DEVELOPMENT OF ELECTRODES FOR SPECIALISED APPLICATIONS

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INTRODUCTION

Over the years welding has developed and occupied an important position and has become the most suitable method for joining materials. Hand in hand with the developments in the field of materials, welding has also developed to accomodate new consumables, new techniques and procedures for welding each one of them. In India, Shielded, Manual Arc Welding (SMAW) which is being used predominantly. has witnessed the development of several new welding electrodes for specific applications.

Not only the new materials have given a thrust to the development of welding electrodes, the changing requirements of technical specifications have also helped in developing new electrodes by modifying the older standard versions. With the developments in technology. the role played by various critical elements have come to light and enhancement of specific properties, control of deleterious effects are possible by suitable adjustments in the chemical composition of the weld metal. Whenever a specific service condition, calls for these properties, a new type of electrode emerges for this specidic application. This paper highlights some of the important developments which have taken place in the recent past.

Development of electrodes for specialised applications

In the recent past , development of electrodes has satisfied a wide range of industries meeting their specific weldmetal requirements. The technical requirements for the weldmetal usually cover a range of properties which are to be consistently maintained for all batches. This necessitates a careful selection of raw materials, establishment of necessary selection of raw materials, establishment of necessary test facilities identification of the role of each variable in the end result at the development and standardisation stage itself so that the end product will suit the purpose. Of late these considerations are of paramount importance since for many consumables the commonly used AWS specification, requirements are only a guideline and

- *changes in minimum/maximum levels of mechanical properties.*
- *restrictions in chemical compositions with or without changes in mechanical properties.*
- *additional properties are quite common.*

Having understoood this we now take a look at the recent developments made.

Electrodes for Lopearl Steel

The sugar Industry uses normally carbon steel for storing molasses. In order to enhance the life of these steels SAIL, R and D developed a special steel under the brand name "Lo Pearl". The composition of the steel can be seen

Table 1 : Chemical and mechanical properties of Loperal Steel

C	Mn	Si	P	S	Cu
0.10 max	0.5-0.8	0.10max	0.04max	0.04max	0.20-0.35

YS	UTS	%El(5.65/-SO)
25-30 kg/mm²	38 kg/mm²min	25.0 min

Table 2 : Typical chemical and mechanical properties of the weldmetal for Lopearl Steel

C	Mn	Si	P	S	Cu
0.06	0.64	0.22	0.020	0.020	0.30

YS	UTS	%El
40 kg/mm²	47.5 kg/mm²	28

in Table 1. With the addition of copper and controlling the amount of pearlite in the microstructure the enhanced corrosion resistance of the steel is obtained. The life of the steel is considerably increased as it resists corrosion by molasses. The development of the steel required the development of a suitable electrode for welding the same. After several efforts/tests the electrode was developed and the composition of the weld metal and mechanical properties are given in Table 2. The procedure qualified with this electrode showed excellent weldability and the joint achieved the desired properties including the corrosion resistance. Table 3 gives the procedure qualification details.

This is an example of the joint efforts put in by the steel manufacturer and the electrode manufacturer to develop an electrode and develop an appropriate welding procedure to weld the steel at the development stage of the steel itself.

Electrodes for high strength castings

Many of the castings are subjected to repair welding after the casting process. For this purpose, the weld metal should have the desired chemical composition mostly matching the base material composition and have the desired mechanical properties. In the castings which are used for oil exploration activities and other related activities the percentage of Ni in the casting is restricted and in some cases to below 1%. Table 4 shows the chemical and mechanical properties of 60K castings. It can be observed that while the nickel percentages are controlled to lower levels, the tensile strength is maintained at a higher level. After a careful analysis of the effect of addition of various elements a carefully controlled chemistry was designed to achieve the mechanical properties. The chemical composition of the weld metal is as shown in Table 5. A similar requirement was also necessary for welding API 75K castings. The chemical composition and the mechanical properties are shown in Table 6 and the weld metal designed for this application is shown in Table 7. It can be observed that a judicious choice of alloying elements are necessary to achieve ultimate service condition requirements together with the mechanical properties.

