Effect of Welding Current on welding between Inconel 625 and Carbon steel using Submerged Arc Welding

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***Abstract*— INCONEL nickel-chromium alloy 625 is used for its high strength, excellent fabricability (including joining), and outstanding corrosion resistance. It is being used widely in the industry of oil & gas. INCONEL 625 and Carbon Steel forging components are made by SAW (Submerged Arc Welding) which has been used in industry since a long time. The present investigation involves an overlay of the material INCONEL 625 on the base material of Carbon Steel ASME SA 105 was made by Submerged Arc Welding (SAW). Different experiments will be performed by varying welding current. After the welding has been carried out, the weld will be tested for physical, mechanical and metallurgical properties. Finally the best optimized parameters were validated based on the results of physical, mechanical and metallurgical properties.**

***Index Terms*—Submerged Arc Welding, Overlay, Inconel 625**

I. Introduction

Nickel-chromium-molybdenum alloys are well known for its creep properties along with high corrosion resistance which finds a very large application in Oil and Petro chemical industries. However due to its prohibitive cost a cheaper alternative of cladding NI alloys on carbon steel base material is widely used Inconel 625 is a corrosion resistant nickel base alloy used extensively for its wear resistance in aggressive, chloride bearing environments. Wrought, cast, powder metallurgy and weld overlay products have been used. Alloy 625 has also demonstrated excellent performance in nuclear power plant operation environments where the operating chemistries are less aggressive but where very reliable long term performance is required. So the alloy has been investigated for applications in the reactor system. In petroleum industry, the quick opening closures used in pipelines are cladded with alloy 625 in the interior for corrosion resistance. The purpose of the present investigation is to develop a method of producing reliable, defect free weld overlays of alloy 625 on Carbon steel using the production welding technique of SAW.

Weld overlay can be produced with a number of arc welding processes. MMAW, SAW wire and strip, MIG/MAG and TIG (hot wire and cold wire) processes are commonly employed. A major concern in an arc welding based overlay is dilution or the extent of change in the chemistry of the deposited metal by the mixing of base metal. Even though some generic information is available on the extent of dilution associated with common arc welding processes, the actual dilution with a particular process itself can vary over a wide range, based on the welding parameters employed. In most cases of overlaying, it is necessary to control the dilution within close limits as an uneven chemistry can reduce the service life. There are number of variables which affects dilution such as welding current, the arc voltage, current polarity, electrode diameter, electrode extension, welding speed, welding position, shielding gas composition etc. It is necessary to control each of these variables within limits to get the desired properties on the overlay. ASME codes and standards gives the information about heat input (essential variable) and can be control or achieved by varying current and the welding speed.

An overlay of the material INCONEL 625 on the base material of Carbon Steel ASME SA 516 Grade 70 /ASME SA 105 will be made by Submerged Arc Welding (SAW) and will be tested to determine the process variables where the maximum optimum properties are obtained. The purpose of this project was for the weld to meet the specifications which were set to ensure that the weld would be able to give service in the required conditions of high temperature (from cryogenic to 5400C [10000F] and corrosion according to ASTM SECTION II PART C.

II. Experimental Work

The carbon steel material was used as base metal and the weld overlay was produced on the top of the plate using SAW process at various currents to deposit Inconel 625 onto carbon steel. The dimension of carbon steel base material was 150 X 150 X 38 mm. The welding was conducted in two layers of 8 mm thickness total. Prior to the welding of the second layer the first layer was machined to remove any surface oxidation. The second surface was machined to generate a smooth surface and penetrant testing was performed to verify soundness of welds. The composition of filler material FM 1used for overlaying is shown in the Table 1. The filler wire namely FM 1 and flux namely F1 were used for experimental purpose and Mechanical properties and physical properties are given in Table 2 and 3 respectively for filler wire FM 1. The Chemical composition of Flux F1 is given in Table 5.

