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FRICTION STIR PROCESSING OF SKD61 TOOL STEEL

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In this study, SKD61 tool steel was friction stir processed (FSP) using a polycrystalline cubic boron nitride (PCBN) tool. Microstructure evolution and mechanical property in FSP zone were investigated. Microstructural observation results showed that the microstructures in FSP zone surface were fine grains in the range of 1 - 4 μm due to large plastic deformation during FSP. Micro-hardness test results showed that the average hardness value in FSP zone was 773 HV, 3.7 times the hardness in base metal (210 HV). The wear test results showed that FSP surface showed a significantly lower wear rate than that of the base material at all loads. The relation between microstructural evolution and mechanical property in FSP zone was discussed.

Keywords: Friction stir processing; tool steel; microstructure; mechanical properties.

1. Introduction

Friction stir processing (FSP) is an emerging surface-engineering technology,[1,2] developed based on the basic principles of friction stir welding (FSW),[3,4] which can provide localized microstructure modification in near-surface layers of processed materials. A rotating tool consisting of a shoulder and a probe is plunged into a workpiece and then travels in the expected direction. The tool serves two primary functions, heating and deforming the material. After extreme levels of plastic deformation and thermal exposure, the processed zone normally exhibits significant microstructural refinement and homogeneity. As a result the material properties such as strength, wear property and corrosion resistance were improved. So far FSP technique has been successfully applied to production of fine-grained structure,[5-10] modification of microstructure of materials,[11-15] and syntheses of the intermetallic compound in situ.[16-18] To date, light metals, namely aluminum alloys or magnesium alloys are the main focus of research. In contrast, high temperature materials, despite their significant industrial importance, have been largely ignored because of the limitation of FSW tools. In this study, SKD61 tool steel is friction stir processed using a polycrystalline cubic boron nitride (PCBN) tool. Microstructure evolution and mechanical properties in FSP zone are investigated to explore the effect of FSP on the surface properties of the target, for instance, micro hardness, wear resistance, phase structure and microstructure.

2. Experimental

A tool steel SKD61 (Nominal chemical composition: 0.32-0.42 wt.% C, 0.8-1.2 wt.% Si, 0.5 wt.% Mn, 4.5-5.5 wt.% Cr, 1-1.5 wt.% Mo, 0.8-1.2 wt.% V, balance Fe) was subjected to surface treatment using FSP in argon atmosphere. The tool fabricated from polycrystalline cubic boron nitride (PCBN) consisted of a shoulder with a diameter of 15 mm and a columnar probe with a diameter of 5 mm. The length of the probe was 1.8 mm. FSP was performed on an FSW machine at a tool travel speed of 30 mm/min and a tool rotation speed of 360 rpm. After FSP, the plate was sectioned perpendicular to the welding direction and studied by optical microscopy (OM). For OM observations, the sample was ground with water abrasive paper, mechanically polished with a 1 μm diamond, and then etched in a 5 ml nitric acid + 95 ml ethanol solution. Micro hardness of the cross-section of the FSP zone was measured by a Vickers micro hardness tester. The test was carried out with a load of 0.98 N applied for 15 s duration. The friction and wear behavior of the surface modification layer were investigated using a reciprocating friction testing machine under dry sliding condition. In the present investigation, loads of 0.98 N and 1.96 N were used to clarify the effect of different load on the friction behavior of surface modification layer. All the tests were carried out at a fixed distance of 5 mm and vibration frequency of 2 Hz. The friction test time was standard 2 hours. Wear surfaces of the as-received and the surface treated SKD61 tool steel were characterized using a scanning electron microscope (SEM). The phases of the base material and the FSP zone were analyzed by X-ray diffraction (XRD).

3. Results and Discussion

3.1. *Microstructure characterization*

Figure 1 shows a typical cross-sectional view of FSP zone of SKD61 tool steel. A defect free FSP zone can be obtained using a PCBN tool. The maximum FSP depth is similar to the length of the probe. It can be seen from this figure that the treated specimen consists of three zones, i.e. the FSP zone, the heat affected zone (HAZ) and the base material (BM). The details of the microstructural variations are demonstrated in Fig. 2. The typical microstructures of positions a, b, c and d shown in Fig.1 are magnified in Figs. 2a, b, c and d.

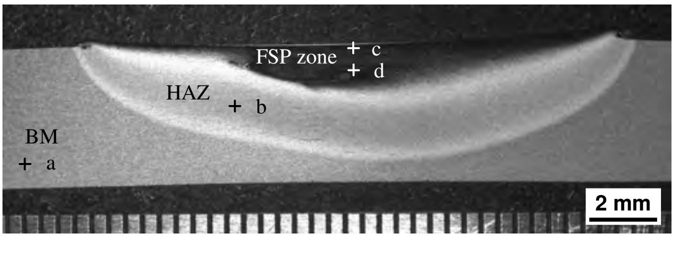

Fig. 1. A typical cross section of FSP zone (360 rpm, 30 mm/min).

