FRACTURE BEHAVIOUR OF A DUAL PHASE STEEL HAVING A HIGH PERCENTAGE OF MARTENSITE

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ABSTRACT

A boron containing microalloyed steel has been subjected to several intercritical annealing treatments to achieve dual phase ferrite-martensite microstructures having volume fraction of martensite in the range of approximately 35 to 56 %. Impact and fracture toughness of these materials were determined using standard Charpy V-notched and bend chevron notched specimens. Qualitative correlations between these mechanical properties and percentage of martensite in the dual phase steels have been sought for. These results along with other mechanical properties demonstrate that a good potential exists to achieve optimum strength-toughness combinations for dual phase steels containing high percentage of martensite.

INTRODUCTION

The development of steels with dual phase ferrite-martensite microstructures has received considerable attention by the steel and the automotive industries, because such steels exhibit good formability and high strength in finished components (Davies, 1978, Lagneborg, 1987, Repas, 1987). The good combination of strength and ductility in these microstructures is derived from the properties of the two constituents. Several attempts (as summarised by Lagneborg, 1987, Repas, 1987) have been made to improve and optimise properties of these materials either by addition of alloying elements or by searching for different heat treatment schedules. In such attempts to optimise the mechanical properties, one of the emphasis has been to limit the volume fraction of martensite to around 20% as to keep a high ductility (percentage elongation >20%). This has led to intensive search of tensile properties and tensile fracture behaviour of these materials (like, Davies, 1978, Su, Sun, and Yang, 1987, Kang, and Kwon, 1987). Attempts to develop dual phase steels using fracture toughness characterisation approach as to optimise the volume fraction of the constituents are almost non-existent, because the tensile properties of the materials, in general, indicate that high strength of such materials having higher percentage of martensite is generally associated with poorer ductility. On the other hand, it is known (Chang and Preban, 1985, Mediratta, Ramaswamy and Rama Rao, 1985) that the morphology of the constituents in a dual phase steel significantly influences the cracking behaviour. The influence of martensite morphology in dual phase steels containing volume fraction of martensite >20% has not been examined in a systematic manner. The primary objective in this report is to study the fracture behaviour of dual phase steels containing high martensite using toughness characterisation approach of materials.

EXPERIMENTAL PROCEDURE

Material, Heat Treatment and Specimen Preparation

The chemical composition of the steel is shown in Table.1. The as-received material was in the form of a plate of 14 mm thickness from which toughness test coupons were cut out in T-L orientation for fabricating standard Charpy (ASTM E-23) and bend chevron notched specimens (Fig.1). All specimens were soaked at 920°C for 30 min and ice-brine quenched. These specimens were then grouped into different sets and were intercritically annealed at 730°C, 740°C to 840°C at 20°C intervals for time duration of 60 min and finally oil quenched. The bend chevron notched specimens (Fig.1) were fabricated using CNC machine, and the chevron notches were prepared using 0.3 mm slitting cutter. A series of specimens for microstructural examinations and other mechanical property evaluations were also intercritically treated in an identical manner.

TABLE 1 Material Composition

Element	C	Mn	S	P	Si	Cr	Mo	B	V	N
Wt%	0.16	1.32	<0.01	0.013	0.44	<0.05	0.09	0.0019	0.056	0.040

Metallographic Examinations

The prior austenite grain size of the material was estimated by a comparative assessment with standard ASTM grain size charts and was found to possess a grain size finer than ASTM No.10 (11 μm). The volume fraction of martensite in the heat treated microstructures was estimated by point counting method using a 10x10 grid on 25 fields of observation. All these assessments were done using a Nikon Epiphot microscope connected to a video monitor. A separate series of microstructural examinations was also carried out using a Jeol JSM5200 scanning electron microscope. The amounts of retained austenite in the materials were determined by X-Ray measurements and were found to be less than 3% in all samples.

Related Mechanical Tests

Hardness measurements were carried out using a digital microhardness tester LECO DM400. Ten measurements were made for each heat treated specimen using a load of 300 gm for 10 sec with the help of a Vicker's pyramid diamond indentor. Tensile tests were carried out using cylindrical specimens of gauge length = 35mm and diameter = 8.75mm as per ASTM standard E 8 using a nominal strain rate of 1.86×10^{-3}/sec in an Instron servo hydraulic machine.

Toughness Measurements

Impact toughness of the materials was determined using standard Charpy V-notched specimens at room temperature. All bend chevron notched fracture toughness (K_{ICV}) tests were carried out in three point bend configuration using an Instron 1344 servo hydraulic machine at a crosshead velocity of 0.02 mm/min at the room temperature of 295 K.

