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TENSILE PROPERTIES OF THE HARDENABLE DUAL PHASE STEEL WITH DIFFERENT MARTENSITE DISPERSION

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Abstract

In this study, a chemical composition of steel having 0,0640 C%, 1,72 Mn%, 0,46Si%, 0,67 Ni%, was used. The volume fractions of transformed phases from austenite were determined by intercritical annealing of the steel having fine and coarse austenite dispersions at three different intercritical annealing temperatures (ICAT) and then cooled at various rates. At constant MVF (15-25%) specimen with fine structure exhibited higher yield and tensile strength than coarse ones. Generally, strain values increased with increasing volume friction epitaxial (new) ferrite. Fine structures showed higher yield and tensile strength than coarse ones which exhibited slightly higher ductility.

Keywords: Dual-Phase Steels, Tensile Properties, hardenability

1. Introduction

Dual-phase and multiphase microstructure steels are produced mainly with thermomechanical rolling or heat treating in α + γ temperature range followed by quenching in water. They are characterized by a microstructure consisting of a dispersion of 10–25 % of hard martensite particles in a soft, ductile ferrite matrix. In addition to martensite, the microstructure may contain small amounts of other phases such as retained austenite, new ferrite, pearlite and bainite, depending on cooling rate and alloys. Many researchers [1-5] have shown that the martensite volume fraction is dominant in controlling strength and ductility. Other factors that have been reported to influence the ductility of dual phase steels include composition of the martensite, alloy content of the ferrite, retained austenite, and the amount of new ferrite (also called epitaxial ferrite) [3,5].

As declared by Matlack and Speer [2] the fundamental basis for the strength-elongation response of the various steel classes summarized in Fig. 1 [4] (this study's results are also addited) is well-founded in the historical steel literature. To achieve the necessary hardening ability to produce martensite on cooling, DP steels often contain high Mn contents which may be greater than 2 wt pct. The presence of the high Mn content may lead to banding and result in local inhomogeneous deformation and less than optimal formability [2]. So this study is aimed at producing dual phase steel with reduced Mn and C content without sacrificing hardenability and formability. Additionally, investigation was designed to study the effect of bit high Mn and Ni content and austenite dispersion on tensile properties of dual phase steels. For this purpose, a hot-cold rolled steels containing austenite dispersions (fine and course) at the different intercritical annealing temperatures were used to investigate the tensile properties of these steels and a production process was followed to simulate the production process of cold rolled dual phase through industrial continuous annealing up to overaging stage [2].

2. Experimental procedure

The steel was produced in a medium frequency vacuum induction furnace. Chemical compositions of used steels (steel 1 and steel 2) are given in Table 1. As cast samples were supplied in the form of 300x300x26

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mm plate. 26x26x300 square bars were cut from the plate and hot rolled to 4mm and finally cold rolled to 2 mm. After cold rolling, 12x12x2mm specimens from cold rolled plates were used for the simulation of the heating, soaking and cooling stages of industrial continuous annealing.

The preliminary investigation was to determine the dependence of martensite volume fraction (VFM) on intercritical annealing temperature (ICAT). (Fig. 2). The Ac1 and Ac3 temperature limits were calculated theoretically from the chemical composition of the materials and then experimentally changing of the martensite (austenite) volume fraction depending on intercritichal annealing temperature were optained and showed at Fig. 2. [6]. As a result of this preliminary study, three ICATs of 735, 755, 815 ^{o}C were selected for steel samples for a detailed study of the effect of cooling rate on the development of the dual phase microstructure and tensile properties. These temperatures were chosen in order to specify a series of heat treatments that would vary the new ferrite content at two levels of constant VFM of ~15% and ~25% and two levels of microstructural refinement

