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Microstructure and mechanical properties of CO_2 welded dual-phase steels

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Abstract

Applications requiring high strength stainless steels are growing at a faster pace. Typical alloys used for these applications are either highly alloyed metals or that materials require secondary heat treatment process. A newly dual-phase steels are has been developed as lower cost option. The microstructure of dual-phase steels consists of a mixture of ferrite and martensite. A unified study on mechanical characterization of Metal inert gas (MIG) welding of Dual phase (DP) steels for structural applications in mind has been reported here**.** The results indicate that as the hardness of the metal increases as the percentage of martensite content increase, there has been significant increase in the ultimate tensile strength, yield strength, impact strength and percentage of elongation. Further it has been found that the microstructure of the base material has a bearing on the mechanical behavior exhibited by the weldments. The mechanical properties of the welded joints were found to be comparable with mechanical properties of the base metal.

Key words: Dual phase steel; MIG welding; Microstructure; Thicker section; Structural applications

1. Introduction

The ongoing needs to reduce vehicular weight while increasing safety is putting stress on design due to the strength limits of conventional steels. Dual phase (DP) steels offer a promising solution to this problem as these materials have higher strength while nearly matching the formability of much lower strength steels. This family of steels differs from conventional automotive steels in that the micro- structural matrix of soft ferrite is strengthened with metastable hard martensitic, and possibly bainitic, phase particles [1]. The ferrite contributes to steel ductility while the martensite determines its strength [2]. Dual phase steel is known to have greater ratio of tensile strength over yield strength than conventional high strength low alloy (HSLA) steel. The higher work hardening behavior of this material correlates to better formability and crash performance of automotive components [3]. Previous work that studied the weldability of DP steels has concluded that in general the sub-critical area of the heat affected zone (HAZ) will soften during welding; this is typically referred to as HAZ softening [4–7]. This phenomenon is caused by tempering of the pre-existing martensite in the sub-critical areas of the HAZ [4–7]. HAZ softening can have a significant effect on weldment strength. Transverse tensile tests on welded DP coupons also show that necking tends to initiate in this region, at stress levels that are lower than the base material strength [4]. Significant softening can also degrade the formability of welded blanks [8]. So far, no detailed or systematic study has been published to investigate the HAZ softening phenomenon of welded DP steels. Softening of DP steels by tempering using isothermal heat treatment has been investigated extensively [9–14]. It has been suggested that martensite in DP steels tempers similarly to martensite in fully quenched low- or medium-carbon steels [10]. On the other hand, little information is available on softening of steels during non-isothermal heat treatments, such as those experienced in the subcritical area of the HAZ during welding. Some initial work has pointed out that lean alloy materials welded with higher heat input and prestrained prior to welding show increased HAZ softening in gas metal arc welds[6] and that martensite volume fraction affects the maximum reduction of tensile strength[15]. However, systematic study of the effects of heat input and martensite content on the softening kinetics of various steels of different strengths is lacking.

In this work, Metal Inert Gas (CO_2) welded DP steels were investigated. Mechanical properties such as tension test, hardness test, charpy impact test and microstructural evaluations are carried out

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2. Experimental Procedure

2.1 Material

Commercially available mild steel of 350X150X16mm thick plates were selected for this study. The composition of this 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 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 920^0C for 30 minutes and quenched in iced-brine solution and then held at different intercritical temperatures, (ICT) of 720, 750, 780, 810,830 and 850^0C for 60 minutes and finally quenched in an oil bath as shown in Table 1.

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 Bath
		750	
		780	
		810	
		830	
		850	

2.3 Metal Inert Gas Welding Parameters

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. The process parameters as follows the electrode of 1.2 mm diameter, current of 90Amps- 300Amps, voltage of 18volts- 30 volts,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 nondestructive 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. Mechanical properties

3.1 Hardness Test

A hardness profile was generated by measuring hardness values using a HWMMT-X7-Micro Vickers hardness tester. Specimens used for hardness characterization were polished and etched. Micro hardness measurements were carried out using a square based pyramidal diamond shaped indenter , reading were taken for 500gms load for fixed loading durations of 10seconds.

3.2 Tensile test

The tensile tests were carried out on a groove weld specimens of rectangular cross section using a universal testing machine of 30tonne capacity. Using the Extension curve obtained, test the yield strength; tensile strength and percentage of elongation were calculated.

3.3 Charpy Impact Test

To study the behavior of welded structure under impact loads using pendulum type impact machine (model FIT 300 EN, 0-300 Joules), specimens used for this testing are of 55mm x 10mm x 10mm with 2mm groove, 45^0 angle and 0.25 mm root radius has been carried out at room temperature.

