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Cite as: AIP Conference Proceedings **2053**, 020005 (2018); https://doi.org/10.1063/1.5084351
Published Online: 19 December 2018

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Magnetic and Acoustic Characteristics of Steel 30CrMnSiA after Rolling and Pressing

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Abstract. A group of magnetic and acoustic parameters of the cold-deformed 30CrMnSiA steel is determined. It has been revealed that the coercive force of this steel starts to decrease steadily at degrees of plastic deformation higher than 6%. A hypothesis is put forward on the relaxation of stresses of the first kind as a result of flat pressing after rolling of steel plates. To test the possibility of determining the degree of deformation of the 30CrMnSiA steel by ultrasound measurements, the propagation velocities of longitudinal, transverse, and Rayleigh waves are determined. The change in the velocity of longitudinal ultrasonic waves is 0.8% at deformation degrees ranging from 10 to 20%. The velocity of transverse and Rayleigh ultrasonic waves increases monotonically over the entire range of deformations, with a change in their velocity of 2.5% and 2.2% respectively. Thus, the most suitable parameter for determining the degree of deformation is the propagation velocity of transversal ultrasonic waves.

INTRODUCTION

Magnetic and acoustic testing techniques are the most applicable in the field of determining the stress-strain state and level of residual stresses of steel products. At the same time, the contradictory nature of the available experimental data on the sensitivity of magnetic and acoustic testing parameters to elastic and plastic deformations is one of the key problems in testing and diagnostics [1]. It is becoming increasingly urgent to developing techniques and devices enabling one measure locally a whole complex of magnetic characteristics, i.e. to perform multiparameter diagnostics [2, 3]. However, multiparameter testing and diagnostics, based on measuring both magnetic parameters and characteristics associated with the dynamics of the rearrangement of the domain structure during magnetization reversal, can provide a more reliable determination of residual stresses and the structural-phase state [1, 4]. An example of such characteristics is the amplitude and frequency parameters of magnetoacoustic emission. In more detail, the phenomenon of magnetoacoustic emission and a setup for its investigation are described in [5] and [6].

The velocity of ultrasonic wave propagation is easy enough to measure even on real products. It is known that the velocity of ultrasonic waves is functionally related to elastic moduli governing important physical and technological characteristics of steels and alloys [7]. Mechanical or thermal treatment of metals leads to the rearrangement of their structure and to the appearance of microdefects. The problems of interrelationships of ultrasonic velocity with residual stresses and deformations are studied by such methods as acoustoelasticity and acoustic tensometry [7]. However, despite the large number of recent studies devoted to these methods, there are still many challenges concerning the presence of the effect of a large number of factors on the propagation of ultrasound in addition to the effect of residual stresses. Another problem is a small degree of change in the velocity of ultrasonic vibrations, which does not exceed 3%. The latter requires that the error of the ultrasonic equipment not exceed 0.1% and that the measurement accuracy be 0.05% or even higher.

Mechanics, Resource and Diagnostics of Materials and Structures (MRDMS-2018)
AIP Conf. Proc. 2053, 020005-1–020005-4; https://doi.org/10.1063/1.5084351
Published by AIP Publishing. 978-0-7354-1781-6/$30.00

This paper presents the results of a study devoted to assessing the possibility of using ultrasonic wave velocity for testing the level of deformation in the 30CrMnSiA alloyed steel. The study was conducted within the framework of a large comparative analysis of the acoustic, magnetic and magnetoacoustic parameters of the stress-strain state of carbon and alloy steels and testing residual stresses in them.

