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STUDY OF MACHINABILITY CHARACTERISTICS FOR TURNING AUSTENITIC (316L) AND SUPER DUPLEX (2505) STAINLESS STEEL USING PVD-TIALN NANO-MULTILAYER INSERTS

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ABSTRACT

In this research work, we have intended to study the machinability of dry turning of austenitic stainless steel AISI 316L and Super Duplex 2507 stainless steel with coated carbide PVD - TiAlN Nano-multilayer. The turning operations were performed at three different cutting speeds (79, 121 and 188 m/min); constant feed rate (0.159 mm/rev) and depth of cut (1 mm) respectively. The effect of cutting speed in cutting temperature, the cutting force, surface roughness, tool wear and chip breaking were analyzed. It reveals that the higher cutting force and poor surface finish were found in the Super Duplex 2507 stainless steel over austenitic stainless steel AISI 316L. It is observed that higher tool wear occur in case of Super Duplex 2507 stainless steel over an austenitic stainless steel AISI 316L. The collected chips of various cutting parameters have shown that friendlier-to-machine chips are obtained when machining austenitic stainless steels over the duplex stainless steel grades. Finally, Super Duplex 2507 stainless steel displays poorer machinability responses.

Keywords: stainless steel, dry turning, cutting force, Surface roughness, tool wear, chip breaking.

INTRODUCTION

AISI 316L stainless steel is being widely used as biomaterials and for the construction of buildings. More specifically, due to its unique property of good corrosion resistance and biocompatibility, AISI316L stainless steel is used in the medical field as an implant material. Duplex stainless steel (DSS) are extensively being used in many industrial sectors like desalination, chemical tankers, pressure vessels, storage tanks, machinery in the pulp and paper industry, and also in civil engineering applications [1].The applications and markets of duplex stainless steels are increasing continuously, owing to its outstanding properties and its relatively low cost.

In general, stainless steels have: low thermal conductivity, high work-hardening rates, high tensile strengths, high toughness, and high ductility. Stainless steels are often considered as poorly machinable materials. High strength and work hardening rate cause difficulties from the machining point of view. Each stainless steel family has its own general set of machining rules. Over the last few years, many research works have been done to investigate the machining of stainless steels.

LITERATURE REVIEW

Jukka Paro *et al* [2] investigated the active wear and failure mechanism of TiN coated cemented carbide tools when machining X5 CrMnN 18 18 austenitic stainless steel. It reported that higher nitrogen content decreases the cutting force and the machinability. Outeiro *et al* [3] investigated the influence of cutting process parameters on machining performance and surface integrity generated during dry turning of Inconel 718 and austenitic stainless steel AISI 316L with coated and uncoated carbide tools. It reported that higher surface residual stresses are generated when machining with the uncoated tool than the coated tool. Also, higher residual stress values were obtained on the transient surface than on the machined surface.

Bonnet *et al* [4] developed the friction model to describe the friction coefficient at the interface during the dry cutting of an AISI316L austenitic stainless steel with TiN coated carbide tools. It has been shown that the friction coefficient is mainly dependant on the sliding velocity, whereas the pressure has a secondary importance. Ilhan Asiltürk and Süleyman Nes_eli [5] determined multi-objective optimal cutting conditions and mathematic models for surface roughness (R_a and R_z) on a CNC turning of AISI 304 austenitic stainless work piece by a coated carbide insert under dry conditions. The influence of cutting speed, feed rate and depth of cut on the surface roughness is examined. The results indicate that the feed rate is the dominant factor affecting surface roughness, which is minimized when the feed rate and depth of cut are set to the lowest level, while the cutting speed is set to the highest level.

Gerth *et al*. [6] analyzed the adhesion between chip and tool rake face by studying the initial material transfer to the tool during orthogonal machining at 150 m/min. Two types of work material were tested, an austenitic stainless steel, 316L, and a carbon steel, UHB 11. The tools used were cemented carbide inserts coated with hard ceramic coatings. Two different CVD coatings, TiN and Al_2O_3, produced with two different surface roughnesses, polished and rough, were tested. The influences of both tool surface topography and chemistry on the adhesion phenomena in the secondary shear zone were thus evaluated. Philip Selvaraj *et al* [7] optimized the dry turning parameters of two different grades of nitrogen

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alloyed duplex stainless steel with TiC and TiCN coated carbide cutting tool inserts by using Taguchi method. The cutting parameters are optimized using signal to noise ratio and the analysis of variance. The effects of cutting speed and feed rate on surface roughness, cutting force and tool wear were analyzed. The predicted results are found to be closer to the experimental results within8% deviations.

