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FRACTURE BEHAVIOR OF THE HARDENABLE DUAL PHASE STEEL WITH DIFFERENT MARTENSITE DISPERSIONS

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Abstract

In this study, low carbon Mn-Ni steel having 0,0640 C%, 1,72 Mn%, 0,46Si%, 0,67 Ni%, was used. The volume fractionsof transformed phases from austenite were determined by intercritical annealing of steels having fine and coarse austenite dispersions at three different intercritical annealing temperatures (ICAT) and then cooling at various rates. By increasing volume fraction of martensite (VFM) strength increased while uniform and total elongation decreased. Generally, strain values increased with increasing volume friction of epitaxial (new) ferrite. Microvoids were found to be nucleated on the martensite particles, inclusions or martensite-ferrite interface in the neck. The density of microvoids increased near to fracture surface. They were smaller in fine structure than that of coarse ones. The coalescence of microvoids were dominant form of fracture in both structure.

Keywords: Dual-Phase Steels, Fracture behaviour, hardenability,

1. Introduction

Dual-phase 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].

The process of fracture can be considered to be made up of two component, crack initiation and crack propagation. Fractures can be classified into two general categories, ductile fracture and brittle fracture. A ductile fracture which is generally available also at advanced automotive body steel for crass whorthness, is characterized by appreciable plastic deformation prior to and during the propagation of the crack. An appreciable amount of gross deformation is usually present at the fracture surfaces. Brittle fracture in metals is characterized by a rapid rate of crack propagation, whit no gross deformation and very little micro deformation. It is akin to cleavage in ionic crystals. The tendency for brittle fracture is increased with decreasing temperature, increasing strain rate, and triaxial stres conditions (usually produced by a notch). Brittle fracture is to be avoided at all cost, because it occurs without warning and usually produces disastrous consequences [dieter]. So for metals show ductile fractures are important to safety and it is formation [6,7]

The current investigation was designed to study the effect of low carbon and defined Mn-Ni content and austenite dispersion on tensile fracture of dual phase steels. For this purpose, a group of the hot+cold rolled steel samples containing different austenite dispersions (fine and course) at the different intercritical annealing temperatures were used to investigate austenite hardenability and tensile fracture behavior 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 [8,9]

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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 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). 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. 1. [10]. 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

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 samples 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.

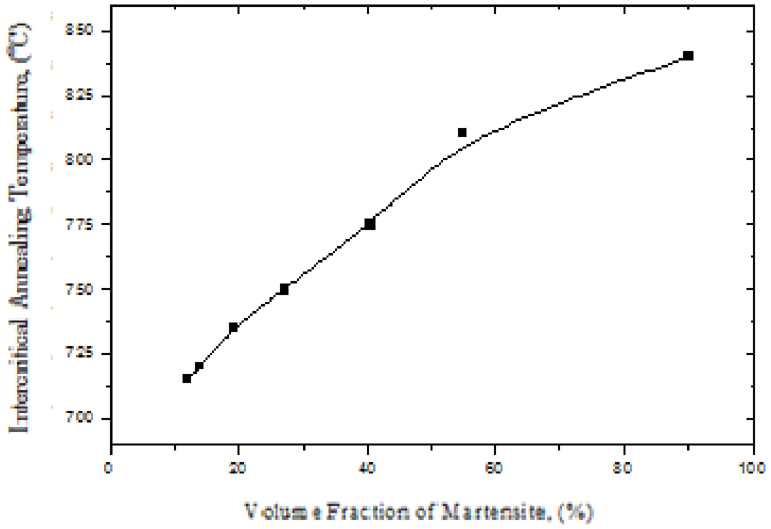


Figure 1. The dependence of austenite (martensite at room temperature) volume fraction on the intercritical annealing temperature

The characterization and examination of micrographs forming the fracture surface and the rupture on-set results of the tensile experiments are performed at optic and SEM microscopy. The tensile experiment samples ruptured to detect the micrographs formation are separated into two from their lengthways axis. These samples are examined lengthways in the direction of tensile and perpendicularly in the direction of tensile.

3.Results and Discussion

Fig. 2. Shows micrographs of the dual phase steel samples which have different phase volume content and as explained at Fig 2. Tittle.

