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Local improvement of structural steels high-friction properties by friction stir texturing

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ABSTRACT

The microstructural, mechanical and tribological properties of textured structural steel surfaces, produced using a friction stir processing (FSP) related technique, called in current work friction stir texturing (FST), are analyzed in this paper. The textured/processed surfaces were produced using a WC-Co pinless tool and varying tool rotation and traverse speeds. Microstructural analysis of the textured/processed surfaces revealed an important grain refinement relative to the initial substrate microstructure. The mechanical strength of the refined structures, evaluated through hardness tests, was found to drastically increase, relative to the non-processed substrate. In the same way, the roughness measurements and friction tests revealed an important enhancement in roughness, as well as in static friction coefficient, of the textured/processed surfaces relative to non-treated and blasted surfaces. A linear relation between surface roughness, stiffness, friction coefficients and processing parameters was found, proving that the proposed texturing technique is suitable to be used in the production of friction tailored surfaces.

1. Introduction

Surface texturing can be defined as the production of desirable patterns on material surfaces. According to the bibliography, to the date, surface texturing of metallic materials is being performed by using several state of the art techniques and envisaging a large range of industrial applications and/or research goals. For example, Zhou et al. (2003, 2005) applied, respectively, ion-beam texturing and argon-plasma etching, to improve the tribological behaviour of the head/disc interface during magnetic recorded disks playing. Laser texturing had also been deeply explored for several applications. Kovalchenko et al. (2005), used laser texturing for analysing the influence of surface patterning on the development of different lubrication regimes, Etsion et al. (2004), for improving the tribological behaviour of steel bearings, Mishra and Polycarpou (2011), for improving the durability, under starved lubrication conditions, of air-conditioning refrigeration compressors and Daguenet-Frick et al. (2012), for enhancing the performance of heat exchangers. More recently, Lopez-Cervantes et al. (2013), used laser texturing to improve the performance of human prosthesis.

The improvement of cutting tools is another important field of application of surface texturing. Microsurface texturing, through photolithography and wet etching, was used by Obikawa et al. (2011), to improve K10 cemented-carbide steel tools. Important reductions in friction force and friction coefficient were registered by the authors in machining of AA 6061-T6 aluminium alloys. Koshy and Tovey (2011) used electrical discharge machining to create a texture that allowed a reduction of the force necessary in 1045 steel and AA 6061 aluminium alloys machining. The authors concluded that surface texturing enabled improving the lubrication conditions during machining. Ling et al. (2013) applied laser texturing on the surface of drills for titanium plates machining, reporting an enhancement of the textured tool lifetime relatively to an untextured one. This was attributed to the reduction of tool/plate adhesion. Laser surface texturing was also used by Voevodin and Zabinski (2006) to improve TiCN coated tools, by Hu et al. (2012) and Ripoll et al. (2013) to improve uncoated Ti tools and Segu et al. (2013) to improve AISI 52100 steel tools. Surface texturing by laser micromachining was also used in tool improvement by Lei et al. (2009) and Ze et al. (2012). Lei et al. (2009) performed texturing of a tungsten carbide tool, reporting an important reduction of tool wear and friction in mild steel machining. Ze et al. (2012) tested surface texturing of a self-lubricating tool used in dry cutting of titanium alloys. Due to an important reduction of the cutting forces, temperature and adhesion, the tool life was improved. Finally, tool enhancement was also tested by Moshkovith et al. (2007), and Basnyat et al. (2008), who used pulsed air arc and ion etching, respectively, in tool surfaces patterning.

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Table 1
Nominal chemical composition of the S690 steel (wt%).

C	Mn	P	S	N	Cu	Si	B
0.22	1.8	0.030	0.017	0.016	0.55	0.86	0.006
Cr	Mo	Nb	Ni	Ti	V	Zr	Fe
1.6	0.74	0.07	2.1	0.07	0.14	0.17	Remaining

