AMSE JOURNALS-AMSE IIETA publication-2017-Series: Modelling B; Vol. 86; N°3; pp 582-592
Submitted May 23, 2017; Revised Jan. 04, 2018; Accepted Jan. 08, 2018

Influence of the Heat Treatments on Martensite Microstructure and Abrasive Wear Behavior of X52 Dual-phase Steel

*Sami Zidelmel, *Omar Allaoui, *Omar Laidi, **Ahmed Benchatti

* Laboratoire Génie de Procèdes, Université de Laghouat,
Algeria, B.P. 37G 03000
(s.zidelmel@lagh-univ.dz, o.allaoui@lagh-univ.dz, o.laidi@lagh-univ.dz)
** Laboratoire de Mécanique, Université de Laghouat,
Alegria, B.P. 37G 03000.
(a.benchatti@lagh-univ.dz)

Abstract

In this study abrasive wear behaviour of X52 dual phase steel with two different microstructures have been examined. Intermediate quenching (IQ) and step quenching (SQ) heat treatments have been applied at Intercritical heat treatment temperatures of 760°C and 800 °C in order to obtain different content and morphologies of martensite. Abrasive wear tests were performed under atmospheric conditions of 25°C using a pin-on-disk apparatus under different normal loads of 1, 2 and 3 kg and sliding speed of 3 m/min at a constant sliding distance of 200 m. The experimental results show that the (IQ) heat treatment with finely dispersed microstructures has higher wear resistance than (SQ) heat treatment with banded microstructures. In order to understand the wear mechanism, wear tracks were examined under scanning electron microscopes.

Key words

Intercritical annealing treatment, Dual-phase steel, Abrasive wear resistance.

1. Introduction

Dual phase (DP) steels are characterized by a composite microstructure consisting of hard martensite phase dispersed in a soft and ductile ferrite matrix. (DP) steels are an excellent

candidate for applications where low yield strength, high tensile strength, continuous yielding, and good uniform elongation are required [1-4]. Therefore, (DP) steel is an attractive engineering material not only for vehicle manufacturing but also for other wear resistant engineering application. It is well known that the mechanical properties of High Strength Low Alloy steels are largely determined by their microstructures. In ferrite–martensite (DP) steels, the morphology of martensite had a significant impact on the mechanical properties of (DP) steels [5, 6]. (DP) steels with fine and fibrous martensite distributing uniformly in the ferrite matrix provided the best combination of strength and ductility compared with those that had blocky ferrite–martensite [7]. Some work has been carried out to understand the influence of changes in the microstructure of low carbon steels on the wear behaviour of steel. [8-10]. Many experimental studies have shown that the wear behaviours of (DP) steel depend on various microstructure factors such as volume fraction, morphology (shape, size), spatial distribution and the carbon content of the martensite phase. Modi [9] has shown that the wear resistance of (DP) steel is greatly influenced by the microstructure and test conditions. It has been indicated that the wear resistance of dual phase steels increases with increasing volume fraction of martensite [8, 11]. Martensite volume fraction and morphology can be controlled by heat treatment temperatures and the initial microstructure of the steel before intercritical annealing [11, 12]. Tyagi et al. [8] have found that the microstructure of the (DP) steel offers higher wear resistance than that observed in normalized steel. In view of the above, the present investigation was aimed at studying the influence of variation in morphologies and content of martensite via heat treatments on the abrasive wear properties of an X52 Dual Phase steel at various loads and sliding speed. The study could help to decide appropriate heat treatment schedules to generate desired combinations of microstructure, thereby leading to superior abrasive wear properties.