MATERIALS AND EXPERIMENTAL TECHNIQUES

A group of samples of the 30CrMnSiA steel was subjected to cold plastic deformation by rolling with a constant speed at room temperature. Magnetic parameters (residual magnetic induction, coercive force, maximal magnetic induction, and maximal permeability) and the degree of deformation of the 30CrMnSiA steel are presented in Table 1. One steel sample was left in the as-received state and not deformed. As a result of rolling, the other five steel plates were bent. In order to correct the shape of the plates, they were subjected to flat pressing. The degrees of deformation of five samples after these treatments ranged from 2.4 to 20% (by a change in cross-section). It can be assumed that the deformation occurring in the plates that have passed through rolling is single-axis. However, due to rolling and subsequent flat pressing, the steel plates acquired a complex stress-strain state, since the stresses in various regions of the bent plates after pressing were relaxed to varying degrees. The steel plates were ground and the edges of the plates were machined on an EDM wire cutting machine. The final dimensions of the 30CrMnSiA steel samples were 3×40×78 mm.

TABLE 1. Magnetic parameters and deformation degree of 30CrMnSiA steel samples

Sample No	B_r ,T	H_c , A/cm	B_m , T	μ_{max}	ε,%
1	1.06	9.81	2.05	461	20
2	0.992	10.3	2.01	410	14.9
3	0.952	10.5	2.04	388	11.1
4	0.952	11.2	2.08	383	5.9
5	1.25	8.79	2.16	575	2.4
6	1.54	8.60	2.17	729	0

The magnetic properties of the steel samples were measured using a Remagraph C-500 magnetic measuring complex manufactured by Magnet-Physik Steingroever GmbH, Germany. The magnetic field was applied strictly along the axis of the sample (along the rolling direction), while the axis of the induction measuring coil was also parallel to this axis. The intensity of the internal magnetic field H, the maximum value of which reached 60 kA/m, was measured with a C-shaped magnetic potential meter. The magnetic hysteresis loop was recorded on the BH plane by storing 2500 points. Before each step of the magnetic measurements and at its end, the sample was demagnetized. The error in the magnetization measurement did not exceed 3%, and the error in measuring the field was 2%. The longitudinal ultrasonic wave velocities were measured using a direct combined piezoelectric transducer with a resonance frequency of 5 MHz, and the transversal wave velocity was measured with a transducer of transversal waves with a resonance frequency of 5 MHz. The transducer of transversal waves was glued onto the surface of steel plates with warmed honey as a couplant. The velocity of the Rayleigh waves was calculated from the approximate expression

$$C_R = C_t \cdot \frac{a + b\sigma}{1 + \sigma}, \tag{1}$$

where $a = 0.875$, $b = 1.125$, C_t is the velocity of transversal acoustic waves, σ is the Poisson coefficient. The ultrasonic measurements were performed on a PC using PCUS electronic board and PCUS software. The time delay was determined by averaging over three peak periods of bottom impulses. The ultrasound velocity measurement error did not exceed 1.5%.

RESULTS AND DISCUSSION

As can be seen from Fig. 1a, the coercive force of the 30CrMnSiA steel increases with the degree of plastic deformation and starts to decline from 5.9% of deformation. The usual behavior of the coercive force would be its growth over the entire range of deformations, since, with an increase in the degree of plastic deformation, an increase in the density of crystal structure defects occurs, mainly, an increase in the density of dislocations [8]. At the initial section of the curve, the most intense increase in the coercive force is observed, i.e. at the given stage of deformation (up to ε = 5.9%), the most intensive growth of dislocation density occurs. Residual magnetic induction (Fig. 1b) increases with deformations higher than 5.9%. A hypothesis was put forward on the relaxation of stresses of the first kind in steel plates as a result of flat pressing after rolling.

