Indigenization of Weld Consumables for Grade of Steels withYS ≥ 690 MPa for Underwater Pressure Hull Construction

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Abstract :

High strength super structural steel, with an excellent combination of strength, toughness and weldability has been developed over the last two decades to replace conventional medium carbon steels. Modern submarines and warshipsrequires high strength steel plate in increasing portions of the hull structure for weight reduction, increased payload, and survivability.Naval ship structures are subjected to a complex spectrum of loads and environments. So the structural steel and welding materials used in hull fabrication must demonstrate high fracture toughness for these extreme conditions.With increasing in the use of high strength super structural steel for construction of modern submarines and warships, the welding techniques and welding process have become highly specialised. Developing requisite welding consumables and ensuring quality of weld joints is a challenge to both the weld industry and the shipbuilder.

The present paper provides the development of indigenous weld consumables for grade of steels with YS ≥ 690 MPa for sub-marine hull construction and warships. Butt welding experiments were being carried out usingindigenous weld consumables and control electrodes for reference. In order to characterize the weldments made by indigenous weld consumables, standard tests were conducted to determine the hardness profile, toughness, tensile properties, diffusible hydrogen, moisture content and coating concentricity etc. The results showthat the properties attained by indigenously developed weld consumables are par with control electrodes.

Introduction:

Development of high strength super structural steel and corresponding weld consumables has always been a challenge to the metallurgist and manufacturer both. The success comes only after prolonged research and engineering innovation. In India, presently Navy and industry are extensively involved in this process. High strength super structural steel strength (≥ 690 MPa YS), which is used for the construction of submarine in India and indigenous weld consumables arerequired for the hull construction of submarine.

Presently, NMRL is working in the indigenization and certification of weld consumables for DMR 249B steel for ships and submarine construction and also involve in creation of indigenous testing facility for certification of weld consumables. At present imported weld consumables is the only one source has supplied high strength super structural steel electrode to shipyard (MDL). Indian Navy / MDL, has therefore requested NMRL to take immediate steps for developing alternate sources based on indigenous technology to make weld consumables for MMAW, GTAW and FCAW welding.

The present paper provides the development of indigenous weld consumables for grade of steels with YS ≥ 690 MPa for submarine hull construction and warships. Butt welding experiments were being carried out using indigenous weld consumables and control electrodes for reference. In order to characterize the weldments made by indigenous weld consumables, standard tests were conducted to determine the hardness profile, toughness, tensile properties, diffusible hydrogen, moisture content and coating concentricity etc. The results show that the properties attained by indigenously developed weld consumables are par with control electrodes.

2. Experimental Procedures :

2.1 Base Plate:

A high strength, high toughness, super structural submarine quality steel, of 30 mm thickness was used for the experimentation. The chemical composition of the base metal is as shown in **Table 1** and mechanical properties are as shown in **Table 2**.For carrying out welding two plates of dimensions 300 X 150 X 30 mm were used to make a single welded test plate of dimensions300 X 300 X 30 mm.

Table1: Chemical analysis of base steelplate:

Materials	% C	% Mn	% Si	% S	% P	% Ni	% Cr	% Mo	Cu	V	Nb	Ti
Base Metal	0.12	0.47	0.22	0.004	0.010	4.17	0.38	0.27	0.12	0.004	0.002	0.036

Table – 2: Mechanical properties of base steelplate :

Materials	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)	Impact Toughness at – 40^0C (J)
Base Metal	**693**	**773**	**23**	**205 - 208**

2.2 Indigenization of Weld Consumables:

For welding of high strength super structural steel plates and structural members, conventional welding processes like manual metal arc welding (MMAW), gas metal arc welding (GMAW) and flux cored arc welding (FCAW) were utilised. MMAW electrodes are main weld consumables. Indian welding industry has already been producing low hydrogen variety of these consumables. However, some of the properties were to be modified to meet the requirement of high strength super structural steel. With guidance from NMRL scientists; A joint effort was made by Navy, MDL and manufacturer to indigenise the weld consumables for high strength super structural steel. Properties were evaluated forcritical yield strength, tensile strength, corresponding percentage elongation and toughness. The value of YS required to be achieved in weld and deposit and HAZ both was greater than 700 MPa and UTS in the range of 780 to 960 MPa, whereas corresponding percentage elongation was not to be lower than 17 % and corresponding toughness value to be required more than 47 joules at -40^0C. This was a difficult combination to achieve. The task of preparing the test coupons was undertaken by shipyard (MDL) to ensure correctness of welding process and uniformity. Elaborate test process was followed.

Following were the results:

(a) Weld consumables of total 6 firms were typed tested

(b) Consumables of TWO firms could not qualify the tests, even after the repeat tests.

