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DEVELOPMENT OF COATED ELECTRODES FOR WELDING OF HSLA STEELS

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ABSTRACT

HSLA steels have acquired a significant position, in the engineering arena as the most important ferrous alloys for design and fabrication of structures. Application of HSLA steels at present is accepted, for almost all specific engineering structures namely – pressure vessels, bridges, buildings, penstocks, construction equipment and machines, etc.For welding of HSLA steels, welding consumables of specific characteristics are required. Present work involved design and development of electrode coatings, keeping in view the scientific findings for welding of HSLA steels. Further, the welded Joints have been subjected to various tests to ascertain the mechanical as well as metallurgical properties of the welded Joints. The various test results have been evaluated and provide information regarding suitability of the use of coated electrodes developed in combination with the base plate. The three sets of experimental coated electrodes have been designed and manufactured in this work. The first set of electrodes is with high silica content, successive iterations were aimed at reducing the amount of silica and increasing the amount of ferro-alloys and the carbon content of the welds. The composition of the base plate has been kept in mind while trying to develop the welding electrodes. In the last set of electrodes nickel was introduced into the weld metal through flux addition to enhance the impact strength of the welds at sub-zero temperatures.

Keywords: HSLA Steels, Coated electrodes, Slag-metal reactions, physicochemical properties

1.INTRODUCTION

WELDING OF HSLA STEELS

The following aspects must be taken into account in welding of high strength low alloy steels.

1. Preheat Considerations
2. Welding processes used
3. Selection of Filler materials
4. Postweld heat treatment

Although it is possible to weld some of these steels with non-low hydrogen electrodes, most steel manufacturers [1,2,3] recommend that low hydrogen electrodes always be used.

Since alloying elements in a weld metal play important role in microstructural evolution, including grain refinement, an appropriate alloying strategy becomes critical to promote a desirable microstructural distribution and to achieve required specifications. Hence, the effect of major alloying elements e.g., C, Mn, Si, N_2, O_2, S, H_2, needs to be examined for the development of a successful alloy system for HSLA steel weld metal.

SLAG-METAL REACTIONS

Attempts have been made by different researchers[4] to evaluate the state of slag-metal reactions during welding to study further the effect of flux composition on weld metal chemistry Most of the research workers have confined their studies with regard to the transfer of elements such as carbon, silicon , and manganese as well as the oxygen content of the weld metal using both commercial as well as experimental fluxes.

PHYSICOCHEMICAL PROPERTIES OF FLUXES

The physicochemical properties of the fluxes such as the size mix, bulk density ,flowability, hygroscopic nature, meltingpoint, meltingrange, surface tension, viscosity, current carrying capacity , welding speed, and electrical conductivity affect welding behaviour of fluxes significantly. The molten flux should be sufficiently viscous for proper coverage of weld pool, To attain the desired viscosity of coating, addition of CaF_2 , CaO, MnO and TiO_2 are made . Interfacial surface tension affects the quality of the weld and hazlett[5] has shown that undercut is generally associated with high interfacial tension .Too low an interfacial tension results in extensive spreading of the flux on metal substrate which may cause poor slag detachability . Low surface tension has been reported to be required to achieve good separation of slag from molten metal [6]. Surface tension may also play a role in the behaviour of arc cavity. It has further been demonstrated by Tuliani et.al.[7] that detachability of carbonate based fluxes is improved by addition of zirconia .Detachability of silica rich fluxes is improved by addition of rutile or corundum . A flux stabilizes the arc by providing easily ionized elements as source of electrons and ions which sustain the arc.Hazlett and Parker [8] have found that weld made under a lime flux resulted in smooth running arcs with high stability.Butler and Jackson[6] also found that arc stability is improved by addition of fluorospar to commercial fluxes. Olson and coworkers [9] showed that additions of either CaO or CaF_2 to the manganese silicate flux improve the arc stability .

METALLURGICAL PROPERTIES OF THE FLUXES

To develop a scientific base for clear understanding, number of fluxes have been investigated in past few decades.The metallurgical characterstics of the fluxes have been primarily defined in terms of its basicity index (BI) and oxidizing power of the flux. J.H. palm[4] has discussed about the metallurgical properties of the fluxes e.g., their chemical properties and oxidation-reduction reaction on the basis of chemical nature of the flux.

(1) EXPERIMENTAL PROCEDURES

(1.1) SELECTION OF COATING COMPOSITION

In the present work, Selection of coating composition was done, making use of binary ternary and quarternary phase diagrams of oxides and fluorides while keeping in view the physico-chemical and metallurgical properties, of the oxide- fluoride formulations.

