THE PUBLISHING HOUSE
OF THE ROMANIAN ACADEMY

PROCEEDINGS OF THE ROMANIAN ACADEMY, Series A,
Volume 10, Number 1/2009, pp. 000–000

THE EFFECT OF HEAT TREATMENTS ON PHYSICAL PROPERTIES OF A LOW CARBON STEEL

S. K. AKAY*, M. YAZICI**, A. AVINC*

*Department of Physics, Faculty of Sciences and Arts, Uludag University, TR 16059 Bursa, Turkey
** Vocational School of Technical Sciences, Uludag University, TR 16059 Bursa, Turkey
Corresponding author: kakay@uludag.edu.tr

Steel contains 0.055%C was intermediately annealed at 780, 825 and 870^{0}C for 60 minutes followed by water quenching to obtain different microstructures. The effect of heat treatment on the microstructure, crystal structure and electric resistivity of heat treated steels were investigated. It was found that the resulting microstructures had ferrite-plus-martensite known as dual phase steels. The volume fraction of martensite increased with growing annealed temperatures. X-ray diffraction analysis showed that dual phase steel microstructures had body cubic tetragonal martensite crystal structures. The individual diffracting planes of body cubic tetragonal martensite were found as (110), (200) and (211). The lowest resistivity (about 8.48 x10^{-8} Ω.m) was obtained for the dual phase steel samples heat treated at 780^{o}C. Scanning electron microscopy studies were also discussed for dual phase steel microstructures.

Key words: Heat treatment; dual phase steel; microstructure; crystal structure; resistivity.

1. INTRODUCTION

New classes of the high-strength low alloy (HSLA) steels known as dual phase steels (DPS) are developed to improve safety standards and fuel economy. DPS microstructures are produced by intermediate annealing steels in the ($\alpha + \gamma$) region of the equilibrium phase diagram. These steel microstructures consist of a ferrite matrix with particle of martensite [1-2]. Depending on the steel chemistry and processing parameters, lower bainite, pearlite may form and some untransformed austenite may be retained in the microstructure [35-5]. To transform from austenite to martensite, quenching from the intermediate temperatures must be sufficiently rapid.

Physical properties of DPS are dependent on the morphology of the two phases. These are determined by changing the annealing temperature and time, the annealing procedure, alloying elements and the quenching media. Electrical resistivity is one of the most characteristic physical properties of materials and is dependent on temperature and on crystal defects, such as solute atoms, dislocations and void and very fine discontinuity. Berrahmoune et al. [7] investigated crystal structures and lattice parameters of DPS microstructures by using X-ray diffraction (XRD) analysis.

This article discusses the effect of heat treatment followed by quenching on the physical properties of the Fe-0.055%C steels.

2. EXPERIMENTAL PROCEDURES

2.1 Materials and heat treatments

The steels used in this study were taken as 2.5 mm thick plain carbon steel. The chemical composition of the material is shown in Table 1.

Table 1. The chemical composition of a studied material (wt. %).

C	Mn	Si	P	Al	Fe
0.055	0.272	0.016	0.005	0.034	Balance

All specimens firstly, were normalized at 910^{o}C hold for 45 minute and air cooled. A group of these specimens are retained and designated as steel As-received. Secondly, intermediate heat treatment (IHT) process has been applied to As-received specimens to obtain different microstructures. In this process, As-received specimens have been annealed at 940^{o}C in the region of austenite (γ) hold for 45 minute and followed by water quenching to form a complete martensite phase. Then, these specimens were heat treated at the temperatures of 780 and 825 and 870^{o}C for 1 hour and water quenched to produce dual phase steel (DPS) in the region (α+γ). The detailed heat treatment scheme is shown in Figure 1.

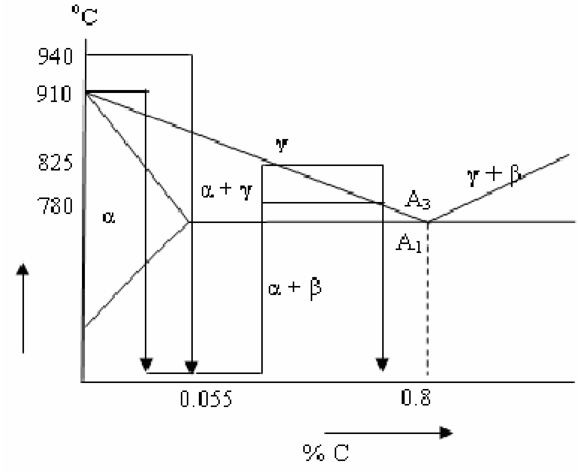

Figure 1. Schematic heat-treatment diagram:
As-received and intermediate quenching processes.
α: Ferrite, β : Cementite, γ: Austenite.

