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Changing magnetic parameters of structural 30KH13 (30X13) steel in relation to the heat treatment and low-cycle loading

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Abstract. The paper considers the magnetoelastic demagnetization of low carbon steel 30X13 under the action of cyclic loading. The change of the piezo-magnetic effect on the state of steel and the number of loading cycles is studied. The study used a wavelet transform to describe the state of the material under cyclic loading. It is established that the wavelet transform reflects the processes of fatigue changes going in steel.

1. Introduction

The paper describes the results of the tests high-chromium 30KH13 (30X13) stainless steel containing 12-14% chromium. It is a high-strength hard steel. After hardening, it is used for manufacturing very solid details. An absence of other alloying elements and optimal chromium content provide this relatively low-cost material with anticorrosive properties. The steel is ferromagnetic, thus enabling the application of magnetic methods to monitor its quality and condition.

Various heterogeneities present in the steel structure exert a significant influence on the steel parameters, including its magnetic characteristics. Admixtures, dislocations and inclusions mostly affect the formation of magnetic domains and their structures, influencing the magnetic characteristics of the material [1-3]. Mechanical varying loads and resulting flaws lead to irreversible reductions of the ferromagnetic remanent magnetization due to the domain structure transformation and domain wall motion [1, 3].

The work [4] analyzes magnetoelastic demagnetization of low-carbon steel under cyclic loading. It states that the magnetization peak values are approximated by the power function with parameters depending on the load amplitude. The work considers the possibility to estimate the steel fatigue limit, judging upon the approximation coefficients behavior. The work [4] also shows that 30KH13 (30X13) steel has the property of magnetoelastic power relaxation. This approach, however, takes into account the values corresponding only to the minimal and maximal loads, in other words, the magnetic cyclograms do not consider intermediate information.

2. Experimental procedures

This work aims at investigating the influence of cyclic loading of 30KH13 (30X13) steel on changing its magnetoelastic signal through wavelet analysis.

The analysis involved magnetoelastic cyclograms obtained in the work [4]. These were magnetoelastic cyclograms of 30KH13 (30X13) steel samples quenched and tempered at various temperatures (200°C-



650°C). Figure 1 presents magnetoelastic cyclograms for a 30KH13 (30X13) steel sample tempered at 530°C and loads of 160 and 960 MPa.

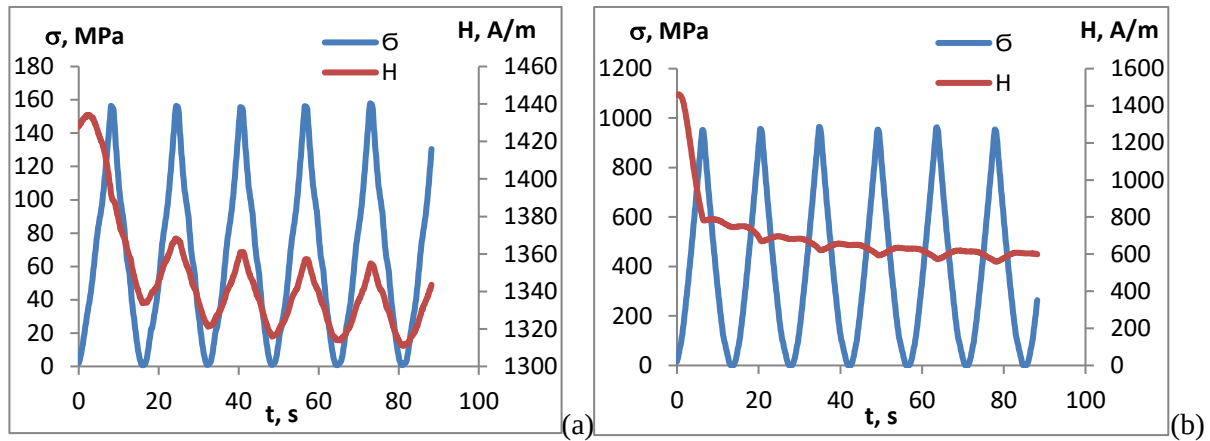


Figure 1. Time dependence of magnetic field intensity and changing mechanical stresses for a sample subjected to the tempering temperature of 530°C at the mechanical load amplitude of: $\sigma=150$ MPa (a), and $\sigma=960$ MPa (b).

