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TRANSFORMATION BEHAVIOR AND SHAPE MEMORY EFFECT OF A CoAl ALLOY

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This paper investigates the microstructure, martensitic transformation and shape memory effect of Co-16Al alloy. The optical micrographs of Co-16at.%Al alloy quenched from 1200°C show that the ε martensite occurs at room temperature, while some remaining γ phase can also be observed. This microstructure analysis can be supported by XRD pattern. It is shown that the alloy undergoes a martensitic reverse transformation at about 220°C during heating. However, no transformation from the fcc phase to hcp phase is detected by DSC measurement upon cooling. It is thought that the precipitation of β phase by aging at high temperature may suppress the martensitic transformation. The tension strain is 12% and the fracture strength is above 800MPa. No obvious yield deformation is observed from the stress-strain curve. SEM images exhibits many dimples on the fracture surface, which means the fracture mechanism is ductile rupture. Bending test show that only 25% deformation can be recovered due to shape memory effect when the pre-strain is 5%.

Keywords: Shape memory alloy; CoAl alloy; martensitic transformation; shape memory effect.

1. Introduction

Ferromagnetic shape memory alloys (FSMAs) have attracted much attention for its promising application as actuator and sensor material. The idea of such materials results from the combination of two characteristic properties, i.e., ferromagnetism and martensitic transformation[1]. Based on this idea, a series of FSMAs have been fabricated and studied including NiMnGa[2,3], NiFeGa[4], Fe-based[5] and Co-based alloys[6,7].

CoAl alloy (the content of Al is less than 20%) is thought to be a kind of new FSMA because of its high saturation magnetization and martensitic transformation from fcc to hcp[8]. Compared with other FSMAs, CoAl alloy has three advantages: (1) The fcc(γ)/hcp(ε) martensitic transformation is one of the simplest transformations crystallographically, since the martensitic transformation can be achieved by stacking-fault formation and expansion, or partial dislocation movement. (2) Higher transformation temperature. (3) High ductility and strength. Especially the last one will make it a focus. T. Omori etc. have studied the microstructure and shape memory behavior of Co-14Al alloy[9]. However, the detailed and embedded investigations are of much importance for the development of CoAl alloys. Therefore, the present author studies the transformation behaviour and shape memory effect of Co-16Al alloy in order to obtain more understanding of CoAl alloy system.

2. Experiment Procedure

A button ingot of Co-16Al(at.%) alloy weighing about 80 g was prepared by arc melting 99.95% Co and 99.9% Al in a water cold copper crucble under an argon atmosphere. The ingot was remelted four times (each time turning the button 180°) and then homogenized at 1200°C for 24h followed by quenching into ice water. The master ingot was rolled at 1000°C to a 1mm thick sheet. Then the experimental samples were taken from this sheet by spark cutting.

Tension experiments were performed on Instron-1168 stretcher with a strain rate of 1mm/min. The mechanical tests were conducted at room temperature (T=20°C) in laboratory air condition. The tension samples were $50\times1\times2mm^3$ (length×thickness×width) and wet polished before the experiments. Hitachi S-4700 SEM was used to examine the fracture surface in order to analysis the fracture mechanism.

The microstructure was observed by optical microscopy. X-ray diffraction (XRD) for bulk specimens was performed using Cu-Ka radiation to identify and characterize the phases. The shape memory effect was evaluated by bending a sheet specimen with dimensions of $1\times4\times50mm^3$ (thickness×width×length) into a round shape at room temperature. Then it is unloaded and spring back to θ_s. Subsequently, the sample is heated to different temperature (T), and the corresponding position is measured using θ_T. The surface strain of bending deformation is defined as ε=t/ (t+2R), where t and r are the specimen thickness and the radius of curvature, respectively. The shape memory strain ε are evaluated by $\varepsilon=(\theta_T-\theta_s)\ \varepsilon/180°$ and the recovery ratio $R=(180°-\theta_T)/180°$, where T=300°C, respectively.

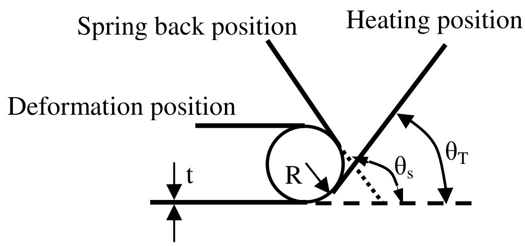

Fig. 1. Schematic diagram of bending test for measuring shape memory effect.

3. Results and Discussion

Figure 2 shows the microstructure of Co-16Al alloy at room temperature. It can be seen that the grain size of this alloy is less than 100 μm. To observe the substructure in a single grain more clearly, the amplified micrograph is taken and shown in Fig. 2(b). Inside the grain, fine lamellar ε martensite distribute evenly in the matrix of γ phase. It should be noted that the grain boundary is very wide, suggesting that a new phase precipitates on the grain boundary.

