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MAGNETOACOUSTIC EMISSION AND DISCONTINUOUS MAGNETOSTRICTION IN TERFENOL – D

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Abstract. – This paper reports measurements of magnetostriction \( \lambda \) and magnetoacoustic emission MAE in a specimen of the most recent \( \text{Tb}_{0.3}\text{Dy}_{0.7}\text{Fe}_{1.0} \) produced at Ames Laboratory. This specimen was produced by float zone solidification and was then annealed at 950 \(^\circ\)C for one hour. The magnetostriction in a field of 3,000 Oe, under a compressive stress of 14 MPa, reached \( 2,200 \times 10^{-6} \). Magnetoacoustic emission signals were found to exhibit peak activity close to the maxima in \( d\lambda / dH \).

Introduction

Recent measurements on the highly magnetostrictive alloy \( \text{Tb}_{0.3}\text{Dy}_{0.7}\text{Fe}_{1.0} \) have revealed large variations in the magnetostriction \( \lambda \) from specimen to specimen, depending on the method of sample preparation. For example, in fields of up to 3,000 Oe under a compressive stress of 14 MPa, the maximum magnetostriction was found to vary from \( 1,500 \times 10^{-6} \) to \( 2,000 \times 10^{-6} \) among a group of specimens.

The high performance specimens, those with magnetostriction in the vicinity of \( 2,000 \times 10^{-6} \) at 3,000 Oe showed a distinctive dependence of magnetostriction on magnetic field \( H \), in which there was a discontinuous jump in magnetostriction at fields strengths between 200-500 Oe depending on the applied stress [1, 2]. This discontinuity has been attributed to irreversible domain rotation occurring in one twin of the twinned dendritic Terfenol-D crystal, while the rotation in the other twin is continuous and reversible. Since this behavior appeared to be common to the specimens with higher magnetostriction the present study of magnetoacoustic emission and magnetic Barkhausen activity was undertaken in an attempt to determine the domain mechanisms occurring at this location.

Results

The specimens were cylindrical in shape, with length of 5 cm and diameter of 0.7 cm. They were subjected to compressive stresses of up to 14 MPa in increments of 3.5 MPa along the axis of the cylinder which corresponded to the crystallographic [112] axis. The magnetic field was also applied along this axis. Measurements were made using a computer controlled magnetic hysteresisgraph [3] which simultaneously measured magnetic field \( H \), magnetic induction \( B \), magnetostriction \( \lambda \) and either magnetic Barkhausen count rate or magnetoacoustic emission count rate. The measured magnetic field \( H \) takes into account demagnetizing effects.

Results presented here were taken on the specimen with the highest magnetostriction measured at 3,000 Oe. This was found to have a value of \( \lambda = 2,200 \times 10^{-6} \) which was substantially higher than other specimens. The magnetic Barkhausen activity [4] figure 1 revealed a distinctive double peak as the field was scanned from \(-3 \) kOe to \(+3 \) kOe. The peaks, which were centered at \( H = -150 \) Oe and \( H = +250 \) Oe under a stress of 14 MPa, corresponded to a region of very little magnetostriction and the region in which \( d\lambda / dH \) was a maximum. It therefore appeared as if two separate mechanisms were responsible for the peaks. These could be 180° domain processes, which do not lead to any change in magnetostriction, and non-180° domain

Fig. 1. – Variation of Barkhausen emission with magnetic field \( H \) for various compressive stress levels. The emissions are measured in counts per second. In order to make the results clearer, the successive curves have been displaced by \( 1 \times 10^5 \) cps along the axis \( H = 0 \). At high fields \( (H > 1,000 \) Oe), the count rates were effectively zero. The field was swept from \(-3,000 \) Oe to \(+3,000 \) Oe in each case. This leads to asymmetry in the curves about \( H = 0 \). When the field was swept in the opposite direction, the curves were merely mirror images in the line \( H = 0 \).

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processes which can contribute to both Barkhausen and magnetoacoustic emission activity.

The subsequent magnetoacoustic emission study revealed a rather complex behavior, figure 2. This showed two very distinctive peaks at zero stress with considerable broadening and additional detail emerging as the compressive stress was increased. The magnetoacoustic emission spectrum under a stress of 14 MPa could be loosely described as double peaks centered at \( H = -350 \) Oe and +400 Oe. These coincide with the maximum values of \( \frac{d\lambda}{dH} \) which occurred at \( H = -350 \) Oe and \( H = 500 \) Oe. It therefore appears that the non-180° domain processes, which are reflected in the magnetoacoustic emission data, occur close to the discontinuous jump in the magnetostriction as a function of field. This result is consistent with the interpretation of Clark et al. [2], although present results are not sufficient to confirm it. The 180° domain processes, which contribute to the magnetic induction \( B \), appear to occur at slightly different field strengths and this gives rise to the difference in the location of the Barkhausen and magnetoacoustic emission peaks.

Finally, although the magnetostriction versus magnetic field plots reveal the existence of a discontinuity due to the rapid onset of non-180° domain processes, it is clearly shown in figure 3 that no such discontinuity occurred in the magnetostriction versus magnetic induction. Here the non-180° domain processes which occur over a very small range of field contribute to the change in \( B \) as well as \( \lambda \), leading to a smooth interdependence.

Conclusions

Present results on magnetoacoustic emission, together with recent Barkhausen measurements, are in accordance with the recent model of Clark et al. [2], although further work is necessary in order to confirm this.

The level of non-180° domain wall processes, as indicated by the amplitude of magnetoacoustic emission activity increased with compressive stress, as did the amplitude of the magnetostriction discontinuity, showing that the discontinuity must be caused by irreversible rotation of domains perpendicular to the stress axis into a direction closer to the stress axis. Since the (111) axes are the easy direction it seems that the mechanism proposed by Clark et al. is the most likely.

The magnetostriction of \( \lambda = 2, 200 \times 10^{-6} \) at a field of 3 kOe was the largest that has been observed in our recent studies of Terfenol-D alloys produced by Ames Laboratory.