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EFFECT OF MARTENSITE VOLUME FRACTION ON THE EROSIVE WEAR BEHAVIOUR OF DUAL-PHASE AISI 8620 STEEL

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ABSTRACT

The aim of this study is to investigate the effect of martensite volume fraction (MVF) on the erosive wear rate of dual-phase (DP) steels. For this experimental study, low carbon and low alloyed AISI 8620 steel was used. As received the cylindrical bars of this steel were homogenised and normalised before DP heat treatment. To determine the effect of MVF on the erosive wear rate 7 critical temperatures were selected between A_{C1} and A_{C3}. 2 mm thick disks of AISI 8620 were intercritically annealed at these 7 different temperatures for 20 min and they were quenched in a brine solution at –10 °C. MVFs of polished and etched specimens of DP AISI 8620 steel were explored by the help of an image analyse program : Image ProPlus ® 5.0. On the other hand, erosive wear tests were carried out at a constant impact angle of 90° and at a constant impact velocity of 30 m/s for time periods of 240 s. It was observed that erosive wear rate decreases by increasing intercritical annealing temperature (ICAT) and MVF.

Keywords: erosive wear, dual-phase steels, martensite volume fraction, intercritical annealing temperature, AISI 8620.

AIMS AND BACKGROUND

Dual-phase steels are new kinds of steels with two main phases in the microstructure that provide both high strength and good formability together. 'Dual-phase' term indicates phases known as ferrite and martensite[1,2].

* For correspondence.

Generally, ferrite in the dual-phase steel microstructure provides formability while martensite phase provides strength[2,3]. The main advantage of this new kind of steels is their better formability than other steels at the same strength[1]. In recent years dual-phase steels have wide use areas in the automotive industry where strength is important without effecting formability[2,4–6].

Dual-phase steels can be obtained from ferritic and pearlitic steels after simple and cheap heat treatment steps that are known as intercritical annealing and quenching[1,2,7]. During intercritical annealing step, pearlite transforms into austenite and by quenching step austenite transforms into martensite. After these two steps, a final microstructure which consists of ferrite and martensite is obtained[1,2].

As previously stated, martensite phase determines the properties of the dual-phase steel by providing strength. It can be said that generally mechanical properties of dual-phase steel generally depend on the volume fraction and mechanical properties of martensite[3,5].

And also, there is an important point that martensite volume fraction and morphology of the martensite phase can be controlled by parameters like intercritical annealing time, intercritical annealing temperature and cooling rate[1,8]. Because of these reasons, 'intercritical annealing step' is the most important step of dual-phase heat treatment. At a previous study it was observed that volume fraction of martensite increases with increasing intercritical heat treatment temperature[9].

On the other hand, erosive wear can be basically determined as the mass loss from a solid surface due to the continuous impact effect of solid particles[10]. Erosive wear rate of a material can be explained as a complex function of internal factors like target material properties (molecular structure, morphology and mechanical properties of the target material), and outer parameters like erodent particles, impact angle, impact velocity and temperature[11].

EXPERIMENTAL

Material and heat treatment procedure. For experimental procedure low carbon and low alloyed AISI 8620 steel was used and its chemical content is given in Table 1.

After homogenisation and normalisation steps 2 mm thick specimens were cut from cylindrical bars for dual-phase heat treatment. Critical temperatures

Table 1. Chemical content of the AISI 8620 steel

Material	C	Si	P	Mn	Ni	Cr	Mo	Fe	Hardness (HV)
%	0.25	0.267	0.001	0.9438	0.525	0.570	0.2092	97.2	149

for AISI 8620 steel were determined as 715 and 831°C by using the Andrews' basic formulas given in equations (1) and (2).

$$Ac_3 = 910 - 203\sqrt{C} - 15.2\,Ni + 44.7\,Si + 104\,V + 31.5\,Mo + 13.1\,W \quad (1)$$

$$Ac_1 = 723 - 10.7\,Mn - 16.9\,Ni + 29.1\,Si + 16.9\,Cr + 290\,As + 6.38\,W \quad (2)$$

