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Effect of annealing temperature on Barkhausen jumps in cobalt–vanadium alloys

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The mean potential difference of Barkhausen jumps (V_B) and the frequency of the clusters of jumps (F_B) were measured in two Co-V alloys of 5 wt% V and 10 wt% V. The behaviour of V_B and F_B as functions of the annealing temperature was correlated to the equilibrium phase diagram of Co-V. $\varepsilon \rightleftharpoons \alpha$ transformation of Cobalt effects the behaviour of V_B and F_B as well as the magnitude of eddy current produced in the sample.

1. Introduction

Cobalt crystallizes in two different phases: up to 417° C it has a hexagonal structure (ε phase), and above 417° C up to its melting temperature (1495° C) it shows face centred cubic structure (α phase). Vanadium addition affects the $\varepsilon \rightleftharpoons \alpha$ transformation of cobalt. Hansen and Anderko [1] give two equilibrium phase diagrams of Co–V; the first was established in 1937 and the second in 1955.

The Barkhausen effect [2] is a microstructure-sensitive phenomenon. Steel samples of different micrographic constituents [3] show considerable changes in the behaviour of their Barkhausen jumps (BJ). The aim of this work was to study the effect of the annealing temperature on the behaviour of Barkhausen jumps (BJ) in Co–V alloys and to correlate the results obtained with the Co–V equilibrium phase diagram.

2. Experimental procedure

An induction technique was used to measure both the mean potential difference of BJ (V_B) and the frequency of the cluster of jumps (F_B). A block diagram of the measuring circuit and the technical data of the coils used have been given previously [4, 5]. The materials examined were two cobalt–vanadium alloys of different vanadium content. The first alloy was 5 wt% V–95 wt% Co, while the second alloy was 10 wt% V–90 wt% Co. Five equal pieces were cut from each ingot. The volumes of the samples examined were found to be in the range 0.10 to 0.13 cm^3 (using the Archimedes principle). V_B of the five samples from each ingot were measured in the as-received state as a function of magnetizing current. The average values of V_B were considered to represent the as-received state of the five samples. From each ingot one sample was kept in the as-received state, and the other four samples were annealed separately at 300, 550, 650 and 900° C. The annealing time was 1 h followed by quenching in ice–water. The samples examined are abbreviated hereafter as 5% V-as-received, 5% V-300° C, 5% V-550° C, 5% V-650° C and 5% V-900° C sample; or 10% V-as-received, 10% V-300° C, 10% V-550° C, 10% V-650° C and 10% V-900° C sample, representing the first or the second alloy, respectively.

3. Results and discussion

Figs 1a and b show the change of V_B for 5% V and 10% V alloys as a function of magnetizing current (the corresponding values of the magnetizing field are given in the figure) for the as-received and heat-treated samples. The 5% V alloy shows higher V_B values than the 10% V alloy. Fig. 1b shows that the 10% V-as-received, 10% V-300° C and 10% V-900° C samples show coincident values of V_B over the whole range of the magnetizing current used, and also that the 10% V-550° C and 10% V-650° C samples show coincident V_B, but of lower values than the three previously mentioned samples. Figs 2a and b show V_B of 5% V and 10% V alloy, respectively, taken at constant magnetizing current of 1.6 A ($H = 2.08 \times 10^4\,A\,m^{-1}$), as function of the annealing temperature. The corresponding values of F_B are given in the same figure. For 5% V alloy, the increase in annealing temperature from 300 to 550° C causes the decrease of F_B and V_B. At 550° C, F_B and V_B show their minimum values. The annealing temperature of 900° C shows a sharp increase in F_B and V_B. For the 10% V alloy, the change of F_B and V_B with the annealing temperature shows nearly the same trend as described above; except for the values of V_B of 10% V-550° C and 10% V-650° C samples being coincident and showing a minimum value, and also 10% V-as-received, 10% V-300° C and 10% V-900° C samples all show the same values of V_B.