Figures 2a and b show the microstructure in the BM and the HAZ. The coarsened grains in the range of 10-20 μm distribute along the rolling direction in the BM. Carbides particles with a spheroidal structure disperse in a matrix.[19] In the HAZ, as indicated in Fig. 2b, the particles become larger as a result of tempering.

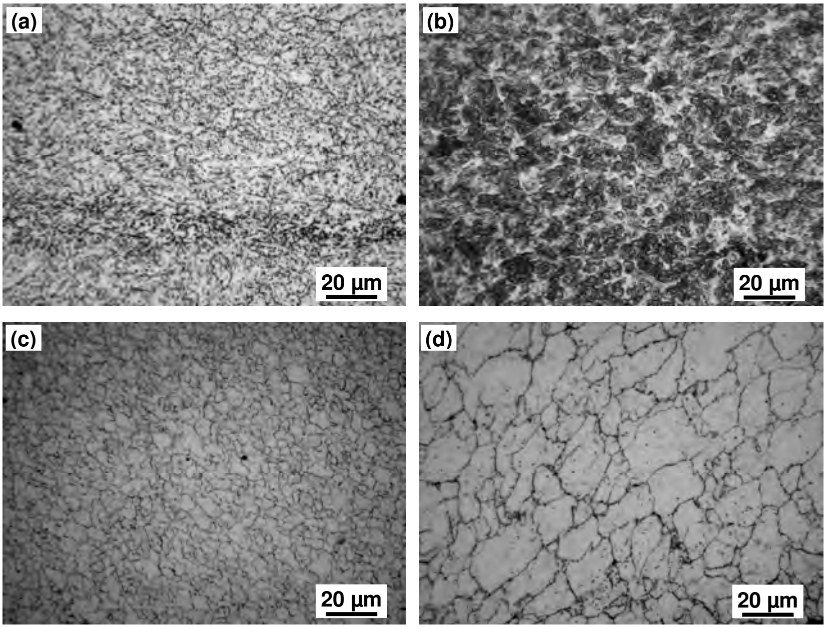

Fig. 2. Microstructure in (a) base material, (b) heat affected zone, (c) friction stir processing zone (top) and (d) friction stir processing zone (center).

Figures 2c and d show the magnified view of the FSP zone. A pronounced grain refinement can be seen in the region. The microstructure mainly consists of fine grains of small sizes. The grain sizes are in the range of 1–4 μm near the top surface of FSP zone. The grains grow up at the FSP center. The grain sizes in FSP zone center are in the range of 10-20 μm. Moreover, a typical lath martensite structure characteristic is observed in the grain and the particles presented in the BM decompose in FSP zone. This result suggests that the peak temperature during FSP is above the austenizing temperature.

In order to examine the phase transformation before and after FSP, XRD analysis of the as-received and FSP surface has been carried out. Figure 3 shows the XRD patterns. Similar diffraction patterns are obtained from both surfaces. A close comparison between Figs. 3a and 3b shows no noticeable change in peak positions. From the above microstructure analysis we know that phase transformation occurs after FSP. Similar diffraction patterns are due to the similar peak positions of these two phases.

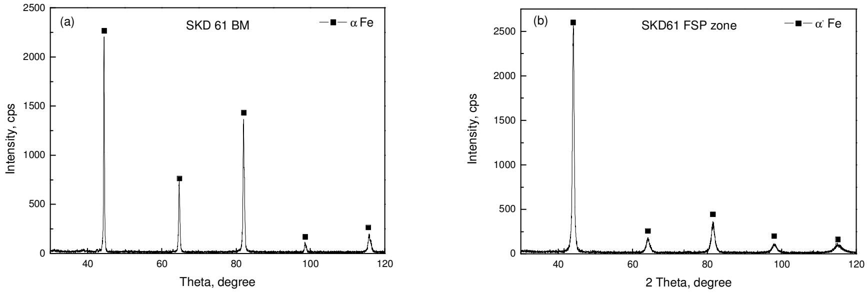

Fig. 3. XRD pattern of the surface of the as-received and FSP surface treated SKD61 tool steel (a) BM and (b) FSP treated surface.

