A Comparative Study on Corrosion Resistance of using Copper and Nickel Buttering Layer on Low Carbon Steel while Cladding with Austenitic Stainless Steel

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Abstract

Cladding has established itself to be a popular, versatile, easy and cost-effective way to enhance the corrosion/erosion property as well as mechanical properties of the job surface materials. Among the several methods cladding by welding is one of the most suitable methods preferred by the industries. Cladding by gas metal arc welding is becoming more popular due to its simplicity, user-friendliness and cost-effectiveness for last few decades. Cladding is basically a dissimilar welding process in which weldibility of individual material can be enhanced by another buttering layer on the base material so that it becomes as a sand-witch. Here in the present experiment 316 γ Steel is been deposited on E350 low carbon fabrication steel in three ways, firstly with no coating and then coated by Copper and Nickel respectively. Cladding is done in all cases applying gas metal arc welding process using full CO_2 shielding atmosphere. Heat input was varying by altering welding current and torch travel speed within a particular range (almost the same for all cases) keeping welding voltage constant during the cladding of each type sample. Three types of clad samples were undergone to accelerated corrosion test in chloride atmosphere and the corresponding microstructure has been analyzed. Results indicate improvement in corrosion resistance of clad parts most in case of nickel buttering layer than that of copper buttering layer and so also for non-coated low carbon steel specimens.

Keywords: Welding, Cladding, Buttering, GMAW, heat input, corrosion rate.

1.0 INTRODUCTION

Cladding is a surfacing technique in which relatively thicker layer of costly, high-alloyed material having good corrosion resistant property is deposited on a comparatively low-alloyed, less costly, material having good formability and machinability to enhance bulk dependent properties as well as surface dependent properties [1-2]. Cladding has established itself to be a popular, versatile, easy and cost effective way to enhance the corrosion/erosion property as well as mechanical properties of the job-surface materials [3-4]. Cladding stainless steel on low carbon alloy steel is used extensively in many industries, such as chemical plant, petroleum and nuclear industries, oil and gas refinery, pulp and paper manufacturing, naval industries, oil and gas exploration, transport and storage industries, offshore rig, etc.Cladding may be produced by several techniques, such as rolling, arc welding, resistance welding, explosive welding, non-conventional welding as well as hybrid welding [5-7].

Among the several methods cladding by welding is one of the most suitable methods preferred by the industries.Cladding by gas metal arc welding is becoming more popular due to its simplicity, user-friendliness and cost-effectiveness for last few decades [8]. Moreover quality of cladding by means of welding, i.e. mechanical strength, corrosion/erosion resistance can be improved through adjusting process variables of GMAW process. Weld bead geometry may indicate the quality of cladding. Optimization of process parameters for GMAW process have been tried successfully for achieving better weld bead geometry in several previous occasions using different combination of materials [9-14]. Heat input is one such factor that plays a great role to modify the weld bead geometry and so also the corrosion rates and mechanical strength [15-18].

Cladding is basically a dissimilar welding process in which weldability of individual material can be enhanced by another buttering layer on the base material so that it becomes as a sand-witch. A buttering layer may produce better bonding and corrosion resistance further [19].

Copper and nickel are two important ferritiser which promotes corrosion resistance properties. They can be deposited on steel by different methods. Cu and Ni when deposited onto steel they improves the corrosion resistance properties of the steel. Pure Ni and Cu can be deposited in very thin layer by electroplating method [20]. Copper and nickel may be used as buttering layer between two types of steel which may enhance overall corrosion resistance properties rather than ordinary cladding. Area of HAZ (Heat Affected Zone) of weldment in case of addition of a buttering layer is comparatively larger than that of without buttering layer. With addition of a buttering layer within the weldment causes widening of HAZ that decreases tensile strength [21]. Cu and Ni have been used as buttering layer with different cladding-base material combinations previously which exhibited good corrosion resistance properties particularly for Duplex stainless steels [22]. Nickel was observed to bear a great role to protect corrosion in various forms for even dissimilar welding [23-27].

In the present work, 316 γ-Stainless Steel clad layer is overlaid onto plain E350 low carbon steel, Copper coated E350 low carbon steel and Nickel coated E350 low carbon steel by GMAW process. In three cases, process parameters like weld current and speed of welding torch have been altered keeping welding voltage fixed. Clad samples from three cases were subjected to accelerated corrosion test for 24 hours. Comparative study has been performed to check the influence of buttering layer within cladding on the corrosion resistance properties of clad layer. Result clearly shows the corrosion resistance may be enhanced to a great extent in case of Nickel coated cladding within the experimental domain.

