Improvement of soft magnetic properties in $Fe_{84-x}B_{10}C_6Cu_x$ alloy system

1. Microstructure

The X-ray diffraction patterns for annealed $Fe_{84-x}B_{10}C_6Cu_x$ alloy ribbons are shown in figure 1. The alloys are almost at amorphous state after annealing when x=0.5-0.7. Crystallization phase α-Fe is seen to precipitate partially as Cu content increase. The average grain size D estimated from Sherrer's relation is 15 nm for x=1.0 and 20 nm for x=1.15, respectively. When x=1.3, the precipitation of crystallization phase α- Fe is obvious. The volume fraction of the crystalline phase is about 30% for x=1.0, 35% for x=1.15 and 45% for x=1.3, respectively. Hence, Cu addition has a vital impact on the precipitation of α-Fe.

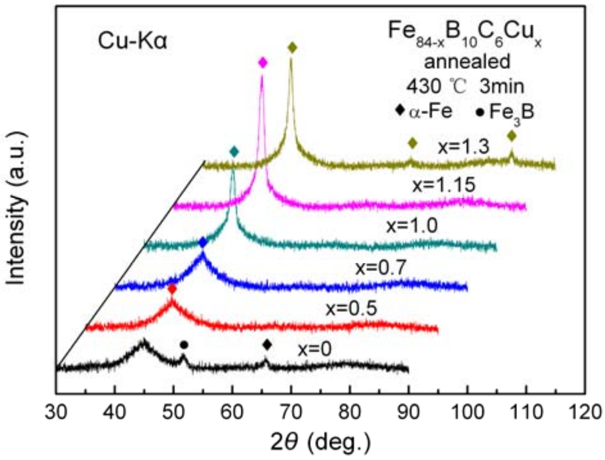

Fig. 1. X-ray diffraction patterns for annealed $Fe_{84-x}B_{10}C_6Cu_x$ alloy ribbons

2. Thermal properties

The DSC curves for $Fe_{84-x}B_{10}C_6Cu_x$ melt-spun ribbons are shown in figure 2. Here, T_{x1} and T_{x2} represent the crystallization temperature of α-Fe and the precipitation temperature of Fe-B compounds, respectively. According to the DSC data, T_{x1} decreases slightly with the increasing Cu content from x=0 to x=1.15. When x=1.3, T_{x1} decreases dramatically, the crystallization peak becomes broad and the crystalline behavior of bcc Fe occurs within a wide temperature range of about 100 °C, whereas T_{x2} shows little variation. Hence, the difference between T_{x1} and T_{x2} increases with the increasing x. Therefore, Cu addition takes important influence on the precipitation of the first phase and widens the crystallization temperature range.

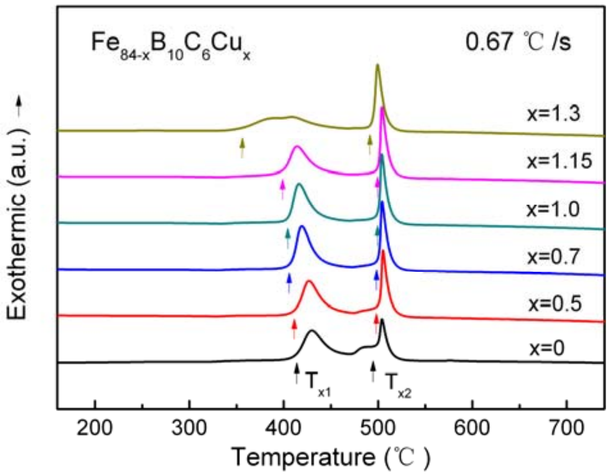

Fig.2. DSC curves for $Fe_{84-x}B_{10}C_6Cu_x$ melt-spun ribbons

3. Magnetic properties

Figure 3 shows Cu content x dependence of (a) coercivity H_c and (b) saturation magnetic flux density B_s of $Fe_{84-x}B_{10}C_6Cu_x$ alloys annealed at 430 °C for 3 minutes. H_c decreases with the increasing x and exhibits a minimum at around x=1.0. Then H_c increases when x=1.15-1.3. This may be caused by the increasing grain size of the crystallization phase α-Fe. While B_s shows an increasing tendency due to the precipitation of α-Fe. So excellent soft magnetic properties got at x=1.0.

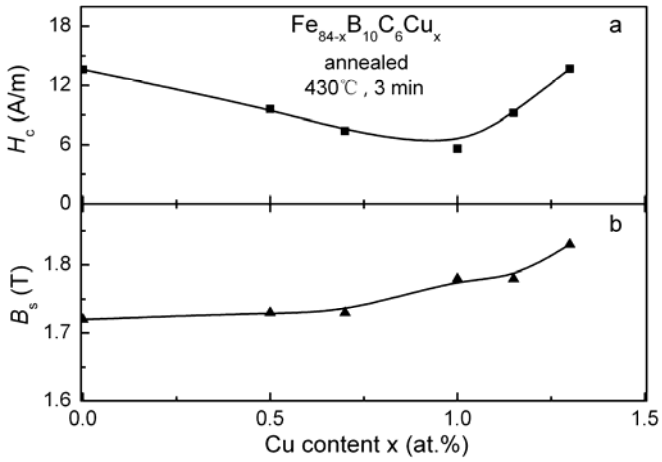

Fig.3. Cu content x dependence of (a) coercivity H_c and (b) saturation magnetic flux density B_s

In table 1, the B_s, H_c and core loss P of $Fe_{83}B_{10}C_6Cu_1$ nanocrystalline alloy under several conditions are compared with those of $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ and $Fe_{83.3}Si_4B_8P_4Cu_{0.7}$ nanocrystalline alloys and oriented Si-steel. The present alloy shows a lower H_c than $Fe_{83.3}Si_4B_8P_4Cu_{0.7}$ nanocrystalline alloy and oriented Si-steel. Although B_s shows a slightly decrease to these material, it is much higher than that of $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ nanocrystalline alloy. The high B_s is due to the high Fe content and not-containing any other metal elements such as Zr, Hf and Nb, which can lead to the decreasing of B_s. Core loss of $P_{10/50}$ for $Fe_{83}B_{10}C_6Cu_1$ is 0.34 W/kg. That is about 80% of that of oriented Si-steel. What is more, the advantage of core losses at high frequencies such as $P_{10/400}$ and $P_{10/1k}$ compared to those of oriented Si-steel is obvious.

TABLE 1

The B_s, H_c and core losses of $Fe_{83}B_{10}C_6Cu_1$ nanocrystalline alloy under several conditions are compared with those of $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ and $Fe_{83.3}Si_4B_8P_4Cu_{0.7}$ nanocrystalline alloys and oriented Si-steel.

Material	**B_s (T)**	**H_c (A/m)**	**$P_{10/50}$ (W/kg)**	**$P_{10/400}$ (W/kg)**	**$P_{10/1k}$ (W/kg)**
$Fe_{83}B_{10}C_6Cu_1$	1.78	5.1	0.34	4.3	12.5
$Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$	1.24	0.53	$P_{2/20k}$=2.1		
$Fe_{83.3}Si_4B_8P_4Cu_{0.7}$	1.88	7	0.12		
Oriented-Si steel	2.03	8	0.41	7.8	27.1

Here, the symbols $P_{10/50}$, $P_{10/400}$ and $P_{10/1k}$ stand for core losses at 1.0T at 50 Hz, 400 Hz and 1k Hz, respectively.

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