Fe-BASED SOFT MAGNETIC BULK METALLIC GLASS WITH FLAT HYSTERESIS CURVES

Teruo Bitoh and Shogo Izumi

Department of Machine Intelligence and Systems Engineering, Akita Prefectural University, Yurihonjo 015-0055, Japan.

Introduction

It is often required for soft magnetic materials that the shape of the hysteresis curve is changed according to the demands of applications. For example, materials with "flat hysteresis curves," which means the magnetic flux density (*B*) and the applied magnetic field (*H*) show a linear relationship up to rather high *H*, are necessary for producing inductors and choke coils. Flat hysteresis curves can be easily achieved by creating an air gap in the magnetic path. However, magnetic flux leakage generated in the air gap inhibits high-density packing of the electronic components. In order to achieve flat hysteresis curves without creating an air gap, Fe-based amorphous alloys are subjected to crystallization by annealing and transformed into thin surface layers of α-Fe; the crystallization results in the compression of the remained amorphous phase [1]. Another way to achieve flat hysteresis curves is the formation of secondary phase (such as Fe_2B) that act as pinning site of magnetic domain wall displacements [2].

Since the success of forming Fe-based bulk metallic glasses (BMGs) with good soft magnetic properties, great attention has been developed to synthesis and properties of the BMGs [3]. The BMGs have high glass-forming ability and, therefore, they can be used to prepare bulk amorphous alloys with a thickness of the order of a few millimeters by casting.

The structure and soft magnetic properties of cast BMGs strongly depend on the type and amount of inclusions (such as oxides) in the molten alloy because these inclusions act as heterogeneous nucleation site for crystallization. Inclusions can be eliminated by heating and cooling the molten alloy while immersing it in a molten oxide flux [4, 5].

In the present study, we investigate the application of the molten B_2O_3 flux technique to the synthesis of $(Fe_{0.75}B_{0.20}Si_{0.05})_{96}Nb_4$ BMG [6]. We found that $(Fe_{0.75}B_{0.20}Si_{0.05})_{96}Nb_4$ BMG with flat hysteresis curves can be obtained by applying the flux melting technique.

Experimental

Materials

Small pieces of the mother alloy and dehydrated B_2O_3 were mixed in a dry and clean fused silica crucible. The mixture was then melted under an argon atmosphere and cooled to a temperature (~1200 K) where B_2O_3 was still molten phase. This thermal cycle was repeated several times, and finally the molten alloy was ejected from the crucible trough a circular orifice into a ring-shaped cavity of a copper mold. This alloy is referred to as the "fluxed" specimen. For comparison, we also prepared specimens from the same mother alloy by conventional copper mold casting without flux melting ("nonfluxed" specimens). The obtained ring-shaped glassy specimens had the following dimensions: outer diameter of 10 mm, inner diameter of 6 mm, and thickness of 1 mm. The specimens were annealed in the absence of an applied magnetic field in a vacuum 600 s at 813 K.

Apparatus and Procedures

The specimen structures were examined by x-ray diffractometry (XRD) with Cu-$K\alpha$ radiation and optical microscopy (OM). Specimens for OM were cut using a diamond wheel, mechanically polished, and etched with a Nital solution (3% nitric acid and 97% ethanol) at room temperature for 10 s. Relative permeability (μ_r) of the specimens was measured with a vector-impedance analyzer. Hysteresis curves were measured using a DC *B*-*H* loop tracer.

Results and Discussion

Fig. 1 shows typical examples of optical micrographs taken from the cross section of the nonfluxed and fluxed specimens. For the nonfluxed specimens, no appreciable contrast attributable to the precipitation of crystalline phases was observed as shown in Fig 1(a). The XRD results reveal that the nonfluxed specimen has a single glassy structure. On the other hand, the micrograph of the fluxed specimen indicates the presence of some precipitates with a size of 50–100 μm as shown in Fig. 2(a).