2.0 EXPERIMENTAL PROCEDURE

Low alloy semi killed E350 steel is used as base or substrate material in the current experiment. The chemical composition of E350 low alloy steels are reported in **Table 01**. 316 Austenite Stainless Steel is used as clad layer whose chemical composition in exhibited in % of weight in **Table 02**.

Cladding and its prior trials are done using ESAB, India made Auto K 400 GMAW set up (**Fig. 01**) with 60% duty cycle. One semi-automated guided vehicle containing fixture for holding electrode torch along with one rail is used for performing the GMAW cladding. **Fig. 01** shows the experimental set-up. 100 % CO_2 gas with a constant flow rate of 15 l/min is used as shielding gas. Single layer cladding is deposited on E350 base metal with 50 overlap in three conditions such as without any coating, with copper coated and nickel coated E350 low carbon steel. **Fig. 02** shows the schematic diagram of single layer 50% overlap cladding.

Table 01 : % weight of Chemical composition of E350 low carbon steel

Composition of base material, E350	C	0.146	Cu	0.0209	Cr	0.0166
	Si	0.192	Ni	0.048	Pb	0.013
	Mn	0.412	Cr	0.017	Sn	0.003
	P	0.056	Co	0.007	W	0.017
	S	0.053	Cu	0.021	Ti	0.002
	V	0.004	Ta	0.012	B	0.001
	Fe	<98.93				

Table 02 : % weight of Chemical composition of 316 austenite stainless steel

316 Austenitic stainless steel	C	0.076	Al	0.011	W	0.026
	Si	0.182	Nb	0.043	Sn	0.010
	P	0.029	Co	0.074	Ce	0.010
	S	0.008	Cu	0.342	B	<0.001
	Cr	15.046	Ti	0.014	Mn	1.102
	Ni	9.9370	V	0.048	Mo	2.091
	Fe	<70.952				

