Influence of Tensile Force on Magnetic Properties of Amorphous $Fe_{80}B_{11}Si_9$ Alloys in Different States of Thermal Relaxation

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Abstract. The paper presents the method of measurements of the tensile stresses dependence of the magnetic characteristics of the ring-shaped cores made of $Fe_{80}B_{11}Si_9$ amorphous alloy in as quenched and annealed state. The results of investigation on influence of tensile stresses on magnetic characteristics of those cores have been done. First core was in as-quenched state, whereas others were annealed in 350°C for one hour, annealed in 355°C for one hour, and annealed in 360°C for one hour. Presented results confirm the high magnetoelastic sensitivity of $Fe_{80}B_{11}Si_9$ alloy in as-quenched and annealed states.

Keywords: amorphous magnetic alloys; magnetoelastic effect; tensile stresses; thermal relaxation.

1 Introduction

Knowledge about the magnetoelastic properties of soft amorphous alloys is very important from both practical and theoretical points of view. Thermodynamically reverse effect connected with the influence of the external tensile stresses on the magnetic properties of this alloys, so called magnetoelastic Villari effect [2, 4, 5], has also significant, technical consequences.

From the other hand knowledge about the influence of stresses on the magnetic properties of magnetic materials, despite the many years of development, is still low. There are many studies on the effects of compressive stresses on both the ceramic magnetic materials [7], as well as amorphous magnetic materials [2, 6, 9, 10–13]. Effect of the shear stresses which is a composite effect of the compressive and tensile stresses acting at 45 degrees to the direction of the magnetic circuit is also known from the literature [8]. However, there is a lack of knowledge about the effects of tensile stresses on the magnetic properties of magnetic materials, both crystalline and amorphous materials. The paper is designed to fill this gap, presenting the method to obtain a uniform state of stresses in the material as well as obtaining a closed

R. Szewczyk, C. Zieliński, and M. Kaliczyńska (eds.), *Recent Advances in Automation, Robotics and Measuring Techniques*, Advances in Intelligent Systems and Computing 267,
DOI: 10.1007/978-3-319-05353-0_63, © Springer International Publishing Switzerland 2014

magnetic circuit. The tested material was also subjected to thermal relaxation aimed at demonstrating the applicability of amorphous materials as the core tension sensors.

2 Methodology of Investigation

Investigation was carried out on four ring-shaped cores made of $Fe_{80}B_{11}Si_9$ amorphous alloy. Cores were wounded of amorphous ribbon to ring shaped cores. Each core had outside diameter 32 mm, inside diameter 25 mm and height 10 mm. First core was in as-quenched state, second was annealed in 350°C for one hour in protective atmosphere, third was annealed in 355°C for one hour and fourth annealed in 360°C for one hour [3].

The tensile stresses σ from the external force F are applied in a perpendicular direction to the direction of the magnetizing field H in the core. The main problem with this method is winding the core. This problem was solved by means of the device shown schematically in figure 1.

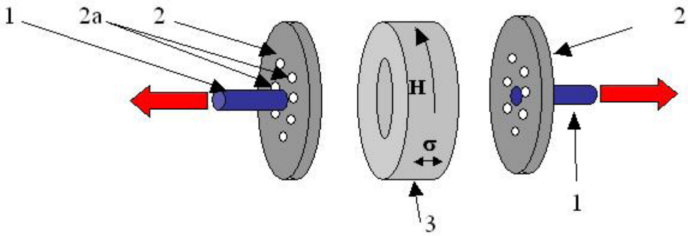

Fig. 1. Schematic diagram of device for application of uniform tensile stresses σ to the ring-shaped core: 1 – rod, 2 – nonmagnetic backings, 2a – holes for the magnetizing and measuring windings, 3 – amorphous ring shaped core

The amorphous ring shaped core (3) is fixed between two special backings (2) made of non-magnetic material (brass). In the backings have been made holes (2a), allowing for winding of the core. The tensile forces are applied to the rods (1).

The presented methodology of the application of the tensile stress on the magnetic characteristics of amorphous ring-shaped cores allows for a uniform stress distribution.

