IRJET International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 09 | Sep 2020 www.irjet.net p-ISSN: 2395-0072

Microstructural Studies on Dual-Phase Steels After Metal Inert Gas (MIG) Welding Process

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ABSTRACT: *Microstructure of dual steels with different volume fractions of martensite are studied after Metal inert gas welding a commercial low carbon steel was selected as base material for making dual-phase microstructures by suitable heat treatments. The as-received steel was in the form of 16 mm thick hot-rolled plates. The IQ treatment consists of double quench operation. The specimens were first soaked at 920^{0}C for 30 minutes and were quenched in ice-brine solution. These were then held at different intercritical temperatures, (ICT) (720,750, 780, 810,830 and 850^{0}C) for 60 minutes and were finally quenched in oil and their microstructures of welded specimens are investigated.*

KEYWORDS;- Dual-Phase Steels, Microstructure, MIG Welding.

1. INTRODUCTION

The most important aspect of any engineering material is its structure. The structure of a material is related to its composition, properties, processing history and performance. Studying the microstructure of a material provides information linking its composition and processing to its properties and performance. Interpretation of microstructures requires an understanding of the processes by which various structures are formed. When low-carbon and low-alloyed steels are annealed between the AC1 and AC3 and then water quenched, due to partial transformation dual phase structure taking place with the mixture embedded martensite islands within the grains of ferrite is usually obtained [1,2]. Dual phase steels belong to the class of high-strength low-alloy (HSLA) steels with composite microstructure consisting of hard martensite particles located in a soft ferrite matrix [1, 2]. Such a structure is obtained by heating in the intercritical temperature range (the double-phase range of existence of austenite and ferrite) and subsequent cooling at a rate sufficient for the transformation of an optimum amount of austenite into martensite [1 – 5]. The heating temperature controls the volume fraction of austenite in the metal and thus affects the hardenability of individual “islands” of austenite. At critical cooling rates the austenite is fully transformed into martensite, which causes formation of a ferrite and martensite mixture. At low cooling rates the “islands” of austenite become smaller due to the epitaxial growth of ferrite on retained ferrite; at still lower cooling rates the carbon- enriched retained austenite transforms into martensite, bainite and_or pearlite depending on the degree of alloying of the austenite and on the cooling rate. The presence of different phases in the microstructure after heat treatment is commonly determined by the initial composition of the alloy [1 – 6]. After etching in a 2% solution of nital and then in a 10% aqueous solution of sodium metabisulfate, martensite in steels with dual structure is colored brown, ferrite acquires a white color, and the ferrite-carbide mixture (pearlite + bainite) becomes black.

The presence of a dual structure ensures excellent mechanical properties in commercial high strength low-alloy steels and number of unique mechanical properties such as gradual transition to the beginning of plastic yielding, low ratio of the yield strength to the rupture strength, high rate of strain hardening, and uniform elongation. Studies [6 – 9] have shown that the volume fraction of martensite (VFM) is a factor determining the strength and ductility of dual-phase steels. It has been established that an optimum combination of properties is obtained in the presence of 20 vol.% martensite in the structure. At a constant VFM a microstructure with fine dispersed martensite ensures a better combination of strength and ductility than a microstructure containing coarser martensite [10 – 12]. The high rate of strain hardening and the uniform elongation of dual-phase steels are responsible for the excellent formability. Combination of these properties with high rupture strength makes these steels very attractive from the standpoint of reducing the mass of automotive parts, which ensures additional saving of fuel [13, 14, 16]. A uniform microstructure with appropriate volume ratio, geometry and aspect ratio of martensite islands are often assigned suitable for mechanical properties assessments [3]. Dual phase steels are preferred in the automotive industry due to their low density and high load bearing capacity [4]. There have been many investigations on the micro structural development and mechanical properties of dual phase steels. It has generally been found that rather than the size, the volume fraction of the martensite islands is very effective on tensile properties [5]. Increasing the amount of martensitereduces the percent elongation considerably. Dual phase steels mostly have low yield strength, but on the contrary have high strain hardening rates during deformation [6]. It is not possible to find any study focusing on the effects of initial ferrite, pearlite and martensite grain sizes on microstructure. It has been verified that microstructure particularly after an intermediate quenching treatment is different from that after an intercritical quenching process [7]. Thus, formation of fine martensite after intermediate quenching mostly degrades the tensile properties, but the percent elongation of the material increases gradually. This has been attributed to an increase in the density of mobile dislocations in the ferrite, while the mean grain size and the interparticle distance between the fine martensite islands becomes smaller [3, 8].In the welding of low-carbon steels, it has been shown that the grain-coarsened (GCZ) and heat affected (HAZ) zones are very critical since embrittlement is concentrated these areas.