Krolczyk *et al* [8] studied the CVD coated carbides tool life and the tool point surface topography. The study, determined the cutting conditions in the process of turning duplex stainless steel (DSS), and detailed identification of wear mechanisms occurring on the rake face and major flank. The results of wear occurring on both tool points were compared with the width of the flank wear in relation to the period of the steady-state wear of the tool point. Occurrences of various mechanisms have been proven, such as abrasive wear and adhesion wear. Where machining without the use of a cooling lubricant occurred, longer tool life has been determined as well as a greater resistance to abrasive wear of the tools which are coated with Al_2O_3.

The cited literatures confirmed that only limited investigations have been carried out on the machinability study of super duplex2507andaustenitic AISI 316L stainless steel. But there is no study on turning of Super Duplex 2507 stainless steel with PVD coated carbide TiAIN Nano-multilayer so far in the literature. Hence, an attempt has been made in this work to investigate the machinability of dry turning operations of AISI 316L austenitic stainless steel and Super Duplex 2507 stainless steel with PVD coated carbide TiAIN Nano-multilayer.

Experimental Conditions and Procedure

The dry turning operations were carried out on an Austenitic stainless steel AISI 316L and Super duplex stainless steel 2507 (Ø 50 * 250) with PVD coated carbide TiAIN Nano-multilayer insert of ISO CNMG120408FF WS10PT.The tool holder used for machining is ISO PCLNR 2020 K12 (Kennametal).The turning experiments were performed at a depth of cut (1 mm), feed rate (0.159 mm/rev) and cutting velocities of 79, 121 and 188 m/min. All the tests were conducted under dry cutting conditions. Dry machining is more popular in manufacturing as a means of reducing overhead costs and protecting the environment. It has great significance for the factors of both economics and environment. Turning tests were performed on a Nagmati-175 lathe with a variable speed between 54 and 1200 rpm. The experimental setup is shown in Figure-1.

The temperature was measured on the rake surface using a non contact infrared thermometer with an accuracy of ±1.0% reading. The chips obstruct the IR rays some time before the target on the rake surface. The major portion of heat generated by the machining process is carried away only by the chips. The measured cutting temperatures do not represent the actual value. The cutting force was measured by an online force measurement system including a Kistler type 9257B piezo-electric three component dynamometer, a Kistler type 5070A12100 multi-channel charge amplifier and a PC-based data acquisition system (Dynaware). The surface roughness was measured using a contact type stylus - Surtronic3+ Roughness Checker. Tool wear was analyzed by a scanning electron microscope (SEM).

Figure-1. Experimental setup.

RESULT AND DISCUSSIONS

The present experimental study involves the dry turning of an austenitic stainless steel AISI 316L and Super Duplex 2507 stainless steel with coated carbide PVD - TiAIN Nano-multilayer. The experiments were conducted at three different cutting speeds (79, 121 and 188 m/min) and constant feed rate (0.159 mm/rev) and depth of cut (1 mm). The effect of cutting speed on cutting temperature, cutting force, surface roughness, tool wear and chip breaking were analyzed for both austenitic stainless steel AISI 316L and Super Duplex 2507 stainless steel.

Cutting Temperature

The variation in cutting temperature with cutting velocities in the turning of austenitic stainless steel AISI 316L and Super Duplex 2507 stainless steel under dry cutting is shown in Figure-2. The cutting temperature increased with increase in cutting velocity in both the work - tool combinations. In all sets of experiments, turning of Super Duplex 2507 stainless steel exhibits higher cutting temperature over austenitic stainless steel AISI 316L. This is because of, higher mechanical strength and lower ductility than standard austenitic stainless steels.

During the machining of Super Duplex 2507 stainless steel, which in turn prone to mechanical strengthening, which alters the mechanical properties of the surface layer and ultimately lead to heterogeneous surface during machining which leads high temperature generation because of two phases possess varying affinities for alloying elements in duplex stainless steels. And also the strength of super duplex 2507 stainless steel

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is higher than that of the single-phase austenitic stainless steel. Therefore, super duplex 2507 stainless steel are expected to be more difficult-to- machine than the standard austenitic stainless steels.

