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Machinability study of first generation duplex (2205), second generation duplex (2507) and austenite stainless steel during drilling process

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ABSTRACT

Machinability tests were conducted on duplex alloys SAF 2205 and SAF 2507, while employing austenite stainless steel 316L as a benchmark during drilling. Tool wear, cutting forces and machined surface finish were compared and analysed under similar machining conditions. Both duplex alloys displayed poorer machinability responses, with 2507 being worst. Abrasion and adhesion are the most common wears appeared on the flank and rake faces. Adhesion wear being the most severe on the flank face, was seen to be triggered by built-up edge formation. Duplex alloys 2507 and 2205 both show a higher response to built-up edge formation. Flute damage was found on the drill tool, while drilling both duplex alloys. It was found this damage can lead to catastrophic tool failure. Higher cutting force and poorer surface finish were found for second generation duplex (2507).

1. Introduction

Stainless steel world consumption has increased year-on-year worldwide at a compound rate of 5% over the last 20 years; more than other metals [1]. Duplex stainless steels, which were originally developed in the 1920s [2], are becoming ever more mainstream materials with increasing applications in the marine, industrial, construction and chemical processing industries. Duplex alloys are desirable engineering materials and offer significant beneficial features, such as, corrosion resistance, high tensile strengths and relative low cost due to lower contents of nickel and molybdenum [3–5]. The lower cost feature of duplex is particularly significant when considering its application in highly corrosive environments where other materials providing similar performance are significantly more expensive. Furthermore, due to the high strength compared to the 300 series, duplex stainless steels are increasingly used as an alternative material to austenitic stainless steel [6–8].

The superior mechanical properties of duplex stainless steel originates from a 1:1 matrix of austenite (γ) and ferrite (α) phases presenting in a banded structure as depicted in Fig. 1 where the lighter phase is austenite and the darker phase is ferrite. The γ phase is responsible for the relative ductility and resistance to uniform corrosion; while the α phase is responsible for the superior strength as well as corrosion resistance [9]. Both phases exist in relatively large separate volumes and in approximately equal fractions rather than an inclusion phase embedded in the matrix formed by one of the other phases [10].

Stainless steels in general are regarded as difficult to machine materials due to their high tendency to work harden; their toughness and relatively low thermal conductivity [11–15]. Other problems stem from their high fracture toughness, which increase tool/chip interface temperatures leading to poor surface finish and poor chip breaking. Furthermore, built-up-edge (BUE) formation is present even at elevated cutting speeds. This deteriorates the finish of the machined surface and increases the cutting forces [16]. The duplex alloys are more difficult to machine than the austenitic grades though these have better mechanical properties. The common basis for its poor machining behaviour stem primarily from the resulting high strength of the alloy but being exacerbated by lack of non-metallic inclusions and the low carbon content [4,17]. However, there is still a deficient understanding in machining of duplex stainless steel.

Investigating the material response during machining processes is a general strategy to understand the machinability of any material. These also provide insight to what are the essential questions, and draw out key areas requiring central focus. There are some studies to investigate machinability of duplex alloys. Paro

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et al., [14] drilled HIPed P/M super duplex Duplok 27 and conventionally-produced A8910 1A stainless steels. They established a correlation between the pitting resistance equivalent (PRE) [18], and the machinability of duplex alloys. A duplex with higher PRE value gives worse tool life. The PRE of HIPed P/M Duplok 27 stainless steel is 25% higher than the PRE-value of cast A890 1A stainless steel thus tool life during drilling HIPed P/M Duplok 27 stainless steel is 40% shorter than that of cast A890 1A stainless steel. Moreover, it was revealed that tool wear in drilling, using TiN-coated cemented carbide drills with through coolant, increased continuously at lower cutting speeds. The plastic deformation of the cutting edges became a limiting factor leading ultimately to flaking of the coating at higher speeds. The micro hardness of both phases present in the chip also increased as the cutting speed increased. Carlborg [22] considered four duplex and one high alloyed austenitic steels during turning process to compare the performance of cemented carbide cutting tool. Their investigation was limited to qualitative discussion on tool wear and quantitative discussion on tool life. There was no information on machining forces or surface integrity.

Having said these, there is no study on drilling of second generation duplex alloy (SAF 2507) so far in the literature. In addition, a comparison of machinability among the first generation duplex, second generation duplex and austenitic stainless steel are also missing. Though these are imperatively needed to optimise the application and improve the productivity of these materials. This paper compares and investigates the machinability of duplex SAF 2205, super-duplex SAF 2507 and 316L austenitic stainless steel in terms of cutting forces and surface roughness with advancement of tool wear (qualitative and quantitative) during drilling process.

