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RESEARCH ARTICLE

STAINLESS STEEL OF AISI 304 TO CORTEN STEEL JOINT USING MAG WELDING PROCESS

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ABSTRACT

The underframe assembly of rail coaches is manufactured with the help of metal active gas welding process. Both ends of the austenitic stainless steel plate are welded to corten steel on the floor assembly of the coaches. The butt weld is done to the joint. Floor assembly is subjected to massive corrosion environment which weakens structural stability on carrying loads, since coaches are designed in a fashion to bare heavy loads on loading condition and also accidental proof for safe journey. Hence mechanical properties are to be optimized for the joint. Weathering steel which turns orange in time, special fillers are required for thicker section so the weld weathers like the plate. Consumables are chosen to match or exceed the chromium content of the parent metal. Weld by very commonly used are welding processes MAG, with optimal filler metal for stainless steel welding chosen based on adequate corrosion resistance for intended use to match base metal content with respect to Alloying elements, e.g. Cr, Ni & Mo.

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INTRODUCTION

Underframe assembly constitute solebar and trough floor, in which solebar is joined to trough floor using MAG welding process. Solebar is made out of corten steel for its structural strength and resistance towards corrosion. Trough floor plays a vital role in bearing loads at various conditions. Hence trough floor should be with high tensile strength and also with high corrosion resistant. Trough floor initially made out of corten steel, by which corten steel to corten steel have been jointed in solebar and trough floor assembly. Then for higher strength trough floor is replaced with AISI 301 austenitic stainless steel which is joined to corten steel. Further for more improvement in corrosion resistant ICF planned to go for using AISI 304 austenitic stainless steel to corten steel joint. This joint has a dissimilar material combination, that's the study of dissimilar joint becomes essential for structural stability and to predict the service of the welded joint.

MAG welding is the most common welding process used to join AISI 304 to corten steel. It uses the cheapest welding gas such as carbon-di-oxide, and creates a good weld. MAG process is evolved from the GMAW process, which has variation on using of shielding gas for protecting weldment from atmosphere. This MAG welding process can be automated to get a good welded joint and it also increases production rate and product quality.

Arc welding process such as welding using stick electrodes is usually carried in joining underframe assembly earlier in the rail coaches. The floor assembly subjects to mechanical loads given by passengers and tends open to natural corrosive environments such as rain water, atmospheric exposure etc. Using stick electrodes may be economical but structural stability and life of the weldment are not so expected, it also requires skilled labour for sound weld. Production rate is high by using MAG welding process than by welding with stick electrodes. Interaction factor of filler metal, wire feed rate, and voltage have been studied by which the mechanical property of dissimilar welding between stainless steel (AISI 304) and corten steel is affected. Mechanical property and microstructure around heat affected zone (HAZ) were monitored due to dissimilar chemical composition of two materials for its effects in mechanical properties. Tensile test should prove that the penetration of weld metal acts as the main subject that contributed to the increasing of weldment strength. With the assist of higher voltage and stable cooling rate, and filler wire size (1.2mm), maximum stress is the highest contributing by well penetration to be studied. This study of that melting rate of filler wire will reduce the possibility of weldment failure. The result of hardness test proves that the filler wire size and arc voltage contribute in strengthening the structure of HAZ. This is because the existing of amount of heat during weldment according to filler wire size and arc voltage applied further increased of treatment process received by HAZ thus contributed in strengthening the structure.

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The microstructure analysis is to be made for finding phase transformation and its contribution in increasing the weldment strength, and makes the structure strength comparison at heat affected zone and weldment.

Experimentaldetail

Parent Material and Filler Material Selection

Trough floor is a nonmagnetic austenitic stainless steel sheet. Sole bar is a "Z" shaped corten steel plate. The underframe is provided with two sole bars of rolled channel section with centre sill of standard `Z' section for stringers. To combat corrosion, corrosion resistant steel has been used. The body bolster is of box type construction fabricated by welding of plates and the cross bars are also of fabricated design made out of plate sections.