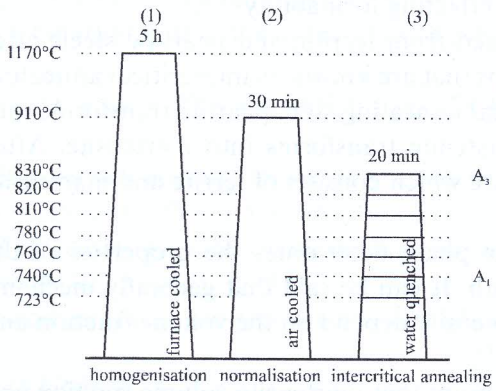

Fig. 1. Schematical view of heat treatment procedures

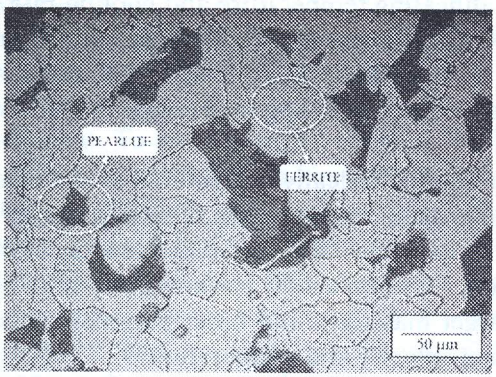

Fig. 2. Microstructure of homogenised AISI 8620

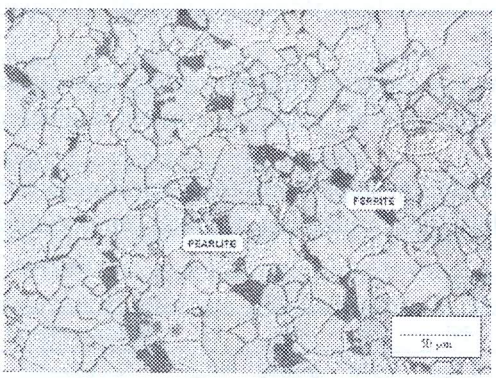

Fig. 3. Microstructure of normalised AISI 8620

To see the effect of intercritical annealing temperature (ICAT) on the martensite volume fraction (MVF) 7 different temperatures were selected (723, 740, 760, 780, 810, 820 and 830°C) between Ac_1 and Ac_3. AISI 8620 specimens were intercritically annealed at these selected temperatures for 20 min and they were quenched in a 10% brine solution at –10 °C. Specimens were coded with DP which refers to dual-phase microstructure and then ICAT. For example, the specimen DP 780 means dual-phase microstructure that was intercritically annealed at 780°C for 20 min and then rapid quenched.

Heat treatment procedures applied to the AISI 8620 steel can be completely seen in Fig. 1.

The microstructures of homogenised and normalised AISI 8620 are given in Figs 2 and 3, respectively.

For each ICAT, 2 specimens were annealed and quenched. One of the specimens was used for metallographic studies while the other was used for erosive wear tests.

Metallographic studies and determination of MVFs. After dual-phase heat treatment completed, all of the