Table 3 : Welding procedure details

1.	Base material	:	Low Pearl steel
2.	Thickness	:	12 mm
3.	Joint design	:	Single Vee 60"
4.	Preheat	:	None
5.	Post weld heat treatment	:	None
6.	Interpass temperature	:	150°C
7.	Backside welding	:	Grinding and filling up
8.	Electrode sizes	:	2.5 and 3.15 mm
9.	Test results	:	
	(a) Radiography	:	Satisfactory
	(b) Transverse tensile fracture stress	:	47.9 kg/mm^2 Breaking in BM
	(c) Bend test (Face and roof)	:	Satisfactory
	(d) Hardness survey	:	BM : 130-140 VPN
			HAZ : 150-170 VPN
			WM : 155-180 VPN

TABLE 4 : CHEMICAL AND MECHANICAL PROPERITIES OF 60K CASTINGS

C	Mn	P	S	Si	Ni	Cr	Mo	Cu
.3	1.0	.04	.045	.8	.4-.8	.4-.8	.3-.4	.5

UTS	YS	%EI	%RA
620-795 Mpa	415 Mpa	18	40

Condition : Normalised and tempered

TABLE 5 : CHEMICAL AND MECHANICAL PROPERTIES OF WELDMETAL (TYPICAL)

C	Mn	Si	Ni	Mo
0.065	1.10	0.35	0.80	0.40

UTS	YS	%EI	CVN Impact strength
68 Kg/mm^2	58 Kg/mm^2	22	at-45°C : 3.0KgM

TABLE 6 : CHEMICAL AND MECHANICAL PROPERTIES OF 75K CASTINGS

C	Mn	P	S	Si	Ni	Cr	Mo	Cu
.30	1.0	.040	.045	.80	.4-.8	.4-.8	.3-.4	.5

UTS	YS	%EI	%RA
690 Mpa	515 Mpa	17	35

Condition : Quenched and tempered

Electrodes for 304Hmaterials

There are applications where stainless steels having specific carbon content are preferred. Some of the equipments using this material are reactor, regenerator, orifled chamber etc. of cracking unit of refineries. These equipments operate under high temperature and severe abrasive conditions. The use of 304H material which has a carbon content in the range of 0.04 to 0.08 provides elevated temperature properties which are highly desired in this application.

For welding of this material,an electrode having carbon content in the same range is desired. The carbon content of normal E308 is 0.08 max and for E308L is 0.04 max. However, the range between 0.04 and 0.08 was left free in the earlier stages. The latest versions of AWS classification includes one specific category E308H which is recommended for welding of 304H materials. The use of above materials called for a development of an electrode conforming to E308H having ferrite content in the range of 3 to 8%. Table 8 shows the chemical and mechanical properties of the weld metal together with the ferrite content. This electrode used to be imported in the past and with this development, the fabricators can have an access for an indigenous product.

Table 7 : CHEMICAL AND MECHANICAL PROPERTIES OF WELDMETAL (TYPICAL)

C	Mn	Si	S	P	Mo
0.06	1.85	0.45	0.018	0.019	0.40

UTS	YS	%El	CVN Impact strength
72 KG/mm^2	66 Kg/mm^2	22	at -51°C : 3 KgM

Table 8 : CHEMICAL & MECHANICAL PROPERTIES OF WELDMETAL CONFORMING TO E308H (TYPICAL)

C	Mn	Si	Cr	Ni	S	P
0.06	1.40	0.40	19.5	10.0	0.015	0.025

UTS	%El	Ferrite
62 Kg/mm2	38	4-6

TABLE 9 : BASE MATERIAL COMPOSITION FOR SOUR GAS SERVICE

C	≤	0.20	Cu		0.20-0.35
Mn	≤	1.40	Ni	≤	0.20
Si	≤	0.15-0.35	B	≤	0.002
Cr	≤	0.20	Al		0.01-0.05
Mo	≤	0.05	Ti	≤	0.02
V	≤	0.05	S	≤	0.003
Nb	≤	0.05	P	≤	0.015
Carbon equivalent			Pcm	≤	0.18
			Ce	≤	0.36