The underframe is of all welded construction with material. The floor plate is made out of AISI 304 Steel and welded to the underframe. Body panel of Coal Wagons like BOXNHA encounter corrosive environment due to presence of sulphur and other carbonic acid components in coal. Use of corrosion resistance steel will face the situation better due to formation of an adherent protective oxide film on the surface if it is left undisturbed. Corten steel has following properties-

- Stronger than mild steel
- Easily weldable
- Develops its own protective film against corrosion.

Composition of AISI 304

Table 4.1. Composition of AISI 304

C	0.08 max
Mn	2.0 max
Si	1.0 max
S	0.03 max
P	0.04 max
Cr	18-20
Ni	8.0-10.5

Mechanical Properties

Table 4.2 Mechanical Properties of AISI 304

Ultimate tensile strength	515 Mpa
Yield point	206 Mpa
Elongation	70%

Corten Steel

Sole bar is a "Z" shaped corten steel plate. The underframe is provided with two sole bars of rolled channel section with centre sill of standard 'Z' section for stringers. To combat corrosion, corrosion resistant steel has been used.

The body bolster is of box type construction fabricated by welding of plates and the cross bars are also of fabricated design made out of plate sections. The underframe is of all welded construction with material. The floor plate is made out of Corten Steel to AISI 304 and welded to the underframe.

Composition of Corten Steel

Table 4.3. Composition of corten steels

C	0.12 max
Mn	0.20-0.50
Si	0.25-0.75
S	0.035 max
P	0.075-0.145
Cu	0.25-0.65
Cr	0.30-0.70
Ni	0.17-0.50

Mechanical Properties

The mechanical properties of CORTEN steels for plates in the state of hot rolled delivery condition according to EN 10025-5. In case of cold rolled CORTEN A, the yield stress is min. 340 MPa and the tensile strength is min. 480 MPa.

The cold rolled sheets COR-TEN A-B ≤3mm in thickness for increased demand to the cold formability the mechanical properties is slightly different i.e. the yield stress is min. 275 MPa; the tensile strength min. 410 MPa and the elongation min. 25%.

Table 4.4. Mechanical properties of corten steels

Ultimate tensile strength	480 Mpa
Yield point	340 Mpa
% Elongation	22%

Weldability of the Material

Welding corten steels of these classes of high impact resistance require strict welding conditions to realize their characteristic potential also in the welds and in their heat affected zone (HAZ).

In particular low hydrogen electrodes should be used, with due precautions in keeping them dry and heating them before use in suitable ovens to drive away any moisture. This is because the welds may be prone to Hydrogen Induced Cracking (HIC).

Filler Material Used

Electrode type: Stainless steel wire, Diameter: 1.2mm 309L gives a weld deposit similar to 309, with reduced carbon levels (.04% maximum) that offer increased resistance to intergranular corrosion.

Type 309L is ideal for joining stainless steels to themselves or to carbon or low alloy steels. 309L is preferred to stainless steels for cladding over carbon or low alloy steels, as well as dissimilar joints which undergo heat treatment.

Mechanical Properties of Filler Wire

Table 4.5. Mechanical properties of filler material

Electrode	Tensile strength	Yield strength	elongation
E309L	555 Mpa	410 Mpa	36%

Composition of Filler Wire

Table 4.6. Composition of Electrode E309L used in welding process

C	0.15 max
Mn	2.5 max
Si	0.90 max
S	0.30 max
P	0.040 max
Cr	22-26
Ni	11-15
Mo	0.5 max

Welding Parameters of MAG Welding

The process parameters were selected based on the initial trial runs, because at the starting of the experiments it is not known, the exact parameters in which welding is to be done for welding steels. The welding parameters are electrode diameter, Electrode type, Shielding gas type and flow rate, voltage, wire feed speed, welding speed, and Electrode angle, Electrode path, and welding position. Those are set one by one for finalizing them.

Welding Current

There are two key modes in conventional MAG welding. These are spray transfer and short circuiting (dip) transfer. Spray metal transfer is used for welding thick section material and for welding aluminum and its alloys. Spray metal transfer is characterized by a smooth, quiet arc, low spatter levels and deep penetration. A large, fluid weld pool is created and the technique may only be used in the flat and horizontal-vertical positions. Short circuiting (dip) metal transfer is used for welding thin sheet materials and for welding in all positions. Short circuiting metal transfer is characterized by a noisy arc; some spatter and moderate-low penetration. The inductance of the welding power supply can be used to optimize metal transfer characteristics and minimize spatter levels. In order to overcome the limitations of both spray transfer and short circuiting (dip) transfer, pulsed and synergic (or controlled transfer) pulsed MIG/MAG welding can be used.