Table 1: Chemical Composition % for filler material FM 1

C max	Si	Mn	P Max	S max	Cr	Ni Min	Mo	Fe Max	Nb
0.03	0.2	0.2	0.015	0.010	22	60	9	0.5	3.4

Microstructure – All Weld Metal: Fully austenitic microstructure

Table 2: Mechanical Properties – All Weld Metal for Filler Material FM 1

Temperature (°C)	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Reduction In Area (%)	Impact strength Charpy V (J)	Hardness, Vickers (HV)
0.03	0.2	0.2	0.015	0.010	22	60

Table 3: Physical Properties – All Weld Metal for Filler Material FM A

Temperature (°C)	20	100	300	500	700
Thermal Conductivity W/m°C	15	16	18	22	700

Table 4: Chemical Composition of Flux 1 (NOMINAL) %

$SiO_2 + TiO_2$	CaF_2	Al_20_3+MnO
14	52	30

The machine used was ADOR Welding unit "Semi-Automatic, Model: COMBO-MS600" which is shown in figure 1. Seven welding currents of 150A, 250A, 350A, 450A, 550A, 650A and 750A were used keeping all other process variables constant. Above 32 mm of section thickness of the metals to be welded the entire section should be preheated. All trials have multiple electrodes and multiple passes per side and the mode of welding was semi-automatic and the position used is 1G. All welded samples were cross sectioned for Spectrochemical analysis. The process parameters are given in the table 6 which were kept constant.

Table 6: Weld Process Parameters

Power source	Polarity	Voltage	Travel Speed
DC	EP	30 V	220 mm/min

The hardness was measured in the transverse sections of all weld overlays at the approximate locations shown in the figure 2 below according to ASME Section IX 2010 industrial practice. The micro-hardness of each weld overlay was measured by Vickers Hardness machine at the locations corresponding to A, B, C and D in the figure 1. The micro-hardness readings begin from bottom to top for A, B and C locations and left to right for location D.

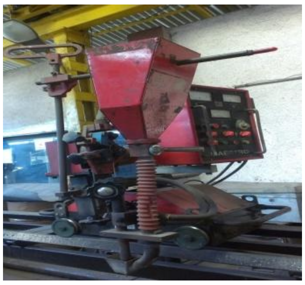

Figure 1: Welding head of the welding machine used.

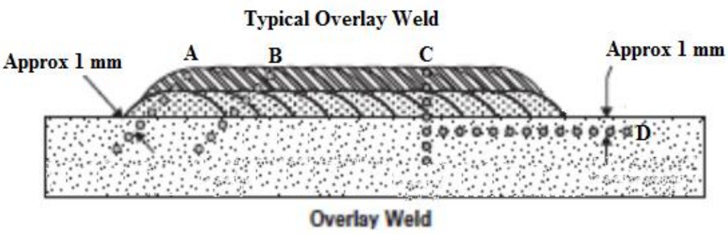

Figure 2: Schematic representation of location of hardness test on specimen cross section

Weld metal composition was analyzed using Spectrometry analysis to determine fraction chemical elements in the weld. The specimens are then tested by mass spectrometry. The surface of the weld is smooth finished and grinded and etched to reveal an ultra smooth surface. The grinding is done on a grinding machine using sand papers. The specimen is then sent for chemical analysis by mass spectrometry. Three readings were taken and then the specimen was reduced by 1 mm thickness. Then the readings were again taken. These way readings were taken continuously and reductions of 1 mm thus made till the base metal was visible. The readings were displayed on computer monitor and noted. The different welds were compared on the basis of weld metal dilution. After this the bend test was done.
Alloy 625 filler wires of diameter 3.2 mm meeting AWS A5.14 ERNiCrMo-3 were used in all experiments. The current was changed keeping all other process parameters constant.

III. RESULT AND DISCUSSION

The weld overlay made at 150A and 250A show lack of fusion and porosity. As the current increases there are minimal increases in the hardness of the HAZ and weld metal. When the current is increased from 250A to 350 A the increase in hardness is more and continues to increase in the welds made at 450A and 550A. The welds made at 650 A and 750 A show undercuts and the weld made at 750 A also shows a crack from the weld metal up to the base metal substrate. Hardness results for weld overlay are shown in the table 7.

