Tribology International 91 (2015) 177–183

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Wear properties of friction stir processed AISI D2 tool steel

Noushin Yasavol [a,*], Amilcar Ramalho [b]

[a] Department of Materials Engineering, Tarbiat Modares University, P. O. Box 14115-143, Tehran, Iran
[b] CEMUC, Department of Mechanical Engineering, University of Coimbra, P. O. Box 3030-788, Coimbra, Portugal

ARTICLE INFO

Article history:
Received 13 February 2015
Received in revised form
15 June 2015
Accepted 1 July 2015
Available online 11 July 2015

Keywords:
Friction stir processing
Wear
Nanohardness
Texture

ABSTRACT

Influences of microstructural and textural properties of friction stir processing (FSP) on dry reciprocating wear properties of AISI D2 tool steel are investigated in this study. The mechanical improvement is attributed not only to the homogenous distribution of very small carbides in a refined matrix, but also to significant development of textures during FSP. The excellent wear resistance is ascribed to nanohardness enhancement of the FSPed steel. Dominant shear components of {111} ⟨110⟩ and {112} ⟨111⟩ with the lowest Taylor's factor and the high density of close-packed planes formation significantly enhance the wear resistance of FSPed sample at 500 rpm.

1. Introduction

Cold work tool steels especially the AISI D series, which are widely used for cutting and forming applications, require both strength and wear resistance properties [1]. Although these steels exhibit almost good wear resistant, it was observed that under severe conditions they show wear failure mostly due to the low surface hardness [2]. In this regard, many authors claimed that formation of a finely homogeneous microstructure surface layer on the coarse heterogeneous bulk via friction stir processing (FSP) promotes the mechanical and therefore wear properties [3–5]. During FSP, a non-consumable rotating tool consisting of a shoulder with or without a pin is plunged into a single piece of material and provides frictional heating and mechanical mixing in the area covered by the tool. Microstructural evolution in different regions of the FSPed zone is closely linked to the local thermomechanical cycle, experienced during FSP. Therefore, the important parameters of the thermomechanical cycle that control microstructural development are total strain, strain rate and temperature [6,7].

The wear mechanisms have widely been investigated in cold work tool steels. For example, Meng and Fanju [8] have compared the wear rate of the quenched, cold and cryogenic treatments of cold work tool steel. They indicated that the wear rate has significantly increased because of decremented amount of remained austenite to zero and formation of twined martensite in cold treatment, and twined martensite and preferential precipitation of η-carbides in cryogenic treatment. They also proved that the predominant wear mechanism of the latter were plowing, fracture and delamination. Das et al. [9] indicated that cryotreatment improves the wear resistance of AISI D2 tool steel by uniform distribution of high volume fraction carbides and formation of secondary carbide particles.

The wear properties and the related wear mechanisms of the friction stir processed AISI D2 tool steel have not still been reported. In this study, the effects of FSP parameters on the microstructure, formed texture and nanohardness properties of as-annealed AISI D2 tool steel are investigated.

2. Experimental procedure

The base material (BM) was as-annealed AISI D2 cold-worked tool steel of 3 mm thickness, with the chemical composition of 11.40Cr–1.49C–0.82Mo–0.79V–0.40Si–0.35Mn–0.31Ni–bal Fe (in wt pct). The pinless FSP tool, made of WC-Co, had a cylindrical shape with a 16 mm diameter. A schematic illustration of the FSP rotating tool and required directions are shown in Fig. 1. The FSP was accomplished in position control, using 3° tool tilt angle (α) and 0.1 mm tool penetration into AISI D2 plates. A constant traverse speed of 385 mm/min and four different tool rotation rates of 400, 500, 600 and 800 rpm were used as processing parameters. Argon gas was used for surface shielding during FSP.

As-processed workpieces were sectioned transverse to the FSP direction, mechanically polished and etched with Nital solution. The microstructure of the FSPed zones was examined by field emission scanning electron microscopy (FESEM). High-resolution EBSD analysis was conducted with a Hitachi S-4300SE FESEM equipped with a TSL OIMTM EBSD system. Orientation mapping

* Corresponding author. Tel./fax: +98 21 88005040.
E-mail address: yasavol114@gmail.com (N. Yasavol).

http://dx.doi.org/10.1016/j.triboint.2015.07.001
0301-679X/

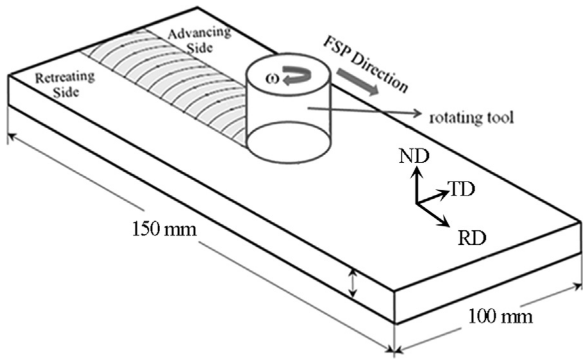

Fig. 1. Schematic of the FSP and related directions.

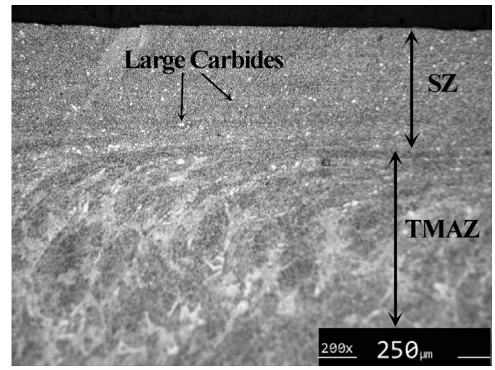

Fig. 2. The cross section of the FSPed sample at rotation rate of 400 including two distinct zones the stir zone (SZ) and the thermo-mechanical affected zone (TMAZ).