Fractographic Studies

Fracture surfaces of tensile, impact, and chevron notched bend specimens were examined using a Jeol JSM5200 scanning electron microscope, and a series of fractographs were taken at regions of interest to understand the fracture behaviour of the dual phase structures.

RESULTS AND DISCUSSION

The ferrite-martensite dual phase structures can be achieved by two types of heat treatment schedules referred here as intermediate quenched (IQ) and step quenched (SQ) treatments as shown in Fig.2. The IQ treatment, in general, gives (Mediratta, Ramaswamy and Rama Rao, 1985) finer dispersion of martensite in ferrite matrix, which, in general, leads to better mechanical properties. This is why the IQ heat treatment schedule has been selected in this investigation. Two typical dual phase microstructures are shown in Fig.3 and Fig.4. The commonly observed martensite morphologies in these microstructures (Su, Sun and Yang, 1987) are: (i) the island type where martensite phase is randomly distributed as island in ferrite matrix and (ii) the lamellar type where the martensite phase is distributed as lamellae alternating with ferrite of the same orientation. The investigated microstructures, in general, exhibited a mixture of both these two types of martensite marphologies (Fig.3).But the lamellar morphology was found to be more predominant in microstructures containing around 50% martensite (Fig.4). The volume fraction of martensite in dual phase structures depends on : carbon content, alloying elements and annealing temperatures. For the employed heat treatment schedules, the percentage of martensite varied with the intercritical annealing temperatures as shown in Fig.5. It is observed that the martensite transformation is relatively sluggish at higher intercritical temperatures.

The hardness, the Charpy impact energy and the fracture toughness (estimated by using bend chevron notch specimens) of the different microstructural states were examined in Fig.6, Fig.7 and Fig.8 respectively. An interesting observation emerges from Fig.6 and Fig.7. that both hardness and impact energy increase with increase in percentage martensite in the microstructures. This observation is contradictory to an earlier report (Kang and Kwon, 1987) where impact energies have been reported to be monotonically decreasing with the increase in hardness values. The values of fracture toughness (K_{ICV}) were also found to increase with increase in percentage martensite upto 50% whereby K_{ICV} dropped with further increase of martensite content in the microstructures. These results support the trend of impact energy variation with volume fraction of martensite. With the help of Fig.7 and Fig.8, it can thus be concluded that dual phase microstructures containing about 50% martensite having predominantly lamellar morphology exhibit reasonably high toughness values and can be considered for structural applications. The yield strength of these microstructural states were found to be approximately 500-550 MPa with uniform elongation between 14 to 16% (the details of which are given in a separate communication (Ray, Bag, and Dwarakadasa, ICF8, 1993). It remains an intriguing question how dual phase steels having high percentage of martensite exhibit a good combination of strength and toughness. This answer is inherent in two typical scanning electron fractographs as shown in Fig.9 and Fig.10. Figure 9 shows transgranular cleavage and Fig.10 indicates dimple fracture for low (but > 20%) and high (≈ 50%) percentage of martensite contents of the materials, and thus support the trend of increased toughness of the microstructure having ≈ 50 % martensite. Following the fracture micromechanism in dual phase steels (Su, Sun, Yang, 1987), it is contended here that in high martensite (≈50%) structures microcracks form at ferrite-martensite boundaries, which grow and coalesce to form the main cracks (Fig.10).

SUMMARY

Boron containing dual phase ferrite martensite (≈ 50%) structures exhibit a good combination of strength and toughness properties. The higher toughness indices for these steels emerge from the particular morphology of the martensite in this microstructures; this specific morphology leads to the fracture micromechanism of void formation and coalescence.

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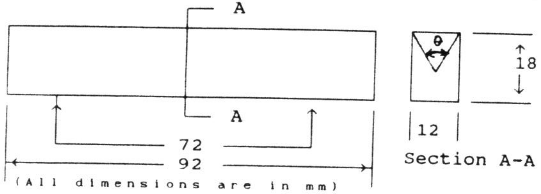

Fig.1 Geometry of the chevron notched specimen.

