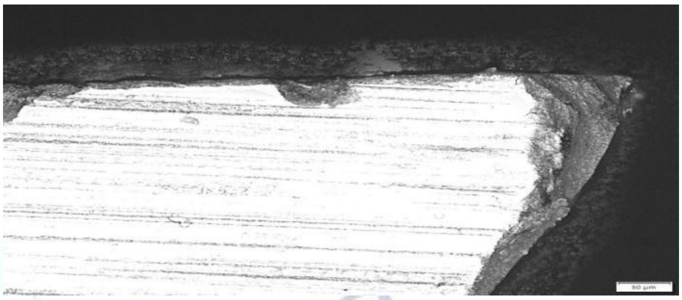

Figure 12: Feed: 1000, Speed: 1500, Depth of cut: 0.3 Microstructure 200x

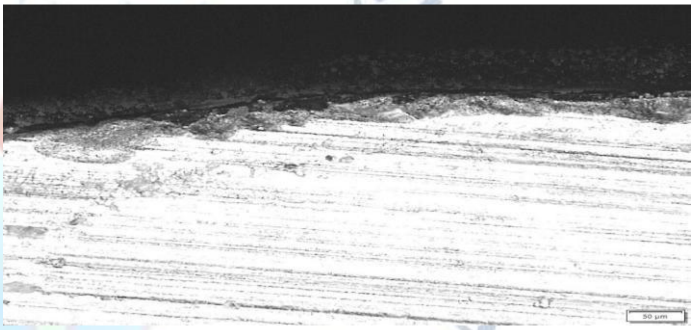

Figure 13: Feed: 1000, Speed: 2000, Depth of cut: 0.4 Microstructure 200x

Figure 14: Feed: 1000, Speed: 2500, Depth of cut: 0.1 Microstructure 200x

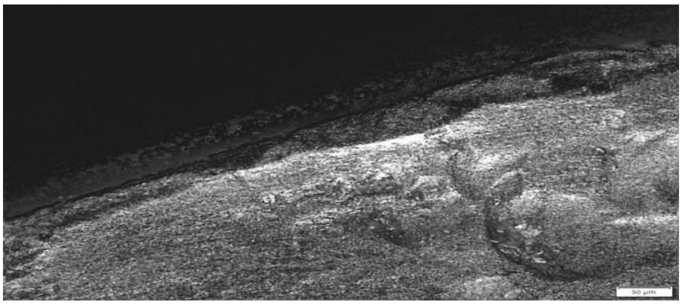

Figure 15: Feed: 1000, Speed: 3000, Depth of cut: 0.2 Microstructure 200x

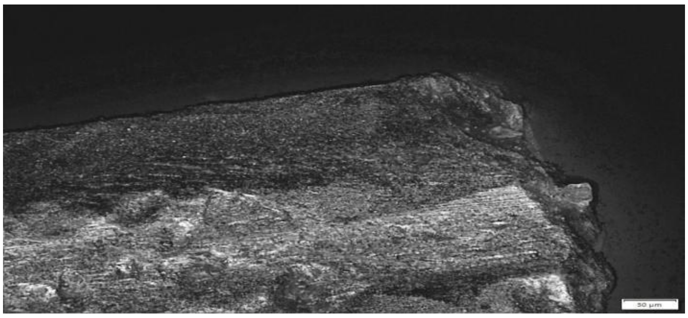

Figure 16: Feed: 1200, Speed: 1500, Depth of cut: 0.4 Microstructure 200x

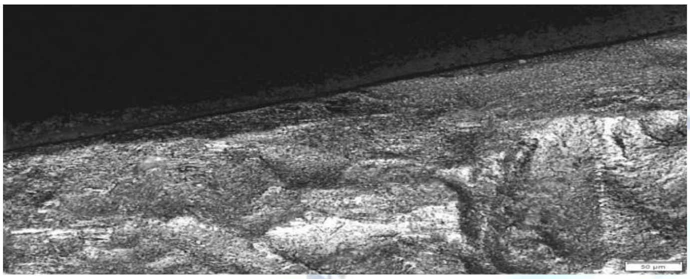

Figure 17: Feed: 1200, Speed: 2000, Depth of cut: 0.3 Microstructure 200 x

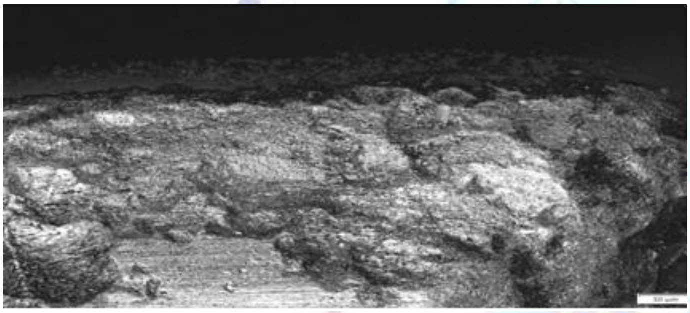

Figure 18: Feed: 1200, Speed: 2500, Depth of cut: 0.2 Microstructure 200x

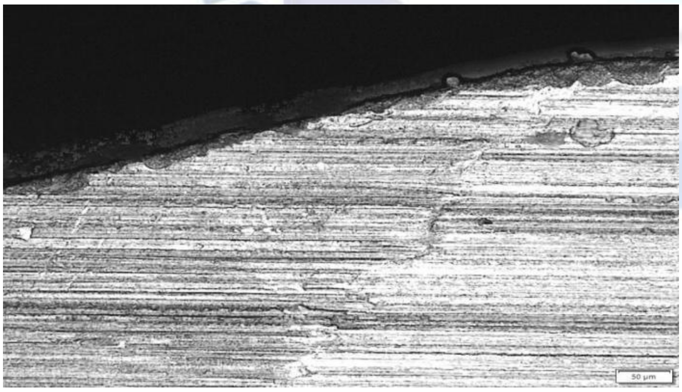

Figure 19: Feed: 1200, Speed: 3000, Depth of cut: 0.1 Microstructure 200x

S .no	Depth of cut	Feed rate	Spindle speed	Tool flank wear(mm)
1	0.1	600	1500	0.028
2	0.1	800	2000	0.024
3	0.1	1000	2500	0.022
4	0.1	1200	3000	0.029
5	0.2	600	2000	0.038
6	0.2	800	2500	0.040
7	0.2	1000	3000	0.038
8	0.2	1200	1500	0.039
9	0.3	600	2500	0.049
10	0.3	800	3000	0.052
11	0.3	1000	1500	0.047
12	0.3	1200	2000	0.048
13	0.4	600	3000	0.052
14	0.4	800	1500	0.063
15	0.4	1000	2000	0.052
16	0.4	1200	2500	0.049

In addition, the machine tools should be simple to automate. This difficulty has been addressed by developing unorthodox machining methods, which are known as unconventional machining processes. The novel machining process's application range is limited by the material's qualities, such as electrical and thermal conductivity, melting temperature, and electrochemical equivalent. These procedures are becoming increasingly common and unavoidable on the shop floor. Developing new machining processes for hard, high-strength, temperature-resistant alloys was motivated by the search for better ways to produce complex forms SS304 and heat resisting steels etc.). Rapid advancement in the aerospace, automobile, nuclear engineering and medical fields has been made possible by using these difficult-to-machine materials.