Voltage

Arc voltage is directly related to current, as indicated above, and with arc length, increasing with it. Voltage also depends on the shielding gas and electrode extension. The increase of arc voltage widens and flattens the weld bead. Low voltages increase the weld reinforcement and excessively high voltages can cause arc instability, spatter, and porosity and even undercut.

Welding Speed

Increase in the welding speed gives a decrease in the linear heat input to the workpieces and the filler metal deposition rate per unit of length. The initial increase in welding speed can cause some increase in penetration depth, because the arc acts more directly in the parent material, but further increase in speed decreases penetration and can cause undercut, due to insufficient material to fill the cavity produced by the arc.

Electrode Extension

The electrode extension is the electrode length that is out of the contact tube. The increase of electrode extension, produced by the increase of the torch distance to the work-piece for a specific parameters set, increases electrode melting rate because of the Joule effect. Electrode extension ranges from 5 to 15 mm for dip transfer, being higher (up to 25 mm) for the other transfer modes.

Shielding Gas

Shielding gases have an effect on arc stability, metal transfer mode, weld bead shape and melting rate. Gases used in GMAW can be pure gases, binary, ternary and exceptionally quaternary mixtures. Common pure gases are argon, helium and carbon dioxide. The first two are inert gases and are used principally in welding of light alloys, nickel, copper and reactive materials.

Helium has a higher ionization potential than argon, providing larger weld pools, but is more expensive. Carbon dioxide is an active gas and is used in welding of carbon steels. It produces high levels of spatter but provides high penetration depth.

Parameter Selection on Trails

The levels of process parameters were selected based on the initial trial runs, because at the starting of the experiments it is not known to us the exact parameters in which welding is to be done for welding steels. The welding parameters are electrode diameter, Electrode type, Shielding gas type and flow rate, voltage, wire feed speed, welding speed, and Electrode angle, Electrode path, and welding position. Those are set one by one for finalizing them. The following table has four observations by varying the inputs such as wire feed rate and voltage.

Table 4.7. Parameter selection on trails

Observation	Input Variables	
	Wire feed rate(m/min)	Voltage (V)
1	6	27
2	6	27
3	7	29
4	7	29

Welding Parameters Range in Mag Welding

Table 4.8 welding parameters of MAG welding

PARAMETERS	RANGE
Open circuit voltage	70V
Closed circuit voltage	20V
Current	160A
Wire feed rate	2.4 – 7m/min
Shielding gas (Co_2) flow rate	12 litres/min
Travel speed(weld zone)	350mm/min
Travel speed(skip zone)	3000mm/min
Skip distance	100mm
Weld distance	30mm
Arc temperature	5000 – 7000
AC/DC	DC
Power source	Constant voltage(electrode positive)
Position	Over head position, Back hand 70^o-80^o
Wire diameter	1.2mm
Electrode stick out	8 – 15 mm

Welding of AISI 304 ToCorten Steel Using MAG Welding Process

MAG welding processes have a profound impact on the performance of the components in service as the microstructural features that these processes induce, in particular for 304 SS accelerate sensitisation. Sensitisation is a phenomenon in which of Cr-rich carbides, Cr_{23} C_6 , precipitate and make the ASS's susceptible to localised attack in the form of pitting and intergranular corrosion in chloride containing electrolytes due to formation of Cr depleted zones near the grain boundaries.Metallurgical methods such as reduction of carbon content, addition of Mo, localised heat treatments and grain boundary engineering have been used to overcome sensitisation in the heat affected zone (HAZ) of welded components. When the process is in developmental stage, we are merely interested in finding mechanical properties and the effect of mechanical properties. These results can be obtained on weld bead. Initially trials were taken on 1.7mm thick AISI 304 stainless steel plate welded to 2mm corten steel plate using MAG welding process. Some initial trial runs were taken to fix the range of process parameter.

