

A Review on Welding Characteristics of CR–MN Austenitic Stainless-Steel Using Smaw and GMAW Welding Processes

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Abstract

Cr-Mn Austenitic Stainless Steel (ASS) generally used in pressurised water reactor and nuclear processing water reactor and nuclear processing reactor etc. due to ease of welding. The welding fillers are used generally ER308L and ER308-16 n SMAW and GMAW. It studies microstructure, tensile strength, hardness, impact strength and intergranular corrosion (DLEPR test). These steels are extensively used in railway, automotive, structural industries where welding is used as an manufacturing process.[1] Among various welding methods, Shielded Metal Arc Welding (SMAW) and Gas Metal Arc Welding (GMAW) are the most widely employed due to their operational flexibility and industrial applicability. This review paper presents a detailed comparison of SMAW and GMAW welding techniques used for joining Cr–Mn austenitic stainless steels. The influence of welding parameters such as heat input, welding speed, filler material and shielding environment on microstructure, ferrite formation, mechanical properties, heat affected zone (HAZ), corrosion resistance and sensitization behaviour is discussed in detail. The review highlights that SMAW generally produces higher ferrite content and better resistance to solidification cracking, whereas GMAW offers superior weld appearance, smaller HAZ and higher productivity. The paper also summarizes recent developments, challenges and future research directions in the welding of Cr–Mn stainless steels.

Keywords: Cr–Mn Austenitic Stainless Steel, SMAW, GMAW, Ferrite, Corrosion Resistance, Sensitization, Heat Affected Zone

1. Introduction

Stainless steels are among the most important engineering materials used in modern industries because of their excellent corrosion resistance, high strength, toughness and fabrication characteristics. Austenitic stainless steels constitute the largest group of stainless steels and are commonly used in pressure vessels, chemical processing equipment, food processing industries, railway coaches and structural applications. Conventional austenitic stainless steels mainly contain chromium and nickel as the principal alloying elements. Nickel stabilizes the austenitic phase and improves toughness and corrosion resistance.

However, due to the increasing cost and limited availability of nickel, the development of low-nickel stainless steels has become an important area of research. Cr–Mn austenitic stainless steels have emerged as promising alternatives in which manganese and nitrogen are used as austenite stabilizers instead of nickel. These steels provide an economical solution while maintaining acceptable mechanical and corrosion-resistant properties.

Cr–Mn ASS exhibits good tensile strength, ductility, impact resistance and formability. Due to these properties, they are increasingly used in structural fabrication, railway components, kitchen utensils, pressure vessels and automotive applications. Since most industrial structures require joining operations, welding plays a major role in determining the final performance and reliability of these materials.

Welding of stainless steels involves complex thermal cycles that significantly influence microstructure and mechanical behaviour. Improper welding conditions may lead to defects such as sensitization, hot cracking, residual stresses and distortion. Therefore, the selection of an appropriate welding process and optimization of welding parameters are essential.

Among various fusion welding methods, Shielded Metal Arc Welding (SMAW) and Gas Metal Arc Welding (GMAW) are widely used because of their ease of operation, availability and industrial suitability. SMAW is a manual welding

process commonly used in field applications and repair works, whereas GMAW is a semi-automatic process preferred for high productivity and better weld quality.

This review paper discusses the welding behaviour of Cr–Mn austenitic stainless steels using SMAW and GMAW processes. The effects of welding parameters on microstructure, ferrite formation, heat affected zone, mechanical properties and corrosion resistance are critically reviewed.

2. Cr–Mn Austenitic Stainless Steel

Cr–Mn austenitic stainless steels belong to the family of low-nickel stainless steels where manganese and nitrogen replace nickel to stabilize the austenitic structure. Chromium provides corrosion resistance by forming a passive oxide layer on the steel surface.

2.1 Chemical Composition Typical chemical composition of Cr–Mn ASS includes:

Element	Cr	Mn	Ni	C	N
Percentage(%)	15-18	6-10	0-4	<0.8	0.1-0.3

Nitrogen improves strength and stabilizes the austenitic phase, while manganese enhances ductility and weldability.

2.2 Properties of Cr-Mn ASS

Cr-Mn stainless steels (commonly 200-series) are austenitic alloys designed to reduce nickel dependency by substituting it with manganese (Mn) and nitrogen (N). They offer high strength, excellent work-hardening rates, good formability, and comparable corrosion resistance to 300-series steels in mild environments, often at a lower cost.

