Machinability studies of Duplex Stainless Steel 2205 using coated tools

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Abstract

In the present investigation, the effect of newly developed PVD coatings on tool life and surface roughness during dry turning of Duplex Stainless Steel (DSS) 2205 is reported. DSS is used in applications like marine, oil and chemical industries due to its combination of corrosion resistance and high strength. However, high toughness along with low thermal conductivity and ductility make them difficult to machine. M35 grade uncoated cemented carbide tool was used for dry turning. High Power Impulse Magnetron Sputtering (HiPIMS) was used for coating of AlTiN and AlTiCrN on cemented carbide substrates. Cutting speed in the range of 100 to 180 m/min and feed in the range of 0.12 to 0.18 mm/rev were used. Depth of cut (DoC) of 0.8 mm was kept constant. Nose wear, tool life and surface roughness were measured as criterion for comparison. AlTiCrN coated tool exhibited 5 times more tool life than uncoated tools and performed better due to high thermal stability. Surface roughness obtained by coated tools was found to be 1.006 µm compared to 3.14 µm for uncoated tools due to faster wear rate of uncoated tools.

Keywords: DSS2205, Dry Turning, Tool Life, Nose Wear, HiPIMS, Coated Carbide.

1. INTRODUCTION

Stainless Steel consumption in today's world is increasing by 5 to 8 % every year more than other metals [1]. Stainless Steels (SS) are generally divided in four groups namely ferritic (FSS), martensitic (MSS), austenitic (ASS) and duplex stainless steels (DSS). Among these types, Duplex stainless steels are having similar alloying elements as austenitic SS but are more difficult to machine due to their high annealed strength [2]. Duplex Stainless Steels (DSS) are used for fabricating tonnage of marine structures. DSS has became a popular material in recent days as it is satisfying the combined need of FSS and ASS in one with lower cost specially as compared to most popular materials like 300 series ASS [3]. DSS is having matrix of austenite (γ) and ferrite (α) phase in a banded structure which provides a combination of properties of both phases [3, 4]. These unique properties make them suitable for many industrial applications, especially in marine, oil, desalination plants, chemical and power industries [5-7] Austenitic grade stainless steels were more popular for applications where Stress Corrosion Cracking is a point of concern but DSS has overcome 300 series ASS because of combination of high strength and corrosion resistance in critical environment.

DSS is considered as difficult to cut material mainly because of combination of high toughness, low thermal conductivity, low ductility and high work hardening ability. Irregular wear during machining DSS is a big concern along with formation of Built up Edge (BUE). This resulted in poor surface quality as well as lower tool performance and productivity [8]. Poor machining ability also causes surface and subsurface damage during machining [9].

Use of oil water or lubricant for cooling during cutting is no more beneficial for healthy environment. On the other hand almost 20% of the total cost is invested on cutting fluids. During DSS machining, it is reported that high temperatures are produced and cooling in cutting zone results in a temper treatment causing a white layer of tempered martensite. Below this white layer, another layer with low hardness but having tensile stress creates more severe cutting conditions [11, 12]. Dry machining is reported with compressive stresses [11].

Krolczyk et. al. studied wet machining of DSS using carbide tools in comparison with dry cutting. Wet turning with mineral oil lubricants negatively affects the DSS machining. Wet cutting resulted in reduction of 65% tool life than dry cutting. Chip breaker tool geometry was reported so as to avoid BUE formation which is a basic concern for DSS machining. But, it was found to be ineffective when lubrication was used [8, 10].

Nieslony et. al. have found no significant effect of lubrication on surface hardness for selected tool corner radius [5]. Krolczyk et. al. in their another research proved that elimination of cutting oil exhibited improved performance for DSS machining as cutting forces were reduced compared to wet cutting [10]. Olszak commented that DSS is almost an unworkable material [11]. To ensure better surface integrity, it is recommended to choose cutting parameters carefully [13, 14]. Philip Selvaraj et. al. found positive effect of increasing speed on surface roughness for Nitrogen alloyed DSS [4].