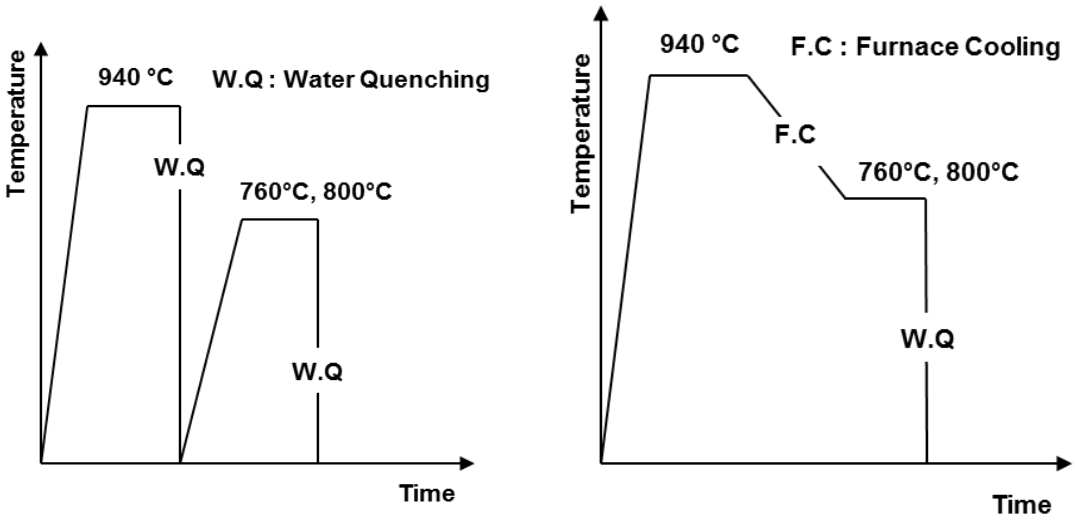
2. Experimental Procedure

The chemical composition of the X52 DP steel used in this investigation is shown in Table 1. The steel was supplied by pipegaz society Ghardaia, Algeria. Impurity levels are very low, especially with regard to the sulphur content.

Table 1. Chemical Composition of X52 Steel (wt %)

Elements	C	Mn	Si	S	Nb	V	Ti	Al
X 52	0.12	1.22	0.23	0.001	0.03	0.03	0.003	0.034

To obtain Dual Phase (DP) steels with various morphologies, two kinds of heat treatments were used as shown in (Figure 1). The (IQ) treatment consisted of double heat treatments: the specimens were first soaked at 940 °C for 30 min and water cooled, held at an Intercritical Annealing Temperature (IAT) of 760 °C and 800 °C for 30 min and water quenched. In the (SQ) treatment, the specimens were first soaked at 940 °C for 30 min, furnace cooled to the (IAT) of 760 °C and 800 °C, held for 30 min, and water quenched. Specimens were cut from different treatments and mounted for metallographic examination. Standard grinding and polishing techniques were employed, and specimens were etched with 3 pct nital solution. Conventional light microscopy was used to make a comparative examination of the overall microstructure of the X52 dual phase steel. The volume fractions of ferrite and martensite were calculated using a manual point-counting technique (according to ASTM E562).



(a) IQ heat treatment (b) SQ heat treatment

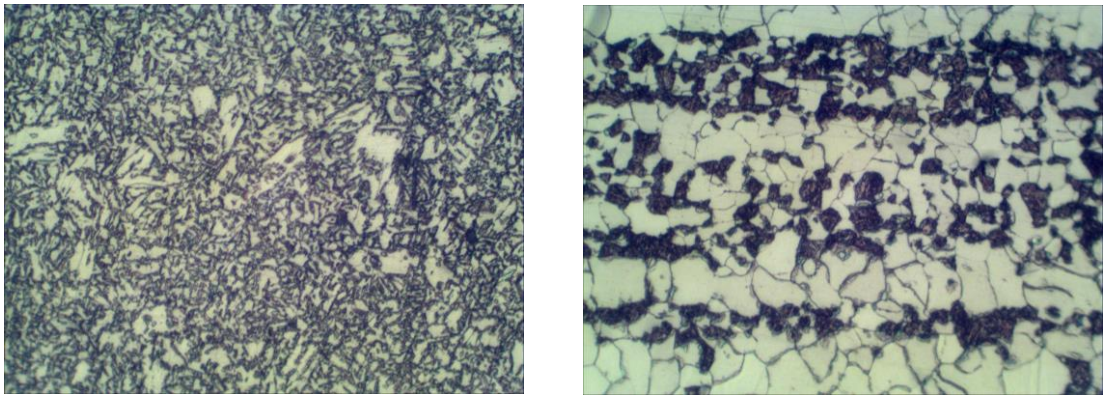
Fig.1. Schematic representation of heat treatment schedules

The abrasive wear tests of the X52 dual phase steel was performed on metallographically polished rectangular specimens (size: 15x15x10mm) using the pin-on-disk machine (model TQuipment Type TE91). The abrasive (SiC) particles embedded on emery paper were fixed on a 100 mm diameter and 8 mm thick aluminium wheel. The samples were tested at different normal loads of 1, 2 and 3 Kg and at fixed sliding speed of 3 m/min and at a fixed sliding distance of 200 m. Weight loss measurements were made using an Ohaus microbalance with 0.01 mg sensitiveness. The worn surfaces of the specimens were examined under TESCAN VEGA 3 scanning electron microscope (SEM).