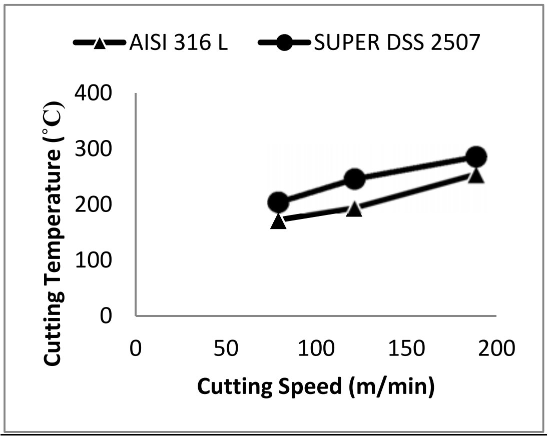

Figure-2. Variation in cutting temperature with cutting velocities.

Cutting Force

The influence of cutting velocity on cutting force in the turning of austenitic stainless steel AISI 316L and Super Duplex 2507 stainless steel is shown in Figure-3. It clearly appears that with the increase in cutting speed, the cutting force decreases due to decrease in shearing area. The cutting force at a cutting velocity of 79 m/min and feed rate of 0.159 mm/rev was 225 N and 245 N for the turning of austenitic stainless steel AISI 316L and Super Duplex 2507 stainless steel respectively. The value of cutting force at a cutting velocity of 188 m/min and feed rate of 0.159 mm/rev was 200 N and 210 N for the austenitic stainless steel AISI 316L and Super Duplex 2507 stainless steel respectively. It was observed that the less cutting force can be obtained by employing the higher level cutting speed when turning both the stainless steel grade materials. This is because with increase in cutting velocities, the chip gets thinner and cutting forces reduced. The decrease in cutting force is due to reduction in contact area and partly due to the drop in shear strength in the flow zone as the temperature increases with increase in cutting speed [9]. It was observed from the experimental results, less cutting force is required for the machining of Austenitic stainless steel AISI 316L over Super Duplex 2507 stainless steel. This is because of Austenitic stainless steel AISI 316L exhibits lower strength and lower hardness over Super Duplex 2507 stainless steel and also Super Duplex 2507 stainless steel have higher toughness and ductility compared to Austenitic stainless steel AISI 316L.

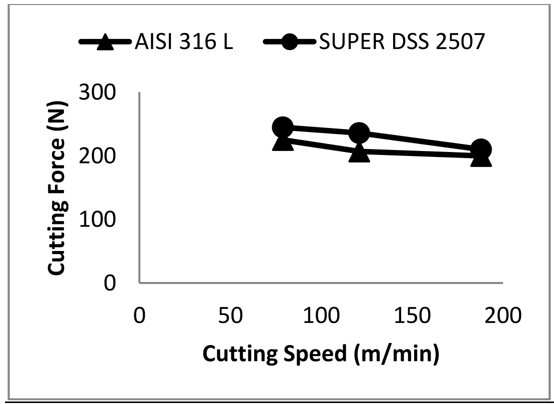

Figure-3. Comparison of cutting forces with cutting velocities in turning austenitic stainless steel AISI 316L and super duplex 2507 stainless steel.

Surface Roughness

Figure-4 shows the comparison of surface roughness value with cutting velocities for turning of Austenitic stainless steel AISI 316L and Super Duplex 2507 stainless steel with coated carbide PVD - TiAIN Nano-multilayer. It is clearly seen from Figure-4, the surface roughness decreased with an increase in the cutting velocity. The value of surface roughness (R_a) at a lower level cutting velocity of 79 m/min are 1.66 µm and 1.79 µm for the Austenitic stainless steel AISI 316L and Super Duplex 2507 stainless steel respectively. Similarly for the higher level of cutting speed of 188 m/min are 1.28 µm and 1.44 µm respectively. It was observed that surface roughness value is higher when turning Super Duplex 2507 stainless steel over austenitic stainless steel AISI 316L. This is because of sticky in nature of Super Duplex 2507 stainless steel. This is the cause for the increasing surface roughness due to the increase in friction between work piece and tool interface and increase in the temperature in the cutting zone due to higher strength and higher hardness over Austenitic stainless steel AISI 316L. The sticky in nature of Super Duplex 2507 stainless steel is the cause for the increased surface roughness value over Austenitic stainless steel AISI 316L.