Mechanical setup in which investigation was carried out is presented in figure 2. Adjustable screw tensile stress generator (5) acts on the reference force sensor (2) coupled with electronic processing (3) and the tested core (1). The amorphous ring shaped core is wound by magnetizing and measuring windings.

Influence of tensile stresses on magnetic characteristics was measured according to the following procedure: 1 – applying the tensile force F, 2 – obtaining the stresses in the core, 3 – demagnetization of the core, 4 – determination of the $B(\sigma)_{Hm}$ characteristics based on the measured characteristics of $B(H)_{\sigma}$.

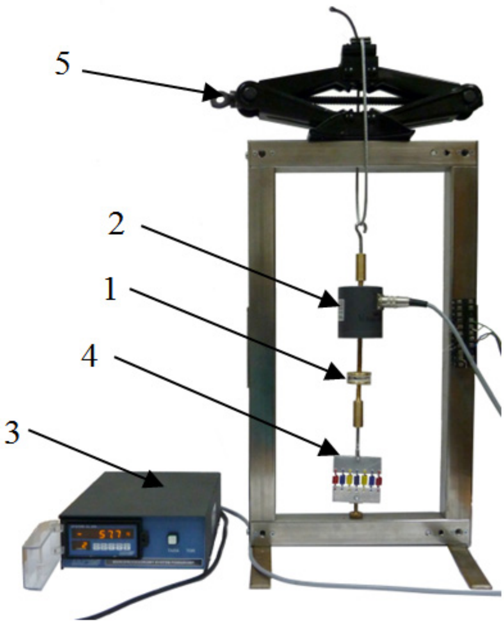

Fig. 2. Mechanical setup for application of tensile stresses σ in the ring-shaped core: 1 – amorphous ring shaped core, 2 – verification sensor, 3 – electronic processing staff of sensor, 4 – set of spring, 5 – force generator

Tensile stresses obtained in the cores during the measurements were from 0 MPa to 3 MPa at 0,25 MPa intervals.

3 Results

Figure 3 shows the influence of tensile stresses σ on the shape of $B(H)_\sigma$ hysteresis loops of $Fe_{80}B_{11}Si_9$ amorphous alloy. Under the tensile stresses σ up to 3 MPa, value of flux density B significantly decreased, and the value of coercive field H_c does not change.

The magnetoelastic $B(\sigma)_{Hm}$ characteristics of cores made of $Fe_{80}B_{11}Si_9$ amorphous alloy is presented in figure 4. Under the influence of tensile stresses, the value of maximal flux density B decreases. Figure 5 shows the influence of tensile stresses σ on the magnetic permeability. Based on these results the magnetoelastic sensitivity can be determined. Sensitivity was calculated as the relative change in the magnetic permeability of the sample for the full load range of 0 to 3 MPa. For core in as-quenched state, the magnetoelastic sensitivity is equal to 58,11%. For core annealed in 350°C for one hour, the magnetoelastic sensitivity is equal to 63,36%, for core annealed in 355°C for one hour magnetoelastic sensitivity is equal to 56,86%. And for core annealed in 360°C for one hour, the magnetoelastic sensitivity is equal to 60,28%.

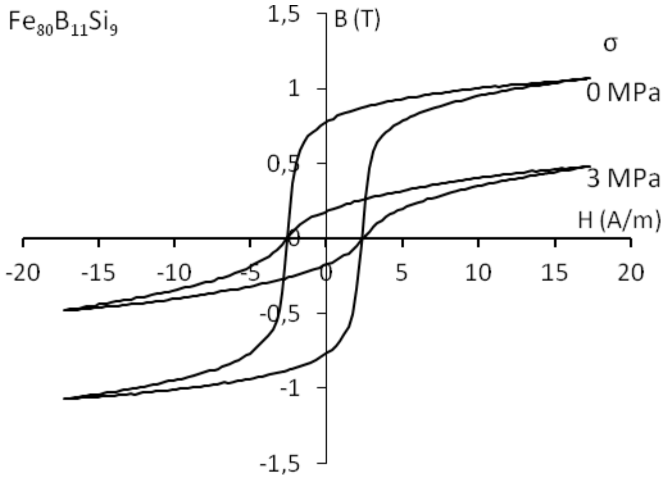

Fig. 3a. Influence of tensile stresses σ on the shape of hysteresis loop $B(H)_\sigma$ of tested cores in as quenched state