3. Results and Discussion

3.1 Effect of heat treatment on microstructures

Dual-phase (DP) microstructures were developed by intercritical annealing heat treatment of two different prior microstructures, namely (I) martensite (IQT) and (II) austenite (SQT). It is evident that all heat treatments have resulted in ferrite–martensite dual-phase (DP) microstructures; however, the shape, size, and distribution of martensite phase vary significantly with the heat-treatment schedules. Figure 2 shows the optical micrographs of X52 (DP) steel subjected to different heat treatment schedules (IQ) and (SQ) treated at Intercritical Annealing Temperature (IAT) of 760°C. The (IQ) microstructures showed fine and fibrous martensite uniformly distributed within the ferrite matrix as shown in figure 2a, whereas (SQ) microstructures revealed blocky and banded ferrite–martensite phase as shown in figure 2b. The differences in the microstructure of samples before intercritical heat treatment may be responsible for the observed differences in the martensite morphologies and distributions [13].



(a) IQ Heat Treatment at IAT=760 °C (b) SQ Heat Treatment at IAT=760 °C

Fig. 2. Optical micrographs of DP steel showing ferrite (white) and martensite (black)

Hence, various morphologies of final dual phase microstructure obtained as a result of existing different amount of nucleation sites during the intercritical annealing. In (IQ) samples, before intercritical annealing, the microstructure consisted of lath martensite transformed from original austenite. The availability of finer and well dispersed nucleating sites has resulted into fine morphologies of martensite uniformly dispersed in the final (DP) microstructure [14]. During the annealing heat treatment, the austenite nucleates and grows at prior boundaries of the martensite plates resulting fibrous microstructure of martensite and ferrite. In the case of (SQ) heat treatment, the initial phase before intercritical annealing heat treatment is austenite. Upon decreasing the temperature to the (α+γ) region, ferrite phase nucleates at the grain boundaries of

austenite phase and grows within the austenite grains [14]. Such a ferrite–austenite structure has resulted in a (DP) microstructure with alternate bands of ferrite and martensite after quenching from the (α+γ) region. We have found that the volume fraction of Martensite (MVF) obtained in treatments (IQ) and (SQ) treated at 760 °C and 800 °C was about 0.35 and 0.52 respectively. We can see that (MVF) increase with the increase in the temperature heat treatments. Similar (IAT) resulted in identical martensite content for different intercritical heat treatments was reported by Ahmed et al., and Shi et al. [13,14].

The hardness of (IQ) and (SQ) treatments for both intercritical annealing temperatures of 760 and 800 °C are shown in **Table 2**. The hardness changes significantly with the heat treatment schedules, which can be attributed to the difference in morphologies and volume fraction of martensite. We can see that hardness increase with the increase in the (MVF) for both heat treatments. Among the different heat-treatment schedules, (IQ) treatment clearly yield the higher hardness value for the same (ICT) compared to (SQ) treatment.

Tab 2. Vickers Hardness of tested X52 DP steel

Treatments	ICT (°C)	MVF (%)	HV_{10}
IQ	760	34	229
	800	52	245
SQ	760	34	212
	800	52	225

3.2 Effect of Heat Treatment on Abrasive Wear Properties

For effective usage of different morphology and content it is indispensable to understand the phenomena of abrasion and the damage caused by (SiC) hard particles; some discussions have been done to understand the response of X52 steel exposed to abrasion.