High strength and Hardness: Nitrogen addition provides significant interstitial solid solution, resulting higher yield and tensile strength compared to conventional Cr-Mn ASS.

Superior work hardening rate: higher manganese level leads to high work hardening rate, making them ideal for cold working applications.

Corrosion resistance: Good corrosion resistance, but often inferior to 304 or 316 Cr Ni grades in harsh environment, particularly in acidic conditions, due to lower nickel content.

Non-magnetic properties: Similar to standard austenitic steels, they remain non magnetic even after heavy cold working, making them suitable for specialised electrical applications.

Improved Formability /Ductility: Frequently alloyed with copper (Cu) to improve ductility, drawability, and ease of fabrication.

Weldability: This steel possesses acceptable weldability; however, thermal cycles during welding can alter microstructure and corrosion resistance.

3.1 Shielded metal arc welding (SMAW)

Shielded Metal Arc Welding (SMAW) uses flux-coated electrode as consumable for the joining of two metals, hence it is also known as stick welding. The flux is coated over the core of metal which is normally made from the same metal to weld. One terminal of power source is attached to electrode and other terminal is attached to workpiece. An electric arc is generated between the workpiece and electrode after the electrode comes close in contact with workpiece. The generation of heat between the electrode and workpiece leads to melting of electrode and metal. The molten flux moves up to the top of surface in the form of slag and is removed after solidification.

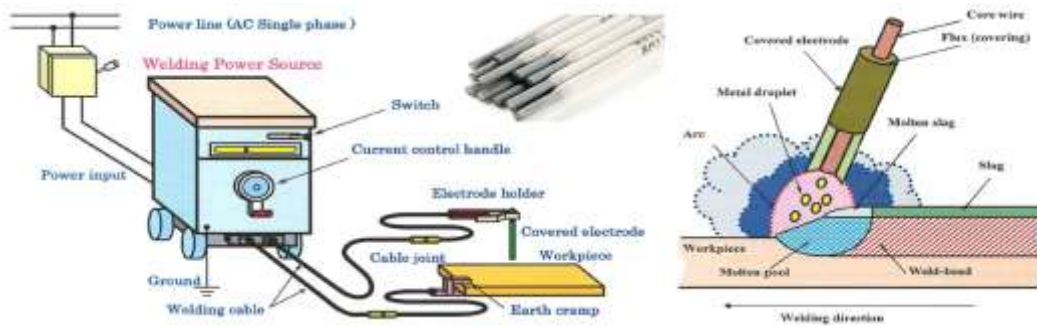


Figure 2.1: Schematic Diagram of SMAW welding process[8]

The SMAW welding equipment is simple as compared to other arc welding process equipment. More portable forms of SMAW equipments are available as per the application causes the process to economical. The productivity is a issue in the SMAW welding as the stick length is limited only up to 35cm leads to frequent replacement of the stick. Current and voltage required for welding is determined on the basis of electrode diameter and thickness of workpiece.

3.2 Gas metal arc welding (GMAW)

Gas metal Arc Welding (GMAW) is also called as Metal Inert Gas (MIG) welding because the shielding is provided by the inert gas such as Argon, helium etc. The heat is generated due to electric arc between the filler wire and electrode. The filler wire is feed continuously into the area of weld joint leads to more productivity of GMAW process. The polarity in GMAW is normally kept Direct current Electrode positive (DCEP) for better arc stability. Type of shielding gas depends on the application and metal. For example, CO₂ as shielding gas is used in GMAW welding of carbon steel. GMAW welding of Al is shielded with Ar and 75% He-25% Ar. Current and Voltage requires for welding depend upon the diameter of Filler wire and thickness of workpiece. The other parameter involve in GMAW are Wire Feed rate, flow rate of gas.[08]

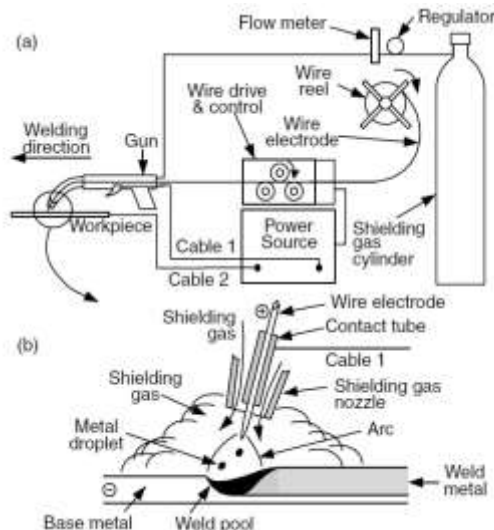


Figure 2.2: Schematic Diagram of GMAW welding process[8]

