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FATIGUE ANALYSIS OF ULTRAFINE GRAINED AL 1050 ALLOY PRODUCED BY CYCLIC FORWARD BACKWARD EXTRUSION

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Abstract

In this work, fatigue behavior of ultrafine-grained (UFG) Al 1050 alloy produced by a cyclic forward-backward extrusion (CFBE) was studied. Initial average grain size of 120 μm was reduced to 1μm, 600nm and 320nm using 1, 2 and 3 cycles CFBE process, respectively. After three CFBE cycles, both yield strength and tensile strength increased about 3.5 and 3 times greater than those of as-received samples. Fatigue tests were carried out under load-controlled mode at a frequency of 15 Hz. Results indicate that grain refinement of Al 1050 samples improved the resistance to fatigue crack nucleation under predominantly high cycle fatigue loading. To explain the formation process of damage surfaces, microstructure changes in the damage surfaces caused by cyclic stresses were studied by scan electron microscopy (SEM).

1. Introduction

Ultrafine-grained (UFG) materials produced by severe plastic deformation (SPD) processes have received remarkable attentions in the recent years because of their unique properties that make them applicable in different fields [1,2]. Among the SPD processes, equal channel angular pressing [3], high-pressure torsion [4] and accumulated roll bonding [5] are the most commonly used methods. One of the most effective SPD methods was recently introduced by Alihosseini and Asle Zaeem, which is a novel cyclic forward-backward extrusion (CFBE) method to produce UFG materials [6]. This process consists of forward-backward extrusion, followed by constrained back-pressing and completed with a conventional extrusion. CFBE was used to produce UFG 1050 aluminum rods. Some of the mechanical properties of Al1050 rods produced by CFBE such as yield strength, tensile strength and microhardness have been studied [6, 7].

In addition to the mechanical properties, fatigue behavior of UFG materials is very important in the usage of these materials. Studies of the UFG materials produced by SPD methods have mainly focused on their microstructure evaluation, and only concerned with the static mechanical properties such as tensile strength and microhardness. Fatigue properties of UFG materials have not been studied profoundly, and only there are a few studies performed to investigate fatigue behavior of pure Al and Cu alloys [8,9]. The fatigue behavior of materials is often controlled by slip bands, grain or twin boundaries, second phases and voids.

In the present work, we report the fatigue properties of an Al1050 alloy subjected to SPD. By applying different cycles of CFBE, submicron Al alloy samples have been produced with different grain sizes. To study the effects of SPD and resulted microstructures on fatigue behavior of UFG Al1050, we performed fatigue tests after different cycles CFBE.

2. Experimental Procedure

2.1. Material and Cyclic Forward Backward Extrusion

The material used in this study was Al 1050 commercial aluminum alloy. CFBE consists of forward-backward extrusion, followed by a constrained back-pressing, and completed with conventional extrusion to produce the UFG rods. These steps are performed using a twin punch setup. Cylindrical specimens with diameters of 30 mm and lengths of 50 mm were machined from as-received AA1050 billets. They were then annealed at 400 °C for 2 hour and cooled down at furnace atmosphere, which resulted in an average grain size of about 120 μm. The CFBE process was carried out using a press with the cross-head speed of 5 mm/min at 25 °C. The produced rods had diameter of 10 mm and length of 20 cm.

2.2. Fatigue Tests

The experimental fatigue tests were carried out on dog-bone shaped specimens. The fatigue test specimen dimensions are shown in Figure 1. The fatigue test samples were cut from the uniformly deformed region of the produced rods by electro discharge machining. After this step the specimens were polished down mechanically to 6 μm grid sizes in order to remove the electro discharge machining effects. All fatigue tests were carried out on a servo hydraulic test. Fatigue tests were done under load-controlled mode at a frequency of 15 Hz at load levels of 0.8 times of the yield strength of the as received sample.

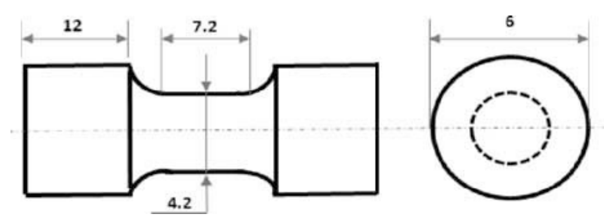

Figure 1. Samples dimensions for fatigue test specimens (mm).

After CFBE, microstructural changes and grain sizes were evaluated and the associated mechanical properties were measured. For detailed investigation of the samples after fatigue test, SEM (JEOL JSM 6490L) was used. Details of fatigue fracture surfaces in different regions were analyzed.