Fig 4.6. MAG welding of AISI 304 to Corten steel

Sample Preparation

Selection of specimen: the specimen was selected from the weldment area with base metal which represents for whole metal.

Cutting of the specimen: the selected area was cut with the help of a handsaw.

Mounting the specimen: The specimen was mounted in Bakelite for easier handling because to do further processing. The temperature for mounting was kept between 150-160°c, heating time for 10min, cooling time for 5min and pressure kept between 100-200 kg/cm^2 throughout the process.

Fig 4.7. Sample mounting machine

Obtaining flat specimen surface: the flat specimen surface obtained because of motor driven emery belt.

Intermediate and fine grinding: The emery paper with grits of 220,320,400,600,800 was properly used for grinding. The specimen was hand rubbed against the abrasive paper.

Rough polishing: the fine grinded specimen was roughly polished with a very small quantity of diamond powder carried in a paste that is oil-soluble is placed on the nylon cloth covered surface of a rotating polishing wheel.

Fine polishing: the alumina (Al^2O^3) powder of a particle size of 0.05 micron was used as the polishing compound placed on a cloth covering rotating wheel. It made scratch free mirror surface on the specimen.

Electrolytic etching: for stainless steel, the electrolytic etching was required. The stainless steel vessel was used as a cathode and the sample was used as anode. 10% oxalic acid was used as electrolyte. 1 A/mm^2 current was maintained throughout the process. The time taken for the process was 30 sec.

RESULTS AND DISCUSSION

Microstructure Analysis

Metallographic specimens were sectioned to the required sizes from the joint comprising weld metal, HAZ and base metal regions and were polished using different grades of emery papers final polishing was done using the diamond compound in the disc polishing machine. Microstructures examination was carried out using a light optical microscope (VERSAMET-3, Japan) incorporated with an image analyzing software (Clemex-vision). Specimens were etched with ferritic chloride acid to reveal the microstructure.

Satisfactory metallographic results can be obtained only, when the specimen has been carefully prepared. Because the metallurgical microscope working with the principle of reflection of light to obtain final image of the metal structure. Microstructure of the base metal and the weld metal was revealed by optical microscope.

Microstructure of This AISI 304 Stainless Steel

The microstructure of the ASS in the as-received condition is comprised of austenitic grains with ferrite ands, α'-martensite laths as well as coherent and incoherent twin boundaries as shown in the optical micrograph in Fig. 3. The presence of α'-martensite was expected as the plates were cold rolled and it is well documented that strain induces α'-martensiteformation. Meanwhile, hardness for base metal stands between HAZ and weldment area due to the structure didn't experience any heat treatment process and stay as austenite.

Microstructure of Corten Steel

The micrographs have the microstructure type that is a combination of ferrite and carbide. There are inclusions in the microstructures which indicate the carbide is not homogeneous. The grains which are parallel to rolling direction are

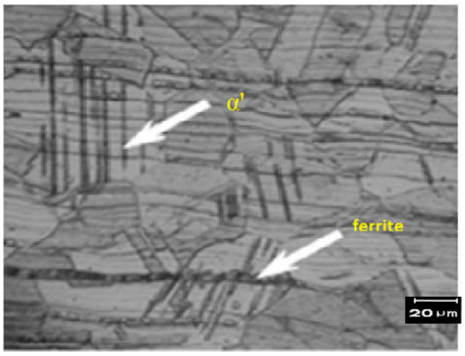

Fig 5.1. AISI 304 BM (1000X)

Fig 5.2. Corten steel BM (500X)

Not texturing but which are perpendicular to rolling direction overcome texturing. Texturing was a result of production process. If texturing is perpendicular to rolling direction it means there is force to the material. The grains which are parallel to longitudinal direction are not texturing (equiaxed).

Microstructure of Weld Interface To Ss 304

The microstructure in the weld interface to austenitic stainless steel is shown in fig. The boundary layer between 304 stainless steel and HAZ is clearly in the microstructure. In the heat affected zone according to theory corten steel also contains carbon and nickel, accumulation of carbon is on weld interface.