3.4 Microstructural studies

The specimens were sectioned using a band saw and mounted in Bakelite. Metallographic samples were then prepared by polishing and etching in 25 Nital to reveal the microstructure. The specimens were successively ground with 240,600and 1200 grit SiC grinding pads and then polished with 6 µm and finally 1 µm diamond paste until a satisfactory surface was obtained. The Microstructure of Base metal, dual-phase steel and Weld gradient using Nikon microscope LV150 with clemex Image analyzer.

4. Results and Discussion

4.1 Mechanical properties

From the hardness survey it reveals that, weld metal is having more hardness than HAZ and Base metal. This may be due to presence of considerable amount alloying elements like Nickel, Chromium and Molybdenum in the filler metal, which are tabulated in Table 2.

All the welded tensile specimens of different volume percentage of martensite had failed in the HAZ region with significant variation in strength. As the percentage of martensite content increases in the weld specimen an increase in ultimate tensile strength, yield strength and percentage of elongation was observed. Details of tensile test and impact tests of welded specimens are mentioned in Table 3.

Table 2. Shows the hardness values of Base metal, Heat affected zone (HAZ) and Weld metal

	Base	HAZ 1	Weld	HAZ 2
MIG Welding sample, 720°C	158	183	204	187
MIG Welding sample, 750°C	163	222	230	174
MIG Welding sample, 780°C	169	195	215	189
MIG Welding sample,810°C	177	180	227	186
MIG Welding sample,830°C	180	187	234	213
MIG Welding sample,850°C	181	187	243	213

Table 3: Details of tensile test and impact tests of welded specimens

Temperature (°C)	Area (mm^2)	Initial gauge length (mm)	Peak load (kN)	Tensile Strength (N/mm^2)	Load at yield point (KN)	Yield stress (N/mm^2)	Load at break point (KN)	Impact energy in joules (J)
720°C	294.7	50	149.80	442.86	117.00	338.80	109.08	100
750°C	322.7	50	143.37	448.51	124.80	353.75	89.00	144
780°C	324.5	50	149.36	462.13	126.08	361.72	103.12	148
810°C	322.6	50	145.32	464.18	128.04	364.31	96.32	168
830°C	324.0	50	172.20	480.34	138.40	417.9	133.24	188
850°C	324.0	50	172.20	533.34	148.40	457.9	133.24	210

There has been an increase in impact strength obtained as the percentage of martensite increases in the welded specimen, even though the filler metal and the welding condition used for all the specimens has been almost same.

4.2 Microstructure evaluation

Microstructure base metal consists of fine grains of ferrite (~90%) with bands of pearlite as shown in Fig. 1. Microstructure of dual-phase steels consists of ferrite and Martensite, Ferrite grain size number 8, as shown in Fig. 2. All the welded specimens made up of different martensite contents show three distinct zones viz, weld metal zone, heat affected zone (HAZ) and base metals zone. In the weld metal zone microstructure, dendritic structure of ferrite, pearlite and martensite along with precipitates of carbides were observed. In the heat affected zone microstructure, martensite, tempered martensite, ferrite and few amounts of carbides (with variation in grain size) were observed. As already mentioned earlier in the base metal zone microstructure, blocky ferrite regions mixed with the martensite domains having globular or plate morphology were observed as shown in Fig. 3

