EFFECTS OF PEENING ON MAGNETIC PROPERTIES IN SOFT MAGNETIC ALLOYS

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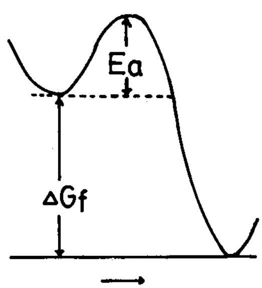
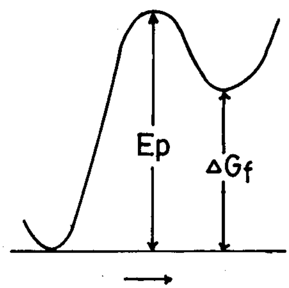
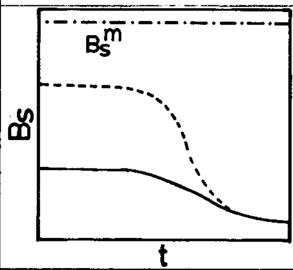
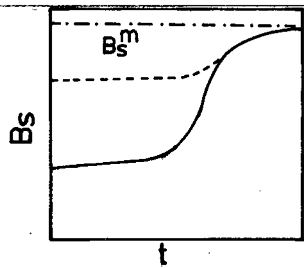
Introduction

Various properties, such as magnetic, electric and mechanical properties, have been reported in liquid-quenched metallic glasses (1 - 6). However, it is difficult to control the properties, homogeniously, because cooling condition radically affects the properties. Aging, close to equilibrium, is a good way of homogenizing magnetic properties of metallic glasses (7 - 8). This homogenization relaxes heterogeneous elastic stress induced by liquid-quenching, although the aging decays ductility (9) (see Table 1).

Peening is effective for increaseing the compressive stress, homogeneously. This stress enlarges resistances to fatigue (10) and stress-corrosion (11). Furthermore, the peening may not only enhance the compressive stress homogeneously on the surface, but also disorder the structure of metallic glasses, homogeneously (Table 1).

Table 1: Rate process of peening and aging

	Aging	Peening
Structure Change	Homogenization	
	① Stabilization ② Ordering ③ Relaxation	① unstabilization ② disordering ③ randam distribution
Rate Process		
Driving Force	thermal energy	collision energy
Bs Change		

The dependence of the saturated magnetic properties of metallic glasses on the cooling rate has been investigated (12). It was seen that the fast-quenched and unrelaxed metallic glasses exhibit high magnetic flux density Bs. With this experience, we have undertaken the present study to observe the effect of peening on the magnetic properties in soft magnetic alloys

Experimental procedure

The foil samples of Fe-15at%Ni-10at%Si-15at%B were prepared by liquid-quenching with a twin-type piston-anvil apparatus under a protective Ar-5%H_2 atmosphere (13 - 14). The samples were quenched from approximately 1700 K. The speed of the piston was about 0.12 m/s. Cooling rate, indicated by a parameter, D, was changed by controlling the thickness of the samples. Unrelaxed and relaxed glass samples are prepared by fast- and slow-cooled liquid-quenching below a critical thickness to which the glass can be prepared.

The peening is performed by an apparatus shown in Fig. 1. The nozzle diameter was 8.0 mm. The velocity of the air at the nozzle was 195.5 m/s. The distance between the nozzle and the specimen was 20 mm. The peening angle was 30° to the specimen. The steel balls were made of SuJ 2 steel (HRc = 64); their mean diameter and weight were 0.4 $\pm$ 0.1 mm and 0.68 mg, respectively, and they were supplied at a rate of 2.660 $mm^{-1}s^{-1}$.

The structure of the the samples was examined by means of X-ray diffraction. Bs was measured with a B-H curve tracer (BHV-3.0, Riken Denshi, Tokyo). We found that the magnetic flux density at 5 kOe was very slightly (1 to 5%) larger than that at 4 kOe. Thus, the value of the flux density at 5 kOe was