Literature survey indicates that, a dual-phase steel over the last three decades is limited to microstructures containing volume fraction of martensite (Vf) within avout 25%. The major cause for this limitation is the apprehension that, though strength gradually increases, ductility and impact toughness may decrease beyond 25% of martensite content and much research work has not been reported covering the entire range of composite microstructure of soft ferrite and hard martensite of different welding techniques, Specifically the DP steels containing higher [>25%] martensite have not been well studied. Therefore in the present investigation, it has been planned to carryout systematic studies in the area of mechanical properties of welded joint of dual-phase steels of thicker sections using Metal Inert Gas (MIG) Welding process.

2. MATERIALS AND METHODS

2.1 Material

Micro alloyed steel of 350X150X16mm thick hot rolled stock was selected for this study. The composition of the material was determined using optical Emission spectrometer BAIRD-DV6E. Chemical composition in weight percentage of the base material was found to be 0.183% c, 0.678% Mn, 0.021% S, 0.022% P, 0.051% Si, <0.050% Cr, <0.020% Mo, and 0.039% Ni by weight percent of the steel.

2.2 Development of Dual-phase steel by Heat treatment

Specimen blanks of size 350mm x 150mm x 16mm were subjected to Intermediate Quench (IQ) heat treatment using a gas carbon furnace. The IQ treatment consists of double quench operation , the specimens were first soaked at 920 ^{0}C for 30 minutes and quenched in iced-brine solution and then held at different intercritical temperatures, (ICT) (720, 750, 780, 810,830 and 850^{0}C) for 60minutes and finally quenched in an oil. The temperature control for the intercritical soaking in IQ treatment was within +2^{0}C. Precautions were taken to obtain uniformity of cooling during quenching operations by continuous stirring of the oil bath.

Table 1. Heat treatment schedule for achieving varied dual-phase microstructure

Type of heat treatment	Austenitizing Treatment for 30 min at 920^0 C followed by cooling	Intercritical soaking temp(^{0}C) for 60 min	Final cooling media
Intermediate Quenching(IQ)	Iced-brine Solution	720	OIL
		750	
		780	
		810	
		830	
		850	

2.3 Welding Parameters and Procedure for Metal Inert Gas Welding (MIG) Process.

The Welding parameters of dual phase steels plates of 16mm thick using Metal Inert Gas Welding (MIG) Process were optimized using bead on plate experiment[12].The process parameters as follows the electrode of 1.2 mm diameter, current of 90Amps – 300Amps, voltage of 18volts – 30volts,and heat input of 0.4KW to 0.7KW, Grade of the electrode AWS 5.18 ER 70S6 (E7018), Number of pass 4 with carbon dioxide(CO_2) as an inert gas. Using these welding parameters the welding was carried out and after welding these specimens were subjected to non destructive testing such as radiographic test and Ultrasonic Inspections to ensure the soundness of the joint and only sound welds were used for this investigation.

3. METALLOGRAPHIC STUDIES

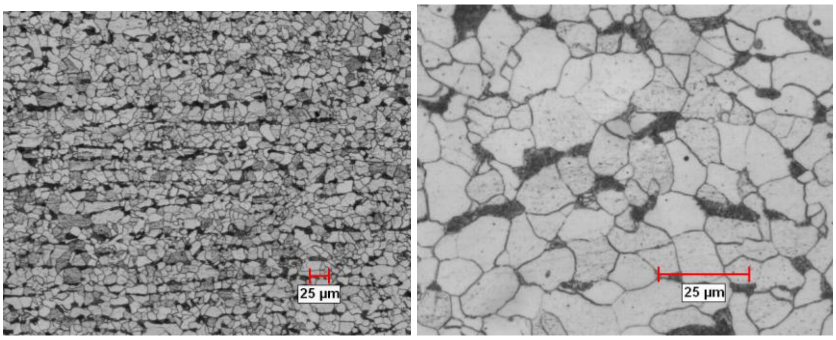
Small samples were difficult to hold safely during grinding and polishing operations, and their shape was not suitable for observation on a flat surface. They were therefore mounted inside a polymer block. Grinding was done using rotating discs covered with silicon carbide paper and water. There are a number of grades of paper, with 180, 240, 400, 800, 1200, 1500, 2000 grains of silicon carbide per square inch. 180 grade therefore represents the coarsest particles and this is the grade to begin the grinding operation. Always use light pressure applied at the centre of the sample. Continue grinding until all the blemishes have been removed, the sample surface is flat, and all the scratches are in a single orientation. Wash the sample in water and move to the next grade, orienting the scratches from the previous grade normal to the rotation direction. This makes it easy to see when the coarser scratches have all been removed. After the final grinding operation on 2000 paper, wash the sample in water followed by alcohol and dry it before moving to the polishers.

The polishers consist of rotating discs covered with soft cloth impregnated with diamond particles (6 and 1 micron size) and an oily lubricant. Begin with the 6 micron grade and continue polishing until the grinding scratches have been removed. It is of vital importance that the sample is thoroughly cleaned using soapy water, followed by alcohol, and dried before moving onto the final 1 micron stage. Any contamination of the 1 micron polishing disc will make it impossible to achieve a satisfactory polish. Transverse metallographic specimens of the dual-phase steel and specimens passing through the central part of the welded pieces were prepared by a standard method and analyzed the microstructure using a Nikon microscope LV150 with clemex Image analyser.