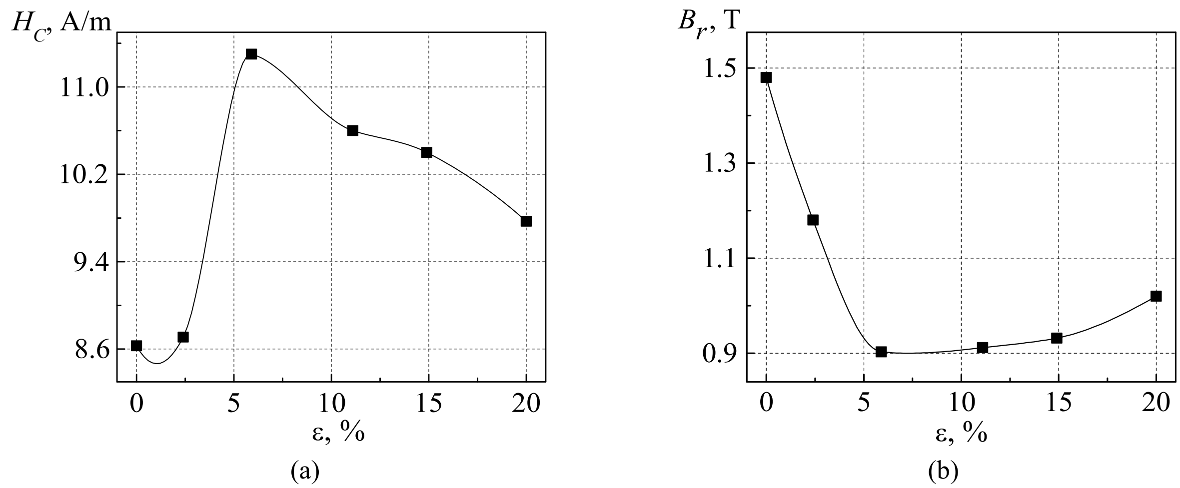

FIGURE 1. Dependences of coercive force (a) and residual magnetic induction (b) on the degree of deformation of the 30CrMnSiA steel

Figure 2 shows that the longitudinal ultrasonic wave velocity decreases with an increase in the degree of plastic deformation above 10%. As a result of rolling, along with the accumulation of residual stresses, the structure of the material and the distortion of the crystal lattice caused by structural transformations also changes. Therefore, the speed of propagation of longitudinal acoustic waves is influenced by far more than one factor, and one cannot expect a linear dependence of the velocity of longitudinal ultrasonic waves on deformation. In addition, as already described, owing to flat pressing, steel plates acquire a complex stress-strain state due to uneven stress relaxation in different parts of the plates. The absence of an explicit change in the speed of longitudinal ultrasonic vibrations in the range of deformations of up to 5% requires further explanation. The change in the velocity of longitudinal ultrasonic waves was 0.8% at deformation degrees from 10 to 20%.

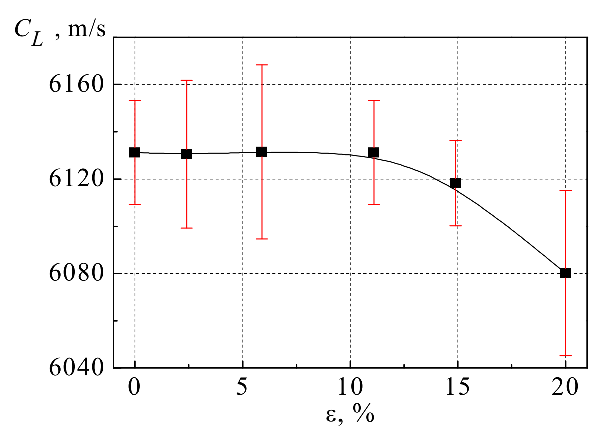

FIGURE 2. The velocity of longitudinal ultrasonic waves vs. the degree of deformation of the 30CrMnSiA steel

Figure 3 shows that the velocities of transversal and Rayleigh ultrasonic waves increase with the growth of plastic deformation degree over the entire range of plastic deformations of the alloyed steel. An increase in the propagation velocity of transverse and Rayleigh waves with the increasing deformation of the 30CrMnSiA steel can be explained by the action of tensile stresses resulting from the rolling of steel samples. Since a direct piezoelectric transverse-wave transducer was used to excite transverse ultrasonic waves, ultrasonic oscillations propagated along the rolling direction during the measurements. The Rayleigh wave velocity was calculated according to Eq. (1). The changes in the velocity of transversal and Rayleigh ultrasonic waves amount to 2.5% and 2.2% respectively, which makes the velocity of transversal waves the most applicable parameter for testing the degree of steel deformation.