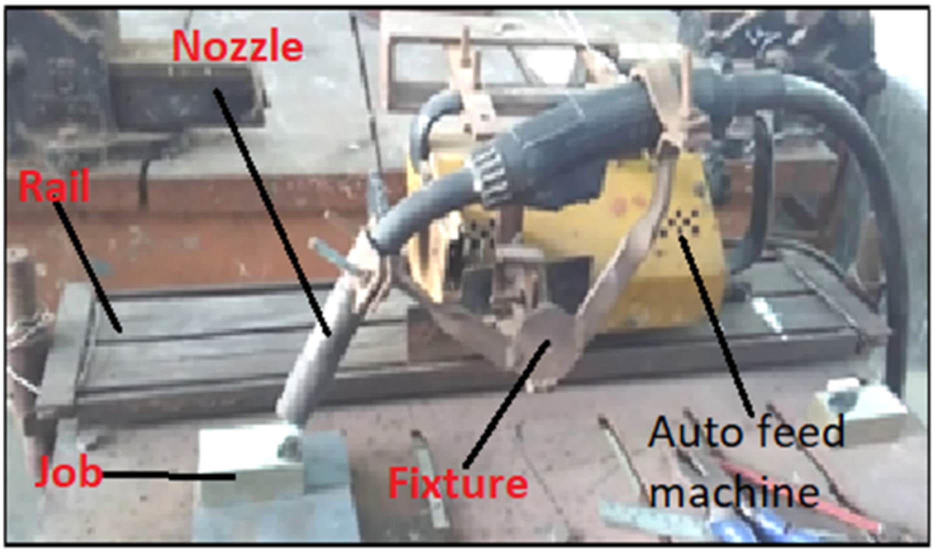


Fig. 01 : Experimental set up for cladding experiments

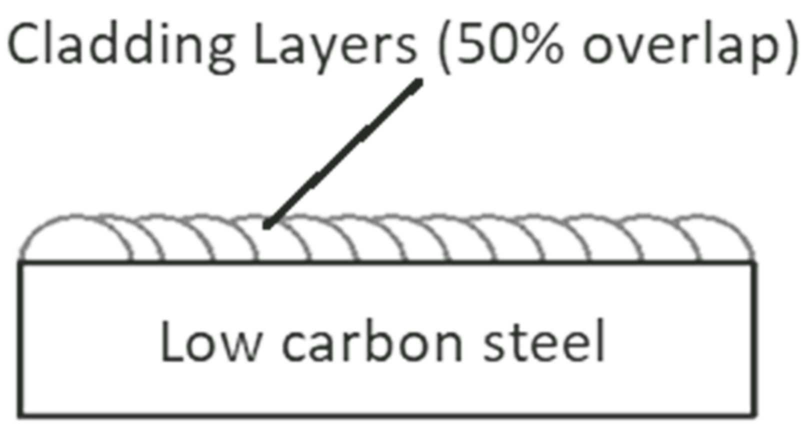
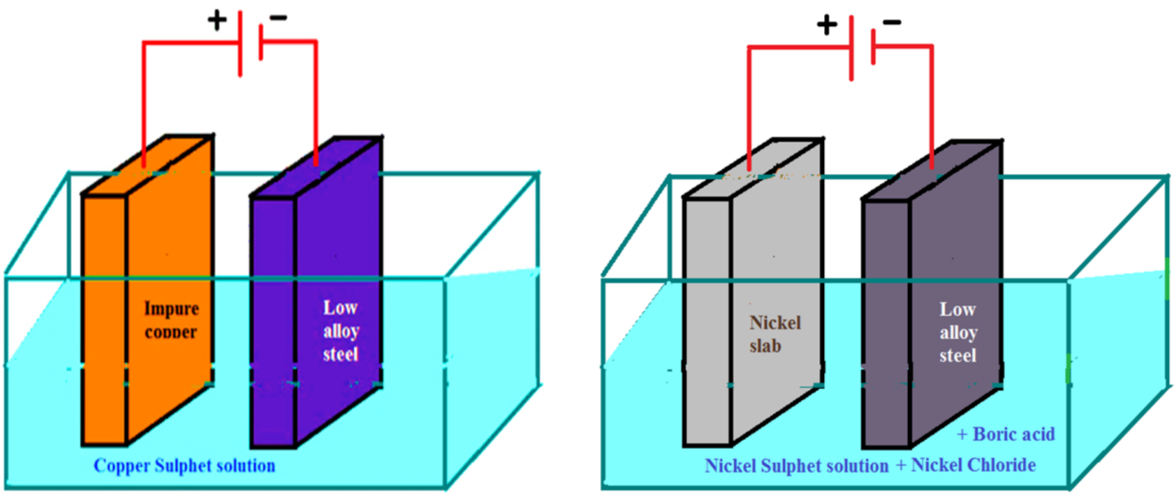


Fig. 02 : Schematic diagram of single layer 50% overlap cladding test piece

Copper and nickel is deposited on E350 by electroplating process and the corresponding schematic diagrams are shown by **Fig. 03 (i & ii)** below. The thickness of copper and nickel coating are maintained as 12μm.

Cladding is done under different heat input values. Process parameters like welding current and arc travel speeds are chosen at three levels such as 140A, 170A and 200A, and 325mm/min, 362mm/min and 392mm/min respectively. 2 parameters in 3 levels generate 9 values of heat inputs at which cladding are done on 9 samples. Welding voltage is kept constant throughout the experiment. The range of process parameters is chosen on the basis of previously done trials where the weld bead formation has been found to be acceptable. Whole experiments are replicated twice. The factors chosen for the experiment are detailed in **Table 03**.



(i) Copper electroplating[19]

(ii) Nickel electroplating [27]

Fig. 03 : Schematic diagram of electroplating

Table 03 : Process parameters selected for the cladding experiments

Workpiece: E350 low carbon steel Electrode: γ-SS 316, GMAW, 100% CO_2, single layer, 50% overlap						
Exp. Sl. No.	Arc Voltage (V)	Weld Current (A)	Torch Travel Speed (mm/min)	Heat Input (kJ/mm)	Gas Flow Rate (l/min)	Replication
1	27	140	392	0.462	15	Twice
2	27	140	362	0.501		
3	27	140	325	0.558		
4	27	170	392	0.562		
5	27	170	362	0.608		
6	27	200	392	0.661		
7	27	170	325	0.677		
8	27	200	362	0.716		
9	27	200	325	0.797		

3.0 TESTS PERFORMED

Different tests such as accelerated corrosion test and metallography tests are conducted for the test samples.