The previously mentioned results could be explained on the basis of the equilibrium phase diagram of Co–V. The two-phase diagrams of Co–V given by Hansen and Anderko [1] show some differences in the temperature ranges of $\varepsilon \rightleftharpoons \alpha$ transformations for the present alloys. Generally, the annealing temperature of 300° C lies in the region $\alpha \rightarrow \varepsilon$ transformation, temperatures of 550 and 650° C are in the region of $\varepsilon \rightarrow \alpha$ transformation, while the temperature of 900° C is in the region of pure α-phase. For simplicity these phase transformation ranges are represented on Fig. 2. For

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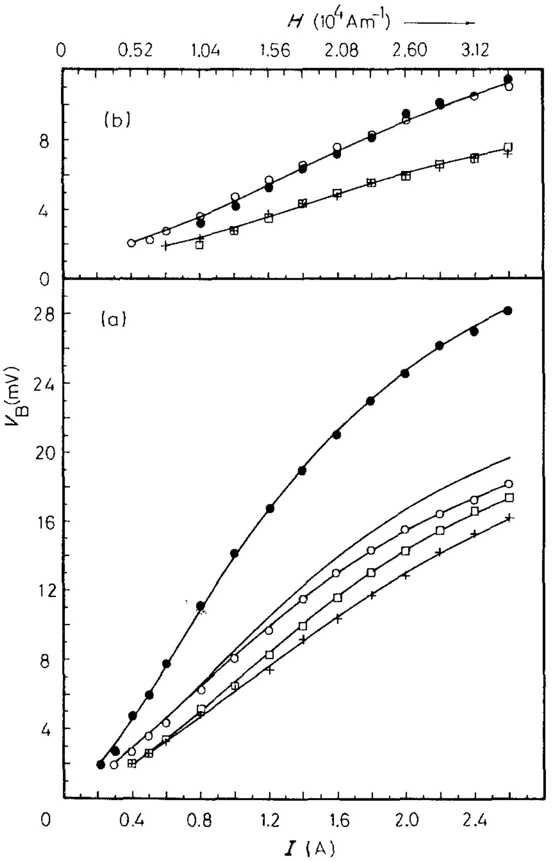

Figure 1 Changes of V_B of (a) 5% V and (b) 10% V alloys as a function of magnetizing current for the as-received and heat-treated samples: (——) as received, (○) 300° C, (+) 550° C, (□) 650° C and (●) 900° C.

alloy 5% V, the decrease in V_B of the 5% V-300° C sample than 5% V-as-received sample, Fig. 1a, could be attributed to the increase in ε-phase percentage. The percentage of ε-phase reaches its maximum value at an annealing temperature of 550° C, causing the number of jumps to be minimum, and giving rise to minimum V_B. The slight increase in F_B and V_B at 650° C ($\varepsilon \rightarrow \alpha$) could be related to the decrease in ε-phase percentage (or increase in α-phase percentage) causing an increase in the number of jumps and the related V_B. At 900° C, the sharp increase of F_B and V_B corresponds to a structure of pure α-phase in which the number of jumps is maximum, giving rise to maximum V_B. For 10% V alloy, the 10% V-as-received, 10% V-300° C and 10% V-900° C samples all show the same values of F_B and V_B. This means that these samples may have the same ratio of ε to α-phases. The samples 10% V-550° C and 10% V650° C show coincident F_B and V_B values indicating growth of the ε-phase by an equal percentage in these two samples.

When V_B of the specimen examined is measured as a function of the magnetizing frequency at constant magnetizing field, first V_B increases to a maximum value. Then V_B decreases with further increase in the magnetizing frequency until it vanishes at a certain value of the magnetizing frequency (vanishing magnetizing frequency). It was considered that the value of the vanishing magnetizing frequency is inversely proportional to the magnitude of eddy current produced in the sample [4–6]. The magnitude of the eddy current produced could be related to the microstructure of the sample as well as to the dislocation density present in the sample [3, 6, 7].