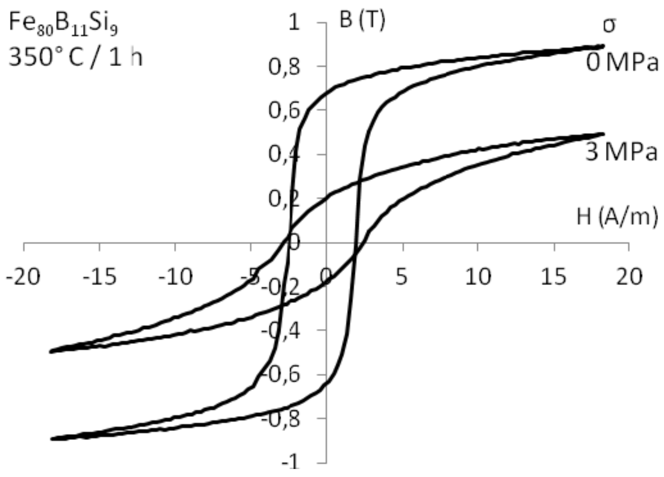

Fig. 3b. Influence of tensile stresses σ on the shape of hysteresis loop $B(H)_\sigma$ of tested cores after annealing in 350ºC for 1 hour

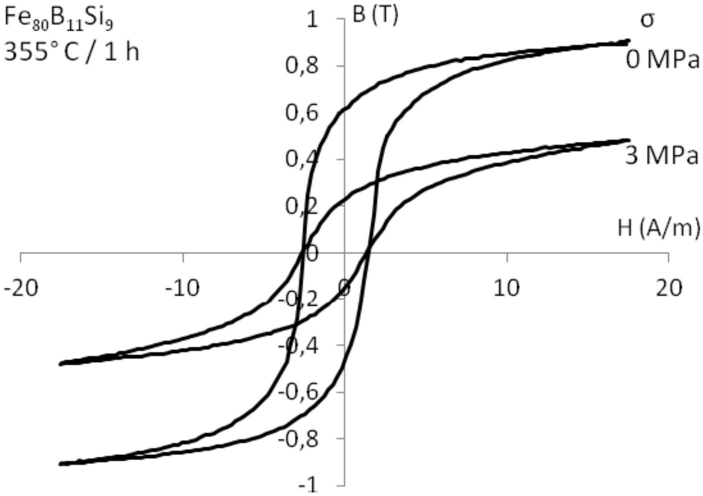

Fig. 3c. Influence of tensile stresses σ on the shape of hysteresis loop $B(H)_\sigma$ of tested cores after annealing in 355 ºC for 1 hour

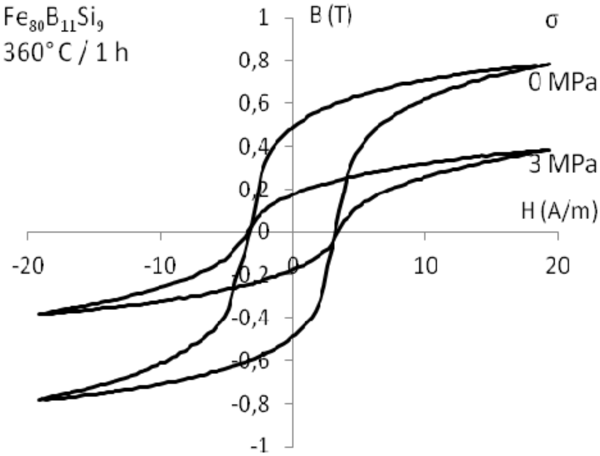

Fig. 3d. Influence of tensile stresses σ on the shape of hysteresis loop $B(H)_\sigma$ of tested cores after annealing in 360ºC for 1 hour