(c) Weld consumables of FOUR leading firms could qualify only in the second trial after repeated improvements.

(d) Consumables of only ONE firm, which entered late and offered the products after detailed research, could qualify in the first trials.

It was also decided that prior to actual usage, each batch of weld consumables will be completely tested till the reliable consistency in the quality of production is achieved. Subsequent to the type testing, when the bulk production of weld consumables was undertaken by the qualified firms.

2.3 Preparation of weld joint

To determine the properties of weld joint, a test coupon of dimension 300 x 300 x 30 mm was made using the base plate and recommended filler metal. A schematic joint geometry is given in **Fig. 1**and the welding parameters used are given in **Table 3**. After radiographic examination, samples were machined from the test coupon for chemical analysis, impact testing, tensile testing and bend testing.

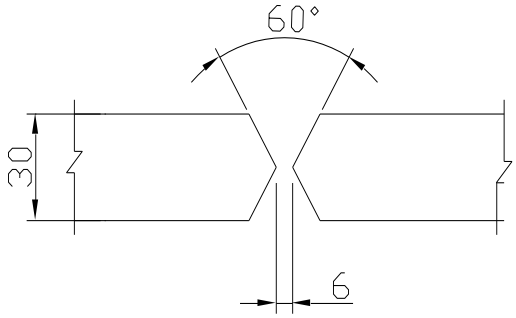

Table 3:Welding Parameters

Sr. No.	Welding Parameters	Values
1	Assembly Type	BW
2	Welding Process	111
3	Electrode Grade	Mangalam 69
4	Welding Position	PF (3G)
5	Electrode Size (mm)	3.15 for root 4.00 Passes
6	Arc Voltage (V)	70
7	Welding Current (Amp)	95 - 135
8	Heat Input (KJ/Cm)	17 - 23
9	Polarity	DCEP
10	No of Passes	17
11	Preheat Temp. ^{O}C	70
12	Inperpass Temp. ^{o}C	70

13	Post Heat Temp. ^{o}C	70 (5 Hrs)

Fig. 1 Weld Joint geometry

2.4 Weld Consumables Qualifications Test :

Weld consumables qualification tests such as manageability test, diffusible hydrogen test, moisture content test,coating concentricitytests, were carried outbefore doing the actual welding trials. The diffusible hydrogen was carried out by mercury method as per Indian standard (IS: 11302 – 1686) and moisture content test was carried out as per SFA – 5.1, section – II. The test results of all the tests are shown **Table 4.**

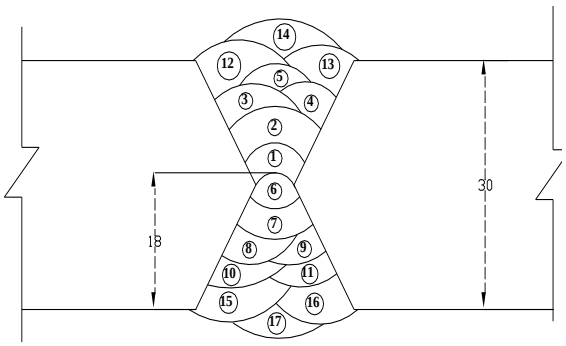

Table 4: Weld consumables qualificationtest before welding trials:

Process Electrode Brand	Diffusible H_2	Moisture Content	Efficiency & Current	Coating Concentricity
Specified	≤ 3ml / 100 gm	M : ≤ 0.10 % In. : ≤ 0.12 %	105%R_N ≤125	≤ 5 % Core Dia.
Control weld consumables	2.8	M : ≤ 0.008	112 DC^+	0.15
Indigenous Developed weld consumables	2.39	M : ≤ 0.007	119 DC^+	0.268

The test results observed of indigenous developed weld consumables were found to be par with control weld consumables and also meet the specified value of the stringent QR provided by Indian navy/Shipyard (MDL).

2.5 Weld Coupon Preparation of Indigenous developed weld consumables :

For characterization of control electrodes and indigenization electrodes testing, two plates of dimensions 300 X 150 X 30 mm were taken for making one set of weld. The

Double V-groove bevels were made on the longer side of the plates with included angle of 60^0 and root face of 0 mm. The plates were tack welded keeping a root gap of 6 mm. The bevel preparation residue (cutting oil or flame cutting remnant etc.)was thoroughly cleaned prior to welding. The welding was carried out using manual metal arc welding (MMAW) process. **Fig. 2 (a-b)**shows the completed welded plate for evaluation of coupon.