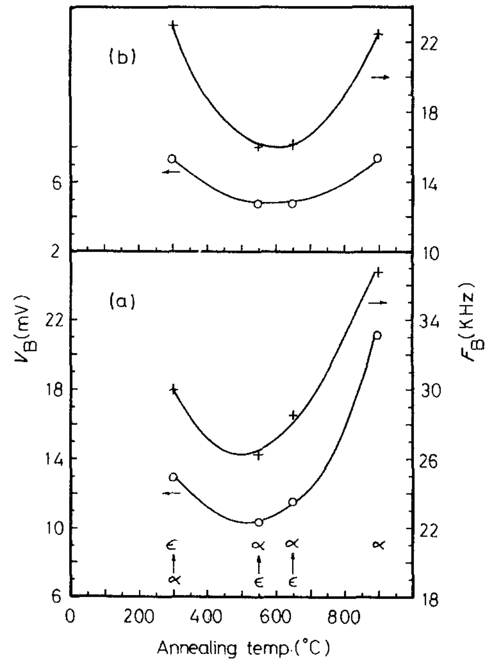

Figure 2 Change of (○) V_B and (+) F_B of (a) 5% V and (b) 10% V alloys, at constant magnetizing current of 1.6 A, as a function of the annealing temperature.

The change in V_B with magnetizing frequency, taken at a constant magnetizing current of 1.6 A ($H = 2.08 \times 10^4\,\mathrm{A\,m^{-1}}$), is shown in Figs 3a and b for 5% V and 10% V alloys, respectively. The vanishing magnetizing frequency of 5% V-550° C, 5% V-as received, and 5% V-900° C samples are 180, 220 and 240 Hz, respectively. This means that, the sample of maximum percentage of ε-phase (5% V-550° C sample) shows the maximum magnitude of eddy current produced, while the sample of pure α-phase (5% V-900° C sample) shows the minimum magnitude of the eddy current. The 5% V-as-received sample shows an intermediate value of eddy current indicating its intermediate ε to α ratio relative to the last two samples mentioned. For

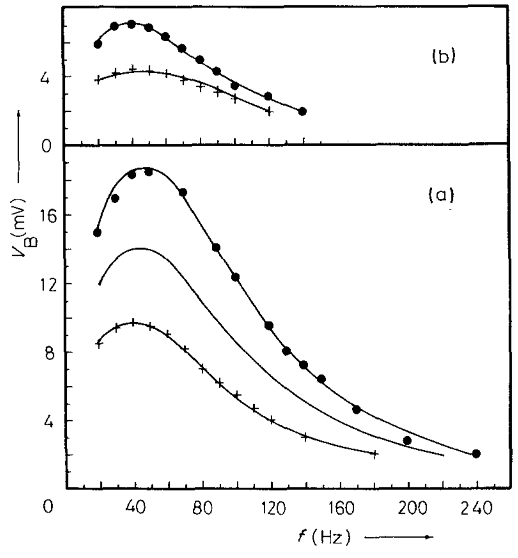

Figure 3 Change of V_B of (a) 5% V and (b) 10% V alloys, taken at constant magnetizing current of 1.6 A, as function of the magnetizing frequency; (——) as-received, (+) 550° C and (●) 900° C.

10% V alloy, the 10% V-as-received, 10% V-300° C and 10% V-900° C samples show coincident f–V_B curves. They show the same vanishing magnetizing frequency of 140 Hz indicating the same ratio of ε- to α-phases present in these samples. The 10% V-550° C and 10% V-650° C samples also show coincident f–V_B curves of vanishing magnetizing frequency of 120 Hz, indicating the same ratio of ε- to α-phases in these two samples.

The previous results lead to the conclusion that the value of V_B and the magnitude of the eddy current produced are affected by the ratio of ε- to α-phases present in the sample. Pure α-phase shows the highest values of V_B and a minimum magnitude of eddy current produced. The growth of ε-phase leads to a decrease in V_B and an increase in the magnitude of eddy current produced.

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