3. Results and Discussion

3.1. Mechanical Properties and Microstructure Evaluation

Table I shows the mechanical properties and average grain size of the as-received and CFBE processed aluminum specimens. For the same initial average grain size of 120 μm, the specimen subjected to 1 cycle of CFBE reached an average grain size of about 980 nm, UFG structures of about 600 nm in size is achieved after 2 cycles of CFBE, and an average grain size about 315 nm is observed after 3 cycles of CFBE [7]. TEM micrographs of samples are shown in figure 2, which show as the number of CFBE cycles increases, the size of grains decreases. The details of the results have been reported in these references [6,7].

Table I. Mechanical properties of CFBEed Aluminum specimens [6,7].

Number of cycles	Average Grain size	Yield strength (MPa)	Tensile Strength (MPa)	Vickers Hardness
0	120 μm	50	70	30
1	980 nm	105	160	55
2	600 nm	120	195	62
3	315 nm	160	215	68

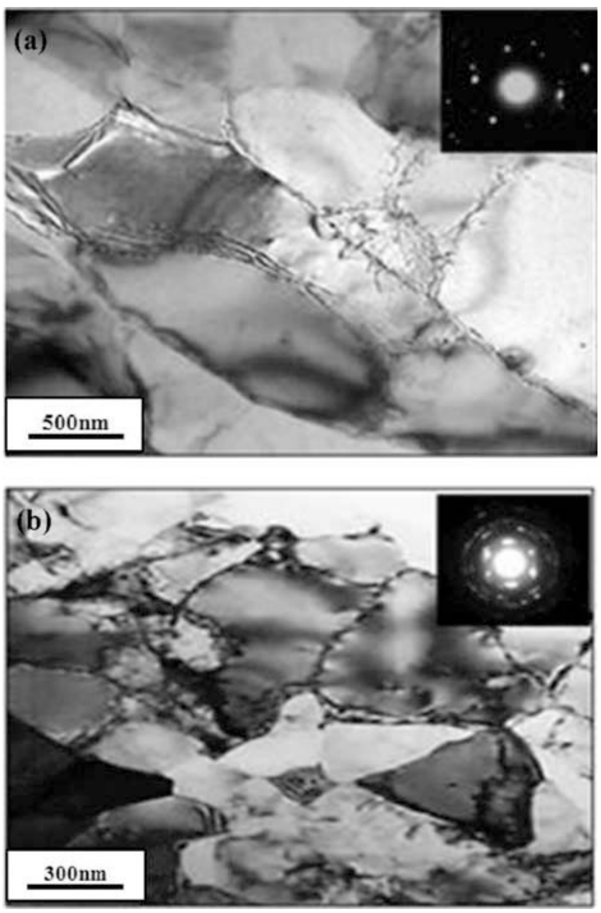

Figure 2. TEM micrographs after (a)1 and (b)3 cycles of CFBE [7].

3.2. Fatigue Behavior of Ultrafine Grained Samples

Figure 3 shows the fatigue S-N curves for as-received and CFBE processed specimens in different cycles. These figures show that the UFG samples have higher fatigue resistance than coarse grained samples. For most metals, the amount of fatigue limit stress for more than 10^7 fatigue cycles is nearly proportional to the static tensile strength [8]. However, there is only a slight difference in fatigue stress between as received and CFBE processed aluminum, due to the fact that the tensile strength of CFBE processed Al1050 is about 3 times greater than as received one. For the stress beyond fatigue limit stress, number of cycles to failure (fatigue life) of CFBE processed specimens was larger than as received ones. As it can be seen in Figure 3, by increasing the stress amplitude there is no remarkable difference for fatigue life of processed samples with different CFBE cycles.

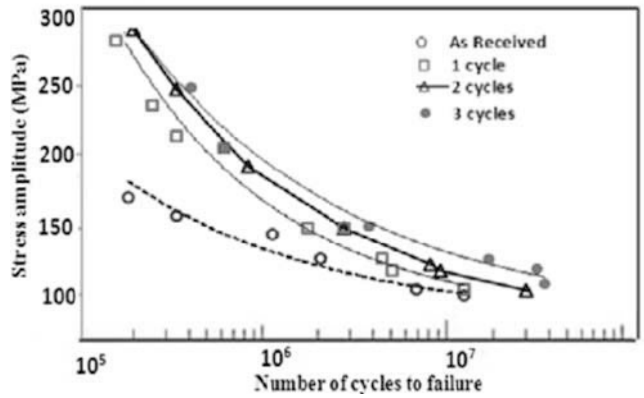

Figure 3. S-N curves showing enhanced fatigue life of SPD Al as compared to coarse grained specimens.