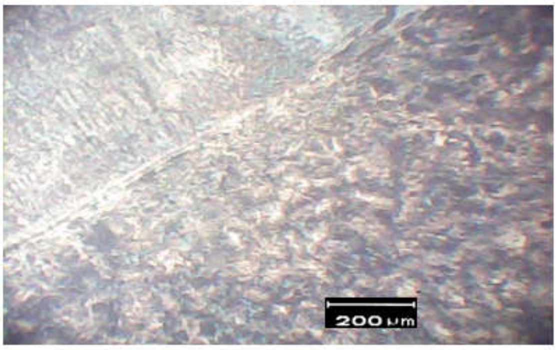

Fig 5.3. Weld interface to SS 304 (100X)

Microstructure of Weld Interface to Corten Steel

The microstructure in the weld interface to corten steel is shown in fig. The boundary layer between corten steel and HAZ is clearly in the microstructure. With the lower hardenability in the heat-affected zone (HAZ), preheat might not be needed to avoid hydrogen-induced cracking. However, the weld deposit is usually an ascast microstructure where only chemistry and solidification morphology can be used to control cold cracking susceptibility. Therefore, cracking susceptibility in these high-strength steels can be expected to be higher in the weld fusion zone (FZ) rather than in the HAZ.

Fig 5.4. Weld interface to corten steel (100X)

The microstructure in the weld interface to austenitic stainless steel is shown in fig. The boundary layer between 304 stainless steel and HAZ is clearly in the microstructure. In the heat affected zone according to theory corten steel also contains carbon and nickel, accumulation of carbon is on weld interface.

Microstructure of Weldment

The microstructure of the weldment reveals that the fusion of the two parent material with filler wire tends to mix in atomic level. Carbide precipitation is a temperature-dependant process with slow kinetics that can occur during welding. Cold deformation before exposure to heat during welding has a combined effect on the degree of sensitization of ASS's. At temperatures higher than 600°C sensitisation was enhanced leading to carbide formation and thereby chromium depletion within austenite grains as well as along grain boundaries. Also, it was reported that the deleterious effects of different intermetallic compounds on pitting corrosion are associated with the formation of Cr-depleted zones adjacent to Cr-rich precipitates. Besides, the presence of martensite in cold worked stainless steels may induce sensitisation at temperatures as low as 350°C, so that precipitation of $Cr_{23}C_6$ occurs within the grain interiors as result of an increase in dislocation density. Formation of $Cr_{23}C_6$ in a 304 SS is thermodynamically favourable between 450°C to 800°C. Thus, all these account for development of the trans-granular and intergranular corrosion in the welded.

At HAZ, the microstructure is the hardest due to the transformation of microstructure from austenite to martensite caused by heat treatment during welding. Whereas at weldment area, the structure hardness is the lowest due to overheat treatment received inside the fusion zone.

Besides, the microstructure of weldment area shows solidification process that formed ferrite at high temperature.

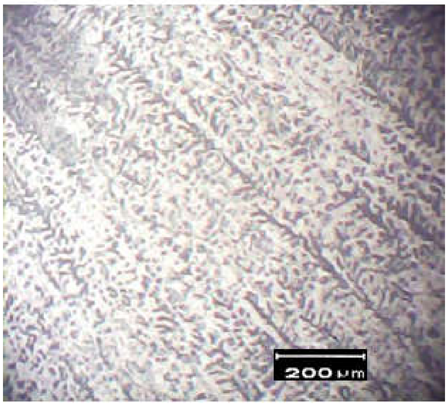

Fig 5.5. Microstructure of weldment (100X)

Hardness Test

Appreciable difference in microstructure was obtained on the top surface of welded joints and hence hardness was measured on the top surface of the weld joints. Hardness for base metal stands between HAZ and weldment area due to the structure didn't experience any heat treatment process and stay as austenite in austenitic stainless steel. If the filler size is bigger, the hardness increased radically. During the microstructure analysis it was observed that the interface region of base metal and weld metal consist of very narrow heat affected zone (HAZ). Within the narrow HAZ two distinct regions were observed.

