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On the role of crystal and stress anisotropy in magnetic Barkhausen noise ☆

Meisam Sheikh Amiri [a,*], Matthias Thielen [b], Madalina Rabung [c], Michael Marx [b], Klaus Szielasko [c], Christian Boller [a,c]

[a] Saarland University, Chair in Nondestructive Testing and Quality Assurance, Campus E3 1, 66123 Saarbrücken, Germany
[b] Saarland University, MWW, Campus E3 1, 66123 Saarbrücken, Germany
[c] Fraunhofer Institute for Nondestructive Testing (IZFP), Campus E3 1, 66123 Saarbrücken, Germany

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ABSTRACT

The article describes the micromagnetic behavior of non- and pre-plastically deformed high strength steel samples under applied stress using different magnetic nondestructive methods such as magnetic Barkhausen noise analysis and hysteresis measurements. It was found that the maximum amplitude of Barkhausen noise (M_{MAX}) increases with applied stress up to a certain point and then decreases again (so-called $M_{MAX}(\sigma)$-curve). Changes of magnetostriction, hysteresis curves and magnetic domain structures have been measured and have been further investigated to find out the reasons with respect to macro- and microscopic material behavior. The results obtained are mainly discussed on the basis of the Villari effect and the relation between applied stress and the Barkhausen noise parameters is described. It is concluded that the interaction between crystal and stress anisotropy is the main reason of the specific $M_{MAX}(\sigma)$-curve observed.

1. Introduction

The effect of applied and residual stress on magnetic Barkhausen noise (MBN) has been a subject of research in the past [1–3]. Karjalainen et al. have studied the influence of tensile and cyclic loading on Barkhausen noise [4]. They have demonstrated that the sensitivity of Barkhausen noise in a material's elastic strain range is much less than in the plastic one. They have also shown that the yield point is detectable with MBN. Jagadish et al. investigated the effect of the uniaxial stress on MBN [5]. They have shown that applied tensile stress increases MBN while compressive stress decreases it. Stefanita et al. have investigated MBN under plastic and elastic strain [6]. They have shown that the effects of elastic strain are much higher than those of plastic strain. Moreover the authors have proposed that elastic deformation creates a new easy axis which is the reason of MBN behavior under elastic strain while pinning of dislocations, changing of crystal easy axis and local elastic strain are three possibilities of how plastic deformation could change MBN. Sablik has proposed a model for simulating the dependence of the maximum MBN signal versus applied stress [7]. He has also demonstrated on the basis of a model that the maximum of MBN increases with increasing applied tensile stress. Lindgren et al. studied the effect of pre-straining and residual stress in soft-magnetic and duplex steel, respectively [8,9]. They have shown that pre-straining generates compressive and tensile residual stress parallel and perpendicular to the loading direction, respectively, in a soft-magnetic steel that can be detected by MBN. Interestingly they have reported that tensile pre-straining in the Lüders band zone induces tensile residual stress in the loading direction which leads to increasing MBN activity. Kleber et al. have also reported those results in Armco iron, but they have shown that in low carbon steel MBN decreases with increasing plastic deformation more than 1% strain, however a small increase in MBN amplitude is visible in their results but has been neglected [10]. Finally they have concluded that the underlying of dislocation tangles and residuals stresses are the cause of the different behavior of Armco iron and the low carbon steel after 1% tensile plastic deformation. Piotrowski et al. also investigated plastic deformation, obtained from cold rolling and tensile deformation, in Armco steel using MBN [11]. They also compared the results of MBN with magnetoacoustic emission (MAE). They reported that MBN and MAE increases with deformation up to maximum and then decreases again. As a reason they mentioned that the role of dislocation tangles are more dominant comparing to the influence of plastic deformation and residual stresses. More recently, Altpeter et al. measured microresidual stresses of the 2nd and 3rd order using MBN analysis [12]. They

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* Corresponding author. Tel.: +49 681 9302 3831.
E-mail address: Meisam.SheikhAmiri@izfp-extern.fraunhofer.de (M. Sheikh Amiri).

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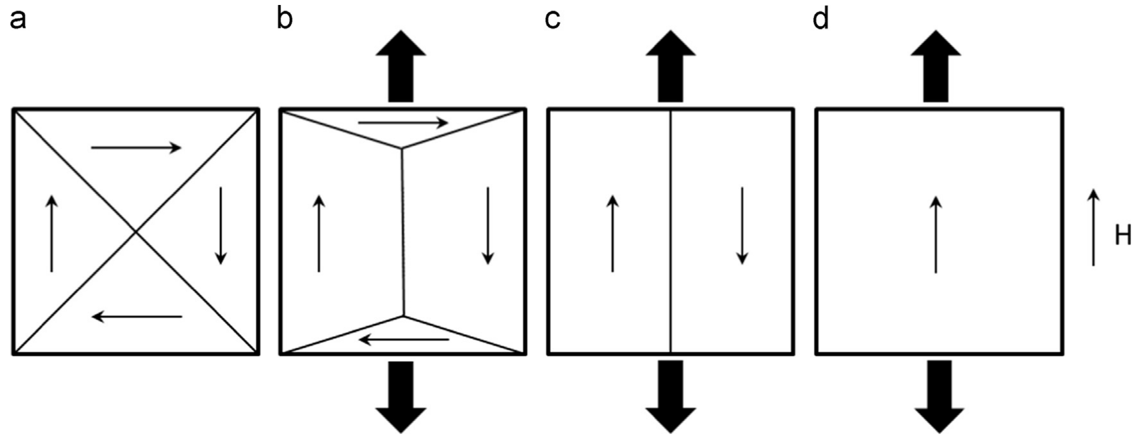

Fig. 1. Schematic magnetization of a material with positive magnetostriction under tensile stress.