The experimental curves obtained made it possible to reveal that, for the steel mentioned, within the given treatment temperature range and beginning with 450°C, the sign of the magnetic piezo effect changes with the mechanical load increase and this effect continues at higher temperatures. This phenomenon is not observed at lower temperatures. Figure 2 presents the results of change in the magnetic piezo effect at treatment temperature 530°C.

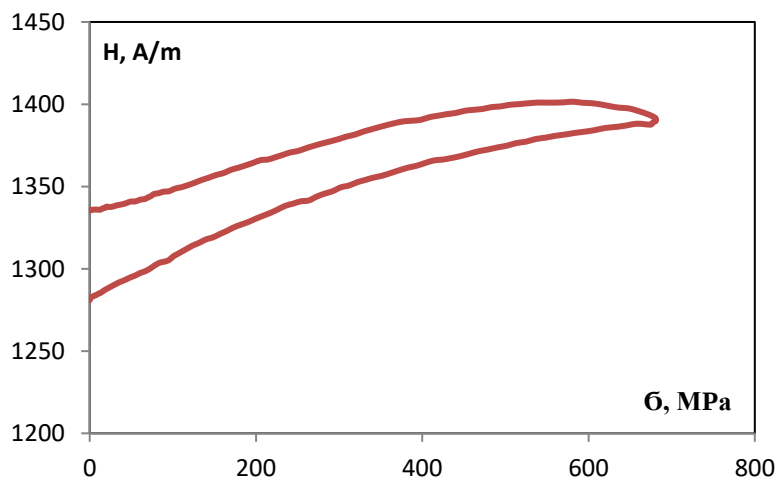


Figure 2. Load dependence of magnetic field intensity for a 30KH13 (30X13) steel sample at the tempering temperature of 530°C in the 40th loading cycle.

The direct piezo magnetic effect means the correlation between the minimum and maximum points of the maximal magnetic field intensity [5-6] and the load minimum and maximum points in the cycle. The reverse piezo magnetic effect implies an antiphase correlation between the values of magnetic field intensity and cyclic load.

3. Results and discussion

Figure 2 shows that the piezo magnetic effect transforms from the direct to the reverse one at 550 MPa. With the increase of the cycle number, this transformation shifts to the lower load range. Changing the sign of the piezo magnetic effect may be due to some more intense changes in the steel structure. These changes result from the coarsening of cementite particles due to the coalescence (the cementite coagulation). The steel structure is formed by the ferrite and cementite phases, also called sorbite [7-8]. These cementite particles serve as barriers for domain wall motion and rotation of magnetization vector. External loads constitute an additional energy source, helping the domain walls overcome structural heterogeneities [3, 7-8, 10].

In this work it is proposed to analyze the magnetic cyclogram in relation to the tempering temperature via wavelet analysis, which enables more detailed presentation of the data obtained.

An algorithm was developed in Mathcad CAS (Computer Algebra System) to investigate the influence of the cyclic load via unidimensional and two-dimensional analyses on the basis of the first derivative of the Gaussian function. The correlation was analyzed between a wavelet response of the magnetoelastic signal at low-cycle loads and mechanical properties of 30KH13 (30X13) steel (figure 3).

The obtained magnetic cyclograms, which were processed through unidimensional discrete wavelet transform, allowed to determine coefficients, and their values make it possible to assess the processes the steel undergoes (figure 3, 4).