Table 7: Hardness Results for Weld Overlay

Location	Vickers Hardness (HV 10)						
	Specimen 1 (150 Amp)	Specimen 2 (250 Amp)	Specimen 3 (350 Amp)	Specimen 4 (450 Amp)	Specimen 5 (550 Amp)	Specimen 6 (650 Amp)	Specimen 7 (750 Amp)
A	179	183	188	201	204	203	207
B	182	185	193	206	208	206	216
C	183	184	192	207	209	206	212
D	187	188	198	216	220	212	225

Dilution is defined as the change in composition of the weld metal caused by the mixing of the base metal or the previously deposited weld metal. The spectrometry was basically done to find out the composition of the HAZ of the weld overlay. The dilution was measured at locations corresponding to A, B, C and D as shown in figure 2 of weld specimen cross section. Spectrochemical results of the specimen are given in the table 8.
The location corresponding to the central region of the weld metal considering the fact that the agitation of the weld metal during welding would make the composition approximately uniform throughout the weld metal except for regions which are very near to the fusion boundary. Significant differences in dilution were observed between the first weld bead and the subsequent beads. This was because, in the first bead, the arc directly strikes on the virgin base metal resulting in significantly higher melting of the parent metal. In subsequent overlapping weld passes, a part of the initial weld bead would be melted reducing the extent of parent metal melting, and a steady state would be reached after certain number of passes. Results of the experiments by varying the electric current showed that the weld width and depth increased by increasing the welding current. These results suggest an increased melted substrate so a higher dilution is observed. The heat input per unit length increases with an increase in welding current. Variation in the weld bead size with increase in welding current was also observed. The width of the weld bead size with increase in amperage increased almost linearly for constant values of other welding parameters. The depth of penetration also showed increase while the weld height showed slight decrease.

Table 8: Spectrochemical Analysis Results

	Min.	Max.	Specimen 1 (150 Amp)	Specimen 2 (250 Amp)	Specimen 3 (350 Amp)	Specimen 4 (450 Amp)	Specimen 5 (550 Amp)	Specimen 6 (650 Amp)	Specimen 7 (750 Amp)
Cr	20.0	23.0	25.79	25.2	22.73	21.82	20.9	13.9	8
Mn	-	0.50	0.44	0.4	0.45	0.44	0.87	0.88	1.23
Fe	-	5.0	2.4	2	4.7	15.7	35.6	36.4	40.8
Ni	58.0	-	71.56	71.33	70.52	61.29	49.87	40.9	33.24
Mo	8.0	10.0	7.39	7.34	7.4	8.5	9.2	11	11

It was observed that specimen welded with 150 A, 250 A, 650 A and 750 A are failed during bend test while specimen welded with 350 A and 450 A were gives satisfactory results shown in the table 9. Cross sections showed that the cracking was present in the overlay down to the carbon steel substrate. The higher heat input results in slow cooling through the solidification range. As the heat input is reduced the cooling rate increases resulting in rapid cooling. The high heat input used in this preliminary investigation of SAW would result in relatively slow cooling through the solidification range. The lesser heat input would result in more rapid cooling. This shows that heat input is a more important factor controlling cracking than other weld process parameters. The difference between the high heat input weld overlay which cracked and the lower heat input weld overlays which did not crack is significant. No sign of cracking was observed in the latter and it is possible that higher heat inputs and deposition rates are possible before a cracking threshold was reached. A lower heat input could be used to achieve higher deposition rates.

Table 9: Bend Test Results

Welding Current (Amperes)	150	250	350	450	550	650	750
Bend Test Result	Failed	Failed	Satisfactory	Satisfactory	Satisfactory	Failed	Failed

After these experiments it was found that the weld overlay with optimum properties was found to be made at 450 amperes. Then a weld overlay over the required job of quick opening closure was made at 450 amperes.

IV. Conclusion:

Cracking was observed in the weld deposited overlay with higher heat input while lower heat inputs resulted in sound weld overlays. Cracking can be avoided by reducing the heat input during welding process. Acceptable deposition rates were observed at reduced heat inputs. The dilution increases with increase in heat input and the Nickel and Chromium content decreases. The bend test results showed that there were cracks observed at very high heat inputs and at 6.136 kJ/mm (750A) the specimen breaks during the bend test. HAZ shows higher hardness than the weld metal. Cracks were observed in the weld overlays made at 550, 650 and 750 amperes while no cracks were observed in weld overlays of 150, 250, 350 and 450 amperes. The hardness increases as amperage is increased up to 450 amperes then a slight decrease in hardness is observed and then there is increase again.

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