4. RESULTS AND DISCUSSION

4.1 Microstructure of Base Metal

The Microstructure of the Base metal at 100x and 500x using Nikon microscope LV150 with clemex Image analyser.



100X 500X

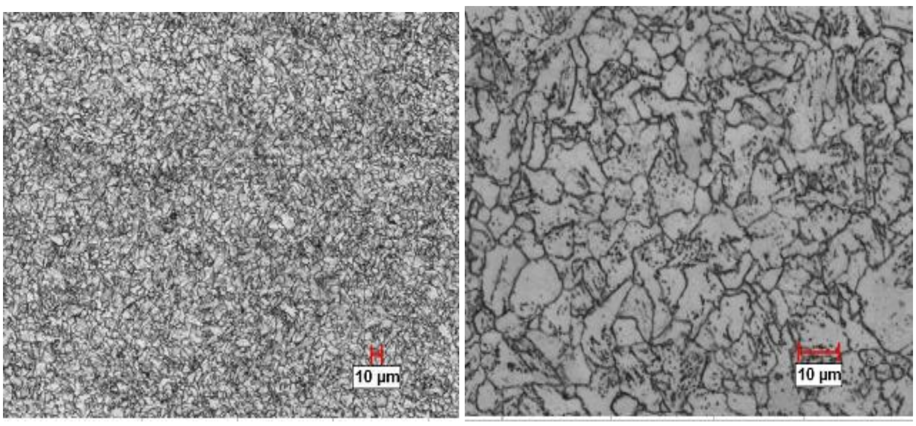
Fig.1. Micro Structure of Base metal

Microstructure consists of fine grains of ferrite (~90%) with bands of pearlite. It is in rolled condition.

4.2 microstructure of dual-phase steel

The microstructure of the dual-phase steels obtained after different intercritical temperatures, (ICT) (720,750, 780, 810,830 and 850^{0}C) for 60minutes and were finally quenched in oil. We established that it consisted of light brown (martensite) and white (ferrite) phases. It can be seen from the figures that the dual-phase steel has primarily equiaxed grains.