2. Experimental details

2.1. Workpiece materials

Duplex SAF 2205, super-duplex SAF 2507 and 316L austenitic stainless steels are workpiece materials in this investigation. The chemical compositions and basic mechanical properties of the three workpiece materials are given in Table 1. Wrought specimens were 20 mm in diameter for both duplex grades and 25 mm in diameter for the austenitic grade.

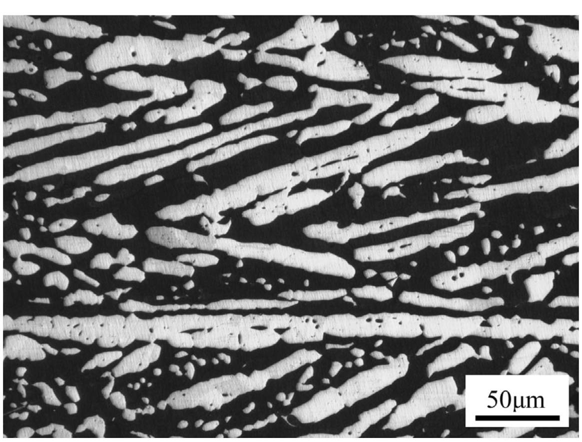

Fig. 1. Typical “banded” duplex stainless steel microstructure.

2.2. Experimental procedure

Drilling experiments were performed on a Haas (XYZ) Super VF-3 CNC vertical machining centre using 12 mm diameter Seco SD203A-M geometry drills, as shown in Fig. 2. These were TiAIN +TiN coated solid carbide twist drills with internal coolant supply. General purpose emulsion type mineral oil based cutting fluid with a dilution concentration of 5% was supplied at a continuous flow rate of 9.9 l/min. Machining parameters for all the drilling trials comprised a cutting speed of 60 m/min; a penetration rate of 0.15 mm/rev; and a hole depth of 30 mm continuous.

A Kistler 9257b cutting force dynamometer coupled with a Kistler 16-channel charge amplifier was used to measure the reaction forces as well as the torque during drilling. Readings were data-logged on computer using ‘Dynaware’ cutting force software. The experimental setup is shown in Fig. 3. The workpiece was mounted in a special fixture that was located rigidly on the centre of the dynamometer platform—i.e. equi-spaced between the four quartz crystals. Tool wear on the flank face was measured at regular intervals using an optical microscope. Drilling continued until a tool wear value (VB_{max}) of 0.15 mm was reached or until tool failure. The surface roughness of machined surfaces of each workpiece was recorded using a stylus measurement device, namely a Talysurf Intra Series 50.

3. Results and discussion

3.1. Tool wear

Different areas, such as, flank face, rake face, chisel edge and all over the flute, of the carbide drill tools were examined for wear/damage. The amount of wear of the tool was dependant on the degree of contact and interaction with the workpiece material. However, in all cases, the amount of wear was found to vary with the workpiece materials. These are described in the following sections.

3.1.1. Flank wear

Fig. 4 shows the progression of maximum flank wear with the number of drilled holes for the three workpieces. The rate of flank wear was very high for the second generation duplex (2507). It reached to the set flank wear criterion after drilling 26 holes. The rate of flank wear development for the drilling of the first generation duplex (2205) was less than that of second generation duplex (2507) from at the start until 40th hole. But the wear stabilised after that. Though the drill tool wear remained below the set criterion, the tool failed after drilling 69 holes. Severe damage in the flute was noted approximately 10 mm above the drill tip as shown in Fig. 5. This damage triggered higher cutting loads and poor chip evacuation. The rate of tool wear during machining of the austenite 316L (Fig. 4) was very low initially (until 15th hole) then it stabilizes (until 35th hole). After that the

Table 1
Chemical composition and mechanical properties of the workpiece materials.

Alloy	C	Mn	Si	S	P	Ni	Cr	Mo	Fe	UTS (MPa)	Yield (MPa)	Hardness $HV_{100\ g}$
SAF 2507	0.02	0.74	0.23	0.01	0.02	6.77	25.1	3.68	Balance	866	570	285
SAF 2205	0.02	0.8	0.4	0.01	0.02	5.2	22.4	3.05	Balance	777	556	279
AISI 316L	0.03	1.5	0.4	0.03	0.03	10.5	17	2.1	Balance	640	326	254