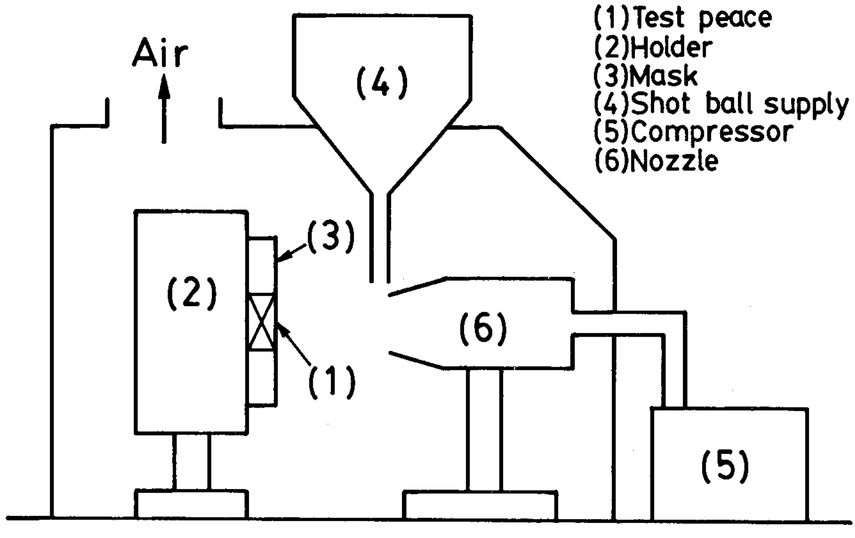


Fig. 1 Schematic peening apparatus.

adopted for Bs. Since it was difficult to obtain the corrected value of the coercive force H_c, the reduced coercive force H_c^r $[(H_c-H_c^o)/H_c^o]$ was taken as a indicator of coercive force. Here, H_c^o is the H_c before peening.

Results and discussions

Besides the glass, the changes in the magnetic properties are studied for Fe-Si crystal alloy. This alloy is commercially used as a typical soft magnetic steel. Figure 2 shows Bs and H_c^r against peening time t of Fe-3%Si crystal alloy. Bs and H_c^r increase with an increase in peening time. It is obvious that the increase in peening time t enhances the Bs and H_c^r. Cold-rolling increases Bs and H_c^r, too (Fig. 3). The cold-working is concluded to increases Bs and H_c^r. The disordering increases Bs and H_c^r. Thus, the peening deduces to increase Bs and H_c^r.

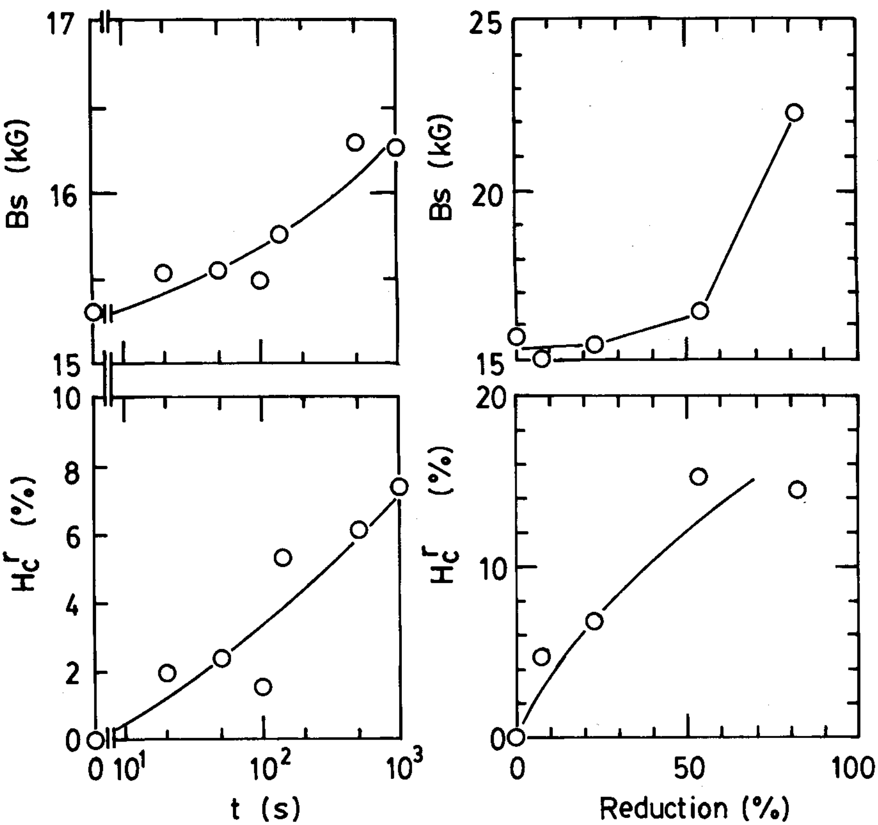


Fig. 2: Change in saturated magnetic flux density Bs and reduced coercive force H_c^r with peening time of Fe-3%Si crystal alloy.