In order to identify the constitution phases in this specimen, XRD examination was performed. The diffraction profiles of Co-16Al alloy before and after annealing treatment are shown in Fig. 3. For the as-cast sample, both γ and ε phases can be detected. While for the as-annealed one, besides γ and ε phases, β (200) peak is seen. It indicates that γ and ε phases are the main phases for Co-16Al alloy after being annealed at 1200°C. In addition, the precipitated phase is considered to be β (B2) phase. It is thought that the precipitation of β phase may affect the transformation behavior, which will be discussed later. The lattice parameters of the γ and ε phases are a_γ=0.3598 nm, and a_ε=0.2511 nm, c_ε=0.4114 nm, respectively. The existence of ε martensite proves that the martensitic transformation temperature is much higher than room temperature.

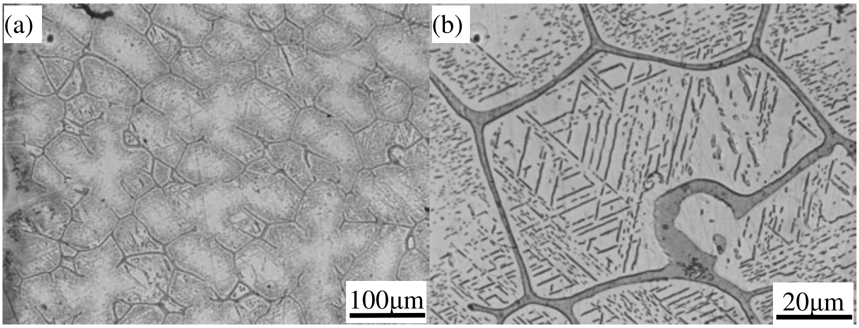

Fig. 2. Optical micrography of Co-16Al alloy: (a) a large range, (b) a single grain.

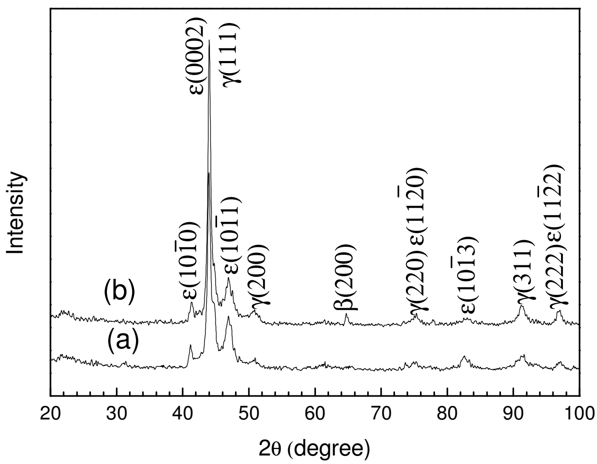

Fig. 3. X-ray diffraction patterns of (a) as-cast and (b) as-quenched Co-16Al alloy.

Figures 4(a) and (b) shows DSC measurement of the transformation behaviour of an as-cast sample and a specimen annealed at 1200°C for 24 h, respectively. The as cast specimen exhibits an endothermic reverse transformation at 185°C on heating. However, there is no exothermic transformation on cooling to even 67°C. A typical shape memory alloy, such as TiNi alloy, experiencing one martensitic forward and reverse transformation, which can be detected by DSC measurement. The causes for the disappearance of exothermic transformation on cooling can be described as follows: Firstly, it is known, from Fig. 4, the heat entropy of the reverse transformation was measured to be 1.15 J/g. Such a small heat entropy indicates that it is very difficult to detect the transformation on cooling. Secondly, Liu has reported that the fcc ↔ hcp phase transformation of CoNi alloy was localised and incomplete[10]. So it is thought that the fcc-hcp martensitic transformation sustained a large temperature range. Further study shows that, after being annealed at high temperature, both endothermic reverse transformation and exothermic transformation can not be found from the DSC curve, as shown in Fig. 4(b). As known that, in CoAl alloy, the martensitic transition is the transformation from fcc(γ) to hcp(ε). Analysis of the optical microscopy and XRD results has shown that the precipitation of β phase is caused by annealing at high temperature. So it is assumed that β phase should suppress the martensitic transformation, which results in no transformation peaks in DSC curve.

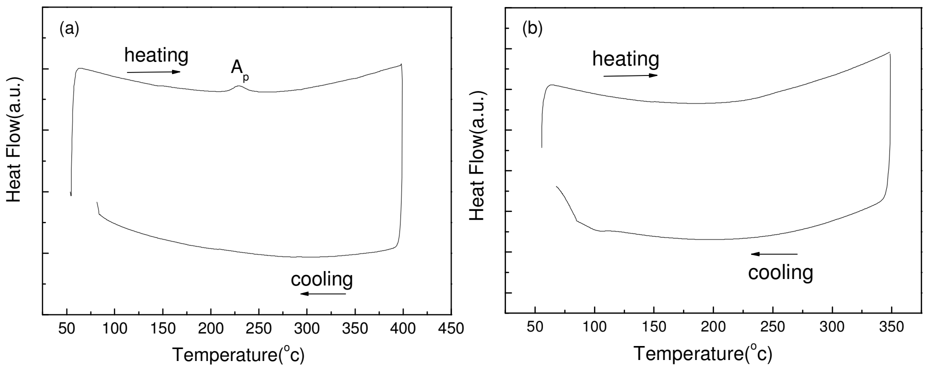

Fig. 4. DSC curve for the as-cast and as-annealed Co-16Al alloy.

