IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

MECHANICAL CHARACTERIZATION OF FERRITE-MARTENSITE DUAL PHASE STEEL

Sunil B[*1] & Rajanna S[2]
[*1]Department of Mechanical Engineering, Siddaganga Institute of Technology, Tumakuru, VTU-Belagavi, India.
[2]Department of Mechanical Engineering, Government Engineering College, Kushalnagar, VTU-Belagavi,India

ABSTRACT
An investigation aimed at evaluating the mechanical properties of Dual Phase steels with varying ferrite-martensite phases has been carried out by Intercritical Quenching (IQ) (between Ac1 and Ac3) technique using low carbon steel as the starting material. The Intercritical temperature selected are 760oC, 780oC, 800oC, 820oC and the DP steels developed were named accordingly as A760, A780, A800, A820. The microstructure examination revealed the presence of ferrite and martensite phases along with minute amount of retained austenite. The volume fractions have been determined using optical microscope with image analyzer by manual point counting technique with circular grid. All the samples were prepared according to ASTM standards and tested accordingly for evaluating their mechanical properties such as tensile, impact, and Microhardness. From the obtained results the DP steel A780 which consists of 54% Ferrite and 43 % Martensite shown better mechanical properties with 585 MPa Yield strength, 923MPa Ultimate strength and 0.5MPa impact strength. The hardness keeps on increasing with the increase in the IQ temperature as the volume fraction of the martensite phase increases.

KEYWORDS-Dual Phase(DP) steel,Intercritical Quenching (IQ), Ferrite, Martensite, Mechanical Properties.

INTRODUCTION

The present day energy crisis has rendered widest of the challenges to the materials technologists to come out with new and improved materials having combinations of high strength, ductility and toughness. This has led to the development of dual phase steel, which represents a distinguished class due to its microstructure. Dual phase steel is a new class of high strength low alloy steel (HSLA) having the microstructure of strong Martensite in a soft ductile Ferrite matrix and small amount of retained Austenite and/or Banite[1-3]. These steels usually exhibit microstructure consisting of about 80 per cent ferrite and 20 per cent martensite, with small amounts of retained austenite depending upon chemistry and processing method adopted. In conventional forms dual phase steel exhibit highly desirable tensile properties like continuous yielding, high initial strain hardening and superior combinations of strength and ductility over that of HSLA steels [4]. Such optimized combinations of mechanical properties have already established their applications in energy efficient transportation system, like automobile industry i.e., from the vehicle point of view these steels provide greater weight reduction over other materials used. Thus the superior length elongation trade off translates into cost effective fuel economy gains [5].

LITERATURE SURVEY

The simplest of the DP steel in this category contain 0.08-0.2 % Wt C, 0.5-1.5 % WtMn, but steels micro alloyed with vanadium are also suitable, while small additions of Cr (0.5% wt) and Mo (0.2-0.4% Wt) are frequently used. These steels have relatively low yield stress of the order of 300-350 MN / m2. The reported results clearly demonstrate the attractive high formability strength property over that of conventional HSLA steels [3] [5]. In addition to this, these steels exhibit high crushing strength properties, and as a consequence these steels are used in automotive components like wheel discs and rims, bumper reinforcements, face bars, jack posts etc and it has been reported that such automotive parts of DP steels permit nearly 25 per cent weight reduction. The attractive combinations of mechanical Properties in dual¬ phase steels are generally attributed to emerge from the individual properties of its phases i.e. ferrite and martensite [6][7]. The primary role of martensite in DP steel is to impart high strength, while the nature and amount of ferrite governs its ductility and formability properties. Reports indicate that the strength of DP steel is a simple function of the volume fraction of martensite; but prediction of the existing is its ductility/formability characteristics is not straight forward, because these are significantly by morphologies of both ferrite and martensite [8][9]. Several attempts have been made to derive the overall mechanical properties of DP steels from the properties of the individual constituents using law of mixture type rules, and a few investigations have emphasized the importance of the nature of interface between ferrite and martensite for the expectation of substantial strengthening from the harder phase

The present investigation is to obtain the dual phase steels from its base material, which is High Strength Low alloy steel (HSLA steel) [10], and also to obtain the varying volume percentage of martensite by heat treating the base material at different inter critical temperatures. In this investigation varying volume percentage of ferrite and martensite were evaluated using Manual Point Counting (MPC) Technique and its micro structural properties were studied and thus the obtained micro structural properties were co-related with its mechanical properties. Different test specimens as per ASTM standards were prepared, tensile, hardness and impact tests were conducted for the prepared dual phase steels [11-14].