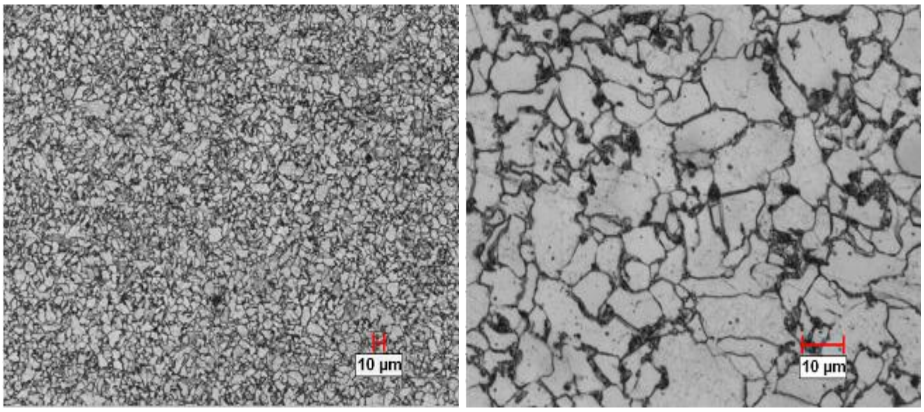
Dual phase-720^0 C



100X 500X

Microstructure consists of ferrite and Martensite (~5%).ferrite grain size no.8

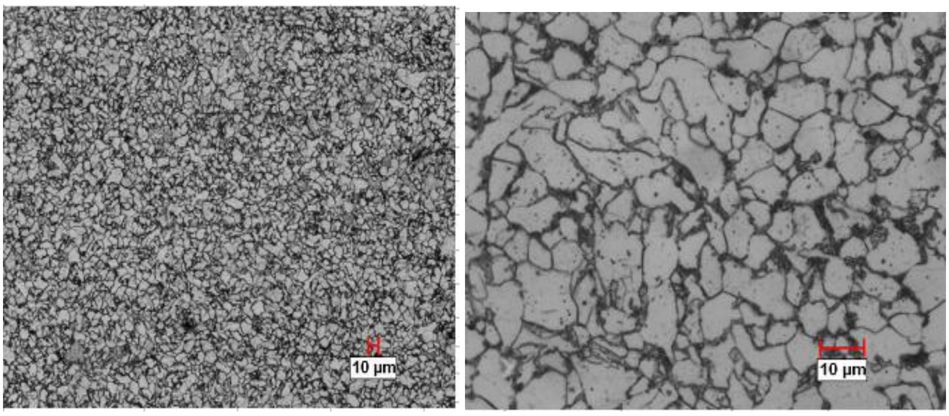
Dual phase-750^0 C



100X 500X

Microstructure consists of ferrite and Martensite (~10%).ferrite grain size no.8

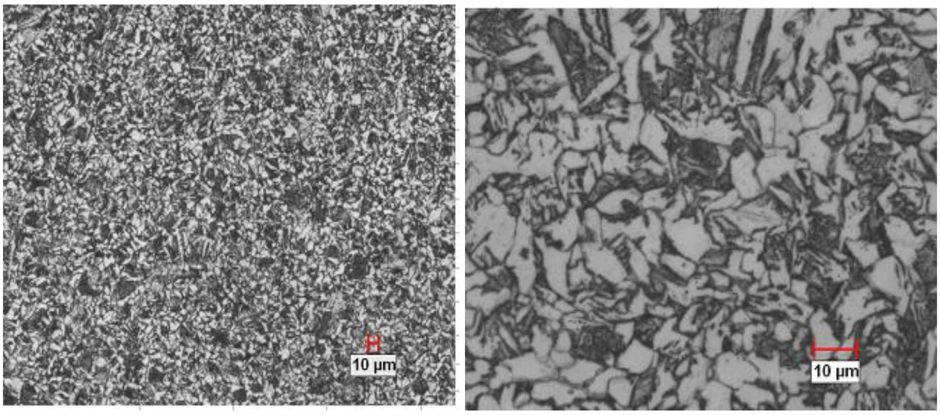
Dual phase-780^0 C



100X 500X

Microstructure consists of ferrite and Martensite (~15%).ferrite grain size no.8

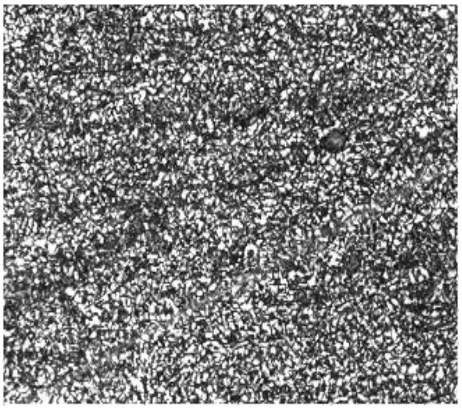
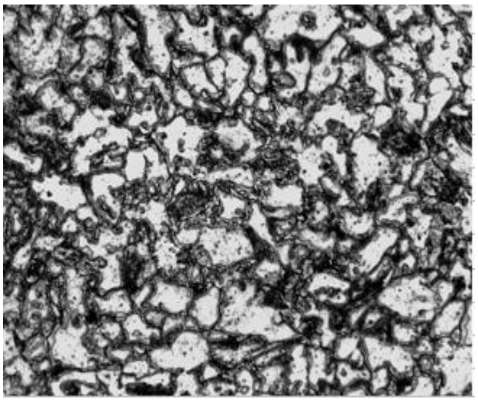
Dual phase-810^0 C