2.2 Metallographic studies

After heat treatments, cross-sections of the samples were polished, etched with 5% nital and observed by scanning electron microscopy (SEM) to reveal the morphology of the phases.

2.3 Physical testing

The surface hardness test was measured by Matsuzawa DXT3 Rockwell test device according to the ISO standards. After different heat treatments, electric resistivity (ER) and XRD measurements of DPS microstructures were investigated. For ER measurements, samples in every heat treated condition were measured by using Jandel Four Point Universal Probe. Nevertheless, after heat treatment crystal structures and the plain orientations were analyzed by Rigaku D-Max. Rint 2200 Series X Ray Diffractometer.

3. RESULT AND DISCUSSION

3.1 Optical Metallography

The microstructures of DPS materials produced by different heat treatments are illustrated in Figure 2a-2b. DPS microstructures compose of martensite (light area) distributed in the ferrite (dark area) matrix. The ferrite phase did not experience any structural change after quenching from the austenite plus ferrite region. The volume fraction (V_m) of martensite increased with growing temperatures. A similar result observed by Bayram et al.[6].

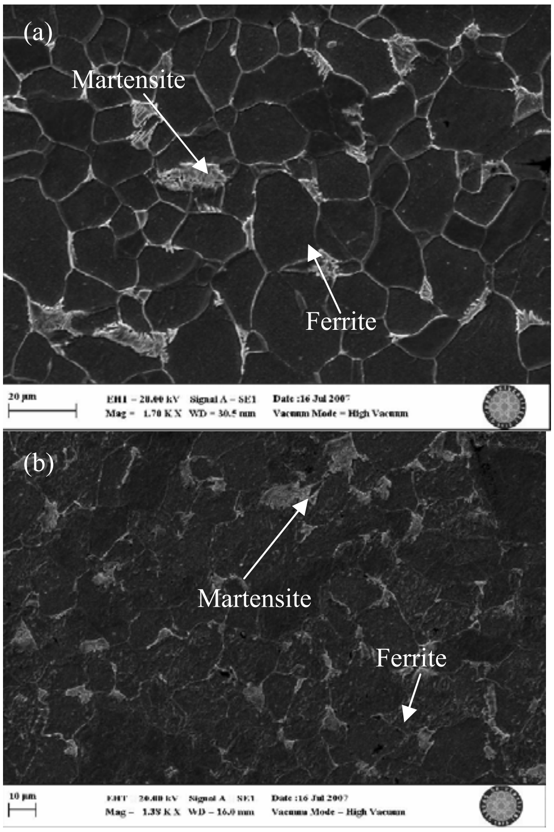

Figure.2. Optical micrographs of the microstructures of:
a) DPS-780^0, b) DPS-825^{0}C.

3.2 Physical Measurements of DPS Structures

Table 2 shows surface hardness and martensite contents (MC) of the DPS structures. It can be seen that surface hardness of DPSs increased with growing heat treatment temperatures. This is related to the MC of the DPS samples. When the heat treatment temperatures are up, surface hardness values of DPS increase.

Table 2. Surface and martensite contents of DPS structures.

Grades	**Thickness [10^{-3} m]**	**Hardness [HRB]**	**MC V_m[%]**
DPS-780^{0}C	2.5	77	9.45
DPS-825^{0}C	2.5	80	11.35
DPS-870^{0}C	2.5	83	13.55

$$\rho = \frac{2\pi D}{3} \frac{V}{I} \tag{1}$$

where D is the distance of the probes as 1.2 mm, I is the applied current and V is voltage. The electric resistivity was recorded by calculating the average values of five measurements for each specimen [8].

Figure 3 illustrates the heat treatments vs. resistivity ρ of DPS microstructures. It is shown in Figure 3 that the resistivity value of DPS-870^{0}C is higher than DPS-780^{0}C and DPS-825^{0}C. This variant is the result of martensite content of the microstructures and retained austenite, respectively. Because when the heat treated microstructures were quenched, crystal structures of materials transformed from face cubic center (fcc) to bct. This transformation causes solute atoms, dislocations, void and very fine discontinuity of the final microstructures. However, as there is a low current passing through on the surface resistivity values of the microstructures increase.