MATERIALS AND METHODS

Material

Commercial low carbon steel was selected as the starting material for making dual-phase microstructures by suitable heat treatments. The as-received steel was in the form of 8 mm thick hot-rolled plates in quenched and tempered condition. The chemical composition of the steel shown in Table.1 was ascertained with the help of a Spark emission spectrometer.

Table 3.1 Chemical composition (wt %) of the as received steel

C	Mn	S	P	Si	Cr	Mo	V	B	N
0.16	1.32	0.002	0.013	0.44	0.03	0.09	0.056	0.0019	0.4

Fig.3.1. Spark emission Spectrometer setup

Methodology

ISSN:2277-9655
(I2OR), Publication Impact Factor:3.785

To Obtain dual phase steel from the base material, an, Intermediate Quenching heat treatment process is followed as shown in Fig. 3.2a and 3.2b. Specimen blanks of size 210 x 70 x 8 mm were cut from hot rolled plates in quenched and tempered condition. The IQ treatment consisted of double quench operation where the specimen was first soaked at 920^0C for 30 minutes and was quenched in 9 per cent iced brine solution (7^0C) [15]. These were then held at different inter-critical temperatures of 760^0C, 780^0C, 800^0C and 820^0C for about 60 minutes and were finally quenched in preheated oil at 80^0C as shown in Fig. 3.3. The Table 3.2 shows the heat treatment schedules.

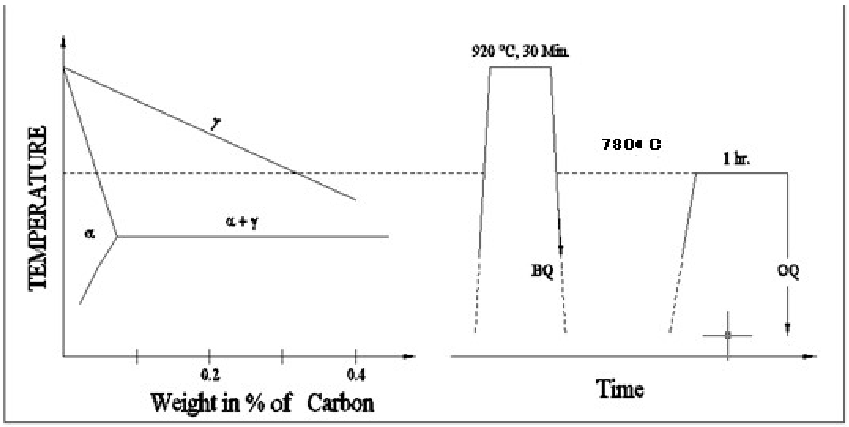


Fig. 3.3. Schematic representation of heat treat scheduled for intermediate quenching operation [4].

Table 3.2. Heat treatment schedules for achieving varied dual phase structures

Heat treatment	Specimen type of code	Austenitizing treatment for 30 mins at 920^0C followed by cooling in	Inter critical soaking temperature(^{0}C) for 60 mins	Final cooling media
Intermediate quenching	A 760 A780 A800 A820	Iced brine solution at 7^0C	760 780 800 820	Oil at 80^0C

Microstructure Examination

metallographic examination specimens were cut from the heat treated blanks in the transverse direction of the rolled plates polishing is done using buehlermetlap platen no 8, platen no 4 and on a nylon cloth,diamond slurry and texment paper cloth using a colloidal suspension (Buehler Masterpolish) at a wheel speed of 140 rpm. Thus the polished test specimens (A760, A 780, A800, A820) was cleaned with Nital sodium meta bi sulphide etchant and examined using EPHI PHOT NIKON microscope of 400x magnification.

Volume Fraction Determination

To determine the volume fraction of the phases involved, by a systematic manual method, in which point-counting technique was employed by following the ASTM standard E562 and thereby estimating the volume fraction of an identifiable constituent of phase from sections through the microstructure[16][18].

The following volume fraction (v_f) of a phase was evaluated using the relation

$$V_f = P / NP_o \qquad \text{------------------- (3.1)}$$

Where

V_f: is the Volume fraction
P: is the total no of points on a phase
P_o: is the no of grid points
N: is the no of fields of observation

And the results of the Quantitative micro structural analysis are shown in the Table 3.3 and corresponding variation of martensite with respect to intercritical temperature are shown in Fig. 3.5.

