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Coated tool Performance in Dry Turning of Super Duplex Stainless Steel

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Abstract

Super duplex stainless steels (SDSS) are widely used in marine environments because of their excellent mechanical properties and corrosion resistance. The presence of different alloying elements and their two phase microstructure makes it a difficult-to-machine material. The use of multilayer coated cutting tools is an effective strategy to improve the cutting performance during dry machining of this material. In this work, the performance of four different coated tools made either by PVD or CVD has been investigated during dry turning of SDSS. Their performances were evaluated in terms of tool wear, cutting force, cutting temperature and surface integrity. Results indicated that [MT-TiCN]-Al_2O_3 coating provided relatively better performance than other coatings in terms of tool wear, cutting force and surface integrity. Their combined properties of higher hardness and oxidation stability make them an effective coating during machining The TiN-[MT-TiCN]-Al_2O_3 coating exhibited higher tool wear, poor surface finish and also less tensile residual stress in comparison with surfaces machined using other coated tools. This may be due to the dominance of plastic deformation by mechanical load over temperature effects during machining.

Keywords: SDSS; Medium Temperature-CVD; Multilayer coatings; Surface Integrity

1. Introduction

Duplex stainless steels are called "duplex" because they have a two phase microstructure with 50 % ferrite and 50% austenite. It is designed for demanding applications which requires exceptional mechanical strength and corrosion resistance such as, heat exchangers, desalination plant, seawater equipment, oil and gas exploration component. The SDSS is characterized by its higher chromium content (25%) than the standard duplex stainless steel (20%) with pitting resistant equivalent > 40 (PREN = Cr% + 3.3Mo% + 16N %). Increasing their alloying elements chromium, molybdenum, and nitrogen increases the resistance to localized corrosion and stress corrosion cracking. The poor machinability of this material is due to very low heat conductivity (50% of that of plain carbon steels), high toughness, high tendency to form built up edge (BUE) and high work hardening rate [1-2]. The

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presence of two phases austenite and ferrite with different hardness also makes them difficult-to-machine. The high heat generated at the tool chip interface combined with the low thermal conductivity of this material produces high localized temperatures which causes rapid tool wear. Nomani et al. (2013) compared the machinability behavior of super duplex SAF 2507, duplex SAF 2205 and austenite 316L in drilling process. The results showed that austenite 316 had better machinability and both duplex grades have a higher response to built-up edge formation, with grade 2507 being the worst. These poor machinability features of this material define the need to improve the machinability of this material.

Multilayer coatings and delivering coolant in the cutting zone are the two effective ways to enhance the cutting performance. The coating layer enhances the surface properties of tools such as wear resistance, hot hardness, oxidation resistance and chemical inertness, which augments the tool life [4]. The common techniques used for coating of cutting inserts include physical vapor deposition and chemical vapor deposition. More recently, medium temperature CVD (MT-CVD) process has also been developed, where the deposition of thin films are done at temperature between 700 °C and 850°C. These coatings have lower tensile thermal stress and have reduced tendency to form brittle η-phase at the interface of substrate and thin film [5-6]. These advancement in coatings technology helps to machine the complicated materials at high cutting speeds and feeds, which could help to increase the productivity. Krolczyk et.al (2014) investigated tool wear of CVD coated tungsten carbides in duplex stainless steel (DSS) turning. In this work two different multilayer coatings TiCN/Al_2O_3/TiN and TiN/ Ti(C,N)/ Ti(N,B/ TiN/ Ti(C,N) were used, the former showed higher resistance to abrasive wear. Peng et.al (2014) studied the effect of single layer TiAlN and multilayer TiN/TiAlN coatings on the oxidation performance. It was found that TiN layer insertion into the TiAlN coating hinders the Al diffusion and enhances the oxidation resistance at the surface. Chen et.al (2011) prepared TiAlN/TiN nano-multilayer coatings with modulation period of ~20 nm in order to further improve the properties of TiN coating. The multilayer structure resulted in an increase in adhesion with substrate and improved oxidation resistance, which improved the overall cutting performance of insert. Ciftci et.al (2006) performed dry turning experiments on AISI 304 and AISI 316 austenitic stainless steels and the results showed TiC/TiCN/TiN coated cutting tools produced lower cutting forces than TiCN/TiC/Al_2O_3 coated tools, because of the lower coefficient of friction of TiN top coating layer. Bejjnai et al (2016) did the characterization on worn surfaces of alumina coatings of insert for different work piece materials. White light interferometry was used to study the grooves found on the flank side after machining. Park et al (2011) performed flank wear analysis on the multi-layer (TiCN/Al_2O_3/TiCN) coated carbide inserts after turning AISI 1045 steel. Using the wavelet filtering, the roughness profiles and groove sizes on the flank surface were also analyzed and compared with confocal laser scanning microscope (CLSM) and SEM. This review indicates the machining problems in SDSS and the need to develop a suitable strategy to improve the machinability. Hence, this present work includes analyzing the comparative performance of different coated tools in SDSS turning. Their performances were assessed in terms of tool wear, cutting force, cutting temperature and surface integrity.

2. Materials and Methods

The material used in this study SDSS has an approximately equal proportion of 50% ferrite and 50 % austenite and its microstructure is shown in Fig 1. The ultimate tensile strength was found to be UTS = 910 MPA with a Rockwell hardness of 32 HRC. The elemental composition of SDSS of grade 2507 is shown in Table 1.

Table 1. Chemical composition of SDSS

Element	C	N	Si	P	S	Cr	Mn	Ni	Mo	Fe
Wt%	0.03	0.25	2.06	0.03	0.02	24.6	1.20	6.1	4.00	Remaining

The turning experiments were performed on a VDF lathe under dry conditions. It offers a variable speed from 150- 5600 rpm with the power rating of 10 kW. Tungsten carbide cutting insert with geometry of TNMG 160408 MP clamped in the tool shank of MTJNR2525M16H4 were used and the details of insert coating is given below in Table 2. The ranges of cutting conditions were chosen based on the industrial recommendations. The process