The influence of the type of heat treatment (IQ) and (SQ) on the abrasive wear resistance of X52 DP steel samples as a function of applied load for a specific sliding speed of 3 m/s and the same IAT = 800 °C can be seen in figure 3. At load value equal to 1 Kg, weight loss obtained is 5 mg for (IQ) heat treatment, but a weight loss has increased up to 20 mg for (SQ) heat treatment. At identical applied loads, the weight loss of the (IQ) heat treatment with fine microstructure was lower than that of (SQ) heat treatment with coarse microstructure samples under similar test conditions. Therefore, at a fixed martensite fraction, the different responses of the DP steels on

the wear abrasion resistance are solely attributable to the different ferrite-martensite morphologies (and the applied loads). There are noticeable differences in weight loss amongst the (IQ) and (SQ) heat treatments. The (SQ) sample with coarse martensite offers a significant weight loss at a fixed martensite fraction, which is much larger than that of the (IQ) sample. The presence of finer (ferrite-martensite) phases (Figure 2a) and hence improved hardness (Table 2) in (IQ) sample could be responsible for an improvement in abrasive wear resistance. As reported in [12], the ferrite-martensite morphology in DP steels influences the load transfer or stress/strain partitioning between two phases, and hence affects the tensile strength. It certainly influences the abrasive wear behaviour as well. After quenching, coherency of fine martensite/ferrite interface is more pronounced than that of coarse martensite/ferrite interface. Thus, it is considered that cracking risk of martensite particle particules in the IQ specimen could be reduced.

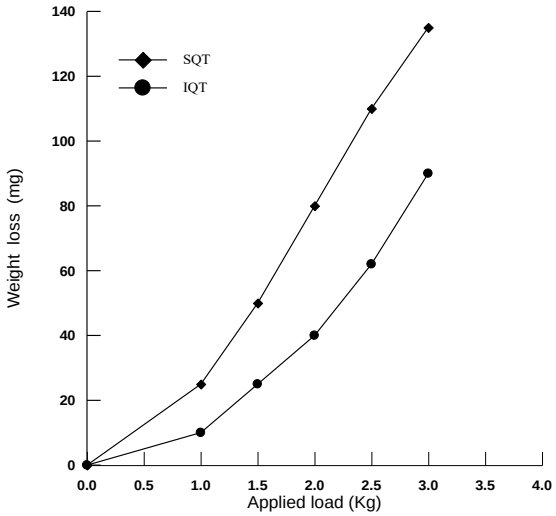
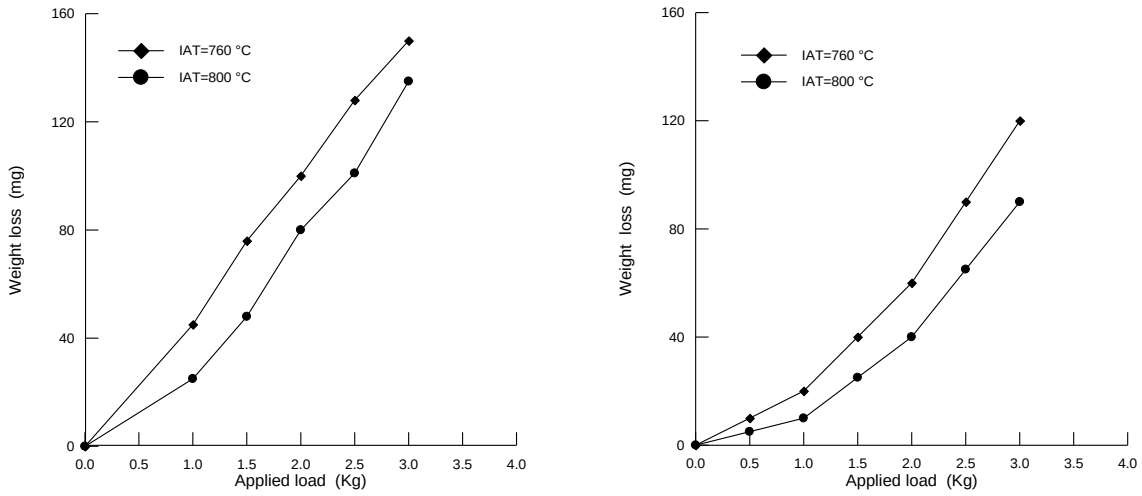


Fig.3. The Influence of the Type of Heat Treatment (IQT) and (SQT) on the Wear Abrasive Resistance as a Function of Applied Load for the Same IAT = 800 °C.

