STRUCTURE-PROPERTIES CORRELATION IN WELDED CA-6NM STAINLESS STEEL

M. K. Sharma and **M. K. Das**

Materials Technology Division, Electrical Research & Development Association, Makarpura Industrial Estate, Baroda 390 010.

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ABSTRACT

Various types of stainless steels are being used for many industrial applications. The martensitic stainless steel CA-6NM is specially used for pumps, impellers and water turbine components. This steel has a very good combination of mechanical as well as microstructural characteristics. However the weldability of this steel is not good. The pre-heating and post-weld treatment is necessary for better properties.

In this paper, the mechanical properties and microstructure of CA-6NM SS welded samples are studied. The correlation between structure and properties of weldments are discussed for SMAW and TIG welding processes. The following welding parameters were used: (1) Welding by SMAW : Filler material-martensitic grade, Current-110Amp, Voltage-25 Volt, Polarity - DCRP, Speed-1.2 mm/sec and PHT / IPT-350 ^{0} C, PWHT-600 ^{0} C/ 4hrs/ FC and (2) Welding by TIG: Filler material -martensitic grade, PHT/IPT-300 ^{0} C, PWHT-650 ^{0} C/10 hrs/AC, Retempering -620 ^{0} C/5hrs/AC, Current-130 Amp, Voltage-12 Volt, Polarity-DCRP, Speed- 2.14 mm/sec and Ar gas pressure-10 Kg/cm ^{2} .

The increase in toughness and ductility is observed in welded samples compared to as cast base metal whereas the hardness and tensile strength was observed lower. The hardness in SMA welded sample at PHT/IPT 350 ^{0} C are observed 309 HV in parent metal,348 HV in weld and 371 HV in HAZ after PWHT at 600 ^{0} C.

The hardness observed in TIG welded samples are as 270 HV in parent, 309 HV in weld and 299 HV in HAZ. These hardness values show lower tensile strength in TIG welded samples than the SMA welded samples. The microstructure shows ferrite in martensite matrix. The studies show that best optimisation of properties can be made by correlation of microstructure and mechanical properties.

Keywords : *Stainless Steel, Welding, GTAW, SMAW, Mechanical Properties and Microstructure.*

INTRODUCTION

There is a growing interest in the relationship between microstrueture and mechanical properties with a view to the development of weld metals with optimum hardness, toughness and ductility [1]. This interest is not surprising, because it is very attractive to be able to understand the mechanical properties of weld metal from the observed microstructure [2].

The literature indicates that low ductile to brittle transition temperature i.e. resistance to cleavage may take place in high acicular ferritic steel. For example in case of low alloyed ferritic steel weld, high resistance to cleavage fracture will occur when the proportion of acicular ferrite is high and that of grain boundary ferrite with aligned martensite low [2]. On the other hand, an increase in the amount of a acicular ferrite in the microstructure is not always beneficial to the weld toughness, if the weld deposit yield strength increases too much as a result of precipitation hardening [3-4].

The microstructure is determined by the thermal history and the chemical composition of the weld metal [5-6]. Weld metal can be characterised by austenitization and transformation conditions, the effect of which is clear on the basis of CCT diagrams. The aim of the work is to characterise the microstructure of CA - 6NM stainless steel and to understand their influence on the mechanical properties. In the present study, the SMAW and TIG weld processes were used.

The metallography by optical microscope was used in characterising the microstructures of both the weldments. These results were completed by hardness, tensile, toughness and ductility data.

MATERIAL AND PROCEDURES

Material : The martensitic stainless steel grade CA-6NM material was used in this study. Two plates of 20mm x 75mm x 250mm and 4.30 Kg were cast. The chemistry of the base material is shown in Table I. Two types of filler materials of similar composition namely martensitic stainless steel electrode for shielded metal arc welding (SMAW) and martensite stainless steel wire for tungsten inert gas welding (GTAW) were used. Before welding, plates were heat treated at 1050°C for 2hrs/oil quenching. After austenitising, the tempering was carried out at temperature 620° /2hrs/ oil quenching [5].

Welding : The welding was carried out on single V-groove at 60° angle. The other welding parameter used in this study is mentioned elsewhere [6]. Typical chemistry of filler materials used in this study is given in Table I. During both the welding processes, pre-heat , interpass and post weld heating was done. During the welding of plate by TIG process, preheat & interpass temperature was used at 300°C and post weld heating was carried out at 650°C for 10hrs. Re-tempering at 620°C for 5hrs followed by air cooling was done. Shielded metal are welding (SMAW) of plate was carried out at 350°C preheat and interpass temperature. Post weld heating was carried out at 600°C in this treatment.