Electrodes for sour gas service

With the increasing interest in oil exploration. the activities pertaining to this field. are on the increase. The effect of various alloying elements on the properties of steel to suit the service conditions of this industry are also being investigated. and restrictions are being laid on various elements to modify the existing grades of base materials to suit this environment. The effect of H_2S atmosphere on the base materials is of particular importance. Materials should resist the hydrogen induced cracking and sulphide stress corrosion cracking as they will be exposed to H_2S atmosphere together with sea water. The specifications for the material i.e. carbon steel used for this application, more commonly known as sour gas applications, is shown in Table 9. As it can be observed, the levels of impurity elements have been restricted to a minimum. It is noteworthy to observed that sulphur is restricted to 0.003%. When this material was to be welded, the specification for the weld metal was fixed as E 7018 with restrictions in sulphur to very low levels preferably below 0.012. Under the normal production procedures and raw materials available, it is practically very difficult to achieve such low levels of sulphur. However, careful selection of raw materials and use of suitable grades of EQMS wires helped in reducing sulphur to lower levels. An electrode conforming to E-7018 having such low levels of sulphur was produced meeting the specification levels of 0.012%. Apart from chemical composition requirements, the weld metal was to meet the sulphide stress corrosion cracking test as per NACE TM-01-77 specification requirements and HIC test as per NACE TM-02-84 requirements, In the begining the facilities for conducting these tests were limited and hence inhouse R & D efforts had to be made to develop these tests so that every batch of these electrodes can be certified for their corrosion properties. A sample test result of HIC and SSCC are shown in Appendix I and II. The development of this electrode is a classic example of how indigenous facilities can be developed right from developing the electrode to testing and guaranteeing the specific properties for the weld metal.

Electrodes for welding duplex stainless steels

Duplex stainless steels are becoming popular as they are being used for various new applications. Even through a stainless steel containing nearly 50% ferrite existed in the past, the later versions with the addition of nitrogen, extra low carbon are becoming more popular as they combined the good properties of austenitic and ferritic structures to achieve superior mechanical properties and corrosion resistance. The offshore field and equipments performing in stress corrosion cracking environment use duplex stainless steels for their superior properties. One of the commonly used duplex stainless steels is detailed in Table 10. The weld metal developed for duplex stainless steel is shown in Table 11. This weld metal meets SSCC test as per TM-01-77 specification and a sample test report is shown in Appendix III.

Recently electrodes of this category have been included in the AWS specification which also gives a new diagram for measurement of ferrite in these weld metals. The development of this electrode calls for not only use of selected raw materials, core wires but also

Table 10 : CHEMICAL AND MECHANICAL PROPERTIES OF DUPLEX STAINLESS STEELS UNS 31803

C	Ni	Cr	Mo	N
0.03	4.5-6.5	21-23	2.5-3.5	0.08-0.20

UTS	YS	%El
620N/mm^2	450N/mm^2	25.0

TABLE 11 : CHEMICAL AND MECHANICAL PROPERTIES OF WELDMETAL

C	Mn	Si	Ni	Cr	Mo	N
0.04	1.5	0.4	9.4	22.0	2.9	0.14

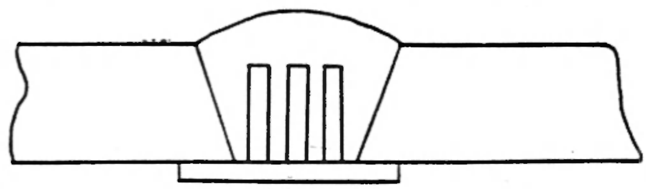
UTS	%El
73 kg/mm^2	25

APPENDIX - I

HYDROGEN INDUCED CRACKING TEST NACE STANDARDTM - 02-8 4

In this test 3 All weld test speciments equidistant from all test assembly (Figure 1) is subjected to test at ambient temperature for 96 hours in synthetic sea water saturated with H_2S. The specimen after the test is examined for blisters and crack sensitivity ratio. The crack sensitivity ratio shall be 0.009% max. A sample test results is as given below :-