Fig. 3: Change in saturated magnetic flux density Bs and reduced coercive force H_c^r with reduction of cold-rolled Fe-3%Si crystal alloy.

Figure 4 shows Bs against peening time t of liquid-quenched Fe-15at%Ni-10at%Si-15at%B alloy samples. Before peening, at T = 0 sec, the thinner the specimens (the faster the cooling rate), the larger the Bs becomes (12). Compared with the crystal sample, the glassy samples show high Bs. For the fast and slow cooled samples, Bs increases with an increase in peening time. It is obvious that the increase in peening time t enhances the Bs. The largest value of Bs is 9.08 kG (t = 1000 s, D = 0.105 mm) of the fast cooled glass.

A relaxed and clustered metallic glass has prismatic structure (15 - 16). Since electrons of metalloid atoms move to holes of transition metal atoms in the relaxed state, the magnetic moments of the transition metal-metalloid glasses are in general lower than those of alloys without metalloids. Since the relaxed glass is obtained by slow quenching, Bs of the fast cooled specimen is higher than that of the slow cooled specimen (see Bs at t = 0 sec in Fig. 4),i.e. the relaxed glass has the lower Bs. Thus, the peening dependence of Bs in the glassy state in Fig. 4 is understood.

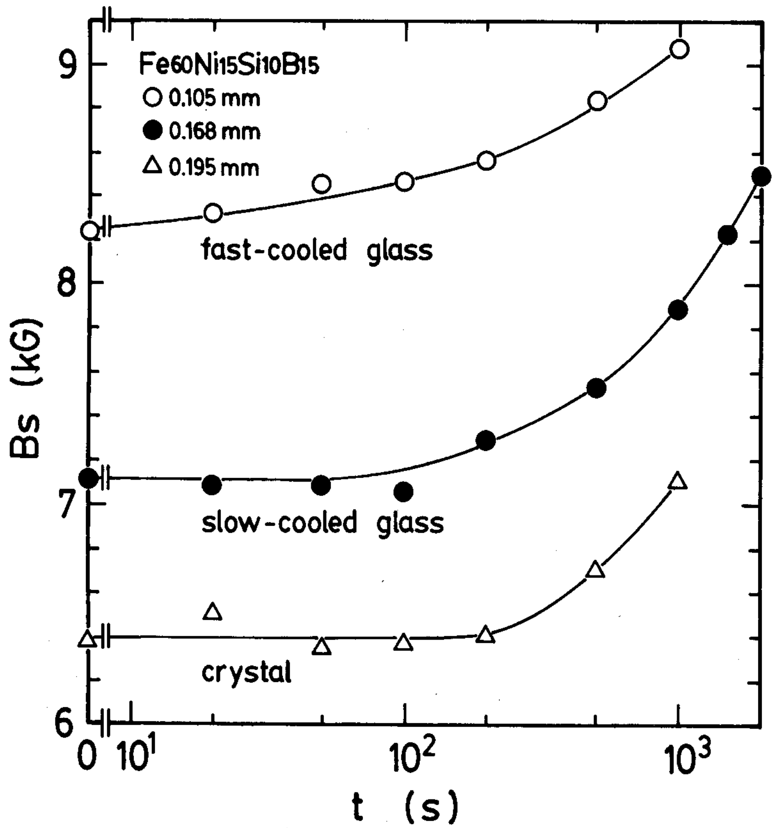


Fig. 4 Change in saturated magnetic flux density Bs with peening time of liquid-quenched Fe-15at%Ni-10at%Si-15at%B alloy.

Figure 5 shows the reduced coercive force H_c^r $[(H_c-H_c^o)/H_c^o]$ with the peening time of the liquid-quenched Fe-15at%Ni-10at%Si-15at%B alloy. H_c^r slightly increases for the crystal alloy, which is prepared by slow-liquid-quenching. For the glasses, H_c^r increases with an increase in the peening time. It is obvious that the increase in peening time t enhances the H_c^r. On the other hand, the cooling condition does not affect the value of the H_c^r for the glasses.