Characterisation : Microstructural studies conducted in this work include optical photomicrography. The standard metallographic method was used to prepare the specimens for microstructural studies. The mechanical properties such as hardness, toughness, tensile strength and elongation were taken on standard samples.

Table I : Chemistry of Materials (Martensitic grade) used in the Study

Sl. No	Filler Material	C	Mn	Si	Cr	Ni	Mo	Cu	S	P
1.	Base Metal	0.04	0.67	0.59	12.9	3.88	0.44	--	0.008	0.022
2.	SMA Rod	0.05	0.60	0.45	13.0	4.0	0.55	–	–	–
3.	GTA Wire	0.04	0.43	0.28	11.5	4.7	0.54	.11	0.008	0.01

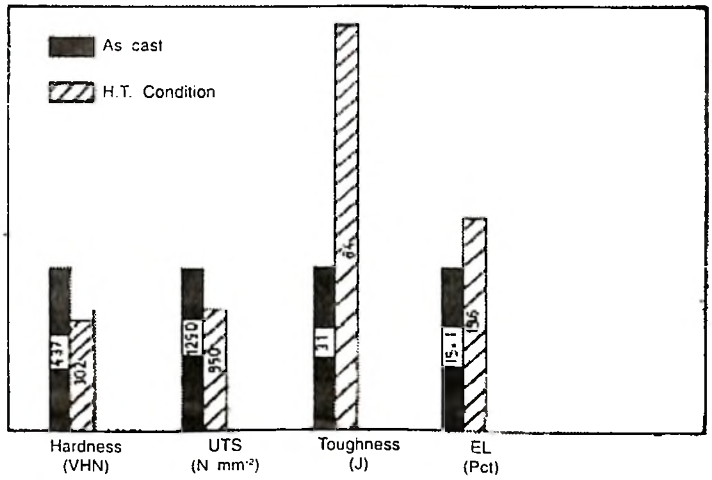


Fig. 1 : Bar diagram showing various mechanical properties in as cast (A.C) and heat treated (H.T) Condition

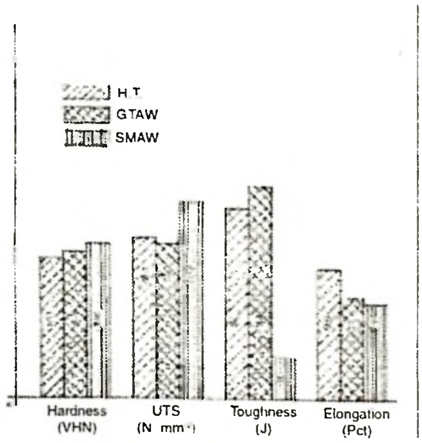


Fig. 2 : Bar Diagram Showing various mechanical properties in welded conditions

Vickers scale was used for hardness measurements to meet industrial practices. The hardness was taken at 30 Kg load and the average of five readings was recorded as final hardness. The tensile strength was taken on reduced section of tensile specimen to register the local elongation in the weld. The average of two readings was recorded. The toughness was measured in charpy V-notch specimens. The notch was made in the center of the weld metal. The average of three readings was recorded.

a
[Mg X 200]

b
[Mg X 200]

Fig. 3 : Microstructure of base metal
a) As Cast b) Heat Treated Material

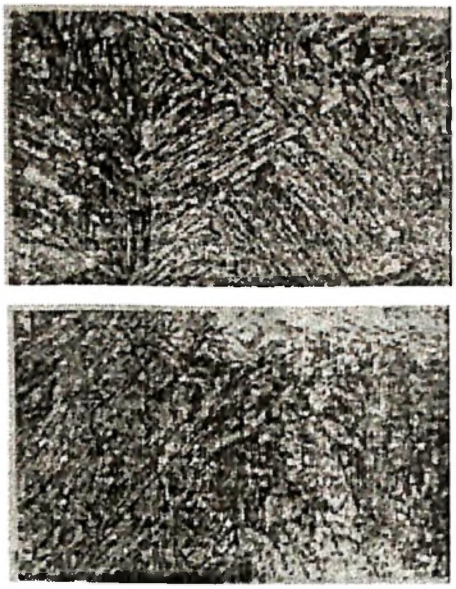
RESULTS

Various results of this study are shown in Figs. 1-5. The mechanical properties in as cast, heat treated

a
[Mg X 800]

b
[Mg X 800]

Fig. 4 : Microsturcture of weld metal from GTA Weldments



a
[Mg X 200]

b
[Mg X 200]

Fig. 5 : Microstructure of weld metal from SMA weldments

and in as welded conditions are shown in Figs. 1-2. The Figs. 3-5 show the microstructure of these conditions.