The effect of Intercritical Annealing Temperature (IAT) on the abrasive wear resistance of the both (IQ) and (SQ) heat treatment samples as a function of applied load for a specific sliding speed of 3 m/s is shown in (Figure 4). For (SQ) samples, at applied load value equal to 2 Kg weight loss obtained is 80 mg for (IAT) =800 °C, but at (IAT) =760 °C weight loss has increased up to 100 mg (Figure 4a). For (IQ) samples, at applied load value equal to 2 Kg weight loss obtained is 40 mg at (IAT) =800 °C, but at (IAT) =760 °C weight loss has increased up to 60 mg (Figure 4b). The lower weight loss was obtained with increasing load for the specimen (IQ) sample with (IAT) =800 °C. In both heat treatments samples (IQ) and (SQ), the abrasive weight

loss increased with increasing applied loads and decreasing (IAT), i.e. decreasing martensite volume fraction (MVF). In (DP) steel, ferrite is the softer phase while martensite is the harder one. Abrasive wear resistance in (DP) steels is offered by the hard martensite phase whereas soft ferrite improves work hardening capability, imparts ductility [15, 16].



(a) SQ heat treatment (b) IQ heat treatment

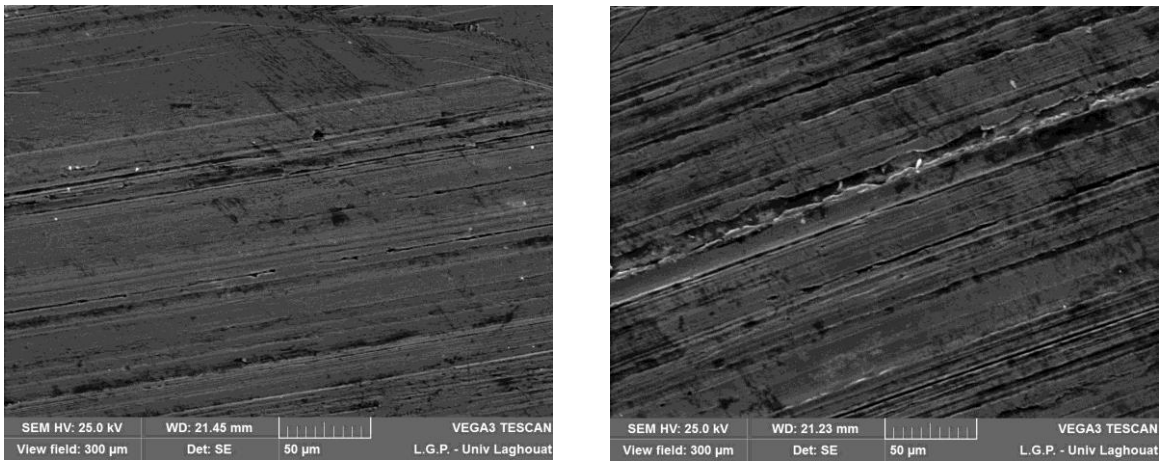
Fig.4. the effect of Intercritical Annealing Temperature on the abrasive wear resistance of various heat treatment samples as a function of applied load

The increasing abrasive wear resistance with increasing (IAT) may be explained on the basis of the strength imparted by incorporation of the hard martensite phase in this steel. Martensite volume fraction (MVF) increased with increasing Intercritical Annealing Temperature (IAT). The steel containing higher (MVF) will have higher strength and therefore it will have a higher abrasive wear resistance at a given applied load. The observed trend is in agreement with the observations of Tyagi et al. [17], who have also reported that the abrasive wear resistance of (DP) steels increases with increasing (IAT). Increasing the volume fraction of martensite decreases the interface of ferrite and martensite and therefore, the suitable places for nucleation and propagation of cracks decrease. Thus the higher wear resistance in steels of comparatively higher martensite volume fraction may be attributed to the increase of probability of crack formation [3]. Some results present the abrasion wear resistance of (martensite + ferrite) dual phase steel influenced by the microstructure and test conditions; wear resistance increases with increasing the volume fraction of martensite. Available information suggests that the abrasive wear resistance of

X52 dual phase steel depends on factors like microstructure (morphology, their size and content), and hardness.