All the earlier mentioned authors applied several surface texturing techniques, or combinations of texturing and coating techniques, in order to reduce the wear, the friction coefficient and the forces, during sliding contact of the transformed surfaces. The friction stir processing (FSP) technique, adapted in current work for the production of high-friction patterned surfaces, has already been proved to be an effective method for increasing the hardness and/or wear resistance of metallic substrates. Escobar et al. (2013) and Grewal et al. (2013) applied FSP in the surface enhancement of two different steels, the UNS S32205 duplex stainless steel and the ASTM 743, respectively. The processed surfaces were tested in extreme cavitation erosion conditions being reported a significant improvement in wear resistance for both processed materials. FSP was also successfully applied in the processing of 1080 carbon-steel (Aldajah et al., 2009), SKD61 tool steel (Chen and Nakata, 2009), IF steel (Chabok and Dehghani, 2012), super-austenitic steel (Mehranfar and Dehghani, 2011), AISI 420 martensitic steel (Dodds et al., 2013) and AISI D2 tool steel (Costa et al., 2014). However, none of these works envisaged the analysis of processed surfaces tribological properties. It is also important to enhance that, among the searched literature, it was only possible to find one example, by Hammerström and Jacobson (2008), of the use of a surface texturing technique featuring the production of high-friction surfaces as envisaged in current investigation.

Actually, since surface hardening, allied to important roughening, resulting from the tool stirring action, are important characteristic of the friction stir processed surfaces, the potential of this technique in surface texturing, featuring the production of high-friction surfaces, is an interesting application to be explored. Actually, as reported by Menezes et al. (2011), friction results from the adhesion and ploughing between the surfaces in contact. According to Blau (2009), both the adhesion and ploughing depend on the real area of contact between the surfaces, the adhesive shear strength between the surfaces in contact and the way in which they are loaded. In this way, material properties such as elastic modulus, yield strength and hardness, as well as surface topography, have a strong influence on the friction properties of the surfaces in contact. By using appropriate texturing techniques it is possible to produce surfaces with controlled high-friction properties prone to be used in non-sliding connections. Envisaging structural engineering applications, in current work, a structural steel traditionally used in metallic construction was used as substrate.

Table 2
Tool traverse and rotations speeds.

Rotation speed [rpm]	Traverse speed [mm/min]		
300	250		
400	250		
500	250	350	450
600	250		

2. Experimental procedure

In this work a high strength quenched and tempered steel, S690, with the nominal chemical composition shown in Table 1, was subjected to surface texturing by friction stir processing. As shown in Fig. 1, a WC-Co columnar tool with no pin and with shoulder diameter of 16 mm was used. Friction stir texturing was accomplished in position control, using a 2° tool tilt angle and 0.3 mm penetration into the base material plates. Argon gas was used for surface and tool shielding during texturing. In order to analyze the influence of the tool rotation (ω) and traverse (v) speeds, on texturing results, these two process parameters were varied according to Table 2, i.e., texturing was performed in two different conditions: at a constant tool traverse speed of 250 mm/min and varying tool rotation speeds and at a constant tool rotation speed of 500 rpm and varying tool traverse speeds.

After processing all the samples were visually inspected and photographed, with a Canon Powershot G5 camera, using a 5× magnifying glass, in order to record the main textured surfaces features. The textured samples were then sectioned, transverse to the processing direction, and mounted in self-curing resin. All the samples were mechanically polished, using metallographic carbon silicate sandpaper. Final polishing was performed using 3 micron diamond suspension. Etching was then performed for 30 s, with Nital solution (2 ml HNO_3 + 98 ml ethanol (95%)). The microstructure of the textured/processed zones was examined by optical microscopy (OM) using Leica DM 4000M LED microscope.

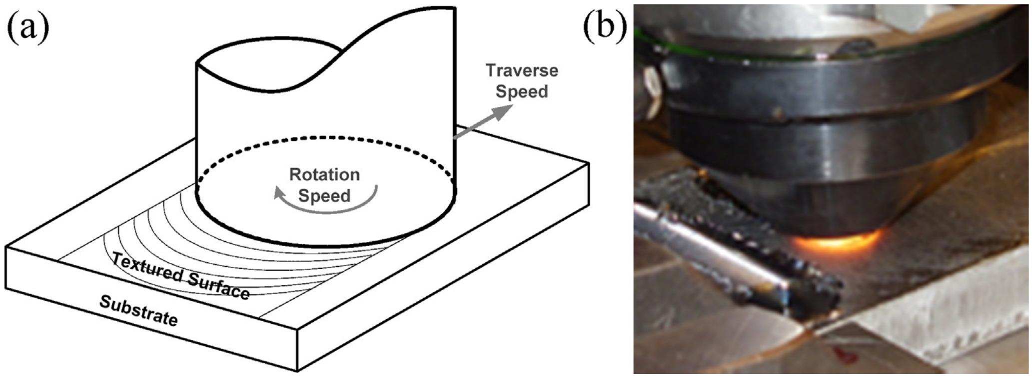

Fig. 1. Scheme (a) and picture (b) of the friction stir texturing setup.