BASE METAL

To provide a baseline for comparision, the mechanical properties and metallurgical properties of the base metal were determined. The base metal in heat treated (1050°C / 2 hrs / A C) and tempered condition (620°C / 2hrs / A C) was characterised by hardness, tension, toughness and percentage elongation (Table II). Hardness and tensile strength was observed high in as cast material. As-cast hardness 437 VHN was decreased to 302 VHN after heat treatment. The toughness 31 Joul to 84 Joul and elongation 15.1% to 19.6%was increased from as cast to heat treated condition respectively (Fig. 1).

Microstructure of as cast material shows the fine needles of martensite in the matrix. Partially transformed phases are also observed. Few carbide can also be seen at the grain boundaries (Fig. 3a). In heat treated condition, the microstructure shows tempered martensite with few retained austenite in the matrix (Fig. 3b).

The result shows that hardness and tensile strength of as cast material is higher due to fine needle martensite. After heat treatment, this hardness and strength is reduced due to tempered martensitic structure. On the other hand, this tempering increases the toughness and ductility of the base metal in heat treated condition.

WELD METAL

The effect of welding processes on microstructure and mechanical properties of fusion zone are shown in Figs.4-5 and Table II. The hardness in 309 VHN in weld metal of GTAW process was observed whereas it increased to 348 VHN in weld metal of SMAW process. Similarly tensile strength 940 N mm^2 in GTA weld metal in

Table II : Mechanical Properties of base metal and weld metal					
Sl. No.	**Treatments**	**Hardness (VHN)**	**UTS (Nmm-2)**	**Toughness (Joul)**	**El (%)**
1.	As cast	437	1290	31	15.1
2.	Heat Treated	302	950	84	19.6
3.	GTAW Weld	309	940	93	15.0
4.	SMAW Weld	348	1175	18	14.0

comparision of 1175 N mm^2 in SMA weld metal were observed. On the other side, toughness (93 Joul) and elongation (15%) were observed in GTA weld metal. The weld metal from SMA weld process shows toughness 18 joul and elongation 14 % which is lower than GTA weld process.

The result shows that on one side hardness and tensile strength of weld metal by GTAW is on higher side whereas on the other side toughness and elongation is on lower side under the same conditions. Bar diagram-2 shows that the mechanical properties in GTA weldment is much more closer to heat treated base metal than the weldment in SMA welding.

Microstructure of weldment from GTAW process shows the very fine martensite (Fig. 4a). At some places fine carbide is also observed (Fig. 4b). Lower bainite can also be seen in this structure. The weldment from SMA process shows pockets of lath martensite (Fig. 5). The structure of SMA Weld metal is coarse grained (Fig. 5), comparatively to the structure from GTA weld metal (Fig. 4).

DISCUSSION

The high hardness is the result of high heat input and due to fine needle martensite in the matrix from the microstructural point of view. Toughness of weld metal depends upon welding parameters and post weld treatments. Welding process that produces a high heat input produces a lower toughness resistance. From a metallurgical point of view at the high heat input, lower toughness, high hardness and tensile strength are expected. To improve the mechanical properties, post weld heat treatment must be performed.

The room temperature tensile test data are shown in Table II . The tensile specimens exhibited strength of all weld metal samples, which averaged the strength of two samples. Elongation data show a weak trend of lower elongation with SMAW process.

Figs. 4-5 show the microstructure in fusion zone produced by both the processes. It is obvious that fineness of the structure is related to the cooling rate associated with each welding process. Fine structure is observed in GTAW weld (Fig. 4) than in weld structure produced by SMSW process (Fig. 5).

The general microstructure of both weldments revealed a martensite structure containing retained austenite. The grain size of these structures is controlled by cooling rate which is dependent on heat input [7-9].

The difference in mechanical properties, microstructure and principal constituents are responsible for different increase in hardness & tensile strength and decrease in toughness and elongation in weldment of SMAW.

It is clear that the higher strength and hardness (Table-II) of SMA weld metal is partly caused by the fine needles of martensite and presence of pockets of lath than in GTA weld metal. Because both microstructural features are, in general, also beneficial to toughness, it is the lower bainite which increases toughness and ductility in GTA weld metal than SMA weld metal.

CONCLUSION

Investigations described in this paper are on the mechanical properties and microstructure in heat treated condition and welded condition. The investigation demonstrates that tempered martensite and fine structure are beneficial to weld metal toughness. This is attributed to a simultaneous increase in hardness and strength.

The weld metal of weldments from GTA welding process shows the good optimum combination of mechanical properties and micro-structure. The very fine martensite with retained austenite is revealed in microstructure. The lower bainite is also observed in this condition. The hardness measurement were the least sensitive measure of micro-structural changes. They show the general trend of lower hardness of martensite in temperd condition. The present study shows that the micro-structure has a definite influence on the mechanical properties.

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