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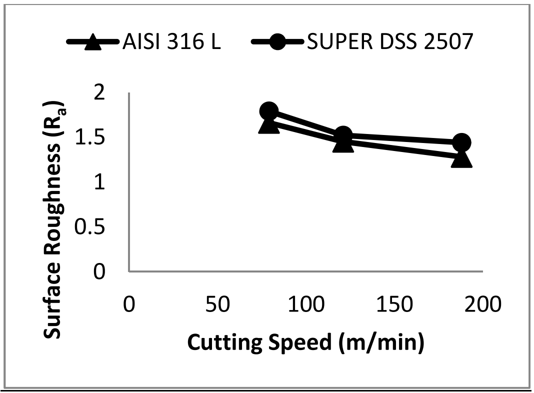

Figure-4. Surface roughness (R_a) vs. cutting velocity in turning of austenitic stainless steel AISI 316L and super duplex 2507 stainless steel.

Tool Wear

The worn surfaces (rake surface, main and auxiliary cutting edge surfaces) of the PVD - TiAIN Nano-multilayer tool bits used in the turning processes of the Austenitic stainless steel AISI 316L and Super Duplex 2507 workpiece materials are examined using SEM. The SEM views (rake surface, main and auxiliary cutting edge surfaces) of the worn out PVD - TiAIN Nano-multilayer cutting tool inserts (cutting velocities of 79, 121 and 188 m/min, constant feed rate and depth of cut of 0.159 mm/rev and 1 mm) after 3 minutes of the turning of Austenitic stainless steel AISI 316L and Super Duplex 2507 stainless steels are shown in Figures 5 and 6. It was observed from that Figures 5 and 6, wear predominantly occurred in three regions during the process, at the rake surface, main and auxiliary cutting edge surfaces.

The SEM images in Figure-5 (a-c) are examined at the rake surface, main and auxiliary cutting edge surfaces of the PVD - TiAIN Nano-multilayer cutting tool inserts in the turning of Austenitic stainless steel AISI 316L for three different cutting speed conditions. The cutting speed V_c value of 79 m/min shows less nose radius wear and crater wear at the rake surface and the minor edge losses at both the cutting edge surfaces. The flaking and small size of adhering chip was observed in the rake surface. The loss in tool material at the rake surface due to abrasion wear and less main and auxiliary flank wear occurred at the main cutting and auxiliary cutting edge respectively when turning the material with the cutting speed of 121 m/min. Increasing the cutting speed to 188 m/min, it was observed from the Figure 5c, chipping off the tool material near the nose radius which in turn increases the depth of the crater wear at the rake surface. And also observed the higher edge lose at the depth of cutting line and auxiliary cutting edge surface. The tool wear mechanisms coupled with the SEM images in Figure-5 indicate that when turning of Austenitic stainless steel AISI 316L with PVD - TiAIN Nano-multilayer cutting tool inserts, the worn morphologies include the flaking, adhering chip, chipping, notch wear and flank wear at the main and auxiliary cutting edge and the dominant wear mechanisms are the attrition wear, abrasive wear, adhesive wear and diffusion wear.

The SEM views (rake surface, main and auxiliary cutting edge surfaces) of worn inserts of the PVD - TiAIN Nano-multilayer cutting tool inserts in the turning of the Super Duplex 2507 stainless steels for three different cutting speed conditions are shown in Figure-6 (a-c). It was observed from the Figure-6a, there is less wear on the cutting edge surface and rake surface at the cutting speed of 79 m/min. At this cutting speed, BUE formed and flaking was observed at the rake surface. The less edge loss occurred at the main cutting edge and auxiliary cutting edge surface. Increasing the cutting speed from 79 m/min to 121 m/min, it was observed from the Figure 6b, more crater wear observed on the rake surface. The high main flank wear was observed along the depth of cut line as well as width of flank band in the main cutting edge surface. The adhering chips are formed at auxiliary cutting edge surface. It was observed from the Figure 6c, higher crater wear at the rake surface. The higher chipping and notch wear was observed on the rake and flank surface. The adhering chip was formed at the main and auxiliary cutting edge surfaces.

It can be seen from the SEM views of the worn tool inserts that higher tool wear occur at the rake surface, main and auxiliary cutting edge surfaces in case of Super Duplex 2507 stainless steel over austenitic stainless steel AISI 316L. This is because of super duplex stainless steels possess higher mechanical strength which in turn develops the higher cutting temperature which causes the tool to lose its strength and develop more thermo - mechanical wear mechanisms.