Figures 5(a) and (b) exhibit the stress-strain curve and fracture morphology, respectively. From Fig. 5(a), the tension strain is about 13% and the fracture strength exceeds 800 MPa. No obvious yield behaviour is found upon loading. SEM image, as displayed in Fig. 5(b), shows many fine dimples on the fracture surface. It indicates that Co-16Al alloy presents ductile fracture. That is, the ductility of Co-16Al alloy is high.

Figure 6 shows the heating position as a function of heating temperature using the bending test. The applied surface strain is 5%. In order to obtain a visual understanding of shape memory effect induced by heating, two photos have been taken and shown in Fig. 6. Here, one photo in the top left corner represents the sample undergoes spring back, the other one in the bottom right corner is the sample after heating above 267°C. Figure 6 illustrates that, with the increase of temperature, the sample dose not change its shape until 197°C at which reverse martensitic transformation occurs. Subsequently, abrupt shape change occurs and finishes at 257°C. A_s and A_f can also be determined by tangent method as in Fig. 6. The values are a little different DSC measurement just because the former experiment is performed in a resistance furnace with higher

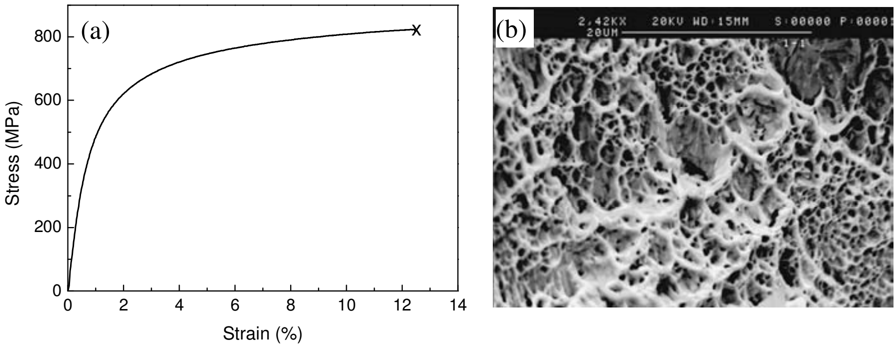

Fig.5. Tension stress-strain curve at room temperature (a) and fracture surface morphology (b) of Co-16Al alloy.

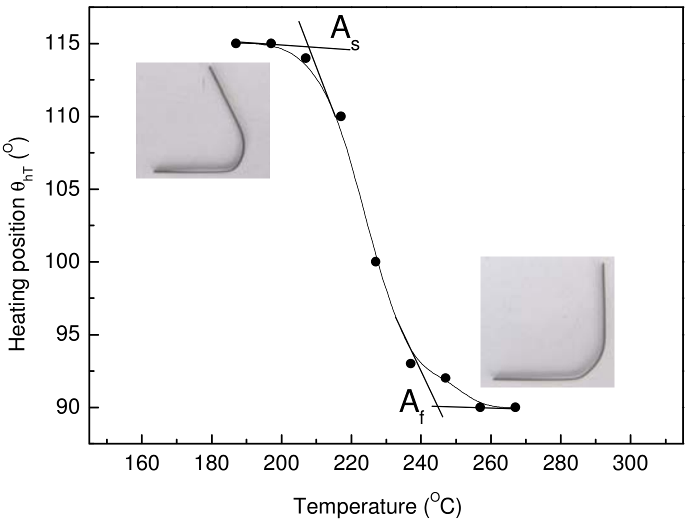

Fig. 6. Heating position as a function of heating temperature: one photo in the top left corner is taken from the sample undergoes spring back, the other one in the bottom right corner is the sample after heating above 267°C.

temperature difference. By calculation, the shape memory strain is about 0.7% and recovery ratio is 50%. It is a little lower than the results reported in Co-14Al alloy[9]. As shown in Ref. 9, more ε martensites appear in Co-14Al alloy than in the present alloy. It is suggested that the Co-14Al alloy experiences a more complete martensitic transformation, which makes it obtain a better shape memory effect. Therefore, the increase of Al content in CoAl alloys should deteriorate the shape memory effect. It has been known that aging treatment will improve the shape memory effect of CoAl alloys. Further work will be carried out to study the factors which affect the shape memory behavior.

4. Conclusion

(1) Co-16Al alloy undergoes a martensitic reverse transformation at about 220°C during heating. However, no transformation from the fcc phase to hcp phase is detected by DSC measurement upon cooling.
(2) Annealing at high temperature will suppress the martensitic transformation.
(3) Co-16Al alloy exhibits high ductility and the fracture mechanism is ductile rupture.
(4) Bending test show that the shape memory strain is 0.7% when the pre-strain is 5%.

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