1. Weld metals detail	:	Type : XXX
	:	Batch No. :- XXX
2. Test specimen	:	All weld : Machined 3 Nos. test specimern equidistant from all weld test assembly
3. Test specimen size	:	100L x 20W x 101mm
4. Test media	:	Synthetic sea water as per ASTM D 1141-75
5. Test environment	:	Test media saturated with H_2S.
6. Test temperature	:	Ambient temperature : 27° ± 1°C
7. Initial pH of test solution	:	8.24
8. Final pH of test solution	:	4.95
9. Total test duration	:	96 hours
10. Test started at	:	2.45 pm on 12.6.1993
11. Test discontinued at	:	2.45 pm on 16.6.1993
12. Visual observation	:	No blisters
13. Observation at 100X	:	CSR : 0.00
of transversely cut	:	CLR : 0.0
metallaorgraphic pieces	:	CTR : 0.0
14. Test result	:	Samples pass the test
15. Remarks, if any	:	--



a. use of modified techniques for measuring ferrite.

b. development and standardisation of equipments for conducting corrosion tests in order to maintain consistent quality.

CONCLUSION

Developement of electrodes requires an analysis of the various technical requirements so that the weld metal can be designed to achieve the desired properties. With the advances in technology, many specifications are able to spell out their exact requirements eventhough many a times it becomes a difficult task for developing the electrode. Some of the recent developments are highlighted in this paper and this should bring to light coordinated work that has been done by the manufacturers, users and approving agencies. The critical nature of the applications has not deferred any of them in developing the welding electrode. This is mainly because of the confidence level each one has built in the other over the years.

APPENDIX - II
SULPHIDE STRESS CORROSION CRACKING TEST NACE STANDARD TM-01-77

In this test an all specimen is subjected to a constant load (normally 80%) of the yield strength of the material) for a specified number of hours (normally 720 hours). The specimen is kept emerged in test solution saturated with H_2S throught this period. The acceptance criteria is that no failure occurs during this period. A sample test report is as given below :-

1. Weld metals detail	:	Type : XXX				
	:	Batch No. :- XXX				
2. Test specimen	:	A test specimen machined from all weld test assembly vide Section-3-Figure-1 of the NACE code.				
3. Chemical composition	:	C	Mn	Si	S	P
		0.055	1.14	0.43	0.009	0.018
4. Initial diameter of the test specimen, mm	:	6.39				
5. Test equipment	:	Constant load device through dead weight				
6. Test media	:	5% NaCl + 0.5% glacial CH_3COOH				
7. Test environment	:	Test media saturated with H2S				
8. Applied load/stress	:	356.08 N/mm^2/36.31 Kg/mm^2				
9. Test temperature	:	Amblent temperature :24 ± 2.6°C				
10. Initial pH test solution	:	2.80				
11. Final pH of test solution	:	3.05				
12. Total test duration	:	720 hours				
13. Test started at	:	2.45 pm on 13.5.1993				
14. Test discontinued at	:	2.45 pm on 12.6.1993				
15. Final diameter, mm	:	6.33				
16. Test result	:	No failure (NF) : Test passes				
17. Remarks, if any	:	--				

APPENDIX - III
SULPHIDE STRESS CORROSION CRACKING TEST NACE STANDARD TM-01-77

1. Weld metals detail	:	Type : XXX
	:	Batch No. :- XXX
2. Test specimen	:	A test specimen machined from all weld test assembly vide Section-3-Figure-1 of the NACE code.
3. Initial diameter of the test specimen, mm	:	6.41
4. Test equipment	:	Constant load device through dead weight
5. Test media	:	5% NaCl + 0.5% glacial CH_3COOH
6. Test environment	:	Test media saturated with H_2S
7. Applied load/Stress	:	355.69 N/mm^2/36.27 kg/mm^2
8. Test temperature	:	Amblent temperature : 24 ± 2.6°C
9. Initial pH of test solution	:	2.81
10. Final pH of test solution	:	3.42
11. Total test duration	:	720 hours
12. Test started of	:	2.40 pm on 11.7.93
13. Test discontinued at	:	2.40 pm on 10.8.93
14. Final diameter, mm	:	6.40
15. Test result	:	No failure (NF) : Test passes
16. Remarks, if any	:	--