3.2. *Micro hardness*

Figure 4a shows the micro hardness profile on the cross sectional plane near the top surface of FSP zone. It can be seen that the micro hardness of FSP surface increases by almost 4 times. The increase in micro hardness may be attributed to the formation of martensite phase and grain refinement. Figure 4b shows the micro hardness profile of the FSP specimen as a function of depth from the surface measured on the cross-sectional plane. It is apparent that the micro hardness of the FSP has significantly increased to 550–820 HV as compared to that of the substrate (about 210 HV). The micro hardness of the FSP zone becomes the largest near the surface and then decreases gradually towards the inside of the FSP zone. This is due to the finer microstructure at the top as compared to the inside of FSP zone.

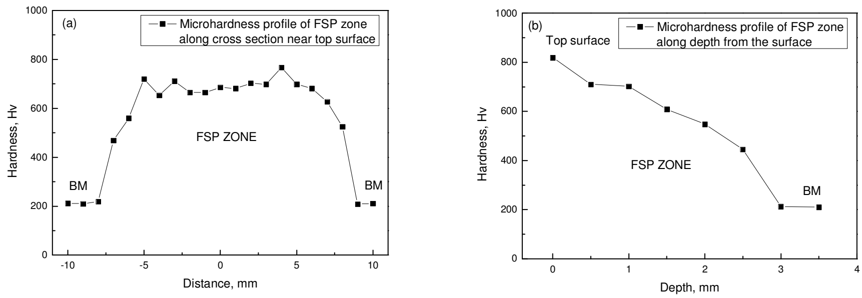

Fig. 4. Micro hardness profile of FSP zone (a) along the cross section of FSP zone near the top surface and (b) along the depth from the surface.

3.3. *Wear behavior*

Figures 5a and b show the micrographs of the worn surfaces of the as-received and the FSP surface at the load of 1.96 N. The abrasive wear is observed in both cases. The micrograph of the base material reveals that numerous long and deep grooves have formed on the wear surface. However, the micrograph of the FSP zone shows a small quantity of thin grooves. These parallel grooves are the proof of micro ploughing and micro cutting. The abrasive particles plough across the surface, finally removing or pushing material into ridges along the sides of the grooves. The width of the wear track on the base material (about 887.8 μm) is much higher than that of the FSP specimen (about 361.9 μm). This significant difference confirms an increased wear resistance of SKD61 tool steel after FSP treatment.

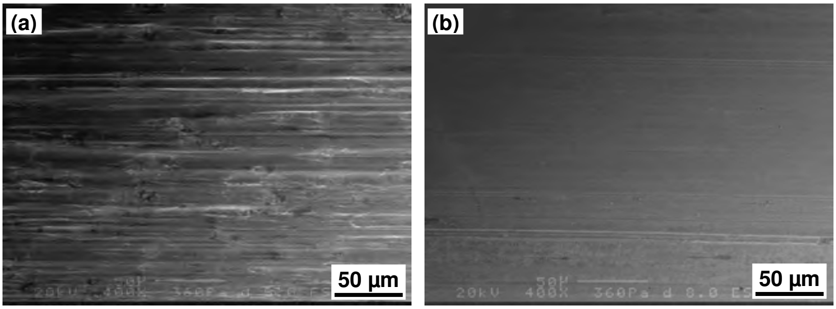

Fig. 5. SEM photographs of worn surface of BM and FSP zone under load of 1.96 N (a) BM and (b) FSP zone.

Table 1. Wear characteristic of BM and FSP zone at 0.98 N and 1.96 N loads.

Type	Width	Depth	Average coefficient of friction
BM (Load 0.98 N)	618.5 um	20.2 um	0.729254
BM (Load 1.96 N)	887.8 um	41.9 um	0.664424
FSP (Load 0.98 N)	291.4 um	4.5 um	0.800215
FSP (Load 1.96 N)	361.9 um	6.9 um	0.759329

The wear characteristic of the BM and the FSP zone at different loads is shown in Table 1. It can be seen that the wear width and wear depth of the FSP zone at the load of 0.98 N are 291.4 μm and 4.5 μm, as compared to 618.5 μm and 20.2 μm of the BM, decreased by 53% and 78%. The average coefficient of friction of the FSP zone is slightly higher than that of the BM. When the load is increased, the basic mechanism remains unchanged and only the grooves become slightly deeper. It is known that by the abrasive wear mechanism, the wear of the material decreases with the increasing hardness. The superior wear behavior of the FSP zone is attributed to the improved micro hardness in this region.

4. Conclusion

This work examined the effect of FSP treatment on modifying the surface of SKD61 tool steel. The major results were summarized as follows. The microstructure of FSP zone surface consisted of fine grains in the range of 1-4 μm; the average friction coefficient of the FSP zone was slightly higher than that of un-treated specimen; the micro hardness and wear resistance of the FSP zone were significantly improved.

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