ENHANCEMENT IN THE WEAR RESISTANCE OF A NICKEL-BASED ALLOY VIA SURFACE SEVERE PLASTIC DEFORMATION

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Introduction

Surface severe plastic deformation (S^2PD) processes have recently been developed to introduce nanograins and grain size gradients into the surface region of bulk materials [1-4]. The key feature of these processes is severe plastic deformation at the surface region of a workpiece induced by repeated impacts of a stream of high-energy balls against the surface of the workpiece [2,3]. Friction and wear are surface-contact dominated processes, and thus S^2PD is expected to have dramatic impacts on friction properties and wear resistance. A recent study [5] has indeed confirmed such an expectation. It is shown that the friction coefficient of a low carbon steel is reduced by ~50% after S^2PD processing. The abrasive wear resistance of the same low carbon steel against a diamond stylus has been improved as well. The enhancement in the wear resistance of a high carbon steel has also been demonstrated recently after combining S^2PD with annealing [6]. In this study we have studied the effect of S^2PD on the wear resistance of a nickel-based alloy. The sliding wear resistance obtained is compared with that of the same alloy without any surface treatment. The improved wear resistance of the C-2000 alloy is related to surface nanocrystallization and work hardening. The details of the results obtained are described below.

Experimental

The as-received C-2000 alloy was in an annealed condition with an average grain size of 50 μm. The nominal chemical composition of the C-2000 alloy is (in wt.%): 23Cr, 16Mo, 1.6Cu, 0.01C, 0.08Si, and balance Ni. The alloy is a single phase material with a face-centered-cubic (FCC) crystal structure. Discs 49 mm in diameter were cut out of the as-received plate and subjected to S^2PD. Five WC/Co balls 7.9 mm in diameter were used to provide the desired impact on the surface of the disc in the S^2PD process. Both the C-2000 plate and WC/Co balls were loaded into the sample holder of a Spex 8000 Mill inside a glove box under an argon atmosphere, as described elsewhere [4]. The S^2PD treatment was performed at room temperature and lasted for 30 min.

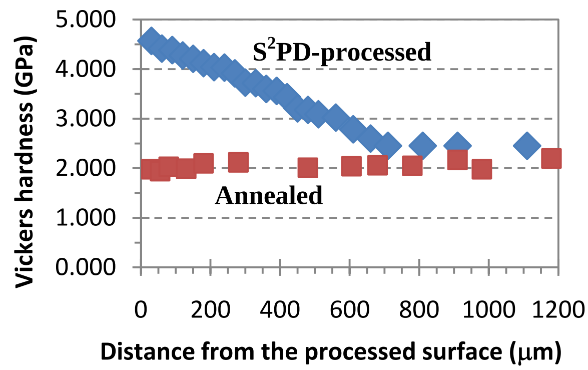

Fig. 1 The Vickers harness of the C-2000 alloy with and without S^2PD processing as a function of the position measured from the processed surface.

The microstructures of the as-received and S^2PD-processed specimens were studied using transmission electron microscopy (TEM). Microhardness was measured on samples at the polished condition using a LECO DM-400FT hardness tester with a 200-g load and a dwell time of 15 seconds. Wear tests were conducted using a pin-on-disc tribometer with a Si_3N_4 ball 0.5 inch in diameter as the pin against the C-2000 disc. The test was performed in air without lubricant and the load was 4.9 N. The linear speed of the pin with respect to the disc was 0.2 m/s. The wear rate, K, was calculated using the Archard formula [7]

$$K = V / (P.L) \qquad (1)$$

where V is the wear volume in mm^3, P is the load in N, and L is the sliding distance in m. The wear volume was measured using a 3D non-contact optical profilometer (Zygo NewView 5000). For each sample the wear volume at three different locations was measured and the average wear volume was used to compute the wear rate shown in Eq. (1).

Results and Discussion

Figure 1 shows the microhardness profile of the as-received and S^2PD-processed samples. As expected, the hardness of the S^2PD-processed sample decreases gradually as the location moves away from the impacted surface. Clearly, the decrease in hardness is due to the reduced plastic deformation as the position moves deeper into the solid. However, the highest hardness at the surface region is related to the formation of nanograins, as shown in Fig. 2.

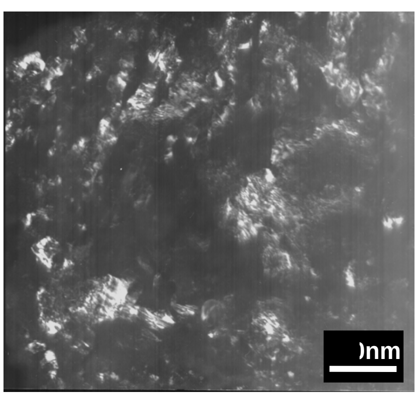

Fig. 2 TEM dark-field image of the nanograins at the S^2PD-processed surface of the C-2000 alloy.

Both nanograins and high hardness can impart the C-2000 alloy with high wear resistance. This is indeed the case. As shown in Fig. 3, the worn track of the annealed C-2000 alloy is very deep, whereas the S^2PD-processed counterpart exhibits a negligible worn track. Quantitative analysis of the worn track reveals that the wear rate of the annealed C-2000 alloy is 1×10^{-5} mm^3/N.m, whereas the wear rate of the S^2PD-processed sample is negligible because the surface of the S^2PD-processed sample remains almost the same as that before the wear test.

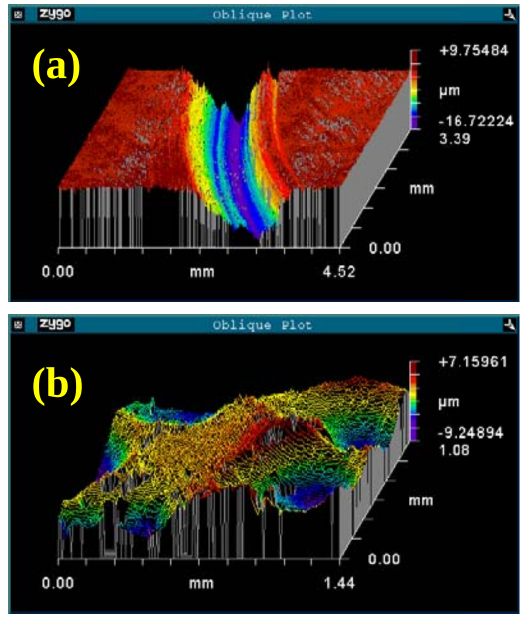

Fig. 3 Three-dimensional worn tracks of the C-2000 alloy: (a) the annealed and (b) the S^2PD-processed sample.

Conclusion

S^2PD can improve the wear resistance of the C-2000 alloy. The improvement is ascribed to the formation of nanograins and high microhardness at the surface region induced by S^2PD.

References

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