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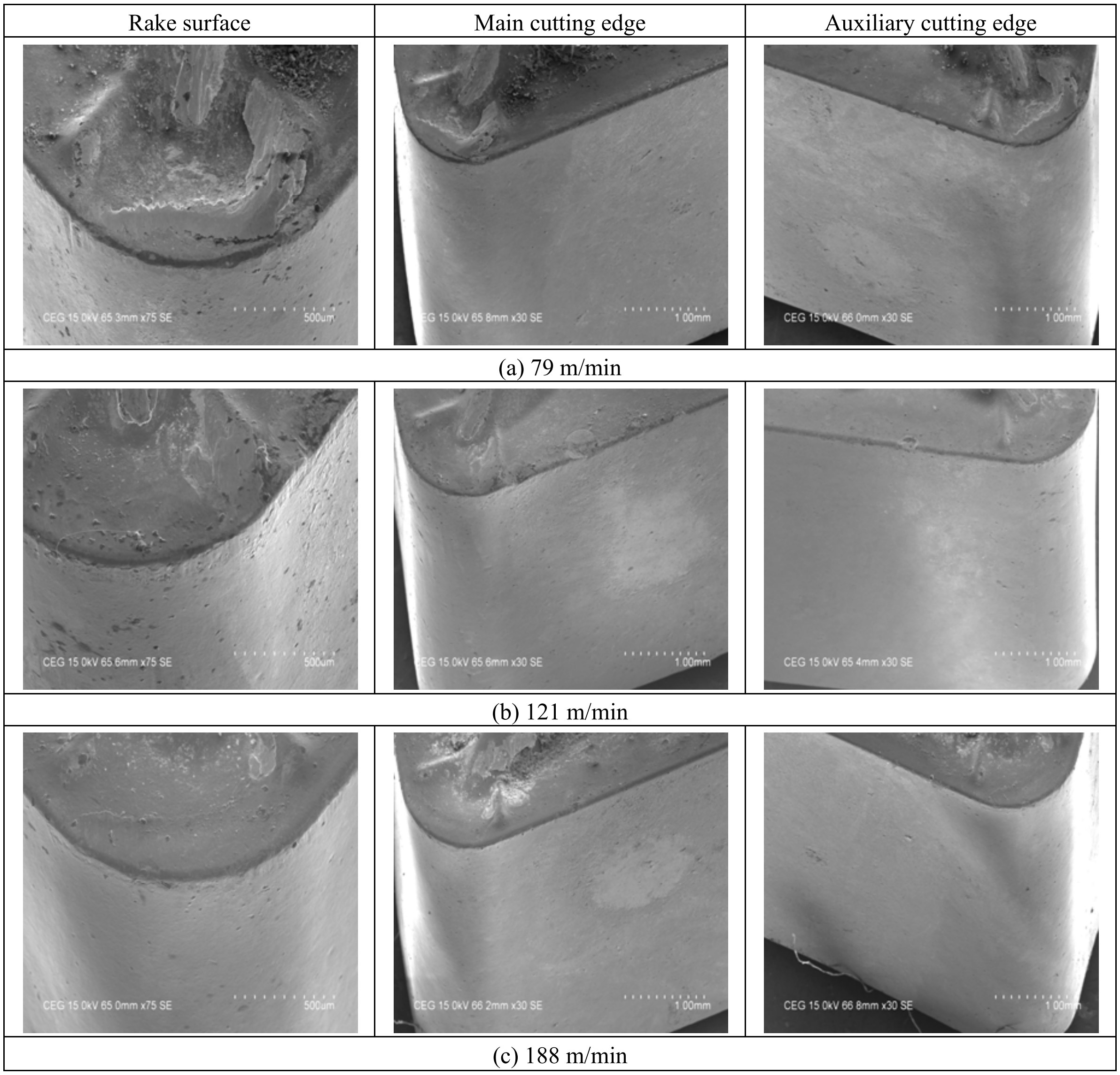

Figure 5. SEM views on PVD-TiAIN Nano-multilayer cutting inserts for turning the austenitic stainless steel AISI 316L.