100X 500X

Microstructure consists of ferrite and Martensite (~20%).ferrite grain size no.8

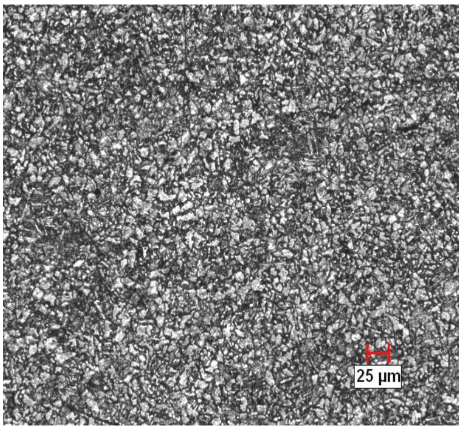
Dual phase-830^0 C

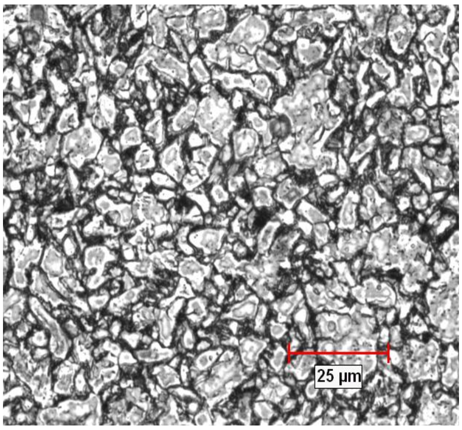



100X 500X

Microstructure consists of ferrite and Martensite (~25%).ferrite grain size no.8

Dual phase-850^0 C





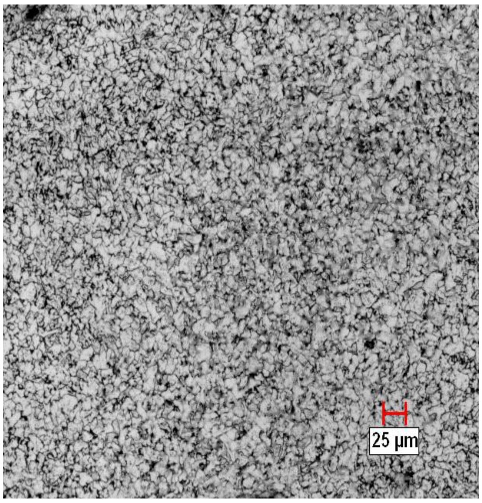
100X 500X

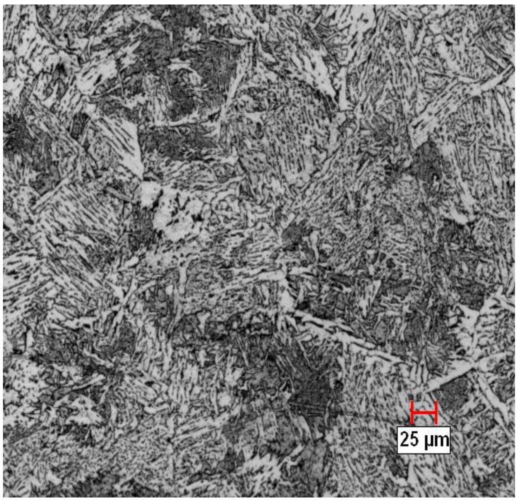
Microstructure consists of ferrite and Martensite (~35%).ferrite grain size no.8

4.3 Micro structural observation of weld gradient

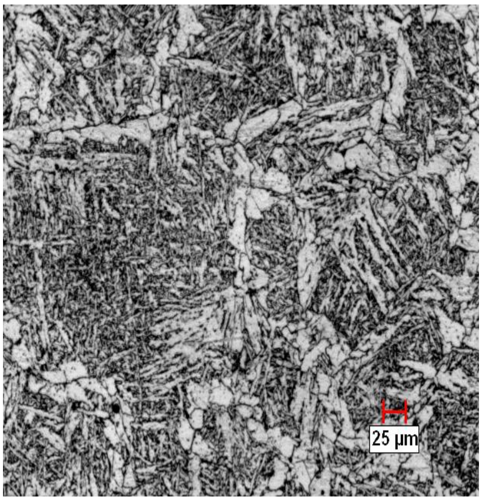
A welded assembly consists of three different zones weld metal, Heat Affected Zone (HAZ) and base metal, each zone will have different micro structural characteristics ,figures represent a typical micro structural gradient of weld metal, HAZ and Base metal of different weldments. The weld metal microstructure zone in the entire welded specimen shows dendritic structure of ferrite, pearlite and martensite, along with precipitates and carbides as shown in below Figures. The HAZ reveals three distinct regions namely i) fusion region ii) normalized region and iii) transition region. The microstructure of these regions consisted of martensite, tempered martensite, ferrite and few amounts of carbides. However, significant differences in grain size have been observed in these regions due to the exposures of HAZ over a range of temperatures during welding. The fusion region was exposed to higher temperature than other regions which is having coarse grains. Where fine grains were found in normalized region and transition region. The HAZ of all the specimens consists of small amount of precipitates (black small dots). These precipitates were formed due to the precipitation of some alloying elements like Boron, Molybdenum and Vanadium during welding.

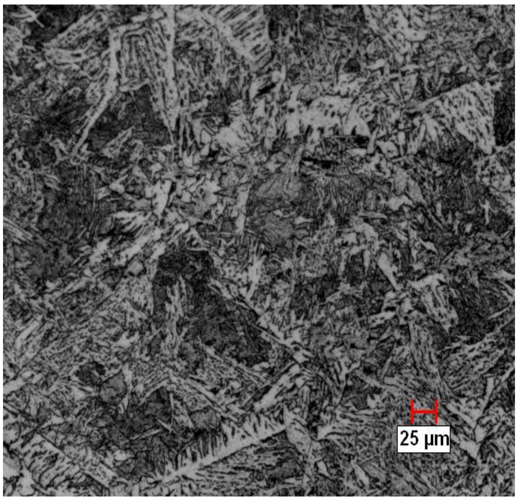
A typical microstructure gradient of weldmetal-HAZ-Basemetal corresponding to weldment specimen 720°C at 100X





