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Original Research Article

Determination of tool life and research wear during duplex stainless steel turning

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ARTICLE INFO

Article history:
Received 4 September 2013
Accepted 3 May 2014
Available online 1 August 2014

Keywords:
Duplex stainless steel
CVD coatings
Machining
Tool life
Wear testing

ABSTRACT

The purpose of the study is to determine the 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 were coated with Al_2O_3. Scanning electron microscopy (SEM) has been used for the wear analysis.

1. Introduction

Austenitic and duplex stainless steels are considered to be difficult-to-machine. Irregular wear and a built-up edge (BUE) often occur in machining operations. From a tool life's point of view, the machining process of DSS poses considerable difficulties. One limitation of the efficiency of turning this type of steel is the wear of a tool point. The wear process of a tool point, which is largely dependent on the cutting parameters, is an important factor. The wear of a tool point leads to a deterioration in quality of the machined surface and, consequently, to lower efficiency and productivity. Paro et al. [1] showed that DSS is often recognized as a difficult material to machine because of its high toughness, low thermal conductivity, and high degree of work hardening. In order to overcome such problems, materials with high durability, reliability, and efficiency should be used. The machinability of austenitic steels has been dealt with by researchers such as Paro et al., Akasawa et al., Abou-El-Hossein and Yahya, Ciftci, Shao et al., Bonnet et al. and Manimaran and Pradeep Kumar [2–8]. Paro et al. [2] investigated active wear and failure mechanisms of coated cemented carbide tools in

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http://dx.doi.org/10.1016/j.acme.2014.05.001
1644-9665/

Nomenclature

a_p	depth of cut (mm)
f	feed rate (mm/rev)
v_C	cutting speed (m/min)
T	tool life
DSS	duplex stainless steel

machining process of austenitic stainless steel. Akasawa et al. [3] described the effects of free-cutting additives on the machinability of austenitic stainless steel in dry and with a cutting fluid cutting process. Abou-El-Hossein and Yahya [4] investigated the possible failure modes of tool wear and the effect of cutting speed and feed rate variation on tool life and tool wear modes in milling operation. Ciftci [5] presented the experimental results of dry turning using CVD multi-layer coated cemented carbide tools. Shao et al. [6] investigated wear and failure mechanism of cemented carbide tools in milling process using SEM analysis. They noted that the tool wear progression follows a three-stage wear pattern and abrasive, attrition, adhesive and diffusive wear appear in different stages. Bonnet et al. [7] presented a friction model during the dry cutting of an AISI 316L austenitic stainless steel with TiN coated carbide tools. Manimaran and Pradeep Kumar [8] presented grinding experiments for three environments: dry, wet and cryogenic cooling. While machining of DSS has been described by Bouzid Saï and Lebrun [9], Ran et al. [10], Nomani et al. [11] and Braham-Bouchnak et al. [12]. Bouzid Saï and Lebrun [9] noted that the burnishing process produces the best quality of the surface when compared with turning or grinding. Ran et al. [10] showed the mechanical properties and corrosion resistance of the DSS designed alloys with lower production cost are better than those of AISI 316L austenitic stainless steel. Nomani et al. [11] showed the machinability tests of duplex alloys 2205 and 2507 during drilling process. They noted that both duplex alloys show a higher tendency to built-up edge and the chisel edge area had a larger wear. Braham-Bouchnak et al. [12] showed comparisons between assisted turning using variable jet pressure and conventional turning for different cutting speeds. They obtained good chip fragmentation and an improvement of tool life with high pressure water jet assistance. Author's earlier investigations showed predicting the tool life [13] and surface roughness [14], tool life [15] and cutting wedge wear [16] in the dry machining of duplex stainless steel, but those publications did not mention about problems related to the tool wear mechanism. Many production companies use coated carbide tools or high speed steel for the processing of DSS. According Gunn [17], low-alloyed DSS such as S32304, while being machined by tools from high speed steels, behaves in a manner similar to austenitic types such as 316 or 317. However, during the machining of coated carbide tools, steel behaves in a manner similar to 317LN and 317LMN. Modern types of DSS are harder to machine than the types produced before this one. The reason for this is the higher content of austenite phase and nitrogen. An increase in the content of alloying elements such as nitrogen and molybdenum makes machinability of these steels less effective. The use of coated carbide tools for machining DSS requires a deeper study of tool wear and associated wear mechanisms.

The article focuses on research problems related to the tool wear of coated carbide consisting of a layer of CVD – Ti (C,N)/Al_2O_3/TiN in DSS turning of a ferritic–austenitic structure. The main purpose of this study was to determine the effect of cutting speed as a key process factor in controlling tool life. Increasing the cutting speed to a range greatly exceeding conventional machining is now recognized as the primary direction of production capacity and efficiency growth, as well as quality and accuracy improvement [18]. As a method for rational selection for DSS machining, a static determined selective-multivariate uniform static – rotatable PS/DS-P:λ program has been selected [19]. The research program includes an assessment of: the influence of cooling on tool life, the impact of cutting parameters on tool life, rake face wear as well as flank wear in the process of turning. It also includes a detailed analysis of wear areas and also distinguishes the dominant mechanisms of tool wear for coated method CVD.

2. Experimental techniques

2.1. *Workpiece and cutting tool materials*

The machined material were cylindrical billets of a duplex stainless steel 1.4462 (DIN EN 10088-1), approximately 256 mm long and 35 mm in diameter with a ferritic–austenitic structure containing about 50% austenite. The ultimate tensile strength where UTS = 700 MPa, Brinell hardness of 293 HB. The elemental composition of the machined material and technical details of the cutting tools are given in Tables 1 and 2, respectively.

Cutting tool inserts of TNMG 160408 designation clamped in the tool shank of ISO-MTGNL 2020-16 type were employed. Based on industry recommendations, a range of cutting parameters were selected, T1: v_C = 50/150 m/min, f = 0.2/0.4 mm/rev, a_p = 1/3 mm. The experiments performed with the T2 tool point involved similar tests and that is why the cutting parameters were: v_C = 50, 100 and 150 m/min, f = 0.2, 0.3 and 0.4 mm/rev, a_p = 2 mm. The study was conducted within a production facility. The research program was carried out on a lathe CNC 400 CNC Famot Famot – Pleszew plc. Before the main study, preliminary research was carried out to determine what significance the cooling effect has on tool life after DSS turning. Mixture with water was used as a cooling-lubricant liquid containing no chlorine-based refrigerant mineral oils – Blasocut 4000CF, universal emulsion for medium-heavy and hard machining of steel. For the determination of the tool life was adopted the value of the wear parameter VB_B = 0.2 mm.

Table 1 – Chemical composition of 1.4462 duplex stainless steel.

Element	C	Si	Mn	P	S	Cr	Ni	Mo	N	Others
at.%	max 0.03	max 1.00	max 2.00	max 0.030	max 0.020	21.0 23.0	4.50 6.50	2.50 3.50	0.10 0.22	–