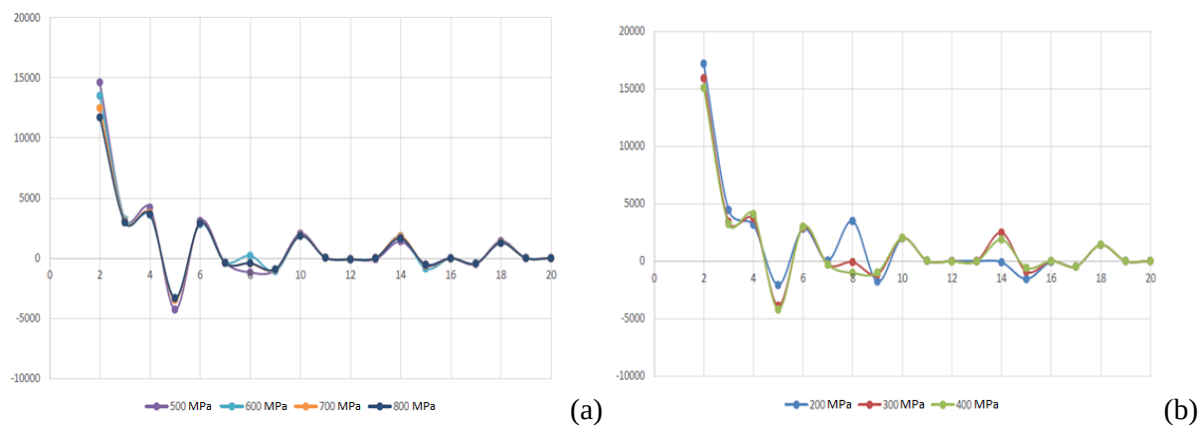


Figure 3. Dependence of unidimensional wavelet transform coefficients in the 1 loading cycle for a sample subjected to the tempering temperature of 200°C at the mechanical load amplitude of: (a) 500, 600, 700, 800 MPa, (b) 200, 300, 400 MPa.

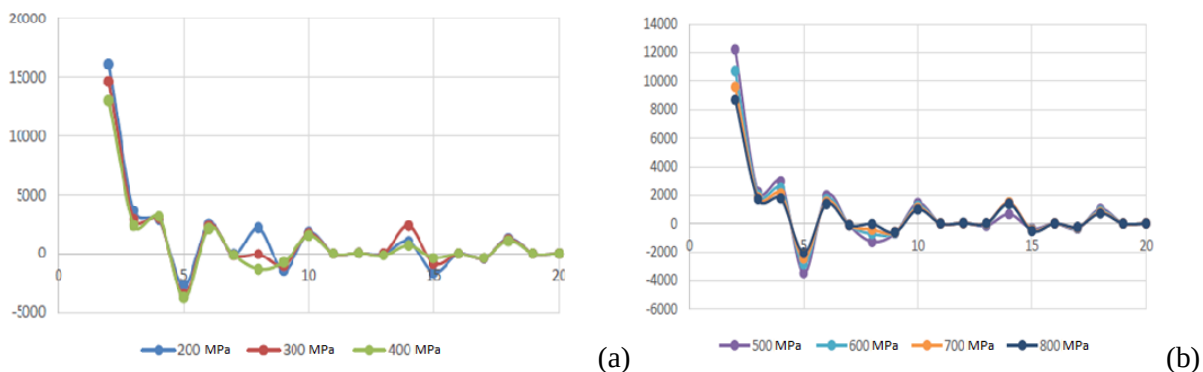


Figure 4. Dependence of unidimensional wavelet transform coefficients in the 99 loading cycle for a sample subjected to the tempering temperature of 200°C at the mechanical load amplitude of: a) 200, 300, 400 MPa, b) 500, 600, 700, 800 MPa.

Having analyzed all the changes in the values of the coefficients obtained (figure 3, 4), we can conclude that, with the increase of the cycle number, as well as with the load increase, the values of unidimensional wavelet transform coefficients decrease, depending apparently on the structural heterogeneities. In addition, with the increase of the cycle number, the values of the coefficients align with the load increase.

Apart from unidimensional wavelet transform, the obtained magnetic cyclograms were analyzed via two-dimensional discrete wavelet transform (figure 6, 7). The data obtained were presented as horizontal relief maps; the graphs depict Z-axis as a level lines (see figure 5), differently colored, where the “red area” refers to the maximum coincidence of the magnetogram with the basic wavelet and the “blue area” refers to the minimum.

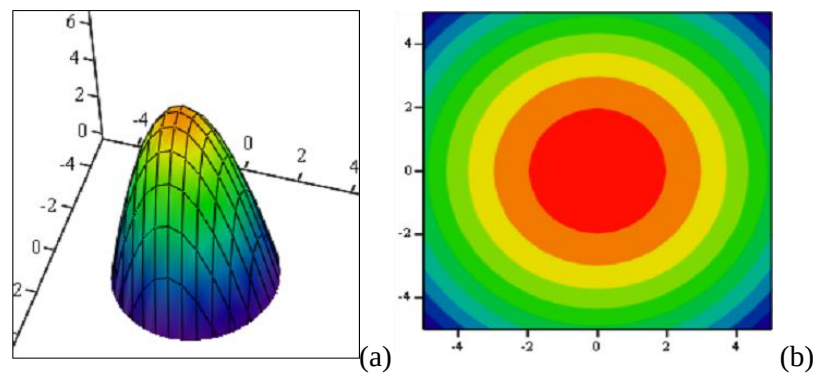


Figure 5. Data presented as a 3D graph (a) and as horizontal relief maps (b).