PVD HiPIMS technology due to its advantages like low deposition temperatures and environfriendly aspects is selected over Chemical Vapor Deposition (CVD). Also, it produces dense columnar structure which is highly suitable for sharp edges. Kulkarni et. al. found better performance of AlTiCrN coating with advanced Physical Vapor Deposition (PVD) technique while dry machining over TiN/TiAlN coated tools [16]. Most of the researchers have concentrated either on using lubricants for machining DSS or try to create mathematical models for prediction of results. There is still a wide scope for optimization of cutting parameters using traditional machining methods. This article focuses on use of newly developed coating techniques for carbide tools for dry machining of DSS. Tool life, tool wear and surface roughness are analyzed as a criterion for optimization.

2. EXPERIMENTAL DETAILS

2.1. Workpiece material

Duplex Stainless Steel (DSS) 2205 is called as standard DSS grade and is the more popular grade used. It is the second most

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difficult to cut grade of DSS. Alloying elements of DSS2205 are as shown in Table1.

Table 1 Alloying elements of DSS2205

Cr	Ni	Mo
22.0-23.0	4.50-6.50	3.00-3.50
C	N	S
0.030 Max	0.14-0.20	0.020 Max
Mn	S	P
2.00 Max	1.00 Max	0.030 Max

2.2. Cutting tool and coating technique

M35 grade Carbide tool inserts, with ISO specification of CNMG120408 were used. Positive chip breaker geometry MF1 for BUE prevention with tool nose radius of 0.8 mm was used. Carbide tools were coated by PVD from CEMECON, Germany. High Power Impulse Magnetron Sputtering (HiPIMS) CC800 was used for coating of tools. Two commercially developed coatings (AlTiN and AlTiCrN) with 4 µm thickness each were used for carbide tools as shown in Fig.1.

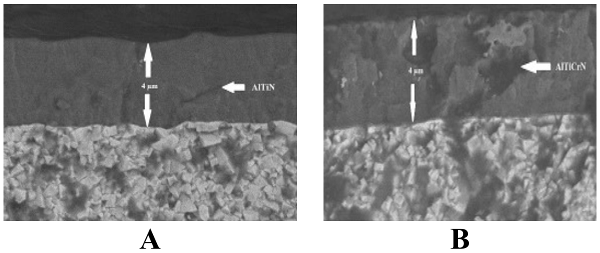


Fig. 1 SEM image of A) AlTiN and B) AlTiCrN coating

Physical vapor deposition using HiPIMS offer smooth, non porous and low stress coatings. These coatings have good adhesion with a scratch load of 130 N. Microstructure of these coatings is highly dense and amorphous. These properties make them hard and tough. Both coatings contain oxidizing elements which forms protective layers resulted in high thermal stability upto 1100^0C. Uniform distribution of coating thickness allows good protection to cutting edge, even for complex tool geometry.

Literature review, data from industrial survey and recommendations from International Molybdenum Association (IMoA) were the basis for selection of cutting parameters. The cutting parameters are as shown in Table 2.

Table 2 Cutting parameters

Parameter	Values
Cutting speed (m/min)	100, 140, and 180
Feed (mm/rev)	0.12, 0.15, and 0.18
Depth of cut (mm)	0.8 (constant)

Round bars of 290 mm* 90 mm were turned dry using CNC LATHE JOBBER XL. A pass length of 245 mm was achieved for every machining cut. SJ 301 2R-C type surface roughness tester was used to measure roughness value (Ra). After every pass, wear was measured with Nikon measuring microscope.

3. RESULT AND DISCUSSION

During machining of DSS 2205 in dry conditions it was observed that the nose wear is the most dominant wear over flank and crater wear for all the tools and cutting conditions used. This is justified by small depth of cut with respect to tool nose radius. So tool nose wear was selected to be a criterion for tool life. According to ISO 3685 (1993) notch wear width $VB_N = 0.3$ mm for regular wear and $VB_N = 0.6$ mm for uneven wear is the criterion for tool life [17].

3.2 Effect of machining length on Nose Wear

Smaller depth of cut causes nose wear to be the most dominant tool wear. Fig.1 shows variation of nose wear with machining length at cutting speed of 140 mm/min and feed 0.18 mm/rev. As the machining length increases the nose wear increases and finally chipping of insert was also observed.

