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QUALITY CONTROL OF INTERCRITICALLY ANNEALED DUAL PHASE STEEL PARTS BY BARKHAUSEN SIGNALS NON-DESTRUCTIVE METHOD

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Abstract

Dual phase steels (DPS) have a composite type microstructure and they take advantages of combination of the hard second phase (martensite) and the ductile matrix (ferrite). This combination could enhance the strength and ductility. In this regard, martensite phase play a decisive role in determination of DPS properties and phase percentage of it is a key factor for quality control of heat treated parts. In order to determination of martensite percentage, present study uses Barkhausen signals, nondestructively. Comparison of test results showed a very good agreement between the metallographic observation and Barkhausen study. In general, an increase in the percentage of martensite results in the decrease in domain wall motion and, therefore, magnetic Barkhausen signals increase. Therefore, results showed the potential of this NDT method to separate the good heat treated samples and the bad ones.

Keywords: Barkhausen signal, Dual phase steel, Intercritical annealing heat treatment, Martensite phase percentage, Non-destructive testing

1. Introduction

Among various non-destructive methods, magnetic Barkhausen technique has received increasing attention in determining the metallurgical and mechanical properties of materials.

The Barkhausen effect refers to abrupt changes in the orientation and size of magnetic domains that occur when an alternative magnetic field is applied to a ferromagnetic material. If a pick-up coil is brought near a sample while a domain wall moves, an electrical pulse (Barkhausen signal) is produced in the coil due to the resulting change in magnetization. Domain wall motion is affected by many factors like microstructure, grain boundaries, inclusions, etc [1, 2].

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Many of the researchers have been used magnetic Barkhausen technique as a non-destructive tool for metallurgical inspections. Study of L. Clapham et al. [1] showed the significant effect of different pearlite content of plain carbon steels on Barkhausen noise generation. Their studies showed that the magnetic responses of steels are very different for ferritic, pearlitic and the samples containing both ferrite and pearlite. V. Augutis et al. [3] showed that using Barkhausen study is possible to determine the depth of hardened surface layer at accuracy of 0.01 mm. M. Blaow et al. [4] investigated the effect of decarburization of the surface layer on magnetic Barkhausen signals. Different magnetic responses of the martensitic core and the decarburized layer introduce various Barkhausen peak values and it can be used as a tool for determination of decarburized depth.

In the present study, Barkhausen signal was used for quality control of intercritically annealed dual phase steels. Dual phase steels (DPS) have a composite type microstructure consisting of a hard second phase (martensite) dispersed throughout the ductile matrix (ferrite) [5, 6]. This combination could enhance the strength and ductility [7]. This composite type microstructure can be achieved industrially in all low-carbon steels by thermo-mechanical rolling or heat treating in austenite-ferrite region followed by rapid cooling [5].

Intercritical heat treatment is the conventional way to produce DPS which was used in this investigation. An increase in the intercritical annealing temperature results in an increase in the martensite phase percentage. Therefore, determination of martensite phase percentage is a key factor for quality control of heat treated DPS parts.

In this study Low-carbon steel (0.08wt%C) was used and different dual phase steels with different martensite phase percentages were manufactured using various intercritical annealing temperatures. There are two methods for measuring the percentage of martensite phase in the DPS. First method is metallographic observation by optical microscope which is destructive, expensive and also time consuming. The second method that is used here uses Barkhausen signals, nondestructively.

The aim of the present study is to compare the two obtained test results and to introduce a suitable system for non-destructive quality control of any heat treated unknown DPS sample.

2. Experimental procedure

The starting material with an initial microstructure of ferrite and pearlite was provided in the form of cold rolled low carbon steel of 1.3mm thickness. The chemical composition (wt%) of investigated steel is shown in Table 1. Rolling bands of previous treatment were observed in metallographic examination of the as-received material. In order to prevent this anisotropy, steel plates normalized in γ region for achieving normalized steels at 950˚C for 20 min.

Table 1- Chemical composition of steel used in this study

Element	C	Mn	Si	P	Ni	Cr	Cu	Fe
Wt.%	0.08	0.41	0.502	0.091	0.232	0.389	0.324	Rem.

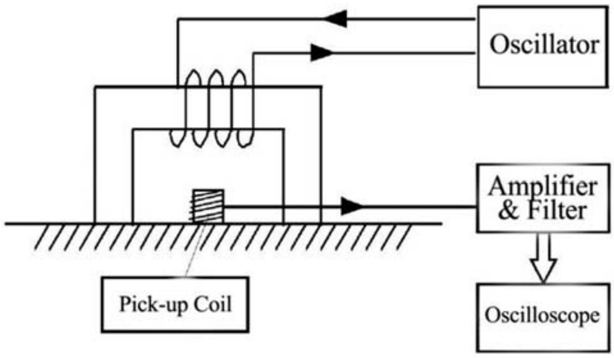

Figure 1- Schematic picture of the Barkhausen device made in the authors' laboratory

For preventing existence of decarburized layer in the heat treated specimens, carbonstop material was used. Then sheets were held in the various intercritical annealing temperatures (745, 765, 782, 802, 810, 820, 832 and 890˚C for 5 min) in order to production of dual phase steels with different volume fraction of martensite phase and then all specimens were quenched in brine solution. Also, one series of specimens were quenched from 950˚C in brine solution.