The hysteresis curves of the ring-shaped bulk specimens are shown in Fig. 2. The nonfluxed specimen with the single glassy structure exhibits low coercivity (H_c = 8 A/m) and high μ_r (= 2.2×10^3 at 100 Hz and 0.4 A/m) in

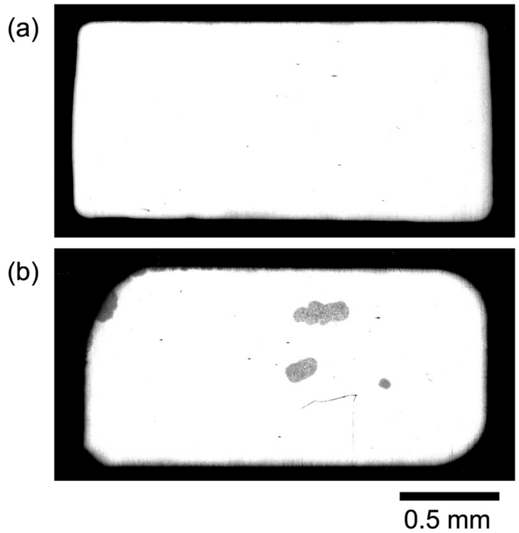

Fig. 1 Optical micrographs of cross sections of etched (a) fluxed and (b) nonfluxed specimens in an as-cast state.

an as-cast state. On the other hand, the hysteresis curve is remarkably flattened in the fluxed specimens; i.e., μ_r of 0.6×10^3 at 100 Hz and 0.4 A/m, and H_c of 37 A/m. It should be noted that the best linear relationship between B and H is achieved in the fluxed specimen after annealing. This is presumably because the undesirable magnetic anisotropies induced by the quenched-in stress are vanished by annealing.

The structural results of the fluxed specimens show that there are two possible reasons for the flat histolysis curves. One is the pinning of the magnetic domain wall displacements caused by the precipitated crystalline phases. The other possibility is the magnetic anisotropy induced by internal stress due to the precipitation of the crystalline phases. In the latter case, the magnetic anisotropy may be deteriorated by annealing because the internal stress is released. However, the anisotropy is not showing a tendency to deteriorate by annealing. This result suggests that the origin of the flat histolysis curve is the pinning of the magnetic domain wall displacements by the crystalline phases.

Conclusion

We prepare $(Fe_{0.75}B_{0.20}Si_{0.05})_{96}Nb_4$ bulk specimens by B_2O_3 flux melting and copper mold casting. The specimens have a flat hysteresis curve; i.e., there is a good linear relationship between B and H. The origin of the flat hysteresis curves may be the pinning of the magnetic domain wall displacements by the precipitated crystalline phases. The results of the present study show that

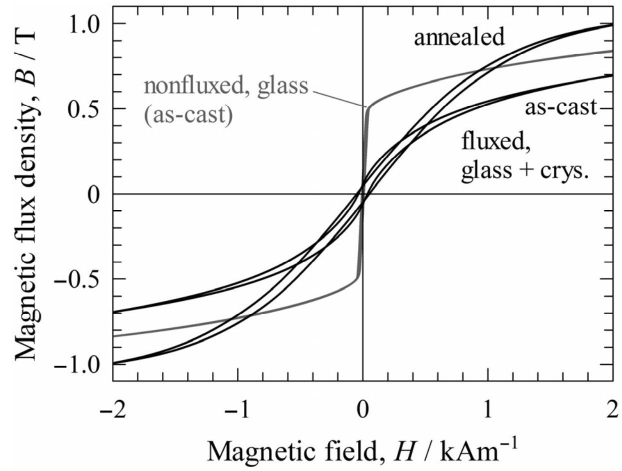

Fig. 2 Hysteresis curves of ring-shaped bulk specimens.

it is possible to develop a new soft magnetic material for inductors and choke coils.

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