Fig. 2(a) Control Weld Consumable welded Coupon(b) Indigenized Weld Consumable Welded Coupon

3. Results and Discussion:

The welded coupons were characterized by non – destructive and destructive testing such as X-Ray Radiography, dry penetration and chemical analysis, Macrostructure, Microstructure, Tensile, Hardness and Impact properties etc. Radiographic inspection was carried out in accordance with the recommended practice ASTM E 94 and reference radiograph was used ASTM E 155. X-Ray Radiography results of control electrode and indigenized welded coupons were found to be non significant defect free weldments. Dye penetrant inspection was done in accordance with ASTM E165, dye penetrant inspection was also found to be free from blow holes, cracks, laps, cold shuts and other deleterious

discontinuities in the both the welded coupons. Three samples for chemical composition were taken from the weldment materials of control weld consumables and indigenised weld consumables welded coupons, representing top, middle and bottom portion of the coupon. The test was carried out as per ASTM E 478. The chemical composition of the weldments meets the specified composition as given at **Table -5.**

Table 5 :Chemical composition of control &Indigenised welds consumable weldments :

Materials	% C	% Mn	% Si	% S	% P	% Ni	% Cr	% Mo	Cu	V	Al
Specified	0.05 0.08	1.45 1.90	0.30 0.60	≤ 0.015	≤ 0.018	1.55 1.90	0.30 0.60	0.30 0.60	≤ 0.30	≤ 0.05	≤ 0.05
Control Weld Consumable	0.075	1.55	0.45	≤ 0.003	≤ 0.010	1.80	0.30	0.40	0.035	0.032	0.003
Indigenised Weld Consumable	0.057	1.62	0.47	0.005	0.017	1.65	0.43	0.49	0.027	0.014	0.008

It has been observed that the Welding Procedure Specification (WPS) adopted for weldingof high strength super structural steel plates resulted in obtaining weld metal chemical composition above the specified level and mechanical properties of the specified level **(Table - 6).**The cross section of the joint was macro etched and the test was carried out as per ASTM E 340 and using standard 5 – 10 % Nital reagent. Typical defect free MMAW joint macrograph obtained in control weld consumable as well as indigenised weld consumable welded coupon. The macro photograph also shows the layered of each passes and proper welding penetration. The macro photograph is shown in **figure 3 (a-b)**.

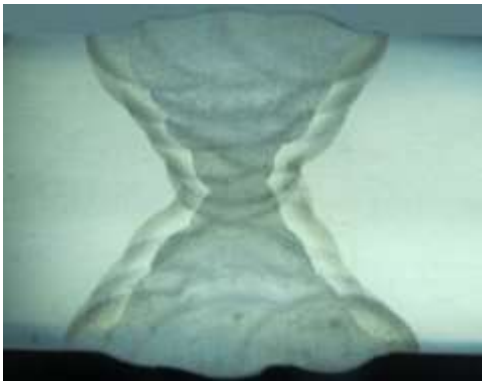

Fig.3(a)Control weld consumables Macrostructure(b) Indigenous weld consumables Microstructure

Optical microstructures of the same joint were shown below in **Figure 4.**This clearly illustrated the microstructure refinement in the weld nugget region of both the welded coupons. The welded microstructure of control weld consumables and indigenized developed weld consumable test specimen are shown in the **Fig. 4 (a-b).** The weld metal microstructure was observed to contain about 70 – 75% very fine acicular ferrite and 15 – 20 % fine free ferrite which is known for improving low temperature impact toughness and resistant to shock loading.

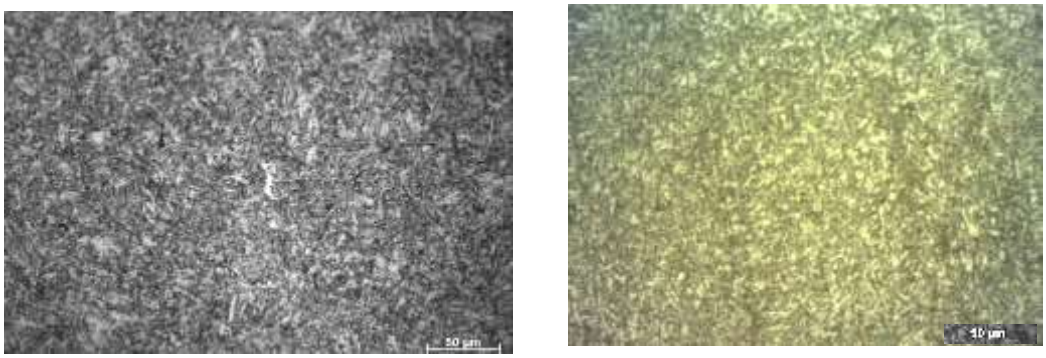

Fig.4 (a)ControlWeld Consumables Microstructure(b)Indigenous Weld Consumables Microstructure

Microhardness profile was taken across the weld from the base metal to the weld metal through the HAZ on the both welded electrode welded test specimens. The microhardness measurement of the bulge test specimen shown in the **Fig. 5.**The hardness was observed to vary between 310 and 325 HV10. The weld metal was observed to posses the maximum hardness.