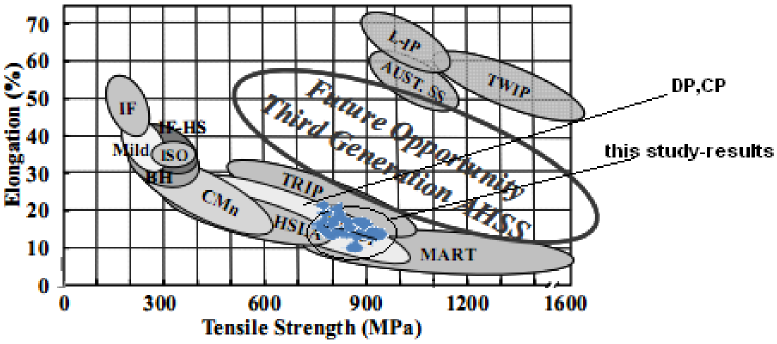

Figure 1. Summary of tensile strength and tensile elongation data for various classes of conventional and advanced high strength sheet steels (AHSS) [2] with as imposed results of the dual phase steels produced in this study

Table 1. Chemical compositions of materials used in experiments (wt%)

Steels	**Chemical composition (weight %)**									
	C	**Mn**	**Si**	**Ni**	**P**	**S**	**V**	***Ti***	**Nb**	**Fe**
1	0,064	1,72	0,46	0,67	0,0131	0,0124	0,07	0.015	0,05	Rest

Fine and coarse dispersions of martensite were obtained for steel 1 and steel 2 from two different starting conditions. Dual phase microstructures derived from hot and then cold rolled starting microstructures were labeled “series A”. These materials had ferrite+pearlite structure. The other starting microstructure for steel was obtained by re-austenitising the series A specimens at 900^{o}C for 20 min and water quenching which produced a microstructure that was nearly wholly martensitic. Dual-phase microstructures derived from these initial microstructures were labeled “series B”. The microstructures of specimens A and B were the starting point for subsequent intercritical annealing heat treatment.

Based on the results of the preliminary investigation, 12x12x2 mm specimens of the starting microstructures A and B were intercritically annealed at 735, 755, 815 ^{o}C for 20 min. They were then cooled at a variety of rates between 1500 and 0.01 ^{o}C/s. throughout these heat treatments; The specimens were coded according to steel number, starting microstructure, ICAT and nominal MVF. For example, in specimen code 1A735(15), 1 stands for steel number, A for the starting microstructure, 735 for ICAT and (15) for MVF. Phase’s volume fractions were calculated by point counting system which was adapted to optical microscopy. The mean linear intercept grain size 8 µm of the ferrite matrix was estimated by superimposing circles on micrographs at a magnification that allowed at least 500 intercepts to be counted. The average grain size in the A series of steel 1 and steel 2 specimens were 7 µm and 10µm respectively, and in the B series for steel 1 and steel 2 were 4 µm and 6 µm respectively.

Tensile test specimens of each series were then intercritically heat-treated to obtain dual phase microstructures, with the objective of obtaining two constant levels of martensite with two different dispersions and varying new ferrite contents. During intercritical annealing of the series, all the tensile test specimens (50 mm gauge length by 12,5 mm gauge section) were machined after heat treatments, and were ground down to the specified size (1,6 mm thickness) afterwards to eliminate the effect of oxidation and decarburisation caused by heat treatment. The flat tensile specimens were tested using a Schimadzu tensile testing machine at a crosshead speed of 1 mm/min. at room temperature. At least 3 specimens were tensile tested for each and average values were calculated.

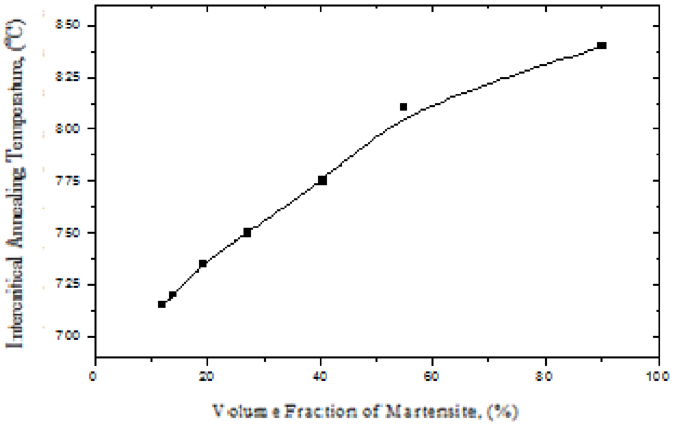

Figure 2. The dependence of austenite (martensite at room temperature) volume fraction on the intercritical annealing temperature

3. Results and Discussion

3.1. Tensile Properties

Tensile test results are shown in Tables 2 with cooling rate from ICAT, volume fraction of phases and martensite particule size of dual phase steel and at Fig. 3 and 4. Additionaly, as seen before in this study's results added to Fig. 1 which is declared by Matlack and Speer [2] the fundamental basis for the strength-elongation response of the various steel classes summarized in it [4] is well-founded in the historical steel literature.