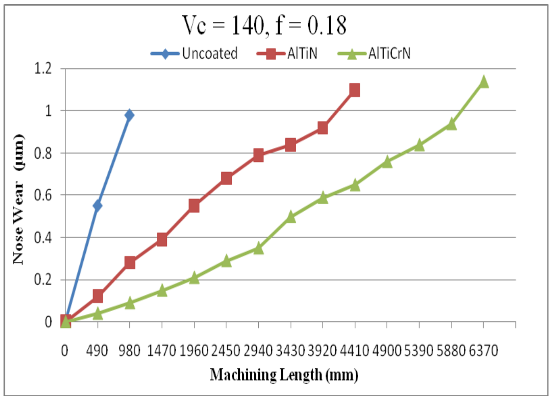


Fig. 2 Effect of Machining length on Nose Wear for Vc = 140 m/min at f=0.18 mm/rev

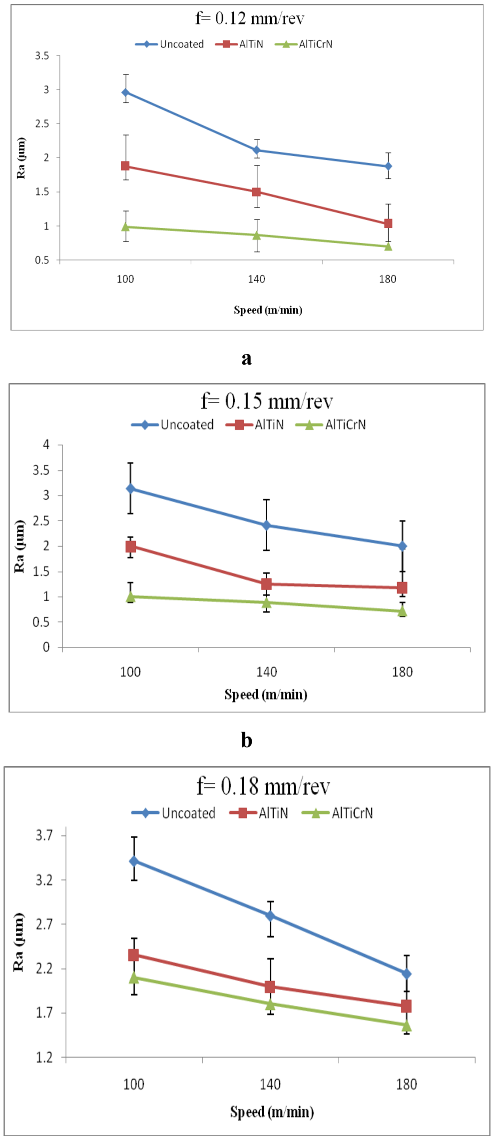
Even for average cutting conditions of cutting speed 140 mm/min and 0.15 mm/rev feed, uncoated tools performed poor giving a tool life of 980 mm. Whereas, AlTiN and AlTiCrN tools gave a tool life 4410 mm and 6370 mm respectively. Higher cutting temperatures and faster tool wear results in very less tool life for uncoated tools. For lower feed values of 0.12 and 0.15 mm/rev, AlTiN coated tools gave almost the same values of wear as compared to AlTICrN tools. But for higher feed value of 0.18 mm/rev, AlTiN coated tool gave higher tool wear because of lower thermal stability (8500ºC) as compared to AlTiCrN coated (1100ºC) tools.

3.3 Effect of Cutting Speed on Surface Roughness

Fig. 2 shows the effect of cutting speed on surface roughness. As the cutting speed increases roughness of machined surface decreases. Increase in cutting speed is having positive effect on surface roughness. Surface roughness obtained by coated tools was found to be 1.006 µm compared to 3.14 µm that is 3 times more for uncoated tools due to faster wear rate of uncoated tools. This is justified by reported lower cutting pressure [18] and cutting forces [16] with increase in cutting speed. Initially higher values of surface roughness were observed. This is because of BUE formation but as the cutting speed increases the tendency of BUE formation decreases and the friction on the workpiece also decreases resulted in good finish.

After certain machining time roughness tends to increase again may be due to nose wear of tool which eventually increases friction between tool and the workpiece.