4 Methodology:

The methodology used Ultra -low nickel Cr-Mn austenitic stainless-steel plates with dimensioning of 120 x 75x4 sq. mm were prepared. The base material contained 0.09% C,0.29%Ni, and14% Cr with other elements. Two filler materials are used ER308L-16 electrode for SMAW and ER308L wire for GMAW.

Single V -butt joints were prepared for both welding processes. The welding speed are investigated as low, medium and high speed. (low welding speed :3 mm/s, medium welding speed:4.5 mm/s and high welding speed: 6 mm/s).The welding parameters (current, voltage) are shown in table below.[1]

Table 2 Welding parameters for SMAW and GMAW[1]

Welding Methode	Welding speed mm/s	Current(A)	Voltage(V)	Heat input (KJ/mm)
SMAW	3	90	21	0.441
	4.5	100	22	0.342
	6	110	24	0.308
GMAW	3	140	17	0.666
	4.5	170	19	0.602
	6	200	21	0.588

Heat input is given by $Q = VI/v$ KJ/mm

V= arc voltage in volts (V)

I= welding current (A)

V= welding speed (mm/s)

$\eta = 0.7$ for Shielded Metal Arc Welding

$\eta = 0.84$ for Gas Metal Arc Welding

5) Literature survey

P. Kumar et.al. [2] reported that SMAW welds exhibited higher ferrite content and improved resistance to hot cracking. Reddy et.al.[3] observed that GMAW produced better weld appearance and narrower HAZ. Singh et.al.[4] concluded that GMAW offers higher productivity and lower distortion. Sharma et.al.[6] studied corrosion behaviour and found that excessive heat input increased sensitization. Patel et.al.[7] reported that welding speed significantly affects microstructure and residual stress. H. Vashishtha et.al. 2016[] examined the effect of shielded metal arc welding with E308, E309 and E30 fillers on Cr-Mn ASS and found that the weld produced with E308 filler has higher tensile strength and hardness but lower impact strength due to its higher delta ferrite contents. The four major categories of stainless steel are ferritic, austenitic, martensitic and duplex stainless steel depends on the microstructure and composition of stainless steels. Excellent resistance of stainless steel to corrosion in seawater make stainless steel more applicable as compared to other stainless steels.[12]. Multipass weld is important in terms of weld repairs or improper welds. GTAW on 304L SS using filler 308 on a multipass reveals that with the increase in number of passes the ferrite content increases δ ferrite content increases. [13]

6) Conclusions

- 1) Tensile strength decrease with increase in welding speed in both GMAW and SMAW on Ultra Low Nickel Cr-Mn ASS (ULASS). The Tensile strength is found highest in SMAW at Low Welding Speed (LWS) of 3mm/s. The Ferriscope test reveals that ferrite Content in the Weld Metal is increasing with the increase in welding speed. SMAW posses higher ferrite content then GMAW.
- 2) Microstructure examination of weld zone shows dendrites of δ ferrite in both the processes. The Heat Affected Zone (HAZ) is decreasing with the increase in welding speed.
- 3) The impact Values decreases with the increase in welding speed in both GMAW and SMAW on Ultra Low Nickel Cr-Mn ASS (ULASS). At Low Welding Speed (LWS) the Impact values are highest.
- 4) The DLEPR results reveal that SMAW and GMAW welded joint are susceptible to Intergranular corrosion of welded joints. Welding of Ultra low nickel Cr-Mn Austenitic stainless steel (ULNASS) with GMAW is more susceptible to intergranular corrosion attack as compared to SMAW. Sensitization decreases with increase in welding speed. However, both SMAW and GMAW are more susceptible to IGC as compared to Base Metal.
- 5) The hardness is decreasing with the increase in welding speed in both the SMAW and GMAW. The Hardness at Heat Affected Zone (HAZ) is increasing with decrease in welding speed. In both the processes the hardness at the weld zone is less than the hardness at the base metal.

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