Metallographic samples were prepared from heat treated specimens and polished surface of them were etched in a solution obtained by dissolving 10g sodium metabisulfite in 100mL distilled water and finally, martensite percentages were measured by CLEMEX image analyzer.

For Barkhausen study, the sheet specimens were prepared with a dimension of 200 mm × 20 mm. Finally, Barkhausen studies were performed on the DPS samples. The Barkhausen signals measurements were carried out using a device made in the authors' laboratory interfaced to a computer for data acquisition. Schematic picture of the used device was shown in Fig. 1. As can be seen in the Fig. 1, design of pick-up coil and excitation coil was conducted with respect to the samples shape. The excitation magnetic field is generated using an excitation coil (500 turns of 0.35 mm insulated copper wire) wound around a U-shaped Fe–Si core. Barkhausen signals were detected by a pick-up coil with 300 turns of 0.13 mm insulated copper wire wound around a ferritic cylinder. The output voltage of pick-up coil is amplified by an amplifier to approximately 10,000 times.

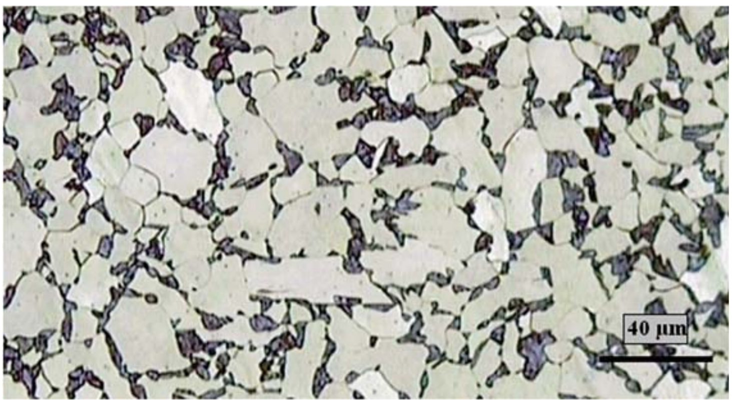

Figure 2- Dual phase microstructure of specimen intercritically annealed at 782˚C with 28% of martensite

Table 2- Variation of martensite in DPS as a function of intercritical annealing temperature

Specimen Name	D-15	D-23	D-28	D-35	D-37	D-40	D-45	D-89	Q-100
Heat Treatment Temperature (°C)	745	765	782	802	810	820	832	890	950
Martensite Percentage	15	23	28	35	37	40	45	89	100

3. Results and discussion

Intercritical annealing heat treatment (heating to the α + γ region) transforms the primary microstructure containing of ferrite and pearlite into dual phase composite type microstructure.

Figure 2 shows the dual phase microstructure of the sample developed by intercritical annealing heat treatment for 5 min at 782 °C, and then quenched in a mixture of ice and brine for obtaining 28% of martensite phase. As can be seen in the Fig. 2, heat treatment of the sample directly to the intercritical temperature results in the dispersion of a hard second phase of martensite throughout the ductile matrix of ferrite (dark areas indicate the martensite phase and ferrite phase are illustrated with white color).

Due to the primary normalization heat treatment in γ region, there is no anisotropy in all dual phase steel specimens and they did not exhibit any sign of banding. As an example can be seen in the Fig. 2, martensite islands have a globular morphology that are finely dispersed.

In the present work, different dual phase steels were produced with various intercritical annealing temperatures. Table 2 shows the variation of the martensite volume fraction by intercritical heat treatment temperature. As expected, an increase in the intercritical annealing temperature results in an increase in the martensite phase percentage. This is due to the larger amount of austenite phase formed at higher temperatures which is consistent with the lever rule [8] in the ferrite-austenite region. According to the lever rule, an increase in the intercritical annealing temperature increases the amount of austenite which transforms into martensite on rapid quenching.

The Barkhausen effect refers to abrupt changes in the orientation and size of magnetic domains that occur when an alternative magnetic field is applied to a ferromagnetic material. If a pick-up coil (surface type was used in this study) is brought near a sample while a domain wall moves, an electrical pulse of Barkhausen is produced in the coil due to the resulting change in magnetization. In the present work, domain wall motion is affected by microstructure changes due to the various amount of martensite.

In order to Barkhausen signal measurement and processing, an experimental device which it is made in the authors' laboratory was used (see Fig 1). Non-destructive testing was performed on the DPS samples with a variety of frequencies and the optimum frequency was determined by regression analysis. Frequency of 8 Hz was chosen as the optimum frequency due to appropriate resolution between the outputs and accuracy.