They are

- Coarse grained HAZ (CGHAZ- just adjacent to the weld metal region)
- Fine grained HAZ (FGHAZ- very close to the base metal region)
- Hence the micro hardness was measured at four different locations. They are WM, FGHAZ, CGHAZ and unaffected BM. At each of the region three readings were taken and average of three readings is presented in table 5.1.

Table 5.1 Hardness at different regions of the weld joint

Location	WM	FGHAZ	CGHAZ	BM
AISI 304	230	243	205	220
Corten steel		162	148	142

The hardness value for weldment area (fusion zone) is always lower than HAZ. This is because at HAZ, the microstructure is the hardest due to the transformation of microstructure from austenite to martensite caused by heat treatment during welding. Whereas at weldment area, the structure hardness is the lowest due to overheat treatment received inside the fusion zone. Besides, the microstructure of weldment area shows solidification process that formed ferrite at high temperature. Hardness for base metal stands between HAZ and weldment area due to the structure didn't experience any heat treatment process and stay as austenite.

Fig 5.6. Vickers hardness machine (MATZUSAWA, Japan)

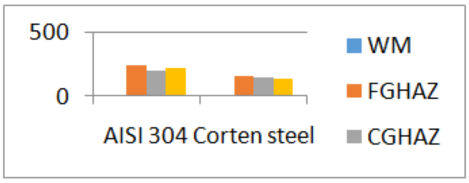

Fig 5.7. Chart represents hardness at different region of welded sample

Tensile Test

The transverse tensile properties such as yield strength, tensile strength, % of elongation, % of reduction in cross section area of base metal and welded joint are presented in table 5.2. The max stress getting higher with the increasing in filler wire size.

Table 5.2. Transverse tensile properties of the weld joint

Material	Yield strength (MPa)	Ultimate tensile strength (MPa)	Elongation (%)	Vickers hardness VHN
AISI 304 to Corten Steel	260	455	40	230

Fig 5.8. Universal testing machine

Fracture of the specimens occurred in the base metal region indicating strength of the weld joint is greater than that of the base metal. The yield strength and tensile strength of un-welded parent metal are 206MPa and 515MPa respectively. The elongation and reduction in cross- sectional area of un-welded parent metal are 70% and 22% respectively.

It is clear from the above table that corresponding values estimated from the tensile tests conducted on the transverse weld joint specimens are greater than that obtained for the base metal confirming weld joint is stronger than the base metal.

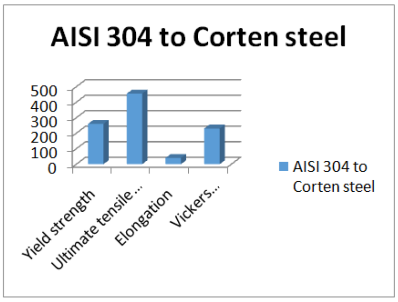

Fig 5.9. Chart for Transverse tensile properties of the weld joint

Fig 5.10. Bending at initial stage

Fig 5.11. Bending at final stage

Less formation of chromium carbide precipitate are reasons for low strength of AISI 304 than 301 steels. These precipitates form due to the solution treatment and subsequent artificial ageing.

Bend Test

The bend test was carried out in the UTM. There are many types of bend test conducted. We use 180º free bend test in both face and root side of the specimen. For less than 4mm two samples are needed for each face and root bend test.

A 5KN load was applied for the particular test. The diameter of the former was d+4t. Where, the t is the thickness of the material. From the bend test result, there is no crack formation in weld metal and base metal of both AISI 304 &Corten steels. So, the MAG joining was satisfied on both steels.

Conclusion

- Microstructure analysis shows fine grain structure in heat affected zone and coarse grain structure in weldment.
- Hardness test proves that the hardness value for weldment area is always lower than heat affected zone thus contributed in strengthening the structure.
- Tensile test proved that increasing of weldment strength due to penetration of weld metal.

Bend test proves that there is no crack formation in weld metal and base metal of both AISI 304 and Corten steels. So, the MAG joining was satisfied on both steels.Two plates of 1.7mm thickness AISI 304 plate and 5mm thickness corten plate were welded. Microstructures of weldments were analyzed and mechanical properties such as hardness, tensile strength and bend test were tested and analyzed. On analysis weldments have satisfied mechanical properties.

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