Table 3.3 Results of the quantitative micro structural analysis

Specimen code	Volume percentage		Retained austenite (%)
	Ferrite (%)	Martensite (%)	
A 760	68.8	31.2	------
A780	54.78	43.05	2.17
A800	47.7	51.04	1.26
A820	39.29	59.07	1.34

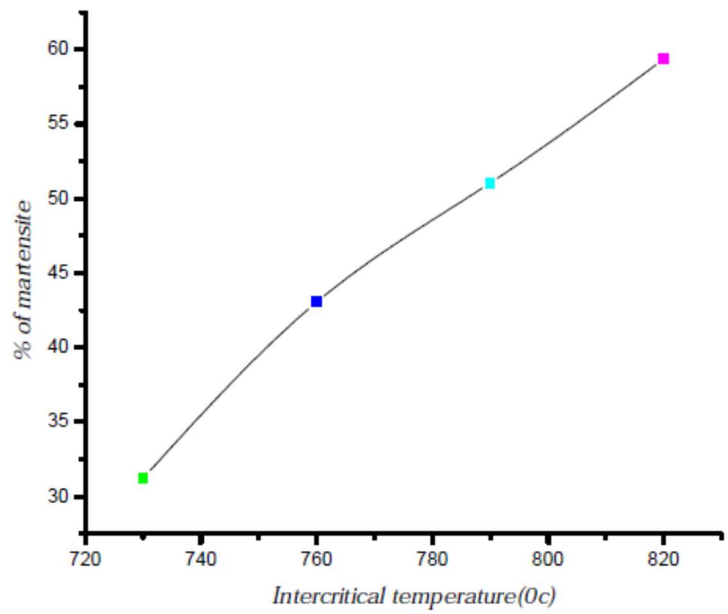
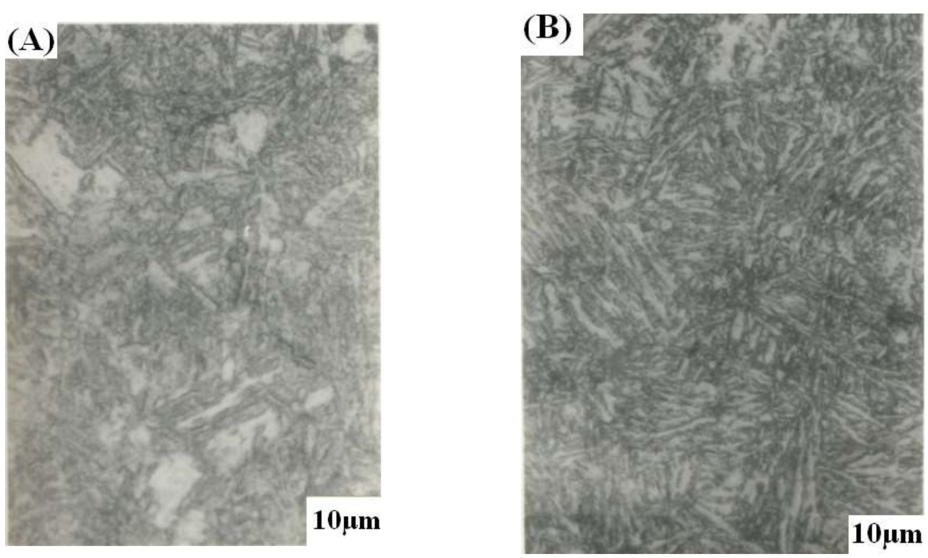


Fig.3.5. Volume percentage of martensite versus ICT in the investigated IQ microstructure



ISSN:2277-9655
(I2OR), Publication Impact Factor:3.785

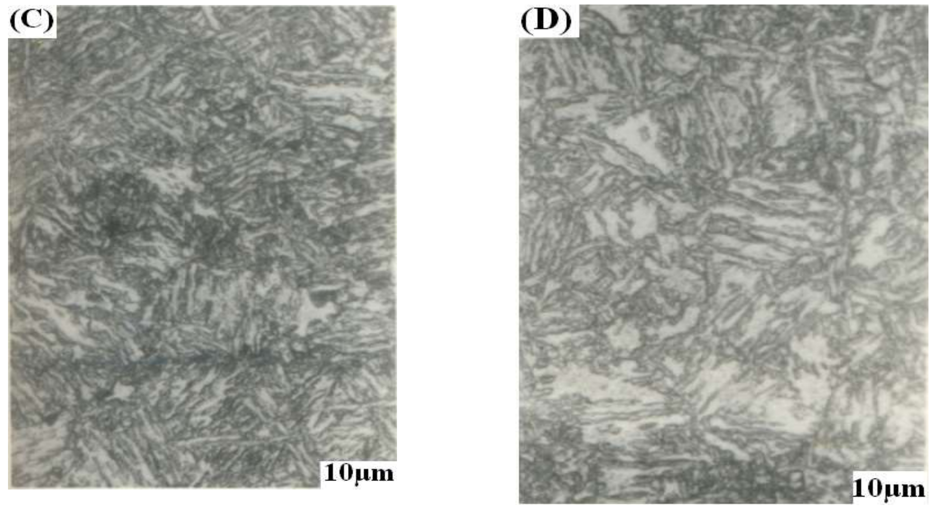


Fig .3.6. representative IQC optical micro graphs corresponding to ICT at:
(A) 760^{0}C (B) 780^{0}C (C) 800^0 C (D) 820^{0}C