Microstructure maps show the volume fractions of phases that form at cooling rates that differ from a fixed ICAT. Old ferrite which existed before critical annealing and which has not undergone any volumetric change during annealing and cooling is called new ferrite (the first ferrite created before conversion), and ferrite converted from austenite in relationto the cooling rate during cooling is either called new ferrite or epitaxial ferrite [11-14]. Cooling rates corresponding to 15% and 25% VFM have been detected from microstructure maps (Fig. 3). Approximate VFM and other phase volume fractions have been obtained by cooling tensile experiment samples at these cooling rates after critical annealing.

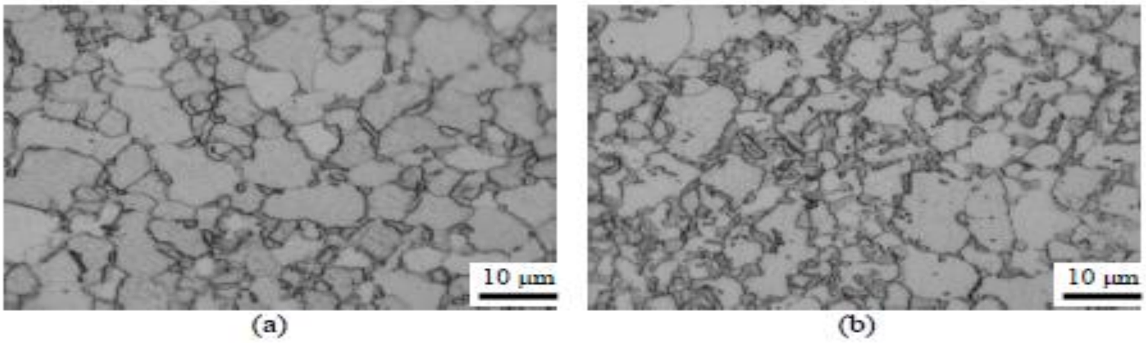
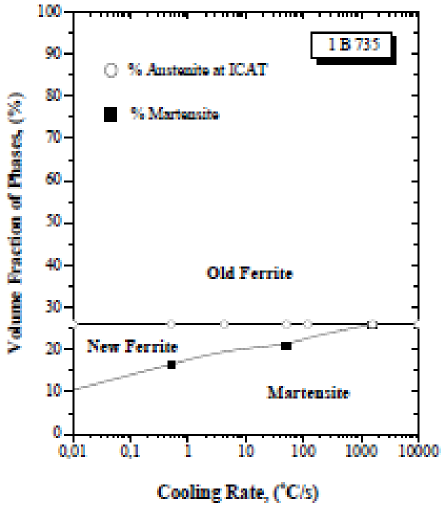


Figure 2. Micrograph of 1A735(15) (a) and 2A755 (25) (b) specimens. 1A735(15) specimen, intercritically annealed at 735 °C and cooled at 0.3 °C /s to give 17% martensite and 8% new ferrite and 2A755 (25) specimen, intercritically annealed at 755 °C and cooled at 5 °C /s to give 25% martensite and 10% new ferrite etched in 2 % nital.



(a)

Figure 3. Quantitative microstructure maps of series B specimens of Steel samples annealed at 735 ^{o}C showing effect of cooling rates on the microstructure (old ferrite: ferrite present during intercritically annealing.

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.

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 [1-5].

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	0,2	12	75	14	1,3	320	819	710	15,5	22
1 B 735	0,3	17	75	8	1,05	383	851	750	13,5	16
1 A 755	0,34	17	65	18	0,9	386	883	777	14	18
1 B 755	0,041	16	65	20	0,8	450	818	715	14,5	20
1 A 815	0,56	14	45	41	1,14	315	825	699	18,5	25
1 B 815	0,45	14	45	41	0,7	382	826	714	15	19
1 A 735	1400	25	75	-	1,75	399	917	813	13	17
1 B 735	1400	25	75	-	1,2	490	971	864	13	15
1 A 755	5	24	65	12	1,65	390	927	810	15	19
1 B 755	4,5	26	66	9,5	1,15	525	985	871	13	15
1 A 815	80	25	45	30	1,35	382	837	740	14	18
1 B 815	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