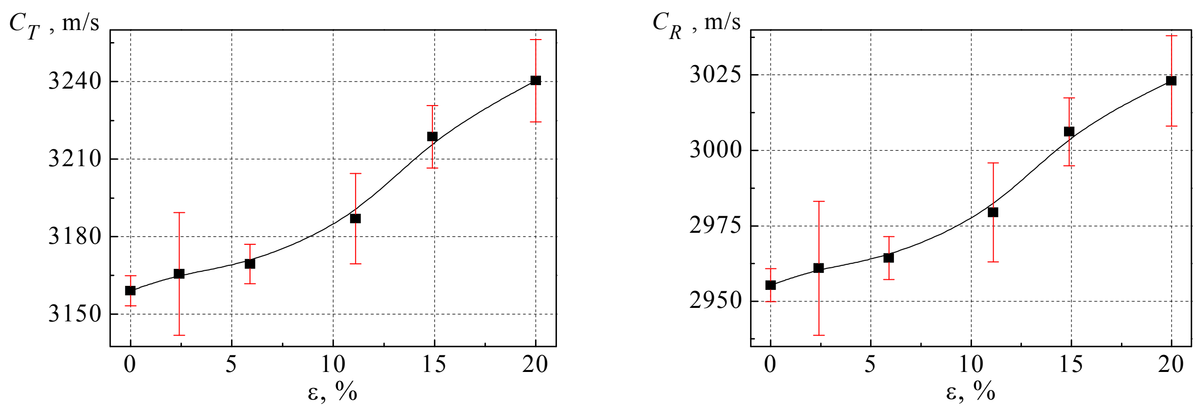

FIGURE 3. The velocity of transversal (a) and Rayleigh (b) ultrasonic waves vs. the degree of deformation of the 30CrMnSiA steel

CONCLUSION

The dependences of coercive force and residual magnetic induction of the cold-rolled and flat-pressed 30CrMnSiA steel on the degree of deformation are nonmonotonic. The decrease in the coercive force with the increase of deformation degree can be related to the relaxation of stresses of the first kind in steel plates as a result of flat pressing after rolling. It has been established that the speed of transversal ultrasonic vibrations is the most informative and easy-to-measure acoustic parameter in assessing the degree of deformation of the 30CrMnSiA steel.

ACKNOWLEDGMENTS

The research was carried out within the project 18-10-2-8 of the Complex program of UrB of RAS (state registration No. AAAA-A18-118020690199-4).

REFERENCES

1. V. N. Kostin, O. N. Vasilenko, D. Yu Filatenkov, Yu. A. Chekasina, and E. D. Serbin, Russ. J. Nondestr. Test. **51**, 624–632 (2015).
2. K. V. Kostin, Ya. G. Smorodinskii, T. P. Tsarkova, V. M. Somova, and E. Yu. Sazhina, Russ. J. Nondestr. Test. **47**, 89–95 (2011).
3. V. F. Muzhitskii, M. Kh. Sultanov, R. V. Zagidulin, and P. S. Makarov, Test. Diagn. **8**, 17–22 (2006).
4. V. N. Kostin, M. A. Gur'ev, O. N. Vasilenko, D. Yu. Filatenkov, and Ya. G. Smorodinskii, Phys. Mesomech. **16**, 103–110 (2013).
5. V. N. Kostin, D. Yu. Filatenkov, Yu. A. Chekasina, O. N. Vasilenko, and E. D. Serbin, Acoust. Phys. **63**, 237–246 (2017).
6. V. N. Kostin, V. I. Pudov, E. D. Serbin, and O. N. Vasilenko, Def. Fract. Mater. **2**, 41–46 (2017).
7. V. V. Muraviev, L. B. Zuev, and K. L. Komarov, *The Ultrasound Velocity and Structure of Steels and Alloys,* edited by L. I. Tushinsky (Nauka, Novosibirsk, 1996).
8. M. N. Mikheev and E. S. Gorkunov, *Magnetic Methods of Structural Analysis and Nondestructive Testing,* edited by V. E. Shcherbinin (Nauka, Moscow, 1993).