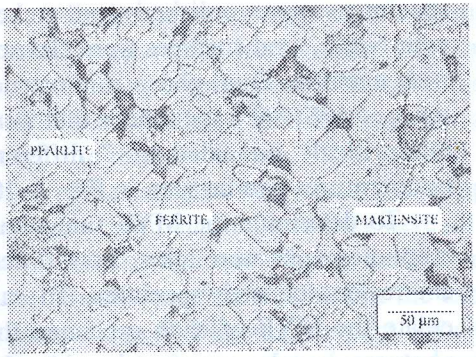

Fig. 4. Microstructure of the AISI 8620 intercritically annealed at 723°C

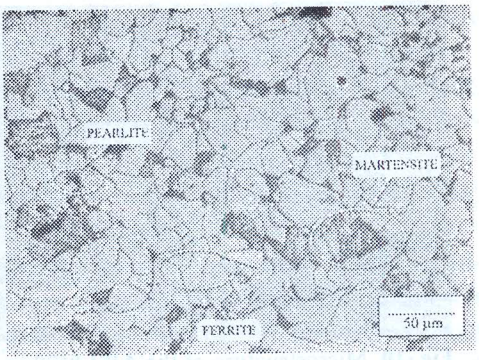

Fig. 5. Microstructure of the AISI 8620 intercritically annealed at 740°C

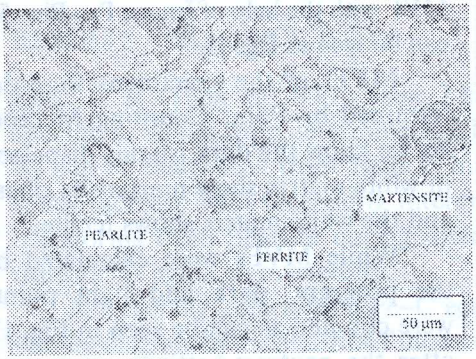

Fig. 6. Microstructure of the AISI 8620 intercritically annealed at 760°C

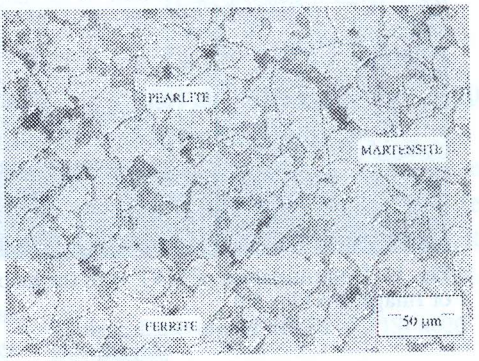

Fig. 7. Microstructure of the AISI 8620 intercritically annealed at 780°C

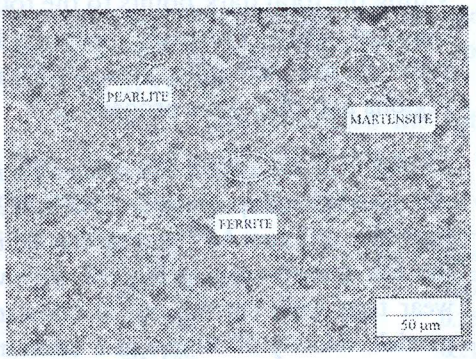

Fig. 8. Microstructure of the AISI 8620 intercritically annealed at 810°C

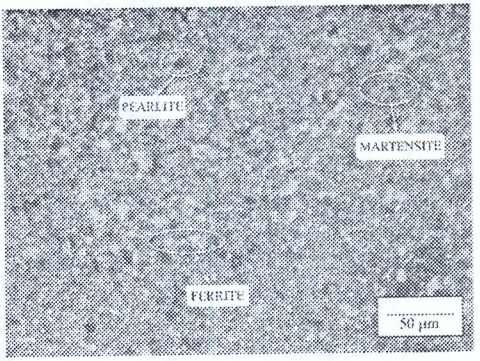

Fig. 9. Microstructure of the AISI 8620 intercritically annealed at 820°C

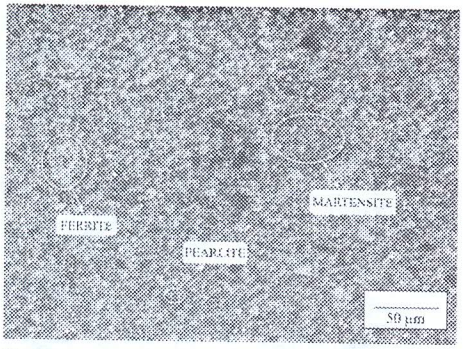

Fig. 10. Microstructure of the AISI 8620 intercritically annealed at 830°C

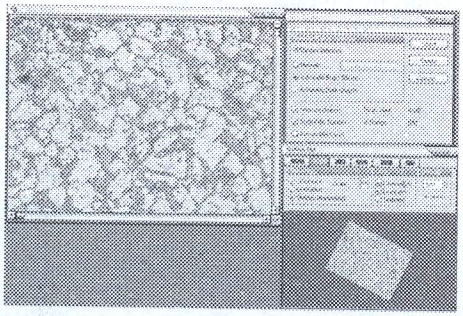

Fig. 11. Determination of MVF with the help of Image Pro Plus 5.0

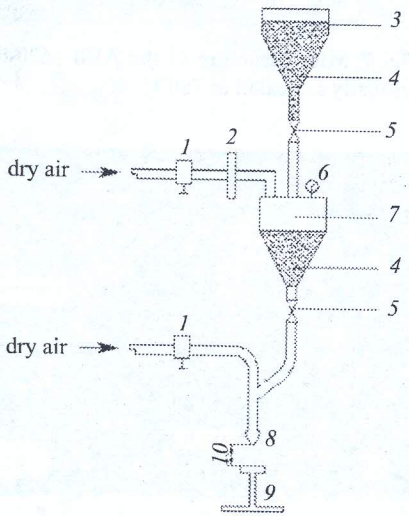

Fig. 12. Erosive wear test system
1 – pressure regulators, *2* – powder filter, *3* – mean reservoir, *4* – erodent particles, *5* – valves, *6* – manometer, *7* – pressured particle tank, *8* – nozzle, *9* – specimen holder

specimens were polished and etched with Nital 2 and surfaces were cleaned with acetone. Dual-phase microstructures of AISI 8620 specimens that were intercriticaly annealed at 7 different temperatures can be seen in Figs 4–10.

To determine the MVF values microphotographs were taken from different regions of each specimen. To calculate the MVF of each specimen the photographs taken were explored by the help of an image processing program: Image Pro Plus 5.0 ®. Determination of MVF with the help of Image Pro Plus 5.0 can be seen in Fig. 11.

MVFs of the specimens were determined by Point Counting Method. As we know the dark islands dispersed in white matrix show martensite phase and the white matrix shows ferrite.

While MVFs were calculated by the program, dark and light points were counted as can be seen in Fig. 11, after the contrast settings were completed, the counted values MVF of each specimen were determined by dividing the total dark points to the total counted points. For each specimen 15 photographs were taken from different regions and they were processed.