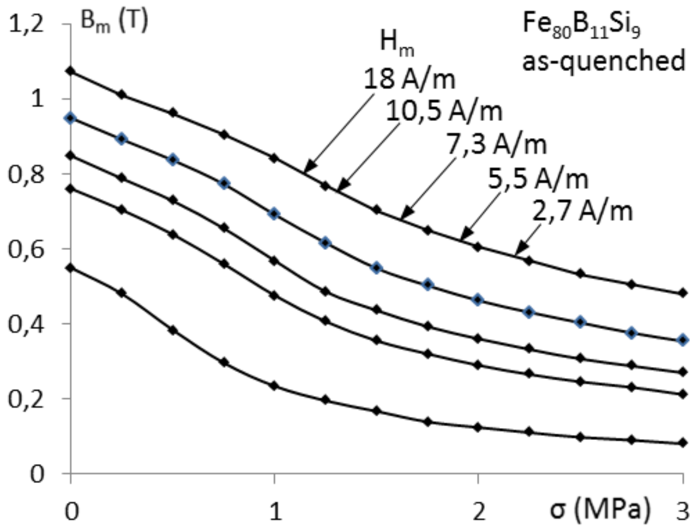

Fig. 4a. Magnetoelastic $B(\sigma)_{Hm}$ characteristics of tested cores made of $Fe_{80}B_{11}Si_9$ amorphous alloys in as quenched state

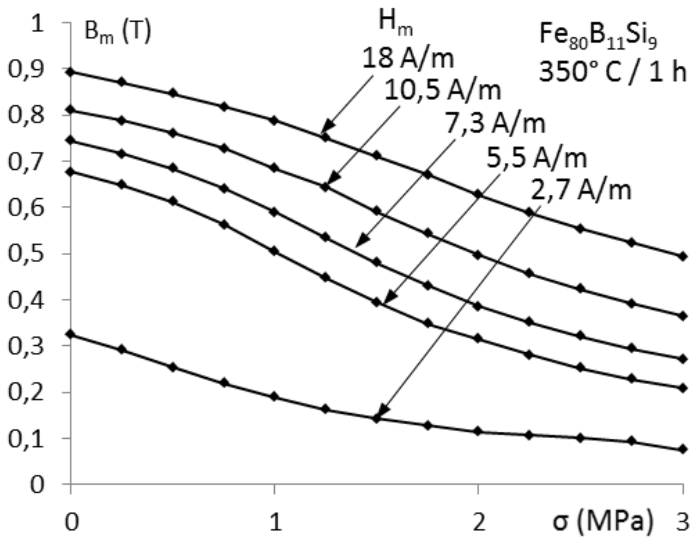

Fig. 4b. Magnetoelastic $B(\sigma)_{Hm}$ characteristics of tested cores made of $Fe_{80}B_{11}Si_9$ amorphous alloys after annealing in 350ºC for 1 hour

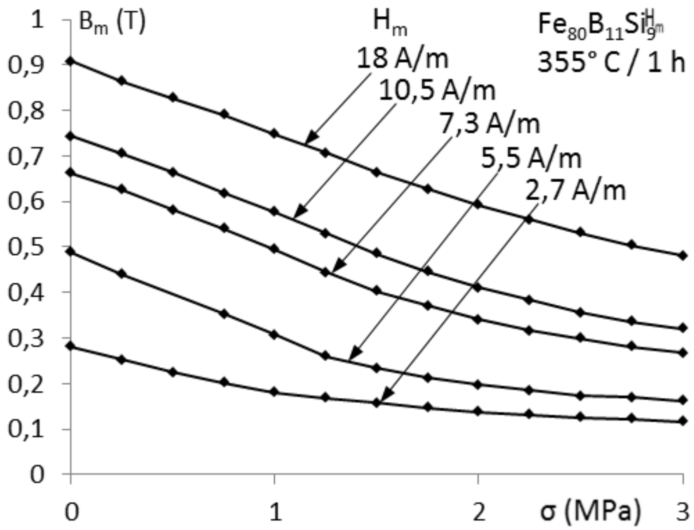

Fig. 4c. Magnetoelastic $B(\sigma)_{Hm}$ characteristics of tested cores made of $Fe_{80}B_{11}Si_9$ amorphous alloys after annealing in 355ºC for 1 hour