3.3 Effect of Heat Treatment on Abraded Surface Morphology

Figure 5 shows abrasive wear surfaces produced by SiC hard particules of (IQ) and (SQ) samples treated for the same (IAT) = 760 °C, tested at a load of 1 Kg and at a fixed speed of 3 m/min. Figure 5a shows a wear surface of the (IQT) sample treated at (IAT) = 760 °C, tested under similar condition. It indicates a smooth surface with shallow abrasive wear scars, due to the high hardness of the sample. Figure 5b shows a wear surface of the (SQT) sample treated at (IAT) = 760 °C, tested under similar condition. As seen in Figure 5, the (IQ) samples with fine fibrous martensite yield the lowest scratches depths (i.e. the best wear resistance), which is consistent with its largest hardness, while the (SQ) samples with their coarse martensite display the largest scratches depths, i.e. the worst wear behaviour. It is seen that the worn surface of (IQ) samples is smoother than that of the (SQ) samples. (IQ) samples were special for the smoothest abraded surface without any deep scratches, suggesting that (IQ) heat treatment had the best abrasive wear resistance in this case.

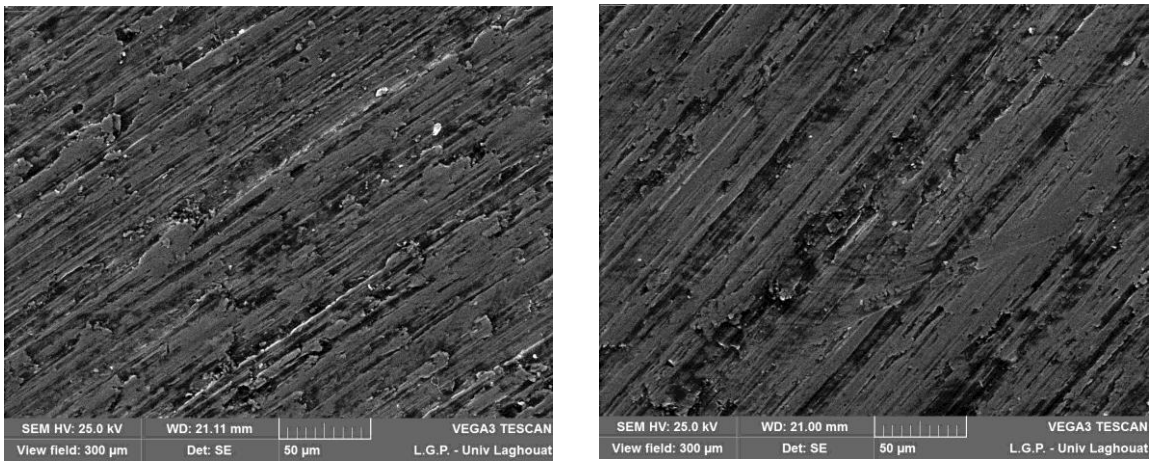


(a) IQ Heat Treatment at IAT=760 °C (b) SQ Heat Treatment at IAT=760 °C

Fig.5. Abraded surface morphologies of DP steel tested at a load of 1 Kg

Figure 6 shows abrasive wear surfaces of (IQ) and (SQ) samples treated at the same (IAT) = 760 °C, tested at a load of 3 Kg at a fixed speed of 3 m/min. With increasing applied load up to 3 Kg, some deeper scratches were revealed on the surface. The abrasion characteristic of the worn

surfaces was a series of parallel scratches, corresponding to the ploughing by SiC abrasive particles. It is observed that in the (SQ) samples wear scars are deeper compared to the (IQ) samples. The order of wear resistance is in good agreement with their corresponding failure mechanisms. As seen in Figure 5 and 6, the (SQ) samples present the largest scratch width and the failure mechanism is that of ploughing in combination with debris formation. Abrasive wear results in the softer material being removed from the track traced by the asperity during the motion of the harder surface. This type of wear mechanism leads to more mass loss. The (IQ) samples show the smallest scratch width and the scratch is relatively smooth, showing only ploughing. It can be seen that the scratch depth as a function of the applied load during wear testing follow the same trend for the (IQ) and (SQ) samples, i.e. the scratch depth increases with increasing applied load from 1 to 3 Kg.



(a) IQ Heat Treatment at IAT=760 °C (b) SQ Heat Treatment at IAT=760 °C

Fig.6. Abraded surface morphologies of DP steel tested at a load of 3 Kg

4. Conclusions

On the basis of the experimental work that has been carried out and presented in this article, the following conclusions can be drawn:

1. Heat treatment has a great influence on the evolution of ferrite and martensite morphologies.
2. IQ and SQ heat treatments resulted in fine and fibrous martensite uniformly distributed within the ferrite, and blocky and banded ferrite–martensite microstructures, respectively.
3. The abrasive wear resistance of the (IQ) specimen with fine martensite particle size was higher than that of the (SQ) specimen with coarse martensite particle size.