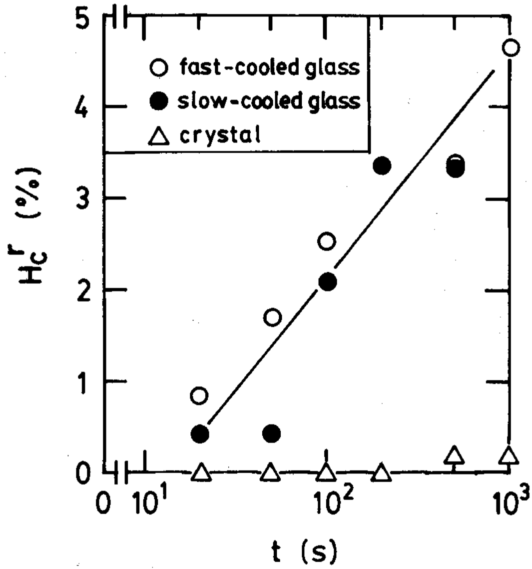


Fig. 5 Change in reduced coercive force H_c^r $[(H_c-H_c^o)/H_c^o]$ with the peening time of a liquid-quenched Fe-15at%Ni-10at%Si-15at%B alloy. Here, H_c^o is the H_c before peening.

<u>Rate process of peened glass</u>

If a driving force of the peening is collision energy, a rate process is applied (see Table 1). Based on the rate process (17), the Bs change (X) is assumed to be expressed by a following equation in relation to the peening time (t; sec).

$$X = 1 - \exp(-k\,t)^n \tag{1}$$

Here, k and n are constant. X is assumed to express

$$X = [(Bs - Bs^o)/(Bs^m - Bs^o)], \tag{2}$$

where Bs^m and Bs^o are Bs of the peened glass at extrimely long period of time and of as-quenched glass (or minimum value of Bs), respectively. Peening for both fast- and slow-cooled glasses, Bs aproaches Bs^m (see Fig. 6). Bs^m of eq. (2) is 9.510 kG, when the correlation coefficient (F) of eq. (1) is maximum (F

= 0.9912 for the slow-cooled glass and F = 0.9853 for the fast-cooled glass) as shown in Fig. 7.

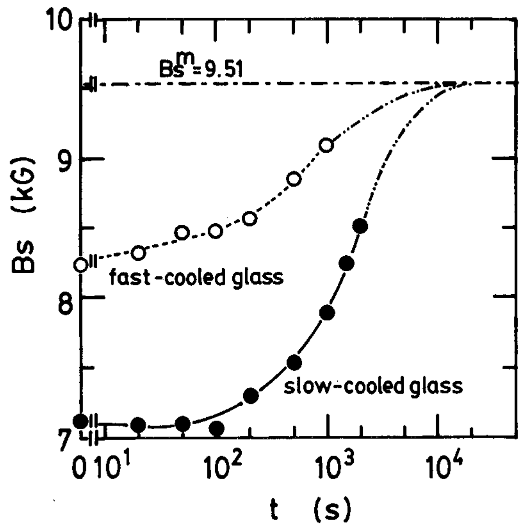


Fig. 6: Change in saturated magnetic flux density Bs with peening time t of liquid-quenched Fe-15at%Ni-10at%Si-15at%B alloy glasses.

From these results, X is expressed by a following equation of fast- and slow-cooled Fe-Ni-Si-B alloy glasses (see Fig. 8).

$$\log_{10} [-\ln(1-X)] = 0.650 \log t - 1.94 \quad \text{(fast-cooled glass)} \quad (3)$$

$$\log_{10} [-\ln(1-X)] = 0.984 \log t - 3.32 \quad \text{(slow-cooled glass)} \quad (4)$$

This linear plotts confirms the assumption of eq. (1). Bs is plotted of the solid line in Fig. 8. Bs of the peened glass approaches Bs^m in Fig. 6.

Conclusion

The Bs and Hc changes with peening is studied for soft magnetic alloys. The peened alloys show the large Bs and the large Hc. If a driving force of the peening is collision energy, a rate process is applied for metallic glass. The parameter of X, $[(Bs - Bs^o)/(Bs^m - Bs^o)]$, is assumed to express, where Bs^m and Bs^o are Bs of the peened glass at extrimely long period of time and of as-quenched glass (or minimum value of Bs), respectively. Based on the rate process, X is expressed by a following equation of fast- and slow-cooled Fe-Ni-Si-B alloy glasses.

$$\log_{10} [-\ln(1-X)] = 0.650 \log t - 1.94 \quad \text{(fast-cooled glass)}$$

$$\log_{10} [-\ln(1-X)] = 0.984 \log t - 3.32 \quad \text{(slow-cooled glass)}$$

This linear plotts confirms the assumption of the rate process. Peening for both fast- and slow-cooled glasses, Bs aproaches Bs^m. Bs^m is 9.510 kG, when the correlation coefficient is maximum.