(1.2) PREPARATION OF COATED ELECTRODES

After selecting the composition of coatings, the different formulations of the coating were prepared. The constituents of the coating were weighed in various proportions according to the weight requirements of the selected compositions. Electrodes were extruded from the electrode extrusion press by charging the flux-mix and Electrode core wire of grade IS- 2879 of diameter 3.15 mm and length 350mm.The extruded electrodes were checked for concentricity of the coating throughout the length and they were dried at the room temperature for one day. These electrodes were then baked at 425^0C in the muffle furnace.

(1.3) WELDING PROCEDURE

Bead on plate welding was carried out by using the coated electrodes Multilayer weld pad was formed on the MILD steel base plate to minimize the dilution effect. Top layer was, ground and polished and pad was analysed in spectrometer for chemical composition of weld metal. porosity and slag detachability were also observed for each electrode, the available information is presented in the Table 2.Single bead was made on the plate using the coated electrodes. The

length of the bead, time involved in making the weld bead, arc voltage during welding and amperage of the current used were measured.
The energy input during welding was calculated by the formula given below:

$$\text{Heat Input (J/mm)} = \frac{I.V \times f}{S}$$

Where I = current in amperes
V = arc voltage
f = energy efficiency
S = welding speed in mm/second

Welding was carried out to prepare all weld test assembly by forming a butt joint between two HSLA steel base plates, having single V groove,. Welding was done using DC electrode positive welding in flat position, each pass was carried out at normal welding speed and welding current. The welding parameters used are shown in Table.1

(1.4) WELD METAL ANALYSIS

The carbon, manganese , silicon, sulfur and phosphorus were determined using Atomic Absorption Spectrometer. The weld metal compositions achieved under different coatings are given in Table 3.

(1.5) TEST FOR DETERMINATION OF COATING MOISTURE

The moisture content of the coating was determined by performing the moisture test.(Table.5).The determination of diffusible hydrogen content of deposited weld metal was made by using mercury method (graph.2), for the three coated electrodes ,after redrying them at 250oC.

(1.6) TENSILE AND IMPACT TESTING

All-weld–metal tensile and impact tests are meant to determine yield strength, ultimate tensile strength, elongation, impact strength and other values of weld-metal deposited by welding consumable and undiluted by the base metal. In these tests, the specimens were so prepared that the sections which were subjected to the test consisted of pure weld metal.
The welds produced by the three sets of fluxes were tested to measure their yield tensile strength and ultimate tensile strength and percentage elongation. Two tensile test specimen were produced for each set of flux having diameter 4mm and gauge length of 20mm by machining from welded samples. (Table 6)
To measure the transition in impact strength or toughness with change in temperature of all-weld metal, produced by using the developed coated electrodes the charpy v-notch test was carried out at temperatures having from -20^{0}C to 20^{0}C.For achieving the different temperature for the specimen, acetone with solid CO_2 was used. Digital thermometer was used to give the temperature readings. After the required temperature for specimen was achieved, the charpy test was conducted.(Table 7)

(1.9) EXAMINATION OF MICROSTRUCTURE AND HARDNESS STUDIES

The microstructure of weld metal is the result of cooling rate history of the weld zone which in turn is directly related to the welding process and techniques employed. Since there is a direct relationship between the weld defects and mechanical properties on the one hand and microstructure on the other, it is most important that a careful and comprehensive study of microstructure of the welds be undertaken. Specimens of cloth polished were etched by 2% Nital and than examined under optical microscope. All samples were photographed on magnification 200 x in order to get the clear picture of different phases which comprised the weld metal, HAZ and base plate. Separate micrographs of WELD METAL, HAZ and BASE METAL(derived from welding using the three developed coated electrodes) at magnification 200 x are shown .(Fig.1-7.)
Hardness values of the weldments were determined along a line perpendicular to the plate surface and starting from weld metal through the HAZ and into the parent metal. The Vickers method of hardness testing was employed for the measurements.