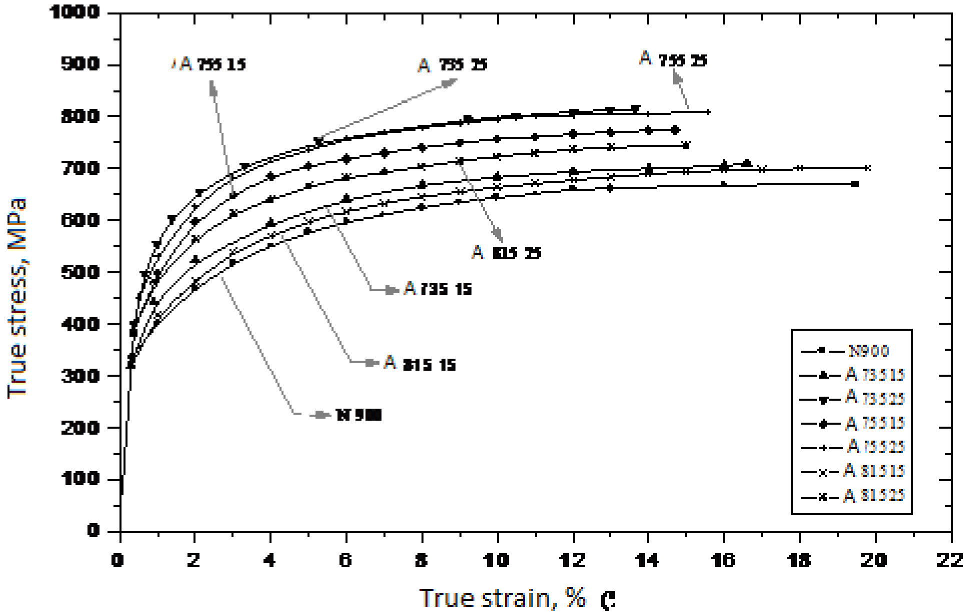


Figure 4. A series samples true stres-strain curves (σ-ε)

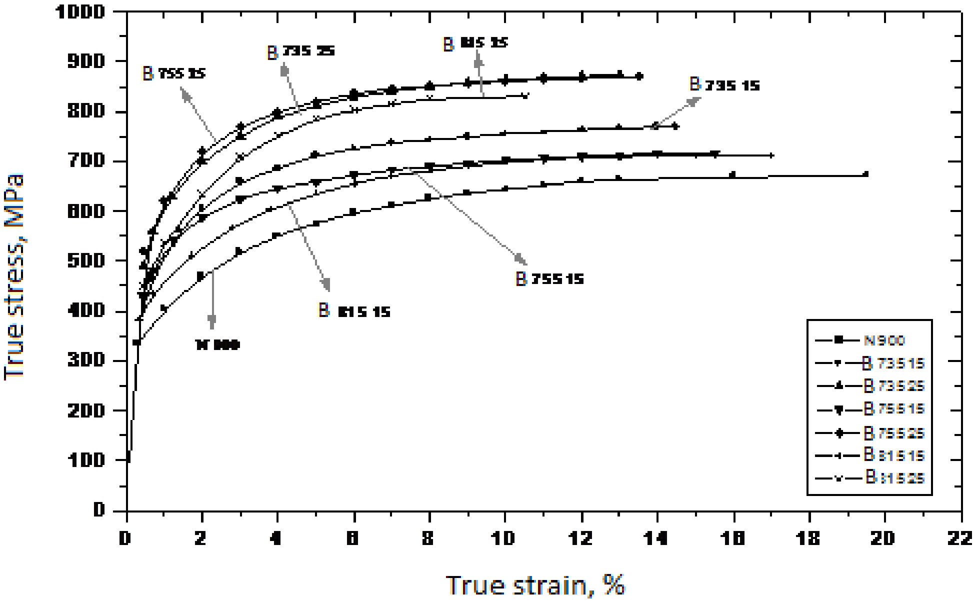


Figure 5. B series samples true stres-strain curves (σ-ε)

3.2. Tensile Fracture Properties

The fracture mechanisms' of tensile samples have been examined with optical and electron microscopes. Fractured surfaces generally demonstrate a cup and cone type fracture mode (Fig. 6). During the examinations, microvoids have been observed in areas close to the broken surface and wasting areas of the broken samples (Fig. 7.). Micrograph formations with the cup and cone break types are typical indications for the ductile rupture character.