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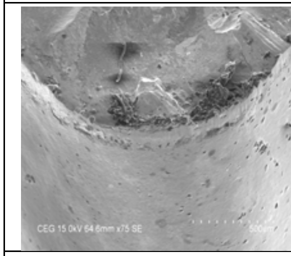
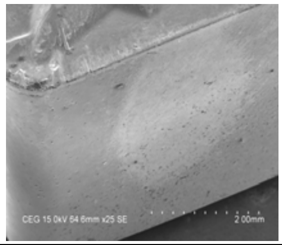
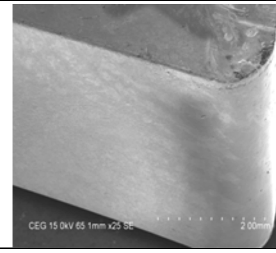
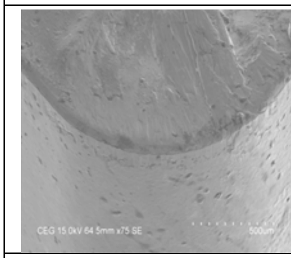
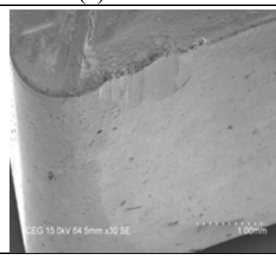
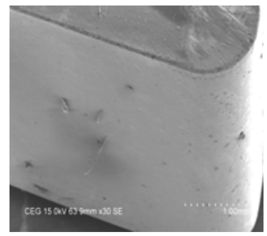
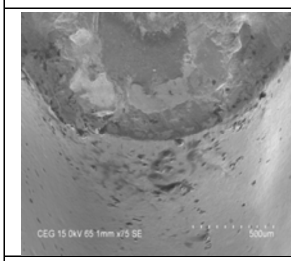
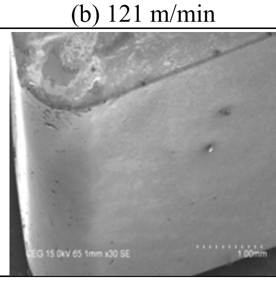
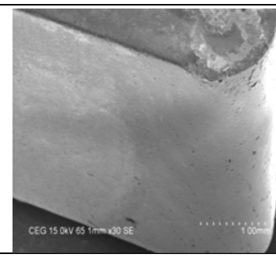
Rake surface	Main cutting edge	Auxiliary cutting edge
		
(a) 79 m/min		
		
(b) 121 m/min		
		
(c) 188 m/min		

Figure-6. SEM images of cutting inserts for machining super duplex 2507 stainless steel.

Chip Breaking

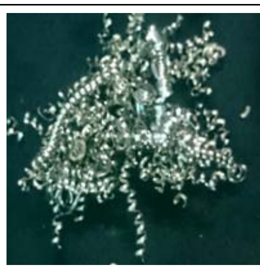
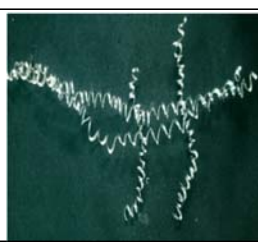
		
79 m/min	121 m/min	188 m/min
AISI 316 L Austenitic Stainless Steel		
		
79 m/min	121 m/min	188 m/min
Super Duplex 2507 Stainless Steel		

Figure-7. Photographic view of chips.

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The collected chip samples from the turning of Austenitic stainless steel AISI 316L and Super Duplex 2507 stainless steels with different cutting velocities are shown Figure-7. It is clearly seen from the Figure-7, a discontinuous chips are obtained in turning of Austenitic stainless steel AISI 316L. When machining super duplex2507 stainless steels, continuous chips are generally produced, they are not necessarily desirable especially with CNC machine tools, as they tend to tangle around the tool holder and the workpiece. It was observed that, friendlier-to-machine chips are obtained when machining austenitic stainless steels than duplex stainless steel grades in all cutting conditions.

CONCULSIONS

The experiments on turning of austenitic stainless steel AISI 316L and Super Duplex 2507 stainless steel with coated carbide PVD - TiAIN Nano-multilayer was carried out under dry environments. The major conclusions from this investigation can be summarised as follows:

1. It reveals that higher cutting force and poor surface finish were found in Super Duplex 2507 stainless steel over austenitic stainless steel AISI 316L.
2. It was observed that higher tool wear occur in case of Super Duplex 2507 stainless steel over austenitic stainless steel AISI 316L.
3. The collected chips at various cutting parameters have shown that friendlier-to-machine chips are obtained when machining austenitic stainless steels than duplex stainless steel grades.

It is evident from the experimental investigation, Super Duplex 2507 stainless steel displayed poorer machinability responses.

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