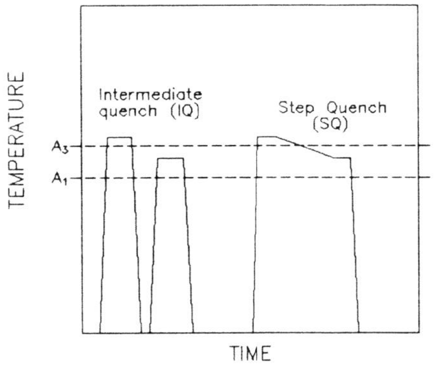

Fig.2 Schematic representation of heat treatment cycles

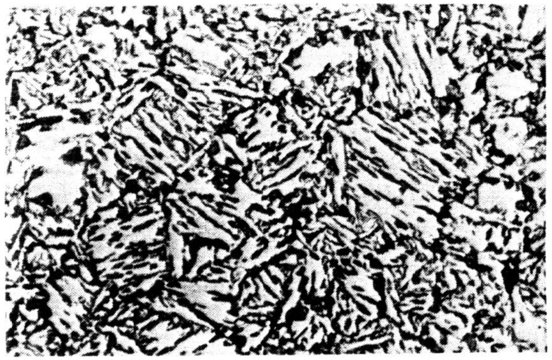

Fig.3 A typical optical micrograph of a dual phase steel

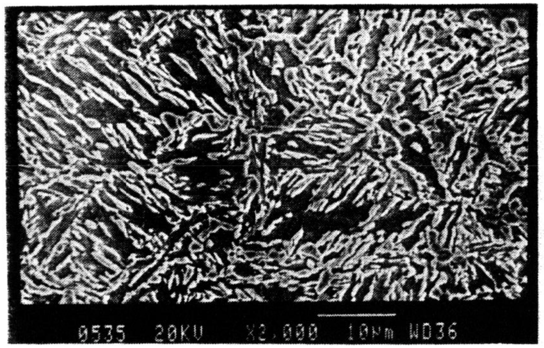

Fig.4 A typical scanning electron micrograph of a dual phase steel

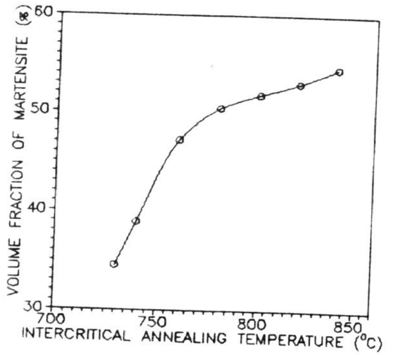

Fig.5 Martensite volume fraction versus different intercritical annealing temperatures.

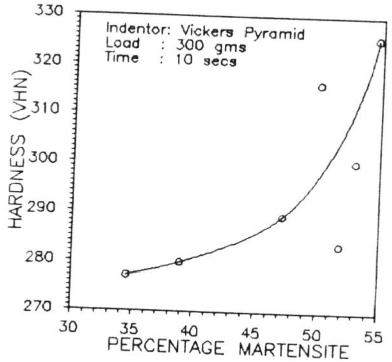

Fig.6 Variation of hardness with volume fraction of martensite

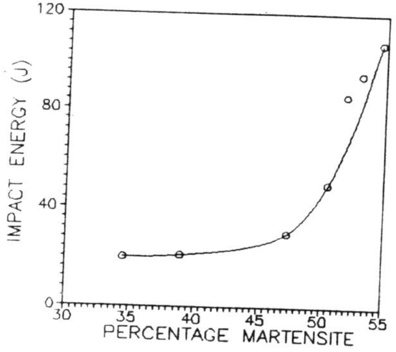

Fig.7 Variation of impact energy with volume fraction of martensite

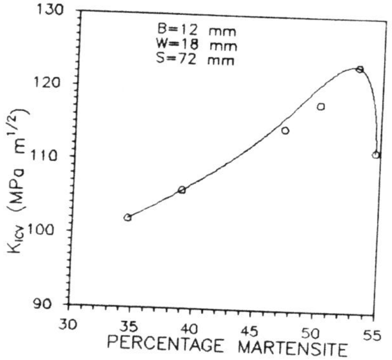

Fig.8 Variation of chevron notched fracture toughness (K_{ICV}) versus volume fraction of martensite

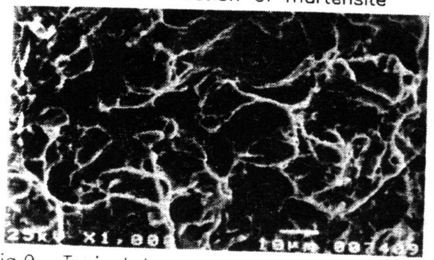

Fig.9 Typical transgranular cleavage in a dual phase steel containing 39% martensite

Fig.10 Dimple fracture morphology observed in a dual phase steel containing 50% martensite