Table 2. Steel 1 dual phase and normalized samples tensile test results with cooling rate from ICAT, volume fraction of phases and martensite particule size of dual phase steel

Speicmen Cod	Cooling rate (^{o}C/sn)	Volume Fractions			Marte. Particle size (µm)	%0,2 prof yield strength (MPa)	Ture UTS (MPa)	Max UTS (MPa)	% True uniform strain	%Total strain
		Marte.	Old ferrite	New ferrite						
1 N 900	6	17,5*	82,5**	-	-	335	797	677	17,5	22
1 A 735 (15)	0,2	12	75	14	1,3	320	819	710	15,5	22
1 B 735 (15)	0,3	17	75	8	1,05	383	851	750	13,5	16
1 A 755 (15)	0,34	17	65	18	0,9	386	883	777	14	18
1 B 755 (15)	0,041	16	65	20	0,8	450	818	715	14,5	20
1 A 815 (15)	0,56	14	45	41	1,14	315	825	699	18,5	25
1 B 815 (15)	0,45	14	45	41	0,7	382	826	714	15	19
1 A 735 (25)	1400	25	75	-	1,75	399	917	813	13	17
1 B 735 (25)	1400	25	75	-	1,2	490	971	864	13	15
1 A 755 (25)	5	24	65	12	1,65	390	927	810	15	19
1 B 755 (25)	4,5	26	66	9,5	1,15	525	985	871	13	15
1 A 815 (25)	80	25	45	30	1,35	382	837	740	14	18
1 B 815 (25)	100	27	45	28	1,02	470	912	830	10	13

Code of the samples: 1 (steel number), 735, 755 ve 815 ^{o}C (ICAT) and 15 or 25 VFM

3.1.1. Yield Strength

Dual-phase steels produced in this study heve not shown yield point, nor yield point elongation. Temporary to plain low carbon or HSLA steel, dual phase steel didn't show yield point and at literature, it is related to high density mobile dislocation occurring during martensitic transformation due to volume expansion and stress around martensite particules in ferrit phase. At tensile condition, this dislocation results in an early start of deformation corresponding to orginal materials [1,13-23].

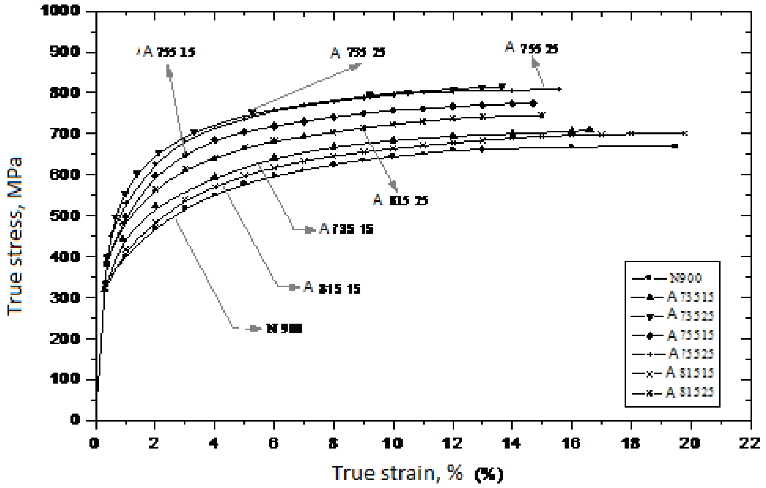

Figure 3. A series samples true stres-strain curves (σ-ε)