3.3. SEM Analyses of Fatigue Fracture Surfaces

Figure 4 shows SEM micrographs of the fracture surfaces after fatigue tests. Fracture surfaces from both of coarse grained and UFG Al samples have shown dimpled rupture. Figure 4(a) shows dimple rapture after 3cycle of CFBE. Similar observations have been observed for fracture surfaces for, nano grained Al-Fe and nano grained Cu [12-14]. The dimples are uniform and distributed across the specimen cross-section. Fatigue crack striations are observed by SEM and are shown in Figure 4(b) and (c). The crack growth can be characterized by the size of these fatigue striations.
Fatigue life is divided into two stages crack nucleation and crack growth. Results can be argued in these two stages; results in Figure 3 indicate that grain refinement improves resistance to fatigue crack nucleation. Two main factors are increasing the strength and increasing the residual stress, which are very effective in this phenomenon [13, 14]. However, such grain refinement can lead to a significant effect on subcritical crack growth [12]. As it can be seen in Figure 4, the fracture surfaces contain regions with lots of striations. The size of fatigue striations in Figure 4(b) is larger than the striations in Figure 4(c). It is well-known that the size of these striations is a measure of fatigue crack growth rate [12]. This means with larger stations higher growth rate is expected. Therefore, by comparing striations sizes in Figures 4(b) and (c), it can be concluded that crack growth rate in the UFG aluminum samples is higher than the coarse grained ones. Intergranular fracture of the UFG samples shows less crack growth resistance than the coarse grained material [14].
As mentioned before, crack nucleation and crack propagation are two main stages in each fatigue process. For studying the effects of grain refinement on fatigue it is necessary to investigate the dominant mechanisms in these two stages. A lot of studies carried out in this area that mainly focuses on coarse grained materials [7, 8]. However, few researchers have studied the effects of grain refinement on these stages [9, 10]. Results have shown that fine grained materials usually have higher resistance to crack nucleation, but have faster crack growth rate [11]. In this work;

we found similar results for UFG Al 1050 alloy. The higher yield stress in the UFG materials prevents macroscopic plastic deformation at the beginning of load controlled cycling, and this increases the crack nucleation period. Several factors may affect the high-cyclic behavior of the UFG alloys. Two main important factors may be progressive softening during fatigue and the low resistance to crack growth [11].

For further understanding of fatigue mechanisms in UFG materials further experimental researches and fatigue tests are required.

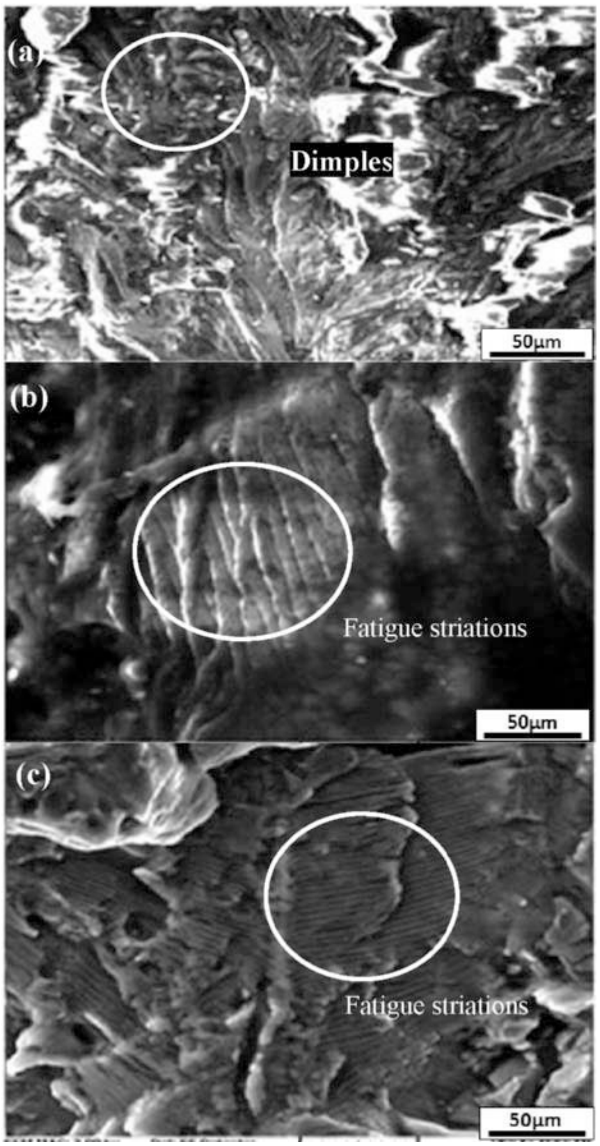

Figure 4. SEM micrographs of fracture surface for Al 1050: (a) dimples after 3 cycles of CFBE, (b) Fatigue striation after 3 cycles of CFBE, and (c) Fatigue striation for as-received samples.

4. Conclusion

Fatigue behavior of UFG Al 1050 alloy produced by CFBE was studied. The main results can be summarized as below:

1. Fatigue S-N curves show that the UFG samples have higher fatigue resistance than coarse grained ones.
2. SEM studies in the fracture surfaces shown the size of fatigue striations in UFG samples is larger than the striations in coarse grained samples.
3. Analysis of fatigue striations shown crack growth rate in UFG aluminum samples is faster than coarse grained ones.

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