Erosive wear test system and erodent particles. Dual-phase specimens of AISI 8620 that have different MVFs were eroded in the test system seen in Fig. 12. Erosive wear tests were carried out at constant particle velocity of 30 m/s at a constant impact angle of 90° with exposure times of 240 s. Particle velocity was controlled by gas pressure regulators and it was measured by using double-disc method.

In the test system the nozzle diameter and the distance between the nozzle and the specimen were constant as 6 and 10 mm, respectively.

During erosive wear tests 420 μm sized G40 particles were used as erodent. G40 particles have 55 HRc hardness, a density of 7.2 g cm^{-3} and uniform martensitic microstructure.

After erosive wear tests, the samples were cleaned with low pressure air, washed with alcohol and they were all weighed to an accuracy of 10^{-5} g.

Generally erosive wear rate is determined as total mass loss divided by total erodent particle weight. For the exposure time of 240 s total erodent mass is weighed as 58.2 kg at an impact velocity of 30 m/s. All specimens were weighed before and after erosive wear tests and by the way total mass loss of each steel was determined. After then total mass losses were divided by total erodent mass to find out erosive wear rate.

RESULTS AND DISCUSSION

Effect of ICAT on the MVF. Table 2 shows the values of MVFs of AISI 8620 specimens which were determined with the help of Image Pro Plus ®.
As can be easily seen from Table 2, martensite volume fractions of dual-phase steels increase with increasing intercritical annealing temperature. Austenite transforms from pearlite during intercritical annealing and by quenching it transforms again to martensite.

As generally known from Fe–C equilibrium diagram by the time ICAT increases volume fraction of austenite increases. That is why the volume fraction of the martensite phase that transforms from austenite during rapid quenching increases as the intercritical annealing temperature (ICAT) goes from 723 to 830°C.