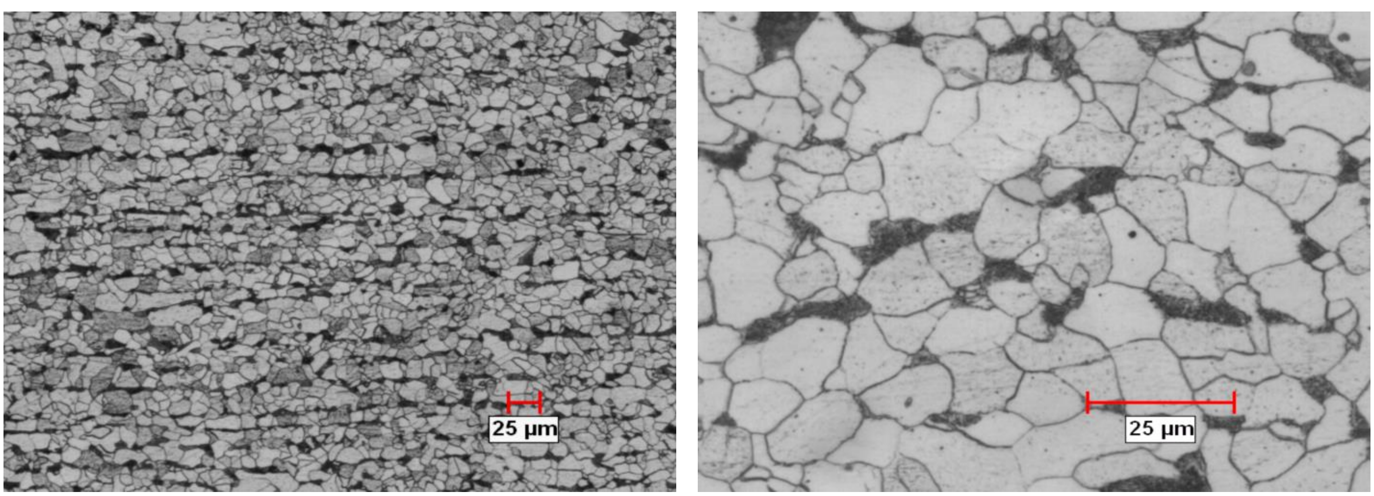


Figure 1: Typical Micro Structure of Base metal

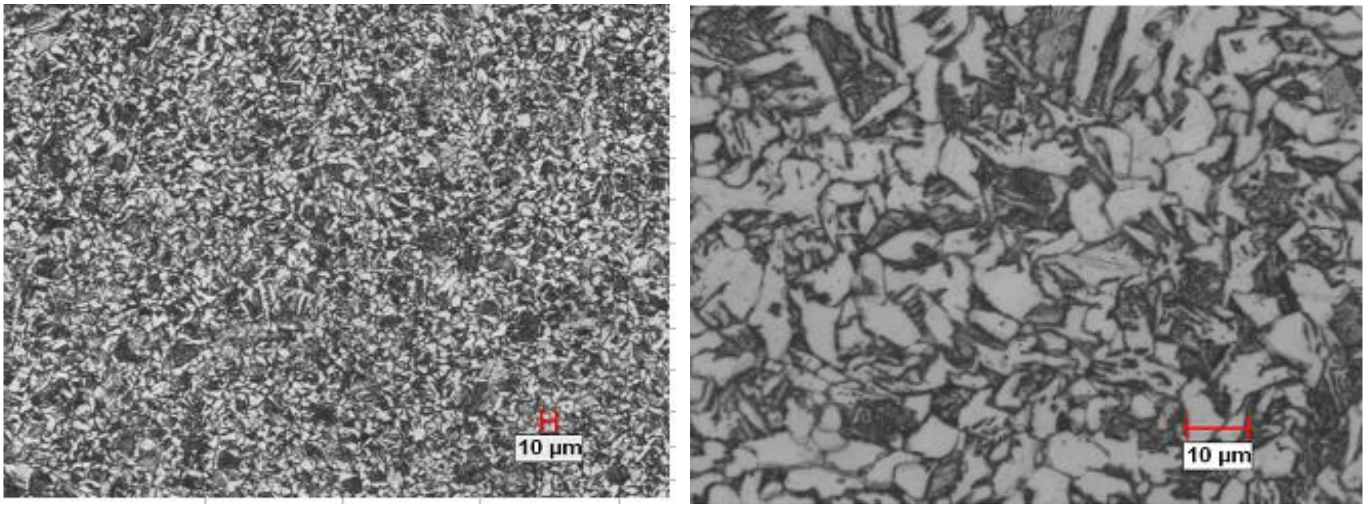
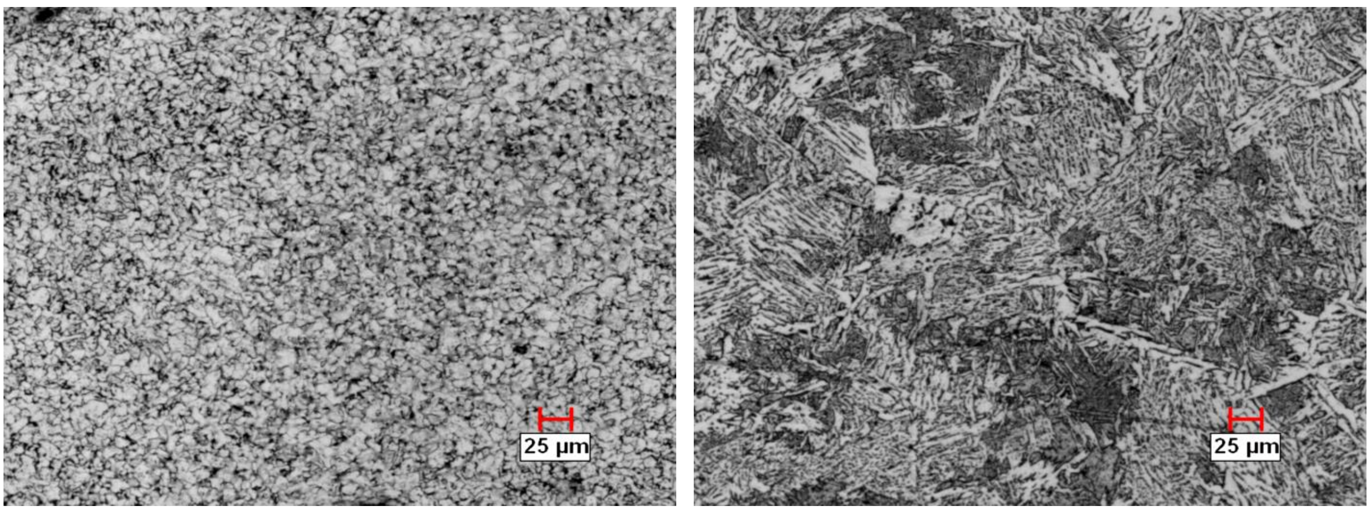
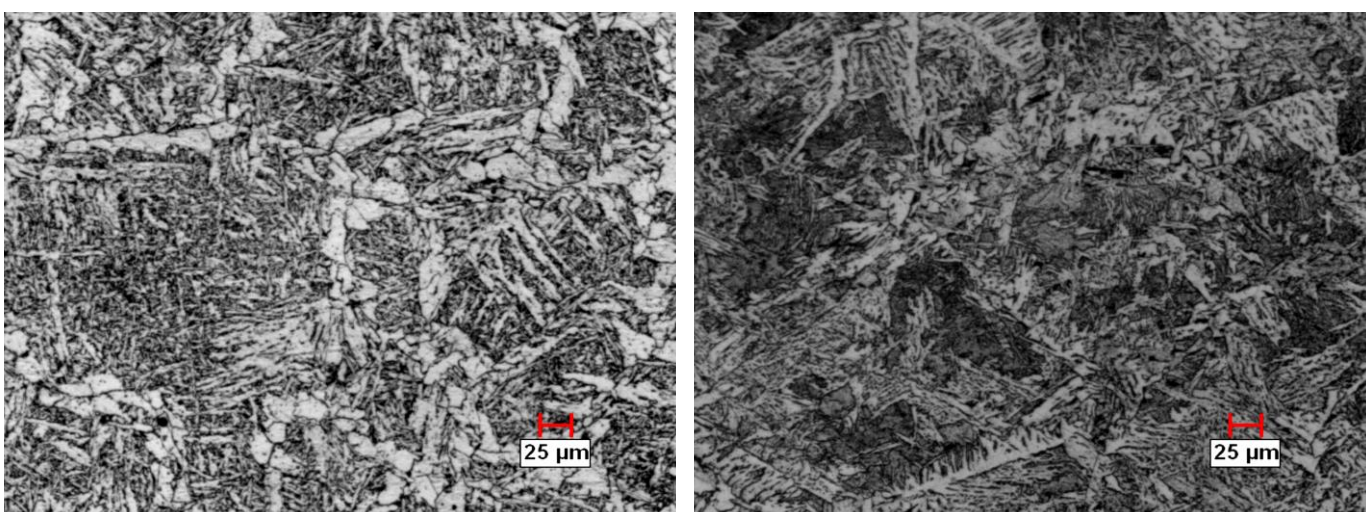


Figure 2: Typical Micro Structure of Dual-phase metal



BASE HAZ1



WELD HAZ2

Figure 3: A typical microstructure gradient of weld metal-HAZ-Base metal.

5. Conclusion

- Microstructure of the base material consists of fine grains of ferrite with bands of pearlite.
- 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 welded assembly being a heterogeneous number consists of three different zones weld metal, Heat Affected Zone (HAZ) and base metal, each zone will have different microstructural characteristics.
- From the hardness survey it reveals that, weld metal is having more hardness than HAZ and Base metal. This may be due to the presence of alloying elements in the filler metal.
- Ultimate tensile strength and yield strength increases with increase in martensite content in the weld specimen.
- There has been an increase in impact strength as the percentage of martensite increases, even though the filler metal and the welding conditions used for all the specimens has been almost the same.

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