With cutting speed the cutting temperature also increase but due to lower thermal conductivity of coated tools heat produced is carried to work piece and chips. For uncoated tools due to higher cutting temperatures wear rate is high and as a result more roughness compared to coated tools.



a

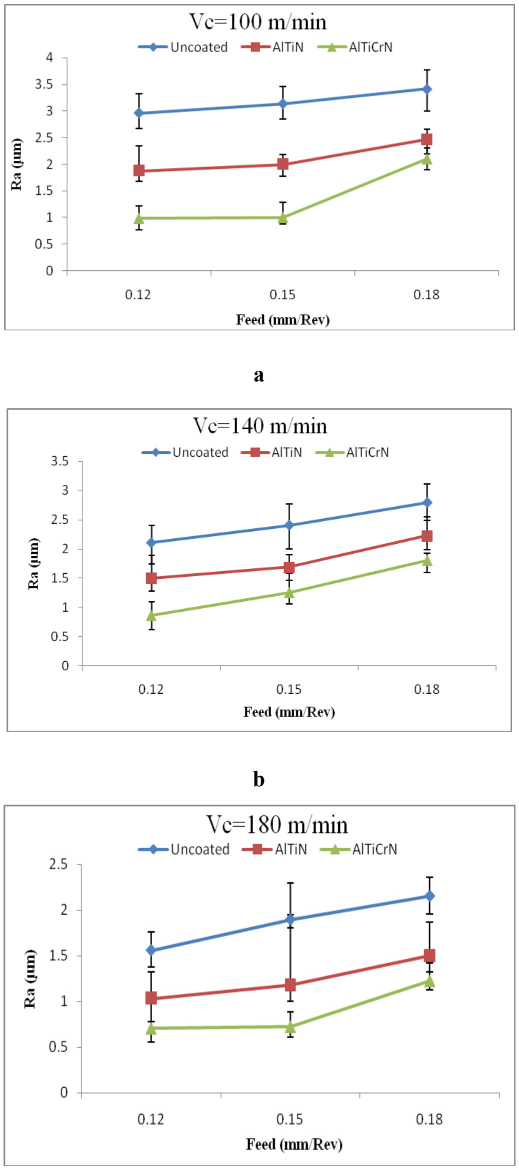
b

c

Fig. 3 Effect of Cutting Speed on Surface Roughness at a) f=0.12mm/rev, b) f=0.15 mm/rev, c) f=0.18 mm/rev

3.4 Effect of Feed on Surface Roughness

Fig. 3 shows affect of feed on surface roughness at a cutting speed of 100 m/min. Increase in feed values causes more material to be removed per time. This increases friction between tool and the workpiece. Due to higher friction the cutting temperatures also increases resulting less shear strength. Reduction in shear strength causes work material to behave in ductile phase.



a

b

c

Fig. 4 Effect of Feed on Surface Roughness at a) Vc = 100 m/min, b) Vc = 140 m/min, c) Vc = 180 m/min

DSS itself is a sticky material and during machining it was reported that it is quite difficult to separate chips causing more area in contact with high friction and roughness [4]. This phenomenon causes surface roughness to increase as the feed increases. Uncoated tools at a feed of 0.18 mm/rev gave more roughness of 3.9 µm, twice the surface roughness given by coated tools of 2.0 µm. This is because of higher thermal stability of coatings used. At higher feeds higher cutting

temperatures are produced. This results in more wear of uncoated tools, giving higher values of surface roughness.
Worn cutting edges tend to increase friction between tool and the work piece and results in rough machined surface.

4. CONCLUSIONS

Following are some of the conclusions made while dry turning of DSS2205:

- AlTiN and AlTiCrN coatings performed better due to combination of properties like hot hardness and wear resistance.
- Lower feed values of 0.05 and 0.10 mm/rev were unable to machine DSS2205 due to longer chip problem; same was the problem with DOC 0.5 mm.
- As the cutting speed increases the surface roughness decreases. For uncoated tools, when speed is increased from 100 m/min to 180 m/min, surface roughness decreased from 3.006 µm to 1.95 µm, at a feed 0.12 mm/rev.
- Effect of increase in feed was found to be negative on roughness. At a speed 140 m/min, as feed was increased from 0.12 mm/rev to 0.18 mm/rev, surface roughness increased from0.789 µm to 1.805 µm.
- AlTiCrN coated tools for low speed (100m/min) and low feed (0.12 mm/rev) gave maximum tool life of 7840 mm.
- Higher tool wear of AlTiN coated tool compared to AlTiCrN coated tool is because of lower thermal stability (850^0C) compared to AlTiCrN (1150^0C) coated tools.