References

1. R.O. Rocha, T. M.F. Melo, E.V. Pereloma, D.B. Santos, Microstructural evolution at the initial stages of continuous annealing of cold rolled dual-phase steel, 2005, Materials Science and Engineering A, Vol. 391, pp. 296-304.
2. K. Park, M. Nishiyama, N. Nakada, T. Tsuchiyama, Effect of the martensite distribution on the strain hardening and ductile fracture behaviors in dual-phase steel, 2014, Materials Science and Engineering A, Vol. 604, pp. 135-141.
3. E. Fereiduni, S.S.G. Banadkouki, Improvement of mechanical properties in a dual-phase ferrite–martensite AISI4140 steel under tough-strong ferrite formation, 2014, Materials & Design, Vol. 56, pp. 232-240.
4. X. Wang, Study on Rolling Process and Fatigue Performance of Hot Rolled High Strength Steel for Wheel, 2017, Chemical Engineering Transactions, vol. 59, pp. 229-234
5. N. Saeidi, F. Ashrafizadeh, B. Niroumand, Development of a new ultrafine grained dual phase steel and examination of the effect of grain size on tensile deformation behaviour, 2014, Materials Science and Engineering A, Vol. 599, pp. 145-149.
6. H. Seyedrezai, A.K. Pilkey, J.D. Boyd, Effect of pre-IC annealing treatments on the final microstructure and work hardening behavior of a dual-phase steel, 2014, Materials Science and Engineering A, Vol. 594, pp. 178-188.
7. R. Tyagi, S.K. Nath, S. Ray, Development of wear resistant medium carbon dual phase steels and their mechanical properties, 2004, Materials Science and Technology, Vol. 20, pp. 645-652.
8. R. Tyagi, S.K. Nath, S. Ray, Dry sliding friction and wear in plain carbon dual phase steel, 2001, Metallurgical and Materials Transactions A, Vol. 32. pp. 359-367.
9. A.P. Modi, Effects of microstructure and experimental parameters on high stress abrasive wear behaviour of a 0.19 wt% C dual phase steel, 2007, Tribology International, Vol. 40, pp. 490-497.
10. A. Basak, D.C. Reddy, D.V.K. Kanth, Computer modelling of wear resistance for plain carbon steels, 1998, Materials Science and Technology, Vol. 14, pp. 776-782.
11. R. Colaço, E. Gordo, E.M. Ruiz-Navas, M.Otasevic, M. Vilar, A comparative study of the wear behaviour of sintered and laser surface melted AISI M42 high speed steel diluted with iron, 2006, Wear, Vol. 260, pp. 949-956.
12. M. Sarvar, R. Priestner, Influence of ferrite-martensite microstructural morphology on tensile properties of dual-phase steel, 1996, Journal of Materials Science, Vol. 31, pp. 2091-2095.

13. E. Ahmed, T. Manzoor, M.M.A. Ziai, N. Hussain, Effect of Martensite Morphology on Tensile Deformation of Dual-Phase Steel, 2012, Journal of Materials Engineering and Performance, Vol. 21, pp. 382-387.
14. L. Shi, Z. Yan, Y. Liu, C. Zhang, Z. Qiao, Improved toughness and ductility in ferrite/acicular ferrite dual-phase steel through intercritical heat treatment, 2014, Materials Science and Engineering A, Vol. 590, pp. 7-15.
15. M. Aksoy, M. B. Karamis, E. Evin, An evaluation of the wear behaviour of a dual-phase low-carbon steel, 1996, Wear, Vol. 193, pp. 248-252.
16. M. J. Perez, M. M. Cisneros, H.F. Lopez, Wear resistance of Cu–Ni–Mo austempered ductile iron, 2006, Wear, Vol. 260, pp. 879-885.
17. R. Tyagi, S.K. Nath, S. Ray, Effect of martensite content on friction and oxidative wear behavior of 0.42 Pct carbon dual-phase steel, 2002, Metallurgical and Materials Transactions A, Vol. 33, pp. 3479-3488.