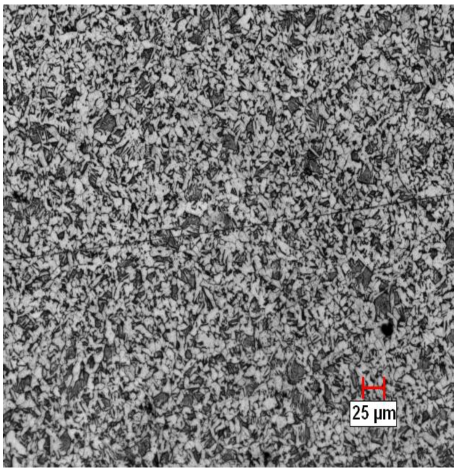
BASE HAZ1

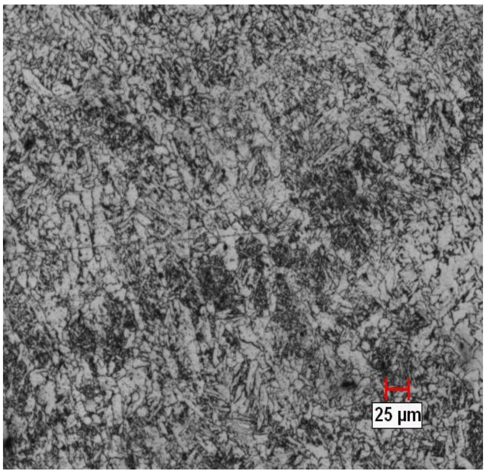




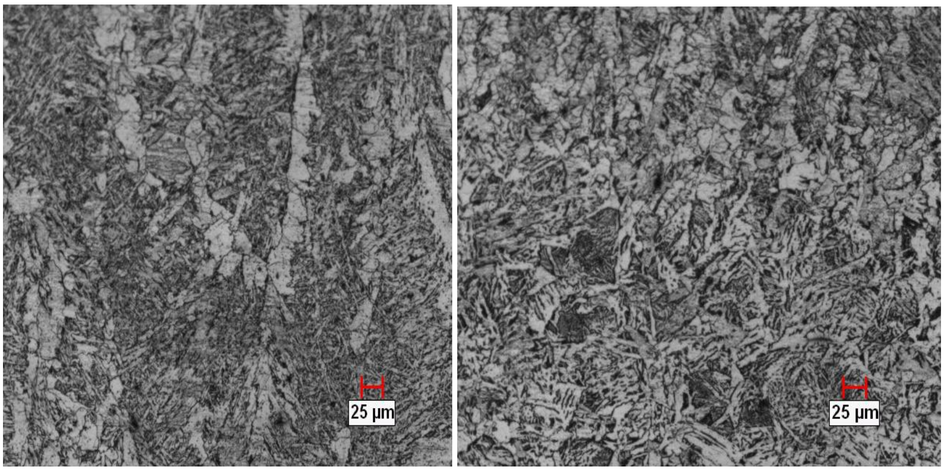
WELD HAZ2

A typical microstructure gradient of weldmetal-HAZ-Basemetal corresponding to weldment specimen 750°C at 100X



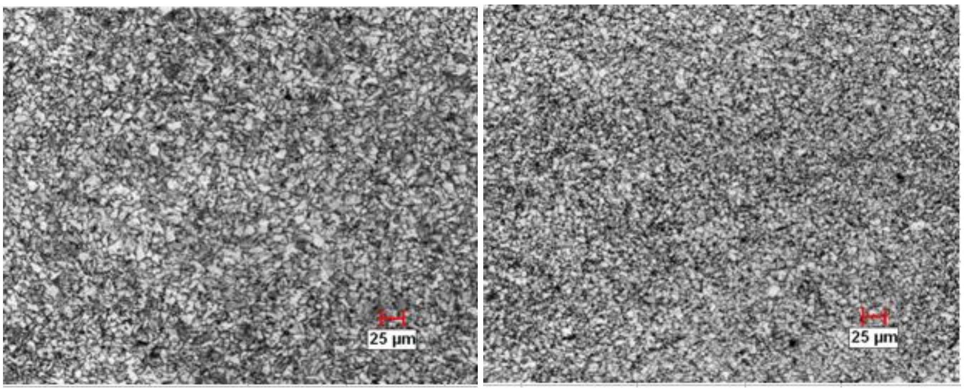


BASE HAZ1

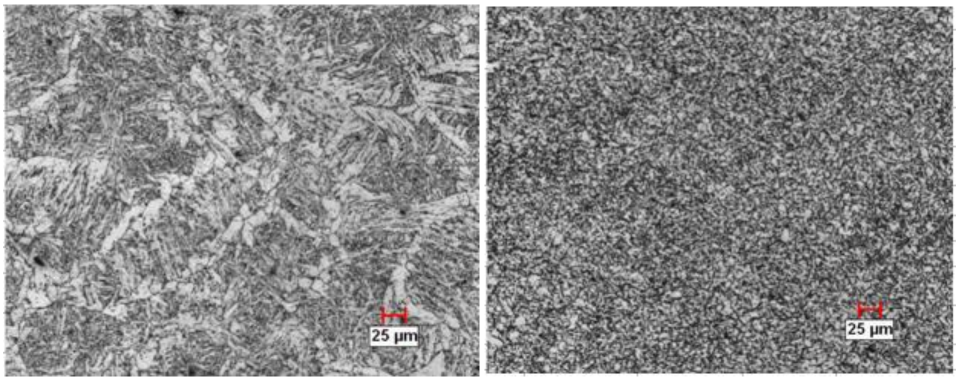


WELD HAZ2

A typical microstructure gradient of weldmetal-HAZ-Basemetal corresponding to weldment specimen 780°C at 100X