From Figure 3.6 the microstructure indicates that composite mixture of ferrite (black) and martensite (white) having plate morphology. The ferrite region appears to remain enveloped by globular martensitic regions but dispersed with both globular and plate martensitic domains. Tempered martensite may be nearly as hard and strong as martensite, but with substantially enhanced ductility and toughness. The hardness and strength may be explained by the large ferrite-cementite phase boundary area per unit volume that exists for the very fine and numerous cementite particles again, the hard cementite phase reinforces the ferrite matrix along the boundaries, and this boundary also act as barriers to dislocation motion during plastic deformation [18].

By the study of microstructure, we can conclude that mechanical properties are mainly dependent on grain size, distribution of grains, shape of the grain size and nonmetallic inclusions. Here we can also examine that mechanical properties are also dependent on uniform distribution of ferrite and martensite. By examining all the four micro structure and test results of (A 760, A780, A800, A820), we can conclude that A780 as better microstructure which increases mechanical property then other specimens**.** Since A 780 have fine grain size, better bonding between the molecules. At this temperature effective phase transformation of austenite in to martensite takes place. A 780 is clean ferrite, uniform grain size, no dislocation and free from interstitial impurities and precipitates found at inter face of ferrite and martensite lattice. Parallel plate grain orientation in different direction and angle is found in the microstructure of A 780. In A 780 percentage of ferrite (54.78%) is greater than martensite (43.05%)which gives good strength and toughness.

In A760 a certain active sites are found at the ferrite phase. These sites are unsaturated atoms resulted in the form of surface irregularities, edge dislocation, improper crystals growth and crack along grain boundaries. As it can be seen micrographs of the specimen with volume percentage of martensite varied from 28- 31 per cent consists of fine particles of undissolved carbide. For A800 minor cracks are observed at the intersection of ferrite and martensite grain boundaries. De-bonding of manganese sulphides (black) and aluminum sulphide are observed in the microstructure which are impurities [23]. In A820 it reveals some fine black dot dispersed in ferrite, this dot represent undissolved carbide particles formed during transformation of ferrite to martensite. Tetragonal distribution of martensite lattice with higher dislocation leads to faster rate of crack propagation.

RESULTS AND DISCUSSION

Mechanical Properties

Tensile Test

The tensile test for the specimen was carried out at room temperature (25^{0}C) using nominal strain rate of 1x 10^{-3} / s.

These specimens were tested for each varied states microstructure of DP steels. The resulted were obtained as autographic records of load-elongation. The load - elongation graphs were digested and the data obtained were first computed in order to obtain a tensile parameter like yield strength, tensile strength, uniform elongation, and total-elongation. The yield strength was estimated using 0.2 strain off set method as suggested in the ASTM standards E8M-94. From this test it is found that DP steel has better yield strength (586MPa) and ultimate strength (927.33MPa) when compared to low carbon mild steel where yield strength is (328MPa) and ultimate strength (617MPa). The yield strength and ultimate strength of DP steel depends on volume fraction of martensite and ferrite. Volume fraction can be varied based on heat treatment process. Martensite gives good strength, toughness and ferrite gives good ductility, elongation to the material. Hence to use DP steel for practical application it should have better combination of ferrite and martensite phase. Here tensile test is carried for different temperatures (A760, A 780, A800, and A820) of DP steel specimens. The test results are tabulated in the Tables 4.1 and stress $_{V/S}$ strain plots are plotted as shown in Figs. 4.1, 4.2, 4.3 and 4.4. From these results we come to know that A 780 and A800 have better combination of ferrite and martensite. Here A760 has higher percentage of ferrite which leads to higher ductility and elongation [15]. Due to this elasticity will be more and ultimate load decreases which limit the practical applications. The material A820 have higher percentage of martensite which gives good ultimate strength but brittleness is more which leads to catastrophic failure.