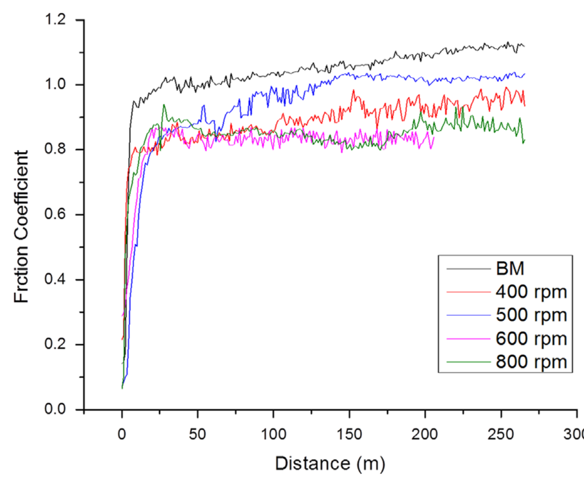

Fig. 3. Coefficient of friction versus sliding distance diagrams for the BM and FSPed samples of different rotation rates in 10N load.

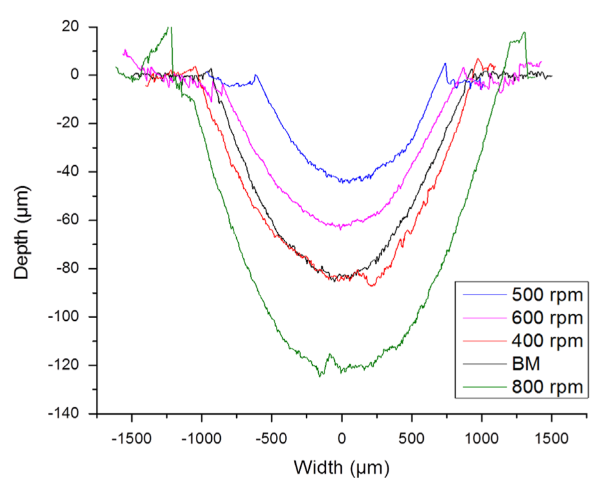

Fig. 4. The surface profilometer charts of wear tracks produced at different FSP rotation rates.

involving automatic beam scanning was performed using a triangular scanning grid. On each pattern, seven Kikuchi bands were used for indexing, to minimize the possibility of miss-indexing error. The orientation distribution function (ODF) was calculated using the PHILIPS X'pert texture software package.

The hardness of the FSPed samples was measured using Vickers nano-indentations under a 30 mN load in 16 QUOTE 4 arrays extending from the stir zones (SZs) into the base metal (BM). Wear tests were carried out using a reciprocating ball-on-plate on the surface of the as-processed samples.

Dry sliding wear conditions were established by rubbing an alumina ball with a diameter of 10 mm against a fixed FSPed steel plate in air at humidity of 33–35% and room temperature. The tests were carried out at constant normal load of 10N. The reciprocating motion was applied by an eccentric shaft which was imposing a sinusoidal wave with a frequency of 4.5 Hz and a stroke of 2.05 mm. The tangential speed was 20 mm/s, rms, and the duration of each test was 65 k cycles, corresponding to a sliding distance of 266 m. The friction force was recorded automatically along the test time. The friction coefficient of the alumina ball against the FSPed samples was calculated from the ratio of the rms value of the friction force to the normal load.

The wear volume loss was measured by a surface profilometer at 3 different locations along the wear track, and its average measured value represents the mean wear volume losses of the specimen. The wear track was examined by an optical microscope (OM) to study the wear mechanism. The wear behaviors of the BM and the FSPed samples under the same processing conditions were also investigated for comparison.

3. Results and discussion

Transverse cross section of the FSPed sample at rotation rate of 400 rpm is shown in Fig. 2. Two distinct zones can be identified: the stir zone (SZ), with the refined microstructure and the thermo-mechanical affected zone (TMAZ), with the grains plastically deformed and oriented according to the tool traverse direction. The wear tests were done on the BM and stir zone (SZ) surfaces of all FSPed samples. Fig. 3 shows the friction coefficient as a function of the sliding distance along the test. Under dry sliding, all FSPed samples lowered friction coefficient compared to the BM. Same results of reducing the friction coefficient with FSP were reported by Aldajah et al. [10] in FSP of 1080 carbon steel and by Mahmoud et al. [11] for hybrid composite of Al_2O_3/SiO_2–Al. It can also be observed that the friction coefficient of all FSPed samples exhibits fluctuations. This could be attributed to the cohesive contact between the tool steel plates and the ball. This behavior results in reduction of the actual contact area between the FSPed surface and the ball due to the presence of carbide particles which weakens the cohesion behavior of contact [12]. It may also be due to the differences in the extent of localized plastic deformation at real contact areas in the early stages of the test. Furthermore, Fig. 3 presents the variation of friction coefficient with FSP rotation rate. At 400 rpm, the friction coefficient oscillates almost slightly around 0.85; while the friction coefficient of 500 rpm surface fluctuates drastically in early stages and then increases slightly. The friction coefficients remain somehow constant approximately around 0.8 at 600 and 800 rpm.