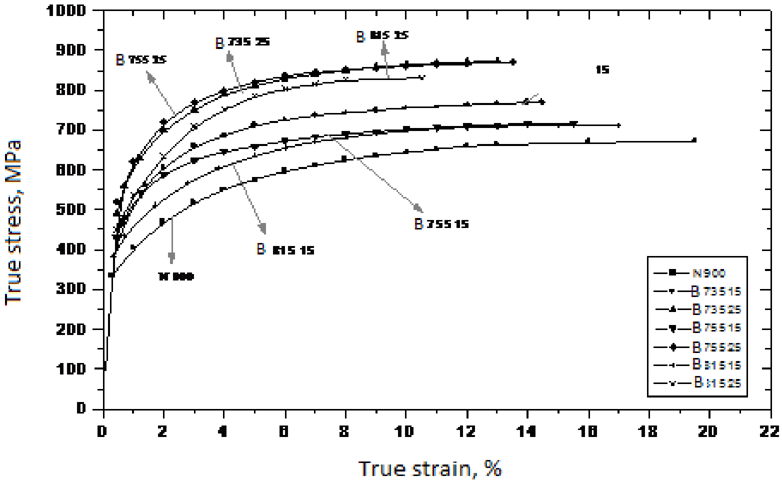

Figure 4. B series samples true stres-strain curves (σ-ε)

Generally, Steel 1 dual-phase steel samples showed higher yield strength than normalized sample and B series. B series have fine structure which increased strength (Table 2, 3). This could be explane that in dual-phase steel, deformation takes place in ferrite phase, it can be expected that ferrite, which has high deformation capacity in thinly distributed structures (B series) where the connection between martensite particles is very low, will deform more compared to new ferrite in structures with coarse martensite distribution [7-11].

When it is considered in terms of dislocation intensity, which occurs in ferrite which is nearby the martensite during the formation of large dimensioned martensite particles in A series samples is lower compared to B series in which thin dimensioned martensite particles form. Since surface is greater in a thinly distributed structure, it is accepted that dislocation regions have a larger area. It can be seen that in A series deformation starts earlier. The main reason for the fact that yield strength is high can be stated as the fine distribution of hard second phase in soft ferritic matrix. Such a structure creates more obstacles for the motion of dislocations in constant VFM.

In Steel samples having the same 15 %VFM which is the same series demonstrated lower yield strength compared to those having 25 % VFM. These results are compliant with the previous research [7-13] yield strength increases with the increase of VFM (Figure 6.).

3.1.2. Tensile strength

Almost all of dual-phase steel samples demonstrated high tensile strength compared to normalized sample. The reason for this can be demonstrated as the fact that alloy elements (Mn, Ni etc) increase the resistance of martensite. In addition to this, alloy elements distort the purity of ferrite, and thus decrease ductility. In dual-phased steels, deformation takes place inside the ferrite phase. The fact that there is a suitable interface between ferrite and martensite ensures protection of interfaces up to high tensile values. When the strain passes from ferrite to martensite, resistance of martensite and suitability of the inter-surface ensure the continuity of deformation up to high strains without any separation and increase of tensile resistance [7,8].

As in yield strength, samples having VFM rate of 25 % from the same series have showed higher tensile strength compared to those having VFM rate of 15 %. Tensile and yield strength increase with the increase of VFM. These results are in conformity with the rule of mixture as indicated in the literature [5]. As a result of the fact that connections between martensite particles and the martensite particle dimension increase in line with the increase of VFM, the tensile strength increases due to the fact that during traction, the strain is transferred prematurely from ferrite to martensite before being fully deformed [7,8].

Thinly distributed B series samples have shown high tensile strength compared to coarsely distributed A series. Soft ferrite creates a more efficient obstacle for preventing the dislocation movement of martensite particles which show thin distribution in the ferrite main structure, and increased resistance [1]. Another reason for increased tensile strength can be explained with the fact that in B series, the particle dimension of ferrite is thinner.

Among steel 1 samples, those having similar or higher NFVF generally showed lower tensile strength. As an exception, 1 A 735 sample, which has 12 % VFM, has showed lower strength, and 1 A 755 sample, which has 18 % VFM has showed higher tensile strength. Based on this, it can be said that VFM is more effective on resistance compared to NFVF. A similar condition can be said for Steel 1 B series. As indicated by the previous researchers [19-21], the new ferrite decreases strength and increases ductility (Fig 7). While a relation could be established between NFVF and resistance in Steel 1 samples, this could not be established in Steel 2 samples, which could be due to the effect of strength increasing elements. As a matter of fact, Geip el al [10], who conducted studies on HSLA steel, have indicated that new ferrite has increased ductility more compared to the older ferrite since it does not contain precipitate. Here it can be accepted that, in connection with chemical composition and heat history, the sharing of alloy elements and precipitate formation are effective together with VFM.