Table 4.1 Tensile data for IQC specimens

Specimen code	**Yield strength (MPa)**	**Tensile strength (MPa)**	**% Elongation total**
A760	610	805	26
	595	787	
	613	809	
A 780	580	917	22
	585	923	
	593	942	
A800	542	937	19
	547	945	
	553	957	
A820	505	970	15
	518	965	
	520	982	

ISSN:2277-9655
(I2OR), Publication Impact Factor:3.785

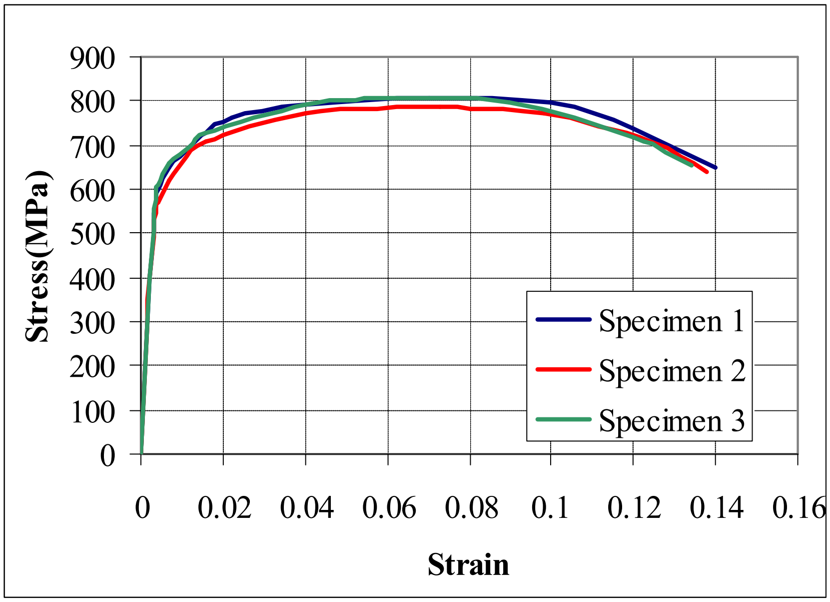


Fig. 4.1. Engineering stress-strain diagram of IQC DP-steels for A 760 coded specimen

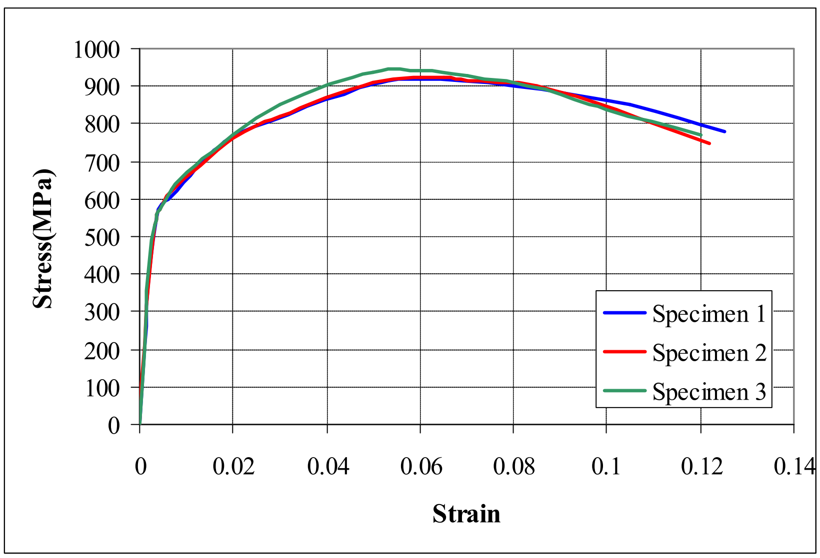


Fig. 4.2. Engineering stress-strain diagram of IQC DP-steels for A 780 coded specimen

ISSN:2277-9655
(I2OR), Publication Impact Factor:3.785

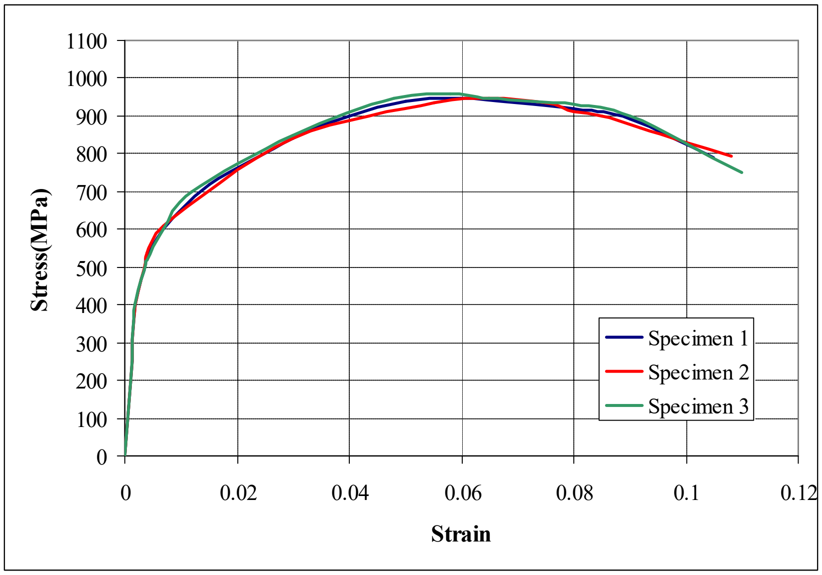


Fig. 4.3. Engineering stress-strain diagram of IQC DP-steels for A 800 coded Specimen