References

[1]. J. Nomani, A. Pramanik, T. Hilditch, “ Machinability study of first generation duplex (2205), second generation duplex (2507) and austenite stainless steel during drilling process”, Wear, 304 (2013), pp 20–28

[2]. Gutakovskis, Bunga, G., Torims, T, “ Stainless steel machining with nanocoated duratomic cutting tools”, 7th International DAAAM Baltic Conference "INDUSTRIAL ENGINEERING” 22-24 April 2010, Tallinn, Estonia

[3]. A. Vinoth, L. Ajaykumar “Weldability, Machinability & Surfacing of commertial Duplex Stainless Steel AISI2205 for marie applications- a recent Review”, Journal of Advanced Research, 8 (2017), pp 183-199.

[4]. D. Philip Selvaraj, Palanisamy Chandramohan, “ Influence of Cutting Speed, Feed Rate and Bulk Texture on the Surface Finish of Nitrogen Alloyed Duplex Stainless Steels during Dry Turning”, Scientific research Engineering, Vol. 2 (2010), pp 453-460

[5]. G. Krolczyk, P. Nieslony, and S. Legutko, “Microhardness and Surface Integrity in Turning Process of Duplex Stainless Steel (DSS) for Different Cutting Conditions”, JMEPEG, 23 (2014), pp 859–866.

[6]. J.M. Cabrere, A, Mateo, “ Hot deformation of Duplex Stainless Steel”, Journal of Matrial Processing Tehnology”, Vol. 143 (2003), pp 321-325

[7]. Y. H. Park and Z. H. Lee, “The effect of nitrogen and heat treatment on the microstructure and the tensile properties of 25Cr-7Ni-1.5Mo-3W-xN Duplex SS castings, Material Science Engineering, Vol 297 (2001), pp 78-84

[8]. G. Krolczyk, P. Nieslony, and S. Legutko, “Determination of tool life and research wear during duplex stainless steel turning”, Archives of civil and mechanical engineering, Vol. 15 (2 0 1 5), pp347-354

[9]. G. Krolczyk, S. Legutko, “Investigations into surface integrity in the turning process od duplex stainless steel”, Transactions of FAMENA, Vol. 38 (2014), pp 77-82

[10]. G. Krolczyk, P. Nieslony, “Dry cutting effect in turning of a duplex stainless steel as a key factor in clean production”, Journal of Cleaner Production, Vol. 30 (2016), pp 1-12

[11]. W. Olszak: Obrobka skrawaniem, WNT, Warszawa (2008)

[12]. G. F. Batalha, h. Delijaicob, “ Residual Stresses Modelling in Hard turning and its Corelation with the Cutting Forces”, Journal of achievements in Materials and Manufacturing Engineering,, Vol. 24 (1) , (2017), pp 350-355.

[13]. J. D. Thiele, S. N. Melkote, “Effcet of cutting edge geometry and work piece hardness on surface residual stresses in finish hard turning of AISI 52100 steel”, Transaction of ASME – Journal of Manufcaturing Science and Engineering, Vol 122-4 (2000), pp 642-649

[14]. Grzegorz Królczyk, Maksymilian Gajek, Stanisław Legutko, “Effect Of the cutting parameters impact on tool life in duplex stainless steel Turning process”, Tehnicki Vjesnik- Technical Gazette”, Vol 20 (04) (2013), pp 587-592

[15]. Ciftci, “ Machining of Austenitic Stainless Steel using CVD Multilayer Coated Cemented Carbide tools”, Tribology International, Vol 39-06 (2006), pp 565-569

[16]. Atul Kulkarni, Viaks Sargade, “Charaterization and performance of AlTiN, AlTiCrN, TiN/TiAlN PVD coated carbide tolls while turning SS304”, Vol. 30 (2015), pp 748-755.

[17]. ISO 3685:1993, “Tool Life testing with single point turning tools”, Edition 2, 1993-11, pp 1-48

[18]. T braham-Bouchnak, G. Germain, “High pressure Water Jet Assisted Machining of Duplex SS: Machinability and Tool Life”, International Journal of Material Forming, Vol. 3 (1) (2010), pp 507-510.