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Nano structure and transformation mechanism of white layer for AISI1045 steel during impact wear

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Abstract

Impact wear was carried out for annealed AISI1045 steel in this study. With the impact frequency of 600 times per min, an 8.29 kN impact load was applied on the constant contact area of 540.08 mm^2 at the individual attack angles 60° and 90°. The microstructure of white layer for annealed AISI1045 steel was examined by SEM, TEM and HRTEM. It was found that nano structures with ferrite and cementite have been formed in white layer after impact of AISI1045 steel. Nano crystallization mechanism for ferrite is from moving, interacting and rearranging of dislocations, resulting in production of dislocation walls. With increasing strain, the density of pinned dislocations, whose Burgers vectors are usually vertical to the wall, correspondingly increases along the dislocation wall, i.e., θ/b increases. That, finally, forms subgrain boundaries with small angle θ. In addition, the density of slippery or shear-susceptible dislocations, whose Burgers vectors are often parallel to dislocation walls, also increases at the same time. The slipping of dislocations in many places along the boundary of subgrains will result in the rotation of crystals to form boundaries with large angles. Nano crystallized mechanism for cementite is mainly due to shearing fracture, neck-like shrinkage fracture and carbides dissolving under the impact. The cementite thinning and the formation of slipping stages will increase the surface energy per volume, which causes the dissolution of cementite. The chemical potential energy difference between carbon atoms and cementite is a driver for dissolving cementite. The moving, reacting and proliferating of dislocations promote carbon atoms diffusing and migrating to distant ferrite from the boundary of cementite, which accelerates the dissolution of cementite.

Keywords: Impact wear; White layer; Nano structure; Nano crystalization mechanism

1. Introduction

Impact wear is frequently met in engineering application, such as piston and rod of rockdrill, liner of jaw crusher, valve and seat of internal combustion engine, liner and balls of ball mill, frog and wheels of railway, padrails of tractor, etc. During service, those parts usually experience strong impact and their impact loads are also two or three magnitude order higher than traditional fatigue loads. This makes impact wear to behave as a dynamic characteristic [1]. Especially, a lot of experimental results will be quite different when impact load increases to two or three magnitude order higher than usual impact load. The reason is that the wear failure mechanism is completely different in the case of large impact load [2].

Under the heavy impact, the "white layer" is easy to form in subsurface of mild steel and shows the bright color in optical microscope. The brittle fracture of "white layer" easily occurs under the impact conditions from the present author's viewpoint. The explanations of "white layer" formation mechanism also vary by now. Some researchers considered that the concentrated frictional heat leads to transformation of martensite, and then is quenched to the secondary martensite [3–6]. Others thought that the strong plastic deformation of subsurface induces the martensite formation rather than frictional heat [1,7]. In a word, martensite or austenite–martensite transformation in subsurface becomes a popular viewpoint of "white layer" formation. However,

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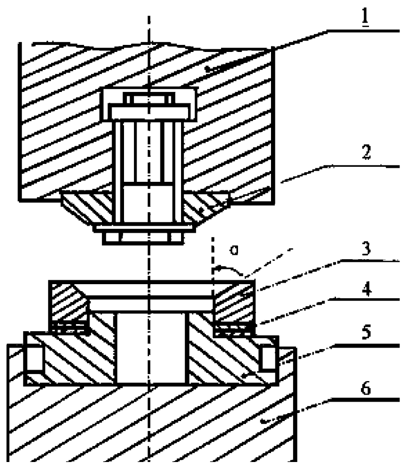

Fig. 1. Sketch of impact wear test rig: (1) specimen holder; (2) upper specimen; (3) bottom specimen; (4) pillow; (5, 6) bottom specimen seat.

there also exists another viewpoint besides above explanation. It has been reported that oxygen, nitrogen or carbon elements can be diffused, transported to subsurface or chemically reacted with counter pairs or medium to form oxide, nitride or carbide [4,8–10]. Dynamic recrystallization is also considered as a mechanism of "white layer" formation [11].

Therefore, it is noticed that the formation mechanism of "white layer" is still unclear at present. In this research, impact wear characteristic of annealed AISI1045 steel was investigated to understand the mechanism of "white layer" formation. Subsurface after impact was examined by transmission electronic microscope (TEM) and high-resolution electron microscope (HRTEM) to analyze the procedure of "white layer" formation.

2. Experimental procedure

Impact wear was carried out on self-built test rig. Fig. 1 shows the schematic of the rig. The upper specimen was monitored on the upper specimen holder which can move up and down driven by a cam gear system. A dead weight was mounted upon the upper impact holder. The impact load can be changed by choosing different dead weights. In this research, dead weight was 9 kg, adjusting the impact energy was 8.2 J. The impact frequency is fixed to 600 times per min. The bottom specimen was fixed on rigid bottom specimen seat which is installed on concrete basement. In this test rig, the attack angle can be adjusted by choosing upper and bottom specimen geometric angle α as shown in Fig. 1. In the tests, the attack angles 60° and 90° were individually used to check the influence of the attack angle on wear behavior. The contact areas were kept constant for both attack angles, being 540.08 mm^2. The impact load was 8.29 kN measured by a force transducer. Before the test, all specimens accepted 18,000 times impact running-in procedure to eliminate the influence of specimen machining on wear. After running-in, all specimens were cleaned in ultrasonic bath immersed in acetone, and then initial weights measured by a balance with 0.1 mg sensitivity. After the test, weights of the worn specimens were measured again in the balance to obtain the weight losses. All impact wear tests were carried out at room temperature without any lubricant added in.

AISI1045 steel specimen was cut from roll bar, and then annealed at 920 °C for 1 h. The final microstructure is ferrite mixed with pearlite. The boundary size of ferrite is about 12–15 μm. The AISI1045 steel specimens were only used for bottom specimens during tests. The upper specimens were made from ASM52100 bearing steel which was quenched and then tempered. After test, only weight loss of bottom specimen was measured and discussed in this research.

In order to examine the formation procedure of "white layer" microstructure after tests, the specimen was sliced away by molybdenum wire cutting to keep a thin layer of worn surface. The specimen was then reduced by mechanical procedure from one side. Finally, the specimen was prepared for the examination of TEM and HRTEM by both-side electrochemical piercing milling.

3. Test results

During running-in stage, the evolution procedure of AISI1045 steel impact wear losses showed a conventional characteristic. At the initial impact stage, an incubated period was observed during which the weight loss has not been selected. With increasing impact cycles, the weight losses increased continuously till 18,000 times running-in procedure. After running-in procedure, the wear curve of AISI1045 steel is as shown in Fig. 2. It is shown from Fig. 2 that the wear

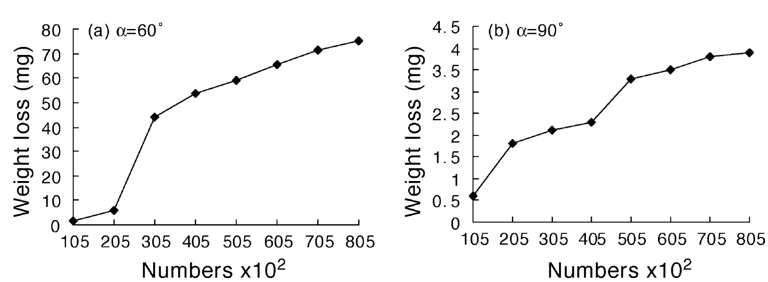

Fig. 2. Weight loss curves of AISI1045 steel in impact load: (a) weight loss at an impact angle of 60° as function of the number of impact cycles; (b) weight loss at an impact angle of 90° as function of the number of impact cycles.