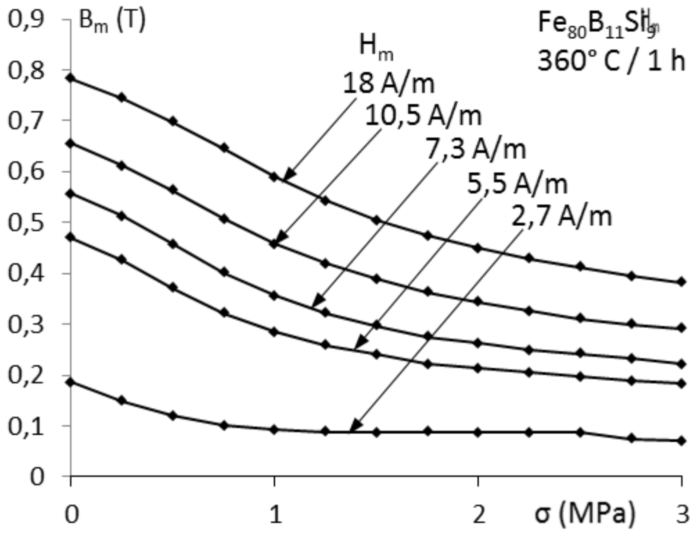

Fig. 4d. Magnetoelastic $B(\sigma)_{Hm}$ characteristics of tested cores made of $Fe_{80}B_{11}Si_9$ amorphous alloys after annealing in 360ºC for 1 hour

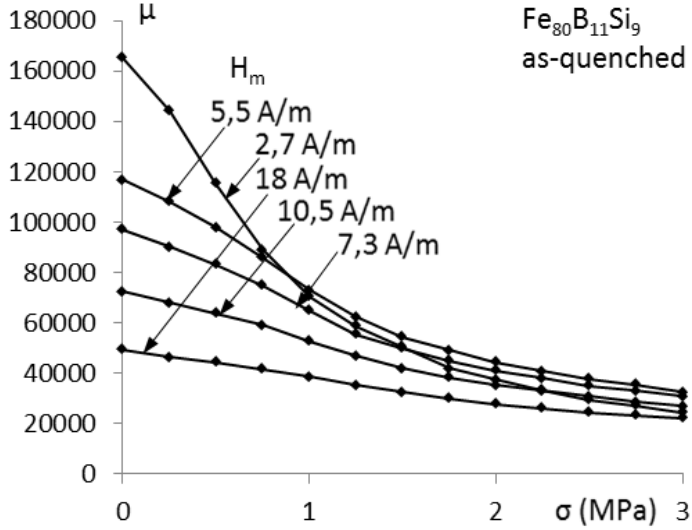

Fig. 5a. Influence of tensile stresses σ on the magnetic permeability of tested cores made of $Fe_{80}B_{11}Si_9$ amorphous alloys in as quenched state

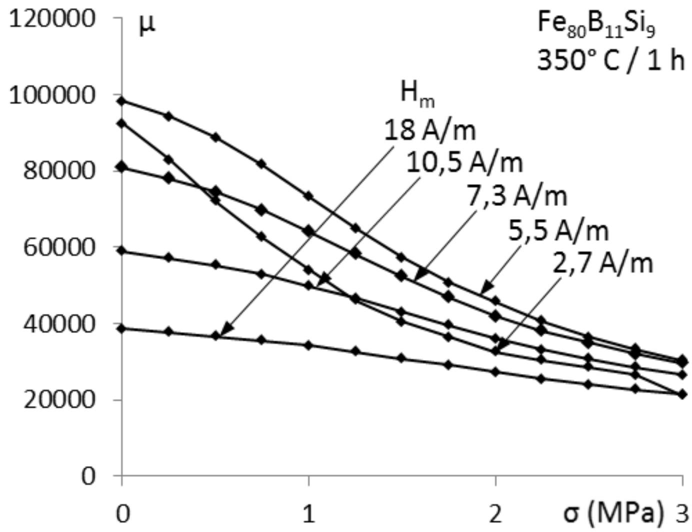

Fig. 5b. Influence of tensile stresses σ on the magnetic permeability of tested cores made of $Fe_{80}B_{11}Si_9$ amorphous alloys after annealing in 350ºC for 1 hour