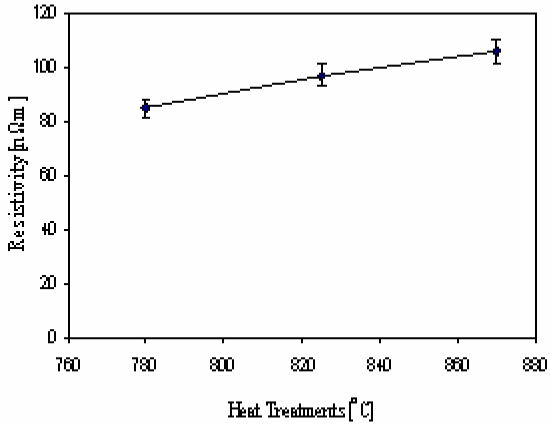

Figure 3. ER measurements of DPS microstructures after different heat treatment temperatures.

Figure 4 shows typical XRD patterns of DPS measured by XRD phase analysis, using Cu K_α radiation at room temperature. The measuring accuracy of DPS by this method is about 5%. A step for 2θ is taken from 40^0 to 90^0.

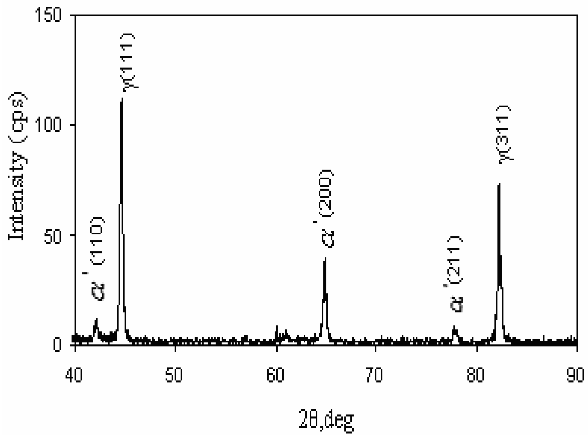

Figure 4. XRD scan using Cu Kα radiation of DPS microstructures, α' : Martensite phase, γ: Retained austenite phases.

The individual diffracting planes from the face cubic center (fcc) austenite and body cubic tetragonal (bct) martensite can be clearly identified and labeled in the figure 4. The presence of (110), (200) and (211) planes are clearly revealed and indicate the formation of α'- martensite phase during deformation. Additionally, the (111) and (311) planes are present characterizing the γ-retained austenite. Similar experimental results were found by the other investigator [7] but this investigation shows that retained austenite is dominant in respect of final microstructures.

4. CONCLUSIONS

On the fundamental of the experimental study that has been carried out and presented in this paper, the following conclusions can be drawn.

Intermediate annealing of low-carbon steels yielded a material with a ferrite-plus-martensite grain structure. The volume fraction of martensite (V_m) increased with intermediate temperatures time.

XRD analysis demonstrated that there was a larger amount of γ-retained austenite forms compared to that of α' -martensite in DPS microstructure.

It was found that ER properties increased with growing heat treatment temperatures. It is related to the deformation of the crystal structures by heat transfer to the microstructures.

ACKNOWLEDGEMENT

The authors would like to thank the Scientific Research Projects Fund of University of Uludag (Research Contact No: 2004/54 and 2005/4) for financial support.

REFERENCES

1. YAZICI, M., DURMUS, A., BAYRAM, A., *Influence of Morphology of Martensite on Tensile and Strain Hardening Properties of Dual Phase Steels*, Materialprüfung, **45 5,** pp. 214-219, 2003.
2. MALEQUE, MA., POON, YM., MASJUKI, HH., *The effect of intercritical heat treatment on the mechanical properties of AISI 3115 steel,* Journal of Materials Processing Technology, **153-154**, pp.482-487,2004.
3. ALP, T., WAZZAN, A., *The influence of microstructure on the tensile and fatigue behaviour of SAE 6150 Steel*, Journal of Materials Engineering and Performance, **11-4,** pp. 351-359, 2002.
4. DAVIES RG., *Influence of Martensite Composition and Content on the Properties of Dual Phase Steels*, Metallurgical Transaction A, **9**, pp. 671-679, 1978.
5. TOMITA Y., *Effect of morphology of second-phase martensite on the tensile properties of Fe-0.1 C dual-phase steel*, Journal of Material Science, **25**, pp. 5179-5184, 1990.
6. BAYRAM, A., UGUZ, A., ULA, M., *Effect of microstructure and notches on the mechanical properties of dual-phase steels*, Material Characterization, **43**, pp. 259-269, 1999.
7. BERRAHMOUNE, MR., BERVEILLER S., INAL, K., MOULIN A., PATOOR, E., *Materials.* Science.& Engineering. A, **3 78** pp. 304-307, 2004.
8. DUNLAP, WC., *An Introduction to Semiconductors*, Moscow, Izdatelstvo Inostran Literature, p. 194, 1959.

Received June 17, 2008