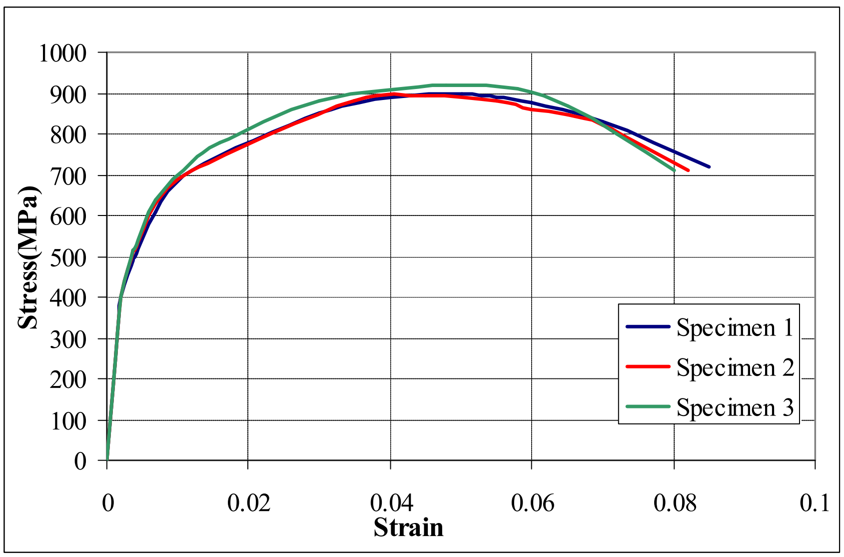


Fig. 4.4. Typical engineering stress strain diagram of IQC DP-steels for A 820 coded specimen

Impact Test

Impact test were carried out on standard charpy V-notch (CVN) bars following ASTM E-23 specification CVN type specimens as shown in the figure 5.5a and 5.5b [18] The test was carried out at room temperature of 25^{0}C using a standard pendulum type impact testing machine Where the specimen is simply supported.

figure 4.5a

figure 4.5b

Table 4.2 Charpy V- notch impact Test results

Specimen	V_m%	Average	Impact
A760	31.2	25	0.3125
A 780	43.05	40	0.5
A800	51.04	33.66	0.4208
A820	59.37	28.33	0.3541

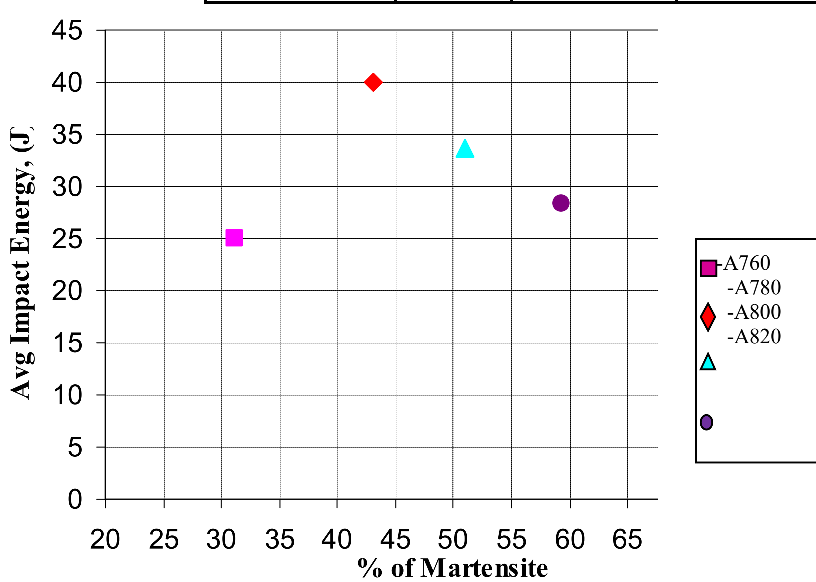


Fig. 4.5. variation of the Average Charpy impact energy values with volume % of Martensite

It is found that A 780 DP steel absorbs good amount of impact energy and it is attributed to the martensite volume fraction present in it. Since A760 have greater percentage of ferrite (68.8%) which has higher ductility, hence resistance to impact energy is less. A820 have greater percentage of martensite (59.37%) which gives more brittleness, hence resistance to impact load is less.