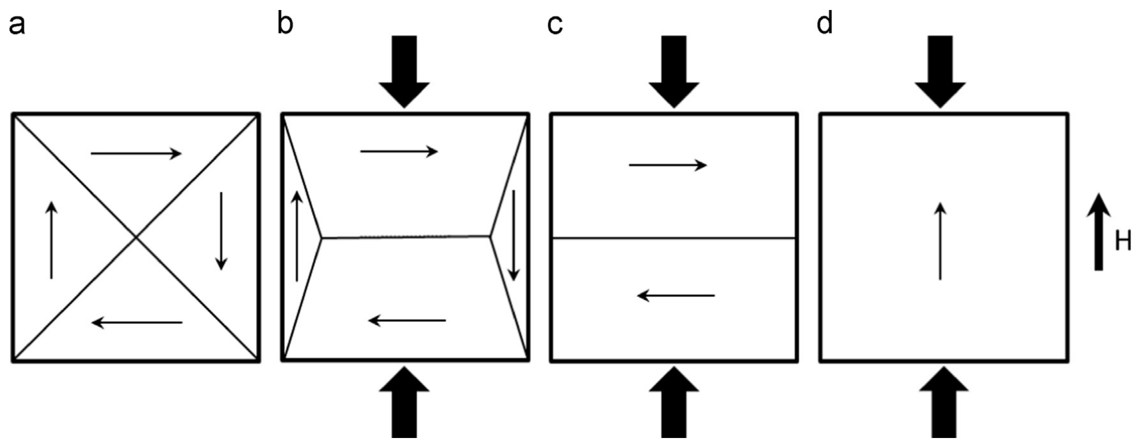

Fig. 2. Schematic magnetization of a material with positive magnetostriction under compressive stress.

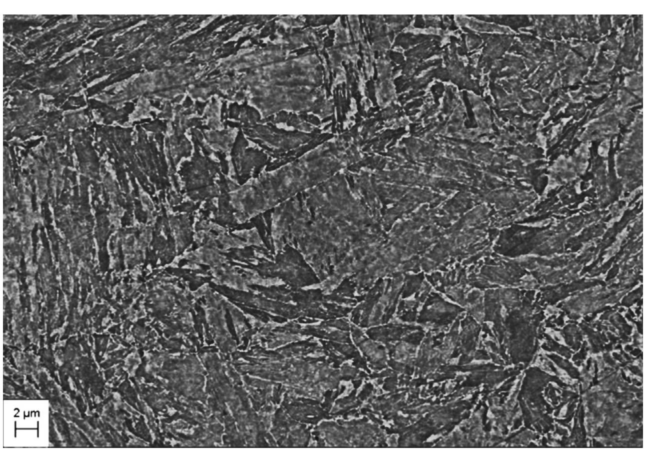

Fig. 3. SEM image of the microstructure of high strength steel for structural application. Polished and etched in Nital.

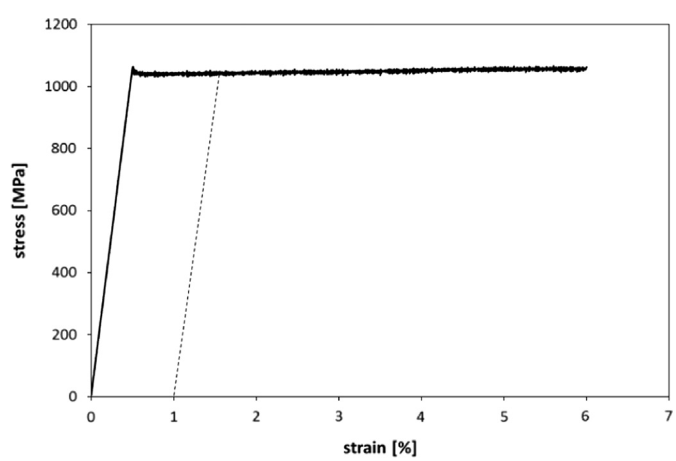

Fig. 4. Stress–strain curve of a high strength steel for structural application.

found for WB 36 steel that M_{MAX} increases with increasing applied stress up to a certain stress and then decreases again. They also showed that an increase in tensile residual stress shifts the maximum of the $M_{MAX}(\sigma)$ curve to the smaller applied stresses values (and vice versa for compressive stress).

So far not too much has been published on trying to generalize the MBN behavior under the effect of applied and residual stresses on a macro- as well as a microscopic scale. Major knowledge in that regard can be found in textbooks such as from Cullity [2]. When trying to determine a unit onto which the effect of stress on a domain wall behavior can be reduced best such that the resulting electromagnetic principle can be generalized best the smallest common 'denominator' turns out to be a material's single crystal. Fig. 1a shows symbolically a single crystal comprising four domains in an unstressed state. A small tensile stress will lead the domain walls to move in such a way that the domains magnetized rectangular to the stress directions will be reduced