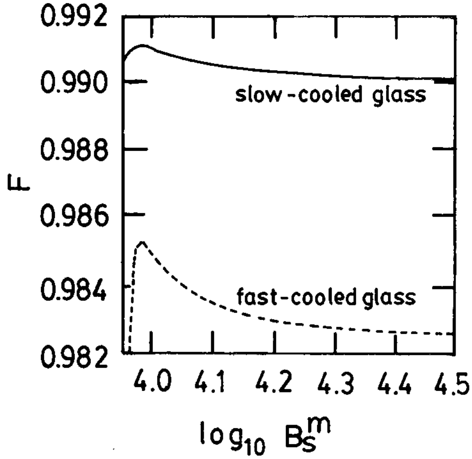


Fig. 7: Change in correlation coefficient (F) with Bs for fast- and slow-cooled glasses. Bs^m, which is the Bs at extremely fast-cooling, is obtained at the maximum value of F.

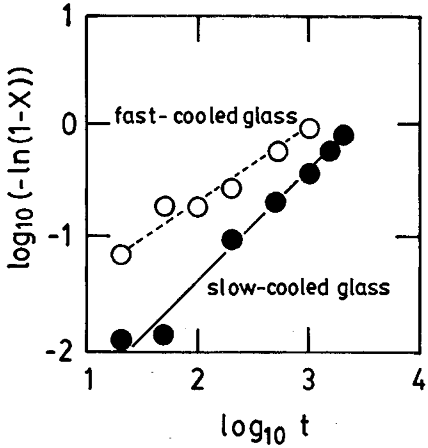


Fig. 8: Linear plotts between $\log_{10}[-\ln(1-X)]$ and log t. $X = [(Bs - Bs^o)/(Bs^m - Bs^o)]$, where Bs^m and Bs^o are Bs of the peened glasses of extremely long period of time and as-quenched glass (or minimum value of Bs), respectively.

References

1. M. Naka, T. Masumoto: J. De Phys. C8 (1980) 839.
2. H. Fujimori, T. Masumoto, Y. Obi, M. Kikuchi: Japan J. Appl. Phys. 13 (1974) 1889.
3. H. Fujimori, H. Yoshimoto, T. Masumoto, T. Mitera: J. Appl. Phys. 52, (1981) 1893.
4. R. Klinger, H. G. Feller: Wear, 86 (1983) 287.
5. D. H. Lee, J. E. Evetts: Acta Met. 32 (1984) 1035.
6. Y. Nishi, T. Kai, N. Inoue: J. Mate. Sci. Lett. 5 (1986) 1137.
7. A. Handstein, J. Schneider, K. Zaveta, Z. Kalva: Rapidly Quenched Metals IV, (1981) 989.
8. M. Mitera, T. Masumoto, N. K. Kazama: J. Appl. Phys. 50, (1979) 7609.
9. A. Inoue, T. Masumoto, H. Kimura: J. Japan Inst. Met. 42 (1978) 303.
10. S. Hirose: Proc. 1st Inter. Conf. on Shot-Peening, (1981) 51.
11. W. H. Friske, J. P. Page: ibid. 485.
12. Y. Nishi, T. Kai, M. Tachi, T. Ishidaira, E. Yajima: Scri. Mett. 20 (1986) 1099.
13 Y. Nishi, S. Kenji, T. Masumoto: J. Japan Inst. Met. 45 (1982) 818.
14. Y. Nishi, T. Morohoshi, M. Kawakami, K. Suzuki, T. Masumoto: Rapidly Quenched Metals IV, (1981) 111.
15. J.D. Bernal: Proc. Roy. Soc. London, A 280 (1964) 299.
16. T. Fukunaga, K. Suzuki: Sci. Rep. RITU. A 29 (1981) 153.
17. W. A. Johnson, R. F. Mehl: Trans. AIME. 35 (1939) 416.