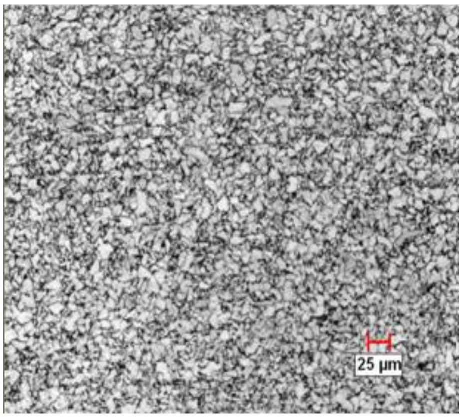


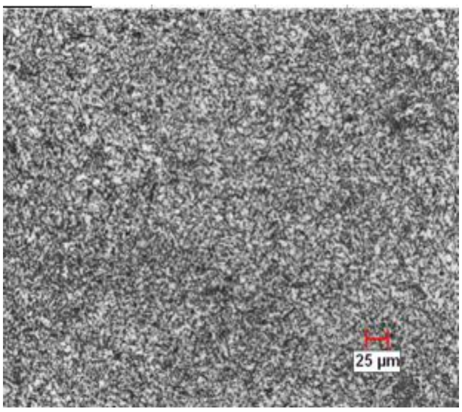
BASE HAZ1



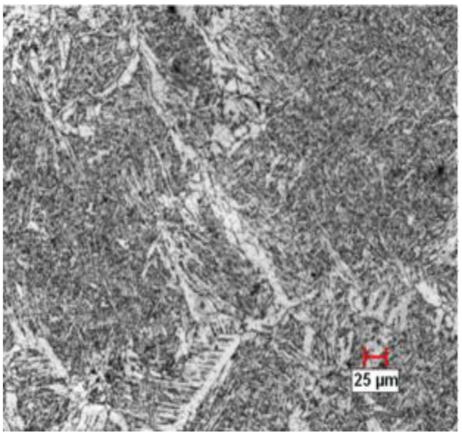
WELD HAZ2

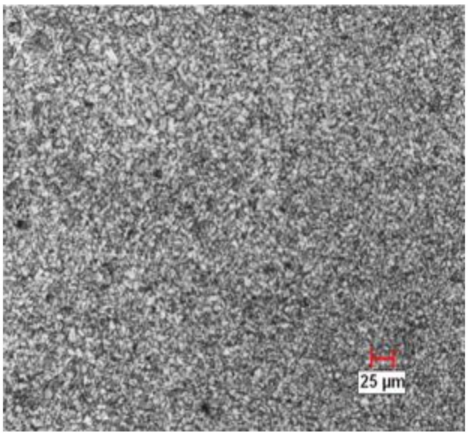
A typical microstructure gradient of weldmetal-HAZ-Basemetal corresponding to weldment specimen 810°C at 100X





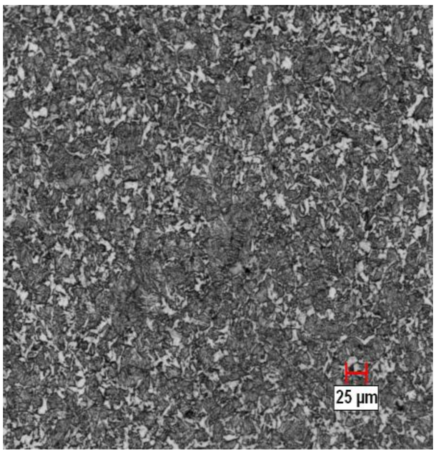
BASE HAZ1

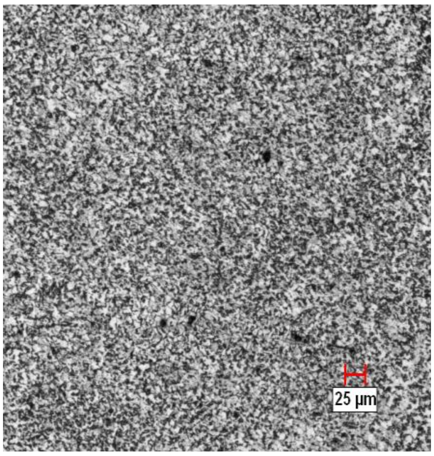




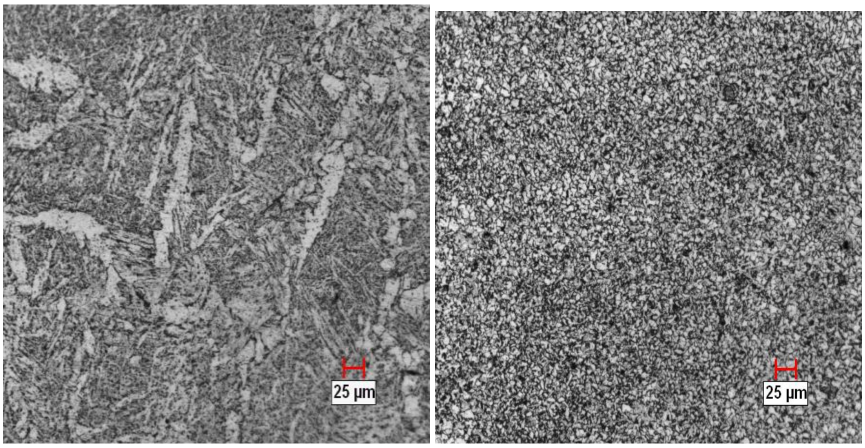
WELD HAZ2

A typical microstructure gradient of weldmetal-HAZ-Basemetal corresponding to weldment specimen 830°C at 100X