(2) RESULTS AND DISCUSSION

In the present work involved, eight preliminary electrode coating formulations were prepared. The coated electrodes prepared were subjected to test for studying their welding behavior with respect to arc stability, gas emission, slag detachability and porosity. The coated electrodes were also found to have very low moisture content ranging from 0.09 % to 0.15%. The electrodes so prepared are essentially low hydrogen electrodes which are suitable for welding of HSLA steels. Bead on plate welding was carried out using coated electrodes F-1, F-2 ,F-3 and F-10.The weld metal analysis carried out showed that Si , Mn and carbon content of the weld metal was very low for F-3 and F-10 whereas the amount of these elements in weld metal deposited using F-1 and F-2, were close to the composition of the base plate. By appropriate addition of ferro-alloying elements in the form of ferro-alloys, in the coating, there is substantial gain in silicon and manganese for coating type F-1, F-2 and F-3.But in case of carbon there is some loss of this element for F-2 and F-3 and gain in case of F-1.The loss of Mn and carbon in case of F-3 (Table.4, graph1) is due to higher silicon content, which is responsible for increase in oxygen potential of the molten coating. Welded coupons prepared using F-1,F-2,F-3, were subjected to metallographic examination.

(3) DISCUSSION OF MICROSTRUCTURES

(3.1) BASE METAL

The microstructure of the base metal in fig.2 shows, ferrite grains and pearlitic regions along the grain boundaries, which are almost uniformly distributed throughout. However the pearlitic regions show a definite orientation which might be due to the history of thermo-mechanical treatment.

(3.2) WELD METAL

Microstructures of weld metal for F-1, F-2, F-3, are shown in fig (5-7). Although the energy input for making the welded joint has been the same, i.e. 909 J/mm, there is a significant difference between the weldmetal microstructures developed using the three types of coated electrodes.For electrode F-1 there is negligible proportion of grain boundary ferrite whereas presence of acicular ferrite is prominent. There are minor quantities of ferrite carbide aggregates, which include, pearlite as well. The microstructure also consists of small quantities of martensite, which is widely distributed throughout. The structure may also contain in certain locations some of the quantities of upper and lower bainite. The presence of bainite is very difficult to identify. There are also some indications of the presence of widmanstatten structure but in very small quantities. This type of microstructure should have good ductility and toughness.In the case of F-2 , the weld metal microstructure shows the presence of polygonal ferrite and substantial quantities of ferrite carbide aggregates. The proportion of Acicular ferrite is much less as compared to the weld metal developed for F-1, there are some regions where grain boundary ferrite is also present. There is substantial indication of presence of upper bainite with cementite with fair distribution. Presence of widmanstatten structure, though in very small proportion is also indicated. Ductility and toughness of this microstructure as compared to that of F-1 is expected to be reduced.

Weld metal microstructure for F-3 shows significant quantities of polygonal ferrite and grain boundary ferrite. Presence of Acicular ferrite is almost negligible. Ferrite carbide aggregate islands are present in microstructure which include pearlite. In certain locations, ferrite is present with aligned martensite, retained austenite and carbides. The structure is such which renders the material low ductility and poor toughness.

(3.3) MICROSTRUCTURE OF HAZ

HAZ microstructures have been taken from fine grain region are shown in fig.1,3,4.

HAZ microstructure for F-1 shows varying size grains of ferrite with finely distributed pearlite all around. In this region as the peak temperatures achieved are low and so carbides do not go into solution .So the ferrite grains are usually fine and the structure as obtained mainly comprises of ferrite, pearlite and carbide. In case of F-2 the structure shows the presence of ferrite grains with colony of ferrite carbide mixture including pearlite. The structure also gives an indication of bainite and martensite in carbon areas. In case of F-3, the ferrite grains are almost uniform in size, with fair distribution of carbides. The structure also shows presence of small quantities of retained austenite.

(4) MECHANICAL PROPERTIES

The mechanical properties of the all weld metal portion of the welded joint are given in the Table 6,7,8. and compared in Graphs.3.The weld metal properties are better in case of F-1 and F-2 as compared to F-3.The weld metal hardness is maximum for F-1 and minimum for F-3 .The hardness of the HAZ for all the three is almost equal .The mechanical properties of the three welds is conforming to the microstructure of the weld metal showing that in case of weld metal F-1 is having higher strength and higher toughness as compared to F-2 and F-3.The values of impact strength obtained at ambient and sub–zero temperature, show that , the weld metal , obtained in case of F-3, is the poorest among the three. The values of impact energy absorbed in this case show that the fracture is almost brittle. This might be due to presence of dissolved gases like hydrogen and oxygen. Presence of oxygen as solution in the weld metal has earlier been shown by other research workers to increase the ductile to brittle transition temperatures.