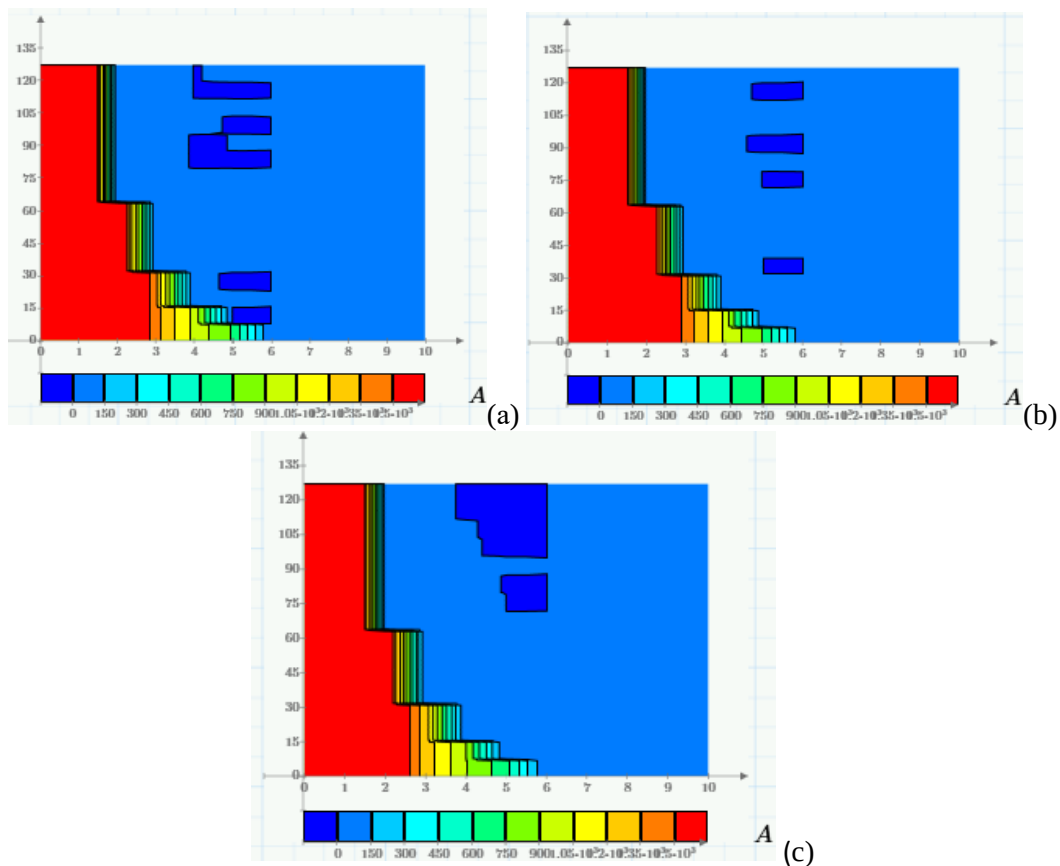


Figure 6. Dependence of two-dimensional wavelet transform coefficients in the 1 loading cycle for a sample subjected to the tempering temperature of 500°C at the mechanical load amplitude of: a) 200 MPa, b) 500 MPa, c) 700 MPa.