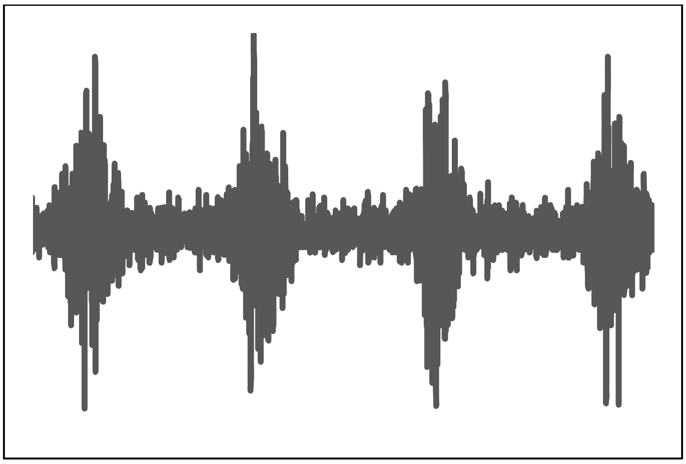

Figure 3- Barkhausen signals

In order to analyze the Barkhausen signals (Fig. 3), the obtained data were processed by the Origin Pro 8 software. Using this software makes it possible to plot the best diagram through the obtained voltage signals and it can calculate the peak intensity of the signal and its position, carefully.

Figure 4 shows the plot of peak intensity versus martensite percentage. As can be seen in this figure, the values of the peak intensity increase with the increase in the martensite phase percentages. It is due to the decrease in domain wall motion by increasing the martensite phase and, therefore, Barkhausen signals increase. Martensitic structure has high internal strain (due to the BCT crystal structure) and also, austenite to martensite transformation introduces many dislocations. Due to these two factors a strong magnetic field is required for the reversal of magnetization because of low domain wall motion and difficulty in creating domain walls which leads to the corresponding increase in the induced voltage and peak intensity consequently.

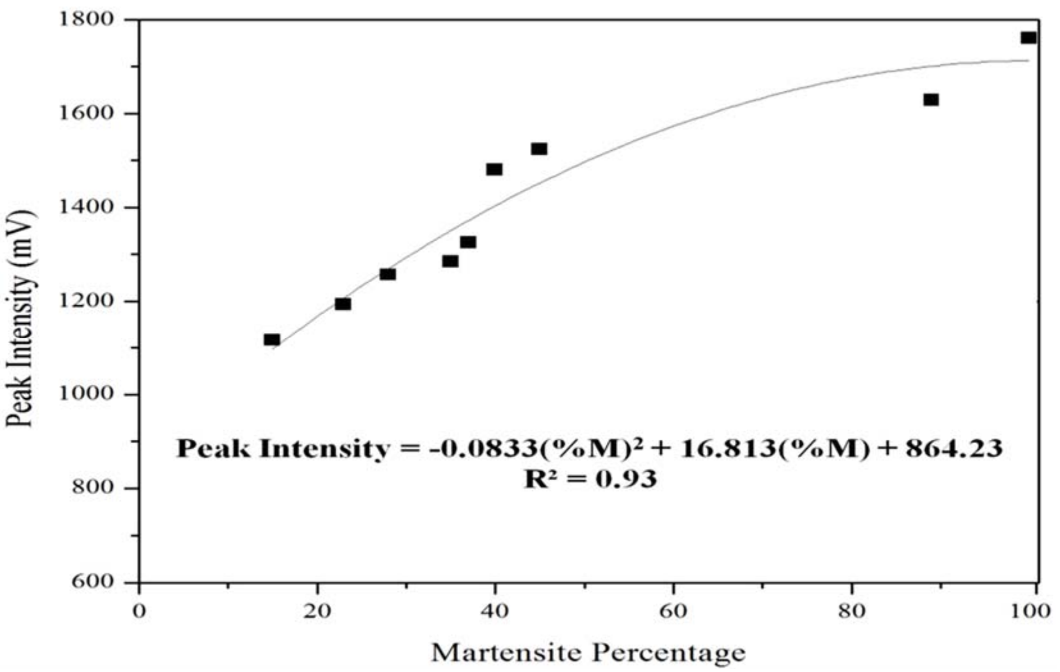

Figure 4- plot of peak intensity versus martensite percentage

In Fig. 4, the relation between the peak intensity and martensite percentage is shown by a mathematical equation and a correlation coefficient. For the obtained equation, the amount of correlation coefficient is very high (R^2=0.93) and this higher accuracy can help to separate the good heat treated samples and the bad ones based on the martensite percentage, carefully. For prediction of martensite percentage with a good accuracy, it is only necessary to non-destructive evaluate of unknown sample by Barkhausen device and put the obtained peak intensity into the equation.

Two important advantages of the automatic calibration method used here (Barkhausen study) are the high calibration velocity (needs about one minute) and the short measuring time (determination of one characteristic value for material properties can be realized in less than 2 seconds). Therefore the presented measuring system is suitable for employment in an online inspection system in a production line of DPS for non-destructive quality control of them.

4. Conclusion

This study examined the potential of Barkhausen signals non-destructive method for quality control of intercritically annealed dual phase steel parts based on their martensite percentage. Comparison of test results showed a very good agreement between the metallographic observation and Barkhausen study. In general, an increase in the percentage of martensite results in the decrease in domain wall motion and, therefore, magnetic signals increase. Therefore the presented automatic calibration method is suitable for employment in an online inspection system in a production line for non-destructive quality control of any heat treated unknown DPS sample.

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