Table 2. Determined MVFs of AISI 8620 specimens

Specimen	ICAT (°C)	MVF (%)
DP 723	723	4
DP 740	740	9
DP 760	760	14
DP 780	780	21
DP 810	810	35
DP 820	820	46
DP 830	830	57

In Table 3 are presented the total mass loss and erosive wear rate values of

Table 3. Total mass loss and erosive wear rate values of dual-phase AISI 8620 specimens

Specimen	Total mass loss (g)	Erosive wear rate (mg/kg)
DP 723	0.271	4.66
DP 740	0.252	4.33
DP 760	0.218	3.74
DP 780	0.208	3.58
DP 810	0.173	2.98
DP 820	0.162	2.78
DP 830	0.127	2.19

Table 4. Change of hardness with ICAT

ICAT (°C)	Hardness (HV_{100})	Hardness of the martensite phase (HV_{100})
723	197	659
740	198	668
760	200	680
780	202	690
810	203	695
820	204	702
830	206	710

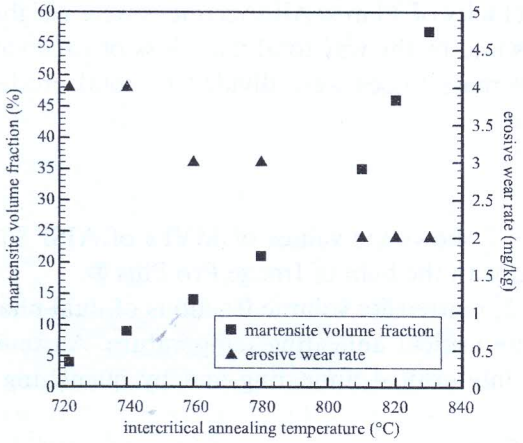

Fig. 13. Changes in MVF and erosive wear rate by intercritical annealing temperature

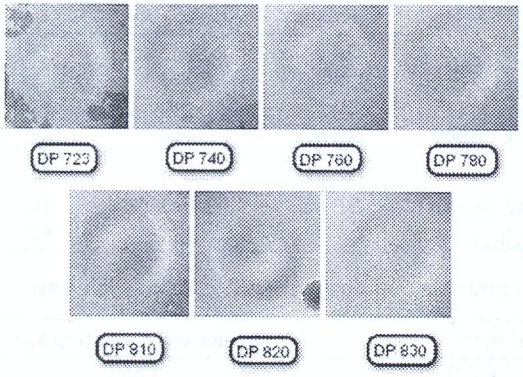

Fig. 14. View of surfaces after erosive wear tests

dual-phase AISI 8620 specimens. Erosive wear rate values were obtained by dividing total mass losses to 58.2 which is the total erodent mass blown from such a system (Fig. 12) for 240 s.

Figure 13 gives the changes in MVF and erosive wear rate by intercritical annealing temperature.

Total mass loss and erosive wear rate decreases as martensite volume fraction increases. That is mainly because of the increasing effect of martensite phase on hardness and strength of steels as can be seen from Table 4. It is also obvious from the Table that both hardness of the martensite phase increases by increasing ICAT.

Figure 14 gives the surface pictures of 7 different dual-phase steel after erosive wear tests.

CONCLUSIONS

The results derived from this study can be summarised as follows:

1. MVF of the dual-phase steels increases with increasing ICAT. As previously stated, austenite transforms from pearlite during intercritical annealing and this phase transforms again to martensite during quenching period. Ac-

cording to the Fe–C equilibrium diagram, volume fraction of austenite that transforms from pearlite increases as the intercritical temperature increases. This increase is the main reason of increasing MVF of dual-phase steels.

2. As the MVF increases the hardness of the dual-phase steel increases. That increase in hardness and strength causes a decrease in erosive wear rate of dual-phase AISI 8620 steel. The specimens which were intercritically annealed at 830°C and have a MVF of 57% have the smallest erosive wear ratios, and also they are the hardest specimens of all.

3. Dual-phase heat treatment may be offered as a surface treatment to provide a better erosive wear resistance than as-received steels. Erosive wear properties of cheap high strength low alloyed (HSLA) steels can be improved by simple and cheap dual-phase heat treatments.

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