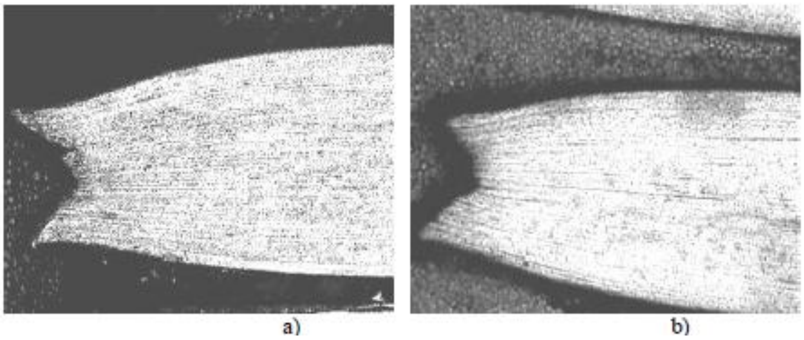
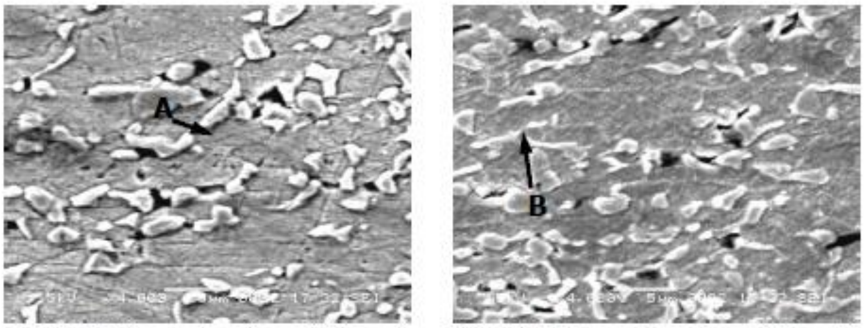


Figure 6. Cup and cone image of samples showing ductile fractures mode, a) 1 B 815 25 b)2 B 795 25

As seen in Fig. 7, microvoids are related to martensite and/or inclusions. The nucleation of microvoids on martensite and inclusions are shown as the cause of this [13-15] The reason microvoids nucleate on martensite is referred to the decomposition of joint martensite particles, and the regional deformation of martensite particles or the decomposition of ferrite-martensite interfaces. Streinbrunner et.al. [15] has reported that microvoids first nucleate on martensite, and the nucleation on inclusions is a secondary incident. The density of microvoids increases towards the fracture surface. The increment of the density of microvoids as it approaches the fracture surface is explained with the high tension in this



a) 1 A 735 15 sample, microvoid formation at ferrite-martensite interface (A)
b) 2 A 717 15 sample, microvoid formation martensite particle (B)

Figure 7. Microvoid formations at martensite and inclusion particles within the necked region for various samples

When the intensity of the tension increases, the Microvoids formed in the ferrite-martensite interfaces proceed inside ferrite in the direction of the tension () (Fig. 8). The connections between martensite particles are an important indication to determine whether or not the crack on-set is on the martensite (Fig. 7). The poorly connected martensite extending throughout the martensite-ferrite interface may be easily broken [16,17]. It is generally observed that the Microvoid combination in the fracture structure is dominating. Fracture surfaces are intensively covered in dimples (Fig. 8).

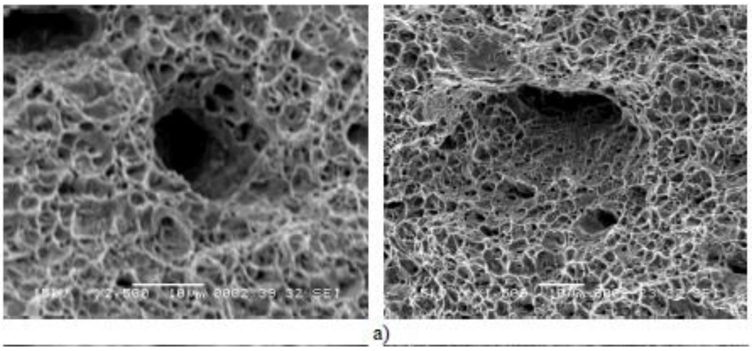


Figure 8. Fracture surfaces of specimens showing big holes (a) and bigs hole with inclusion and the wavy nature along the hole

Consequently, in this study, the conclusion may be reached that the critical fracture tension does not ocur inside the ferrite at the final fracture moment. This is most likely due to low VFM and presence of. Speich and Miller [18] have stated that dual-phase steel with martensite containing low VFM and high carbon break easier in fraction to dual-phase steel with martensite containing high VFM and low carbon.

4. Conclusions

The following conclusions could be drawn from the above discussions.

1. In the specified chemical composition, dual-phase steel having two different austenite distribution and martensite volume fractions (15 and 25%) have shown ductile fracture.

2. In dual-phase steel having coarse and fine structure, in the wasting area, Microvoids are formed in the martensite particles, in martensite-ferrite interfaces and inclusions. Martensite fractures are less in fine structures compared to coarse structures, and the dimensions of Microvoids are smaller.

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