Dual-phase steel samples have generally showed lower yield ratio compared to normalized sample. Yield ratio was lower in B series samples compared to A series samples. Tomita [16] has also stated a similar result. Including the normalized sample, yield ratio which could be obtained around 0.5 as approximate, are quite affirmative values in terms of shaping capacity. Whereas yield ratio is around 0.7 – 0.8 for HSLA steels, it could change between 0.5 – 0.7 in dual-phase steels [5,6-11]. In general, the yield ratio decreases in connection with the increase of VFM. Tomita [8] has indicated that yield ratio decreases highly in B samples. As can be seen from the results in this study, yield ratio of A series samples were higher compared to B series, though not at a high level.

3.1.3. Elongation

Whereas strength values increase with the increase of VFM (Table 2 and Fig. 3,4), uniform and total elongation values decrease (Table 2 and Fig 3-4). Martensite particles are smaller and less connected in low VFM (15 %), compared to higher ones (25 %). Besides, there is more ferrite volume fraction for deformation. Therefore, samples having higher VFM containing less ferrite and more connected martensite particle have showed earlier fracture and lower uniform and total elongation. Rate of uniform elongation to total elongation was higher in B series samples compared to A series samples.

Tensile and flow resistances increase linearly with the increase of VFM (Table 2). These results are in compliance with the rule of mixture as indicated in the literature. In line with the increase in VFM, the particle dimension and connections between martensite particles also increase. This situation may lead to early breaks on martensite particles as a result of tensile being immaturely transferred from ferrite to martensite before the ferrite is fully deformed during traction. Thus, while strength decreases, elongation values increase.

As opposed to what is expected, uniform and total elongation values in B series samples compared to A series samples were approximate or less. The reason for this may be the fact that critical annealing time is kept lower here (15 min.), which is different from the previous researchers who conducted similar research. Austenite diffusion takes place in alloy elements included in long termed annealing in line with the period ((t >20 min), though not long enough to allow full balance. As a result, these alloy elements increase the efficiency and resistance of martensite. Otherwise they distort the purity of ferrite, and decrease ductility. In this manner, the martensite is not sufficiently efficient, and ferrite is not sufficiently ductile. Together with this, the fact that the annealing time is long is not rational for commercial applications.

Total elongation values notified by Kim and Thomas [7], who conduct study using A and B microstructures, are lower than the values in this study. Together with this, they have demonstrated higher elongation values in B samples compared to A samples. However, the elongation values of B samples obtained in this study were similar to or lower than A samples. The reason for this difference may be due to the fact that the material used and the heat treatment conditions are different. These researchers have subjected the material to homogenous annealing before critical annealing, and supplied water at a different temperature in order to create the initial microstructure.

The effect of new ferrite on total and uniform elongation has been generally demonstrated. As an exception of low temperature samples obtained with VFM lower than 15 % (such as 1 A 735 15), they have been shown to be more uniform and longer in overall elongation compared to samples having high new ferrite volume rate. As indicated by the previous researchers, the new ferrite increases ductility. Together with this, the impact of new ferrite is very sensitive to VFM [12,13].

4. Conclusion

The following conclusions could be drawn from the above discussions.

1. VFM, martensite particles morphology and VFNF are controllable parameters and alloying elements are very effective on them.
2. Thin martensite distribution highly increases yield strength. It can be said that the effect is more than different VFMs. That is, it is expected that samples having 15 % VFM will show lower yield strength compared to samples having 25% VFM. Together with this, B series samples having 15 % VFM showed similar or higher yield strength compared to samples having 25 % VFM.
3. When it is considered in terms of dislocation intensity: It can be considered that the dislocation intensity which occurs in ferrite which is nearby the martensite during the formation of large dimensioned martensite particles in B series samples is lower compared to B series in which thin dimensioned martensite particles form. Since surface is larger in thin distributed structure, it is accepted that dislocation regions have a greater area. It can be seen that in A series deformation starts earlier. The main reason for the fact that yield strength is high can be stated as the fine distribution of hard second phase in soft ferritic matrix. Such a structure creates more obstacles for the motion of dislocations in constant VFM.

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