From these results we can conclude that DP steel should have higher percentage of ferrite than martensite within the specified limit to resist impact load where ferrite provides the ductility and martensite gives strength.

Micro-hardness

The micro hardness values of the IQ samples were determined using a LECO-DM 400 BRINELL HARDNESS TESTER. All specimens used for micro hardness characterization were inthe polished and etched condition, but special care were taken to eliminate the possible deformed layers on each specimen by repeated polishing and etching as shown in Fig. 5.9. Micro hardness measurements were carried out using a circular shaped tungsten carbide indenter and readings were taken for 3000 Kg load for fixed loading durations of 10 seconds in all cases.

Fig. 4.9. Specimen employed for hardness test

Table 4.3 Average Brinell hardness number values

Specimen	V_m%	AVG
A760	31.2	280
A 780	43.05	293
A800	51.04	317
A820	59.37	332.33

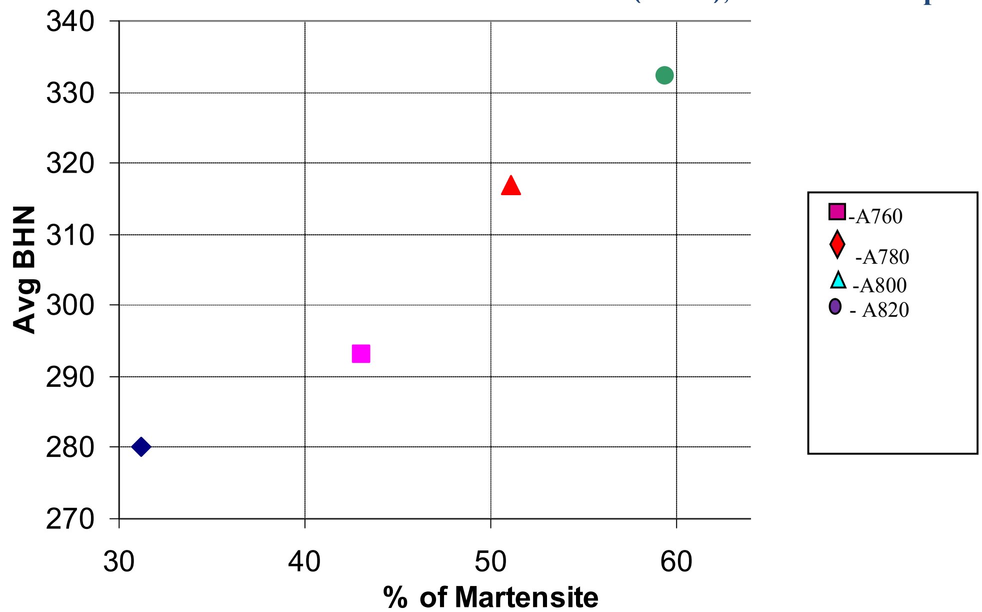


Fig. 4.6. Variation in micro hardness with volume % of martensite in IQ specimen

From Fig. 4.6 and Table 4.3 it can be observed that hardness value increases with increasing V_m per cent in the range between 30-60 per cent. But at higher hardness material becomes brittle and machining becomes cumbersome. If the material is brittle catastrophic failure may occur and crack propagation will takes place at faster rate. The increase in the hardness of the material is attributed to the finer distribution of marten site and ferrite obtained by increase in the IQ temperature. At lower IQ temperatures the ferrite distribution is coarser due to the presence of carbide precipitates.

CONCLUSION

1. Intermediate quenching of low carbon steel yielded a material with a ferrite and martensite grain structure. The volume fraction of martensite (V_m) increased with intermediate quenching time.
2. From the studies made, it was found that A 780 has better grain refining, solid solution strengthening and unique combination of strength and ductility as compared to other heat treated specimens (A760, A800 and A820).
3. DP steel exhibits continues yielding which has no sharp yield point and has a relatively low yield stress and it also have lesser weight to strength ratio when compared to mild steel because yield and ultimate strength of DP steel is higher than the mild steel (σ_{ys}= 328MPa and σ_{us}= 617MPa).
4. The intermediate quenching heat treatment procedure was so effective in improving the mechanical properties like tensile strength, impact toughness, hardness, bending strength and fracture toughness of developed DP steel due to effective phase transformation of austenite to martensite.
5. The A 780 DP steel has yield strength of 586MPa and ultimate tensile strength of 927MPa which is much higher than other heated treated specimens. Here A 780 has better combination of ferrite and martensite which gives good ductility and strength. The material A800 and A820 has higher per cent of martensite which gives good ultimate tensile strength than A 780 but brittleness is more which leads to catastrophic failure.
6. The hardness and impact toughness values of A 780 DP steel specimen with finely distributed constituents (V_m=43.05%) is superior to those of coarse microstructure materials such as A73, A79 and A82. The best combination of hardness and impact strength values were observed for A 780 specimen. This is attributed to the finer micro structural constituents and carbide free ferrite obtained in A 780 material.