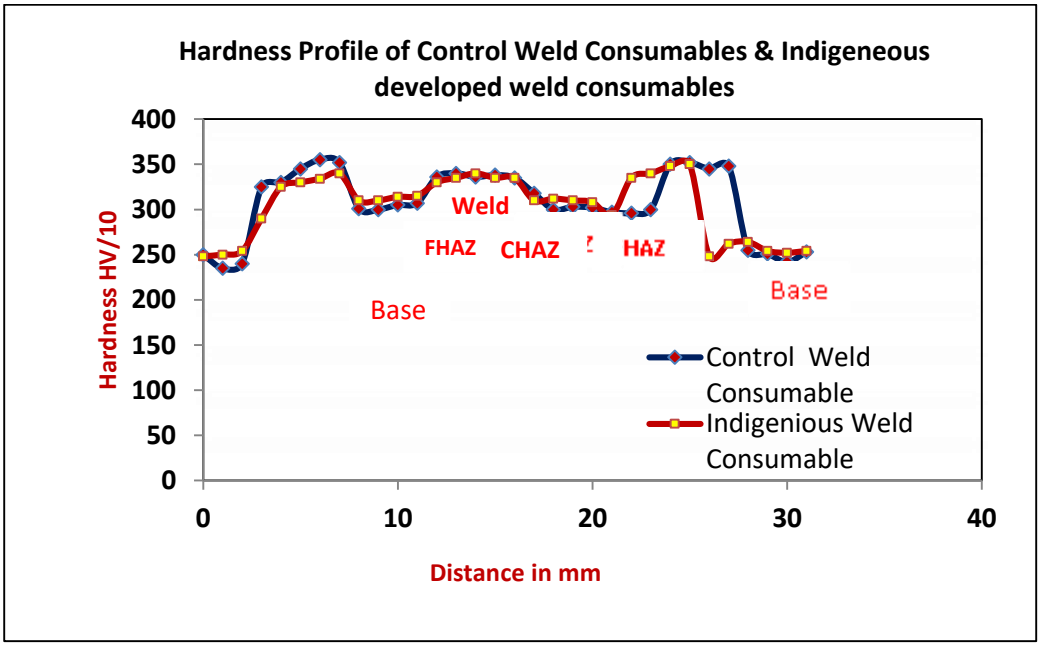

Fig. 5 Micro Hardness Profile of control and Indigenized weld consumables weldments

For impact testing, the charpy V-notch specimens were cut transverse to the weld andwithin 3 mm of the weld surface, with through thickness notch. In this way, the notch sampled several passes simultaneously as the fracture ran along the weld direction, thus giving an average effect. The Charpy tests were done in accordance with ASTM E23, using the specimens in triplicate at the temperature of – 40^{o}C. For tensile testing, all-weld specimens were drawn from direction longitudinal to the weld by ensuring that no portion of base metal lies within the sample gauge length. The testing was carried out as per ASTM E8M Standard. Bend testing was carried out as per ASTM E190 standard. The weld metal properties are given in **Table 6.**

Table6 : Mechanical Properties of Control &Indigenised Weld Consumables weldments:

Materials	No. of Specimen Tested	Yield Strength (MPa) Avg.	Ultimate Tensile Strength (MPa) Avg.	%El Avg.	Impact Toughness at -40^{0}C, Avg.
Specified	3	≥ 700	780 960	≥ 17	≥ 47
Control Weld Consumables	3	750	795	17	68
Indigenised Weld Consumables	3	864	912	20.83	62

Actual welded coupon of control weld consumables and indigenised developed weld consumables were undertaken when the weld metal properties were observed to be above the specified level, as illustrated in **Table 6.**

4. Conclusions :

1. The weld consumables used and the welding procedure adopted resulted in achieving desired weld metal mechanical properties and required resistance to fracture.

2. Test results such as weld consumables technological properties, mechanical properties of indigenous developed weld consumables as par with a control weld consumables and meet the stringent QR provided by Indian Navy/Shipyard (MDL).
3. It has taken about two years to establish effective control over the quality of indigenous welding consumables. Each batch received at shipyard (MDL) was subjected to complete range of testing prior to use.
4. The certification of each band of weld consumables is re-validated by tests after a span of two years. Same procedure is recommended for all new warship projects.
5. Strict measures were implemented to ensure the quality of weld consumables and the skill welders.
6. The quality of welding work being carried out at shipyard (MDL) is compatible to the world standard. This is a significant achievement for our indigenization “Make in India” programme, weld consumables manufacturers and the shipyard.

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