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Influence of hydrogen content on room temperature compressive properties of Ti−6Al−4V alloy at high strain rate

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Abstract: Electromagnetic forming tests were done at room temperature to reveal the influence of hydrogen content on the compressive properties of Ti−6Al−4V alloy at high strain rate. Microstructure was observed to reveal the mechanism of hydrogen-enhanced compressive properties. The experimental results indicate that hydrogen has favorable effects on the compressive properties of Ti−6Al−4V alloy at high strain rate. Compression of Ti−6Al−4V alloy first increases up to a maximum and then decreases with the increase of hydrogen content at the same discharge energy under EMF tests. The compression increases by 47.0% when 0.2% (mass fraction) hydrogen is introduced into Ti−6Al−4V alloy. The optimal hydrogen content for cold formation of Ti–6Al–4V alloy under EMF was determined. The reasons for the hydrogen-induced compressive properties were discussed.

Key words: Ti−6Al−4V alloy; hydrogen content; electromagnetic forming; compressive property; thermohydrogen processing

1 Introduction

Titanium alloys and magnesium alloys are attractive lightweight structural materials, which have high specific strengths [1−5]. They are widely used in aerospace industry and automobile industry because light weight is being taken seriously by various engineering industries. However, they suffer from low plasticity at room temperature, which restricts their applications [6]. Therefore, how to improve the plasticity of the lightweight materials has been an important research topic.

Recent researches have shown that many methods can significantly enhance the room temperature plasticity of titanium alloys and magnesium alloys, including equal channel angular extrusion (ECAE) [7−9], high pressure torsion (HPT) [10,11], repetitive upsetting-extrusion (RUE) [12,13], accumulative roll-bonding (ARB) [14,15], compound extrusion [16], multi-axial forging (MAF) [17,18], addition of alloying element [19] and thermohydrogen processing (THP) [20,21].

Among the plastification methods of lightweight materials, the thermohydrogen processing is an effective method especially for titanium alloys [22,23]. This is a technique in which hydrogen is used as a temporary alloying element in titanium alloys to control the microstructure and improve the final mechanical properties of titanium alloys. The basis of THP is the modifying effect of hydrogen as an alloying element on phase compositions, development of metastable phases and kinetics of phase transformations in titanium alloys. The addition of hydrogen can refine the microstructure [24,25] and improve the plasticity of titanium alloys at room temperature [26,27] and high temperature [28,29] and superplasticity [30,31]. Among them, the notable characteristic of room temperature hydrogen plastification is the increase of ultimate compression when the first macroscopical crack appears at the cylindrical surface of specimen.

Cold forming is a very economical process for titanium alloy products. But most kinds of titanium alloys are difficult to form at room temperature because of their low plasticity. Although some work has been done on the cold forming of the hydrogenated titanium alloys [26,27], little work has been reported on their compressive properties at high strain rate. Electromagnetic forming (EMF) [32] is an impulse or

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high-speed forming technology, which uses pulsed magnetic fields to apply forces to tubular or sheet metal workpieces, made of a material of high electrical conductivity. EMF has peculiar advantages in forming of metal materials because of the improved formability and strain distribution [33].

Therefore, in this work, EMF tests were carried out at room temperature to reveal the influence of hydrogen content (0.1−0.5%, mass fraction) on the room temperature compressive properties of Ti−6Al−4V alloy at high strain rate. Fracture surface and microstructure were observed to reveal the mechanism of hydrogen-induced compressive properties of Ti−6Al−4V alloy at high strain rate.

2 Experimental

The material used in the present work was a Ti−6Al−4V alloy. Cylindrical specimens, 4 mm in diameter and 6 mm in height, were used for hydrogenation treatment. Details of the hydrogenation process were described in our previous work [34]. The hydrogen contents in the hydrogenated specimens produced in this way were controlled by changing the equilibrium pressure of hydrogen and determined by weighing the specimens before and after hydrogenation using an electronic balance providing a measurement accuracy of 0.01 mg. The specimens with hydrogen contents in the range of 0.1%−0.5% (mass fraction) were obtained.

EMF tests were performed on an EMF 30/5-IV type apparatus at room temperature to investigate the compressive properties of Ti−6Al−4V−*x*H alloys at high strain rate. The parameters of the EMF apparatus are listed in Table 1. Compression was determined by measuring the height of specimens before and after EMF tests, as described by

$$\varepsilon = \frac{H_k - H_0}{H_0} \times 100\% \quad (1)$$

where H_0 is the initial height of specimen before EMF test, H_k is the height of specimen after EMF test, and ε is the compression. The compressive specimens were cylinders of 4 mm in diameter and 6 mm in height. MoS_2 lubricant was coated on the both end faces of the specimen in order to reduce the friction between the specimen and the compressive bars. The specimen was under uniaxial compression instantaneously in EMF test. Capacitance used in EMF test was 2660 μF. The different compressions and ultimate compressions to appearance of the first crack on the lateral surfaces of specimens were obtained by changing the discharge voltage.

Table 1 Parameters of electromagnetic forming apparatus

Machine	Capacitance/μF	Ceiling voltage/kV	Ceiling energy/kJ
EMF 30/5-IV	2660	5	33.25

Microstructures were investigated by an optical microscope (Olympus BHM-2UM) and a scanning electron microscope (Hitachi S-570). Fracture surfaces were observed by a scanning electron microscope (Hitachi S-570). Microhardness was determined on a HVS-1000Z digit-display hardness tester with a load of 200 g and a test duration of 15 s.

3 Results and discussion

3.1 EMF tests

The mechanical properties of Ti−6Al−4V−*x*H alloys at different discharge voltages in EMF tests are shown in Table 2. It can be seen that all Ti−6Al−4V−*x*H alloys do not reach their ultimate compressions when the discharge voltage is 0.9 kV, because no crack is found on their lateral surfaces. Compressions of Ti−6Al−4V−*x*H alloys in EMF tests at 0.9 kV are shown in Fig. 1. It can be seen that compression first increases up to a maximum with increasing the hydrogen content and then decreases, which increases by 47.0% when 0.2% hydrogen is introduced into a Ti−6Al−4V alloy. The results indicate that hydrogen has favorable effects on the room temperature compressive deformation of Ti−6Al−4V alloy at high strain rate, which can improve the plasticity of Ti−6Al−4V alloy at room temperature and decrease the demand of forming apparatus and dies.

From Table 2, it can be seen that the compression of specimens with the same hydrogen content increases with the increase of discharge voltage, which is attributed to the increasing discharge energy during the process of EMF tests. Each specimen fractures until it reaches its ultimate compression when the discharge energy reaches one value. However, the discharge energy of the non-hydrogenated specimen is higher than those of the hydrogenated specimens, which indicates that these hydrogenated specimens have lower resistance of deformation and are easier to deform than the non-hydrogenated specimen. Softening of the hydrogenated specimens is mainly attributed to the microstructure evolution after hydrogenation. The amount of softer beta phase and orthorhombic α'' martensites increases after hydrogenation, because hydrogen is a beta-stabilizing element and can decrease the beta transus temperature, as described in our previous work [35].