REFERENCES

[1] A. Kumar, S.B. Singh, K.K. Ray, Influence of bainite/martensite-content on the tensile properties of low carbon dual-phase steels, Materials Science and Engineering A 474 (2008) 270–282. doi:10.1016/j.msea.2007.05.007
[2] Huaxin Li, R.H. Jones J.P. Hirth, D.S. Gelles. "Effect of loading mode on the fracture toughness of a

reduced-activation ferritic/martensitic stainless steel", Journal of Nuclear Materials, 212-215 (1994) 741-745.

[3] J.S. Dubey, S.L. Wadekar, J.K. Chakravartty, "Elevated temperature fracture toughness of AISI 403 martensitic stainless steel", Journal of Nuclear Materials, 254 (1998) 271–274.

[4] S. Ulu, H. Aytekin, G. Said "An alternative approach to the fracture toughness of dual phase steels", Strength of Materials, Vol. 45, No. 5, 2013. https://doi.org/10.1007/s11223-013-9498-2.

[5] Kenneth KanayoAlaneme, "Fracture Toughness (K1C) Evaluation for Dual Phase Medium Carbon Low Alloy Steels Using Circumferential Notched Tensile (CNT) Specimens", Materials Research, 14(2), 2011 pp 155-160.

[6] M. Tayanc, A. Aytac, A. Bayram, The effect of carbon content on fatigue strength of dual-phase steels, Materials and Design 28 (2007) 1827–1835. doi:10.1016/j.matdes.2006.04.016.

[7] YangboLiu,ShouxinLi,Zhengou Yang, JingyuCui,JialinGu, and Bingzhe Bai, Improving fatigue strength of bainite/martensite dual-phase steels in very high cycle fatigue regime by refining microstructures, Theoretical & Applied Mechanics Letters 2, 031005 (2012).

[8] N. Farabi, D.L. Chena, Y. Zhou, Fatigue properties of laser welded dual-phase steel joints, Fatigue 2010, Procedia Engineering 2 (2010) 835–843. doi:10.1016/j.proeng.2010.03.090

[9] D. Parkes, W. Xu, D. Westerbaan, S.S. Nayak, Y. Zhou, F. Goodwin, S. Bhole, D.L. Chen, Microstructure and fatigue properties of fiber laser welded dissimilar joints between high strength low alloy and dual-phase steels, Materials and Design 51 (2013) 665–675. http://dx.doi.org/10.1016/j.matdes.2013.04.076

[10] B. Wang, Q.Q. Duan, G. Yao, J.C. Pang , X.W. Li, L. Wang, Z.F. Zhang, Investigation on fatigue fracture behaviors of spot welded Q&P980 steel, International Journal of Fatigue (2014). http://dx.doi.org/10.1016/j.ijfatigue.2014.03.004

[11] Lee, J.H., Park, S.H., Kwon, H.S., Kim, G.S., Lee, C.S., Laser, tungsten inert gas, and metal active gas welding of DP780 steel: comparison of hardness, tensile properties and fatigue resistance, Materials and Design (2014), doi: http://dx.doi.org/10.1016/j.matdes.2014.07.065

[12] P. Movahed, S. Kolahgar, S.P.H. Marashi, M. Pouranvari, N. Parvin, The effect of intercritical heat treatment temperature on the tensile properties and work hardening behavior of ferrite–martensite dual phase steel sheets, Materials Science and Engineering A 518 (2009) 1–6. doi:10.1016/j.msea.2009.05.046

[13] S Rajanna, HK Shivanand, BN Akash Deep. Improvement in mechanical behavior of expulsion with heat treated thermite welded rail steel, Proc. of World Academy of Science, Engineering and Technology, Vol 60, (2009) P558-562.

[14] M.A. Maleque, Y.M. Poon, H.H. Masjuki, The effect of intercritical heat treatment on the mechanical properties of AISI 3115 steel, Journal of Materials Processing Technology 153–154 (2004) 482–487.

[15] Ahmad Zare, Influence of martensite volume fraction on tensile properties of triple phase ferrite– bainite–martensite steels, Materials Science and Engineering: A, Vol 350, (2011) 440-44.