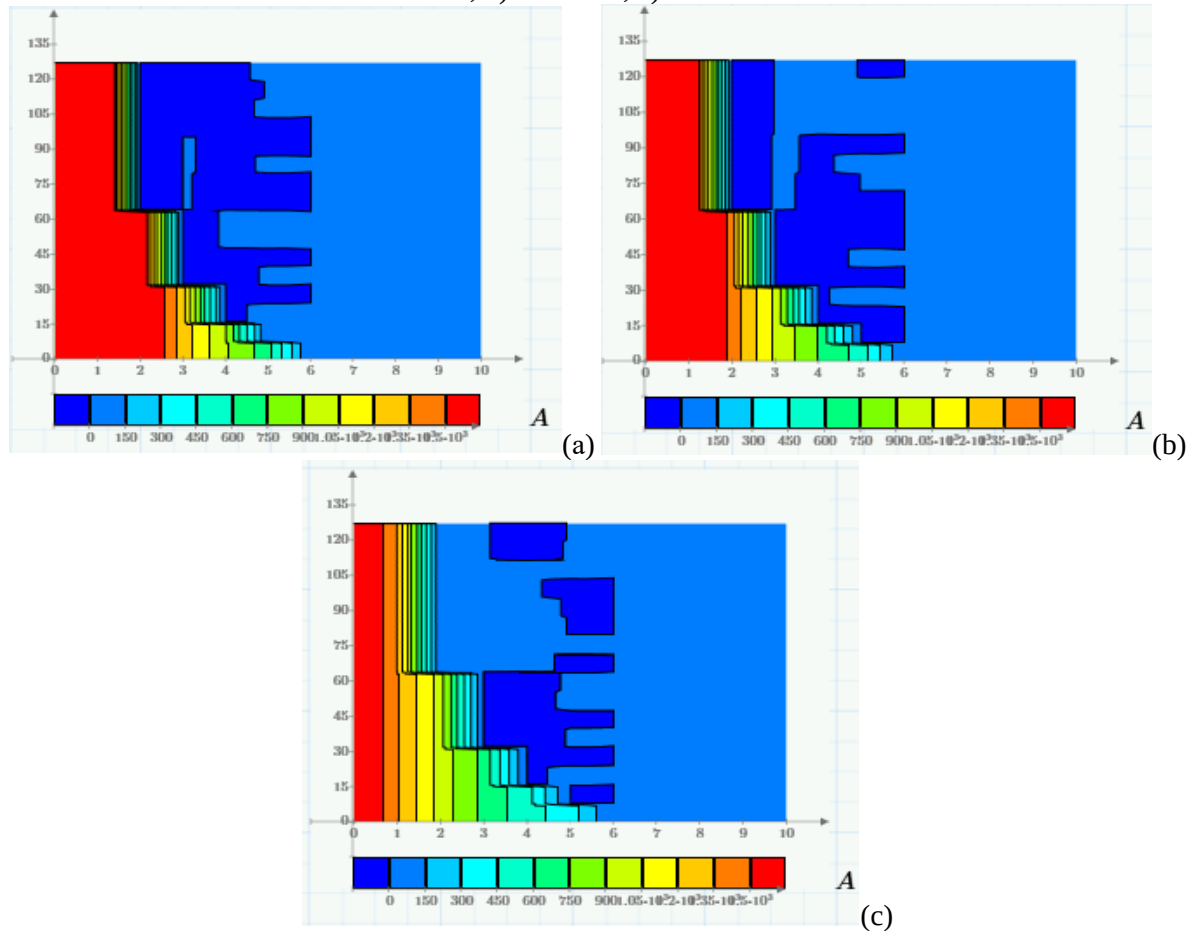


Figure 7. Dependence of two-dimensional wavelet transform coefficients in the 99 loading cycle for a sample subjected to the tempering temperature of 500°C at the mechanical load amplitude of: a) 200 MPa, b) 500 MPa, c) 700 MPa.

Figures 6 and 7 show that the “red area” is the largest at the initial load of 200 MPa and decreases monotonically with the increase of the cyclic load amplitude.

We also may suppose that the increase of the “red area” for the samples subjected to the tempering temperature range 200÷500°C is connected to intense structural changes, namely, transformation of the martensite structure into the pearlite one. This behavior is supposed to reflect the mechanisms of structural stress relaxation without microplastic deformations. The martensite structure is known to be stronger than the pearlite one. Thus, microplastic deformations of crystallites may be supposed to take place.

4. Conclusions

Two-dimensional wavelet transform analysis on the base of WAVE wavelet proved the following regularity: with the increase of the cyclic load amplitude, the “red area” (area with red color on the figure 6 and 7) decreases monotonically. The largest “red area” of two-dimensional wavelet transform is observed at the load of 550 MPa for all loading cycles, which may be connected to the structural features.

For 30KH13 (30X13) steel beginning with tempering temperature of 450°C, the sign of the magnetic piezo effect changes with the mechanical load increase.

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