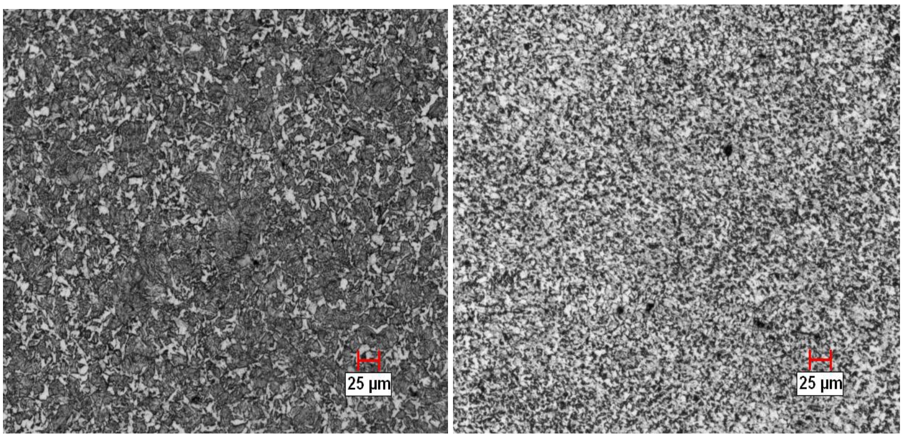


BASE HAZ1

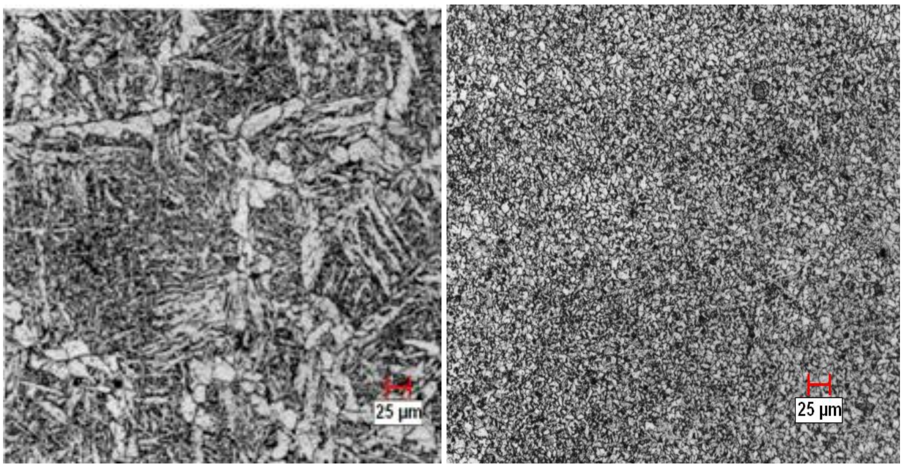


WELD HAZ2

A typical microstructure gradient of weldmetal-HAZ-Basemetal corresponding to weldment specimen 850°C at 100X



BASE HAZ1



WELD HAZ2

5. CONCLUSION

Microstructure of the base material consists of fine grains of ferrite with bands of pearlite. The volume fraction of martensite (VFM) in dual-phase steels increases with growth in the temperature of heating in the intercritical range during heat treatment. This is accompanied by growth in the micro hardness of the metal. The microstructure of dual phase steels consisted of light brown (martensite) and white (ferrite) phases and more over it is confirmed from the microstructures that the dual-phase steel has primarily equiaxed grains.

A welded assembly being a heterogeneous number consists of three different zones weldmetal, Heat Affected Zone (HAZ) and base metal, each zone will have different microstructural characteristics. The weldmetal microstructure zone in all the welded specimen shows dendritic structure of ferrite, pearlite and martensite, along with precipitates of carbides.

The HAZ reveals three distinct regions namely i) fusion region ii) normalized region and iii) transition region. The microstructure of these regions consisted of martensite, tempered martensite, ferrite and few amounts of carbides. However, significant differences in grain size have been observed in these regions due to the exposures of HAZ over a range of temperatures during welding. The fusion region was exposed to higher temperature than other regions which is having coarse grains.Fine grains were found in normalized region and transition region. However, with respect to microstructure, slight differences in microstructures were observed in HAZ . The HAZ of all the specimens consists of small amount of precipitates (black small dots). These precipitates were formed due to the precipitation of some alloying elements like Boron, Molybdenum and Vanadium during welding.

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