(5) CONCLUSION

Among F-1, F-2, and F-3, the F-1 is the most appropriate coating formulation for C-Mn type HSLA steel. The coating F-2 is workable but needs to be investigated further for modifying the existing formulation so as to obtain better results. The formulation F-3 is not suitable for welding of C-Mn type HSLA Steel and needs further improvement in coating composition to provide adequate mechanical properties.

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TABLES AND GRAPHS

Table 1 Welding Parameters and Heat Input

Welding current(ampere)	Arc voltage (volts)	Welding speed (mm/sec)	Energy efficiency	Heat input Joules/mm
110	26	2.83	0.9	909.5

Table 2 Observations of Porosity ,Gas emmisions Slag Detachability and Arc stability

Coating	Arc stability	Gas emissions	Slag detachability	porosity
F-1	EXCELENT	LOW	GOOD	NOT PRESENT
F-2	EXCELLENT	LOW	GOOD	NOT PRESENT
F-3	GOOD	MEDIUM	MODERATE	NOT PRESENT

Table 3 WELD METAL ANALYSIS

Coating Type	%Fe	%C	% Si	%Mn	% P	% S	% Mo	% Ni	% Al	% Co	% Cu	% Nb	% V
F-1	97.48	0.066	0.44	1.54	0.017	0.019	0.008	0.232	0.002	0	0.006	0.001	0
F-2	97.86	0.055	0.415	1.4	0.018	0.02	0.004	0	0.003	0	0	0	0
F-3	99.27	0.032	0.084	0.316	0.025	0.026	0	0	0	0	0.004	0.001	0
F-10	99.49	0.036	0.047	0.17	0.019	0.031	0	0	0	0	0.001	0	0
BASE PLATE	97.86	0.08	0 .33	1.58	0.015	0.005	0	0	0.029	0.0057	0	0.043	0.04
ELECTRODE	99.45	0.06	0.03	0.42	0.022	0.015	0	0	0	0	0	0	0

Table 4 % change in element composition of welds from the composition of electrode wire

COATING TYPE	%Fe	%C	%Si	%Mn	%P	%S

F-1	-1.98	10	1366	266	-22.7	26.6
F-2	-1.59	-8.3	1283	233	18.1	33.3
F-3	-0.18	-46.66	0.18	-24.7	13.6	73.3

Table 5 Table of Moisture content

COATING	Initial weight of absorption tube	Weight of absorption tube after blank determination	Blank reading	Weight of tube after moisture	Moisture reading	% moisture
F_1	27.152	27.1522	0.0002	27.1584	0.0062	0.15
F_2	27.594	27.5941	0.0001	27.5978	0.0037	0.09
F_3	27.361	27.3611	0.0001	27.3652	0.0041	0.1

Table 6 WELD METAL AND BASE PLATE MECHANICAL PROPERTIES

WELD METAL type	E-modulus (MPa)	Yield stress (MPa)	Maximum Stress (Mpa)	Strain at yield %	Elongation at break %	Weld metal hard ness HVA 30	Hydrogen content in ml/100 gm of deposited weld metal
F-1	15757.5	495.3	572.5	3.394	29.825	208	2.1
F-2	15773.5	480.1	561	3.074	32.72	181	2.16
F-3	14355	358.5	384	7.6	15	160	4.82
BASE PLATE	4965	496	544	7.95	27.56		

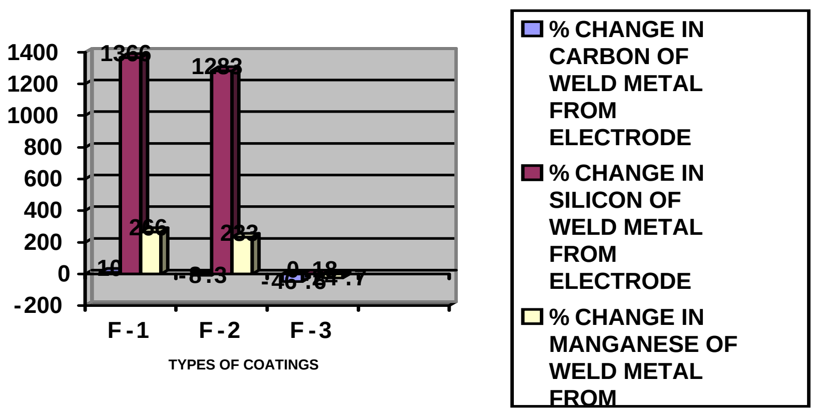
Table 7 Impact energy measured by charpy v notch impact test for actual dimensions