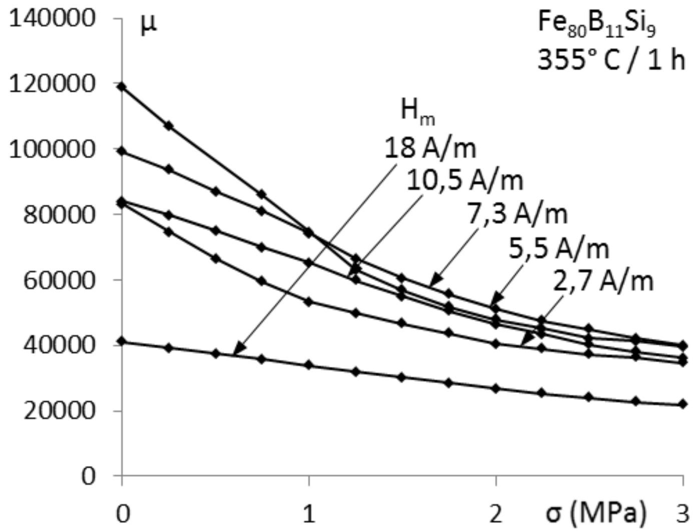

Fig. 5c. Influence of tensile stresses σ on the magnetic permeability of tested cores made of $Fe_{80}B_{11}Si_9$ amorphous alloys after annealing in 355ºC for 1 hour

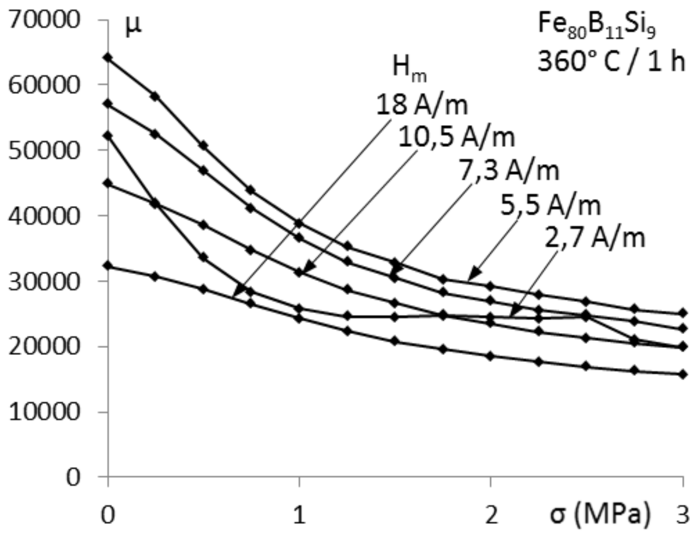

Fig. 5d. Influence of tensile stresses σ on the magnetic permeability of tested cores made of $Fe_{80}B_{11}Si_9$ amorphous alloys after annealing in 360ºC for 1 hour

4 Conclusions

The measurement method presented in this paper is adequate for the measurements of the tensile stresses dependence of the magnetic characteristics of the ring-shaped cores made of $Fe_{80}B_{11}Si_9$ amorphous alloy in as quenched and annealed state.

It was observed, that the magnetoelastic sensitivity changes with the thermal annealing of the amorphous alloy sample. The highest value was obtained after annealing in 350ºC for 1 hour. However, for the remaining cores, the magnetoelastic sensitivity was also very high.

Presented results confirm, that the amorphous $Fe_{80}B_{11}Si_9$ alloy can be used in the development of magnetoelastic sensors of the tensile stresses σ. Due to the high magnetoelastic sensitivity such sensors can be used in industrial applications, mechatronic systems, civil engineering [1].

Acknowledgment. This work was partially supported by The National Centre of Research and Development (Poland) within grant no. PBS1/B4/6/2012.

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