Conclusion:

Tungsten carbide-coated Austenitic Stainless steel and uncoated Austenitic Stainless steel were studied for wear, corrosion, and SEM surface characterization. The results of the experiment led to the following assumptions.

For both uncoated and coated materials, the erosion rate increases as the erodent flow rate increases.

- This wear occurs as a result of increased velocity and pressure applied to both the coated and uncoated materials.
- In comparison to untreated specimens, coated specimens showed extremely good corrosion and erosion resistance.

- For uncoated materials, SEM image analysis shows that corrosion causes grooves, craters, and debris on the surface to form over time. On the other aspect, the layered material does not show any major surface defects

Therefore, it has been suggested that machining of hard material at higher speed with an average feed rate and depth of cut can produced ideal machining condition as a solution to secure the best machinability.

- While comparing the performances of textured and plain cutting tools, abrasive wear mechanism was noticed
in plain cutting tool and adhesive wear on textured nose. Due to adhesion built-up edge was found at tool tip
to produce discontinuous chip on machining process.

- A solution has been suggested to ensure the best possible mechanical characteristics by using high-speed machining with an average feed rate and depth of cut to cut through challenging materials.

Abrasive wear mechanisms were found in simple cutting tools, while adhesive wear was found on the textured nose of a textured tool. A built-up edge at the tip of the tool was observed to produce a discontinuous chip during the machining process because of adhesion.

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