COATING TYPE	Impact energy (J) absorbed At -20oC	Impact energy (J) absorbed At -10oC	Impact energy (J)absorbed At 0oC	Impact energy (J)absorbed At 10oC	Impact energy (J)absorbed At 20oC
F-1	100	106	116	130	140

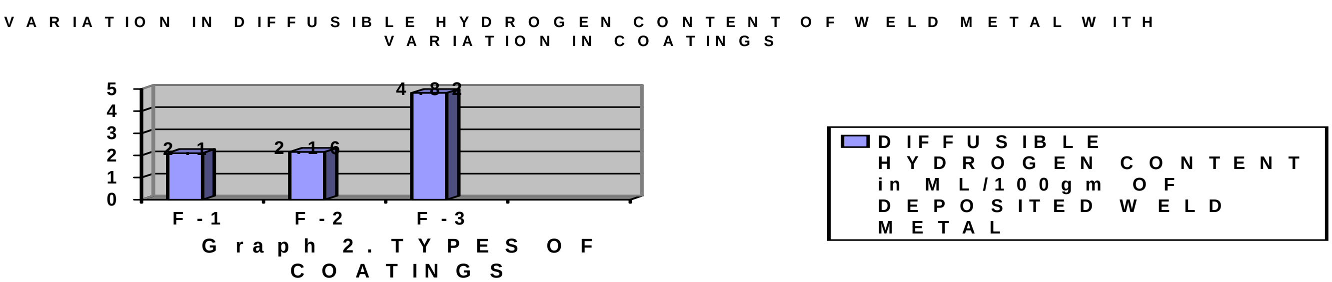
F-2	108	114	127	138	146
F-3	6	13	33	52	83

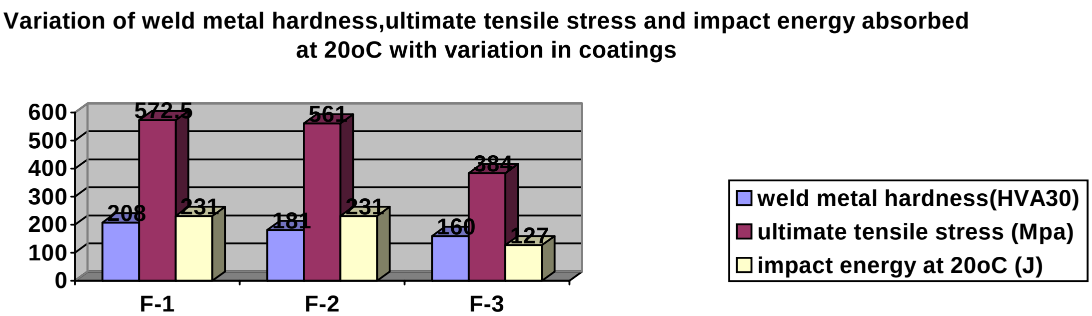
Table 8 WELD METAL AND HAZ HARDNESS FOR COATINGS

TYPE OF COATING	Weld metal hardness HVA30	HAZ Hardness HVA30
F-1	208	216
F-2	181	214
F-3	160	216



Graph 1: % change in C, Si and Mn for the weld metal for the different coatings





Graph 3. Types of coatings

FIGURES

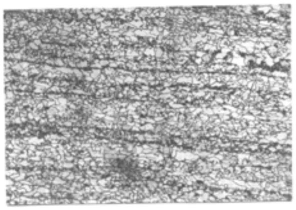


fig.1 Flux -2 HAZ

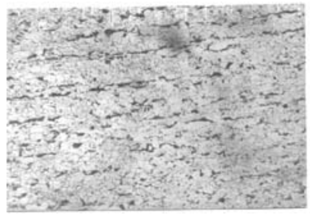


fig.2 BASE METAL

fig.3 FLUX -3 HAZ

fig.4 FLUX-1 HAZ

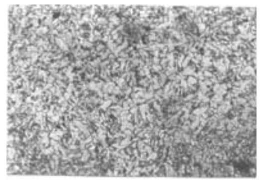


fig.5 WELD METAL FLUX-2

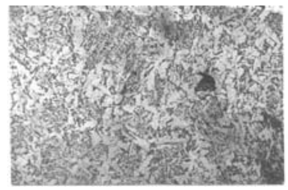


fig.6 WELD METAL FLUX-1

fig.7 WELD METAL FLUX-3

MICROSTRUCTURES