Corrosion test: Samples for corrosion test are prepared whose length, breadth and height are 10mm, 10mm and 20mm in size from cladded specimens. The test piece surfaces are made ground finished so that it can be exposed to corrosive medium. **Fig. 04** shows the samples for corrosion test prepared from 1st replication of cladding experiment. The cladded area exposed to the corrosive medium for 24 hours, the corrosive medium being a solution of 29g ferric chloride, 24 ml HCl and 76 ml distilled water. Set up of corrosion test is shown in **Fig. 5**. Corrosion test chamber is made with glass plates. The rectangular chamber is made by glass plate that is inert against chloride atmosphere.

Studying metallography: For studying metallography, total nine numbers of test samples from 1st and 2nd replications are prepared. The size of length, breath & height of the test specimen are made as 15mm, 15mm and 25mm respectively. The test specimens are generated by cutting and grinding. The surface of each sample is rough-polished by using a belt grinder (using 60, 80 and 120 grade belt), and then semi finish-polished by using 200, 400, 600, 100 and 1200 grade emery papers. Finally, the samples are mirror-polished on velvet cloth using alumina suspension as abrasive material to obtain mirror finish by using a disc grinding cum polishing machine. Samples of 316γ SS cladding on non-coated E350 steel are then under etching process using waterless Kalling's reagent and Ralph's reagent one after another. Microstructure evaluation at 200X magnification is carried out using metallurgical microscope. γ-SS clad steel samples having copper buttering layer are etched with Glyceregia solutions (ASTM E407 designation is 87 Glyceregia and comprises 15cc HCl, 10cc Glycerol and 5cc HNO_3 in 100 ml distilled water). These samples are observed under metallurgical microscope (Make: LEICA, Model: 2700M) at 500x magnification. In case of nickel buttering polished test samples are etched with 10% oxalic acid. Microstructures of these test specimens are observed at three locations at 200X magnification, such as top of clad layer, middle of clad layer and at the interface.

4.0 RESULTS AND DISCUSSION

Result of corrosion test of base metal is shown in **Table 04**. The results from the corrosion test of three types of samples are expressed in tabular form in **Table 05**. These values of corrosion rate are actually average values of corrosion rate of the samples from two replications.

Fig. 4 : Teflon coated sample solution

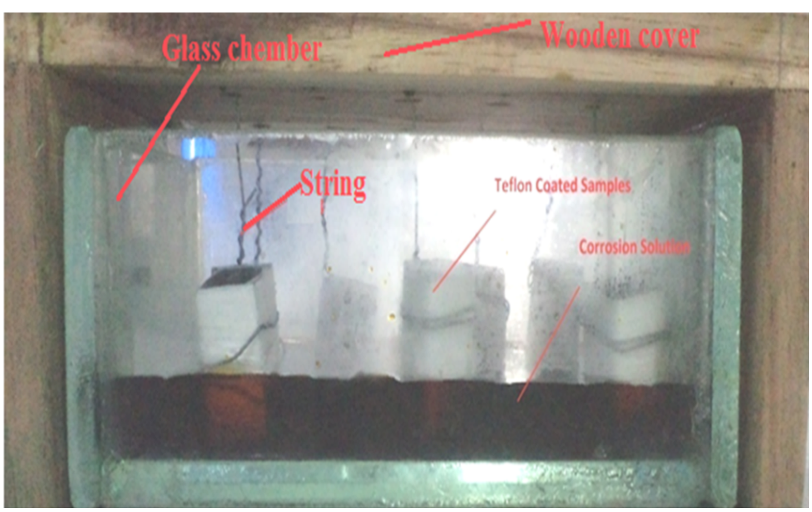


Fig. 5 : Corrosion test apparatus containing corrosive

Table 04 : Corrosion test results of base metal, E350

Base Plate	Corrosion Rate (g/m^2hr^{-1})
Low alloy steel E350	453.22

Table 05 : Corrosion test results of non-coated, copper coated and nickel coated clad samples

Sl. No.	Cladding on Plain E350 low carbon steel		Cladding on Cu coated E350 low carbon steel		Cladding on Ni coated E350 low carbon steel	
	Heat input (kJ/mm)	Corrosion Rate (g/m^2hr^{-1})	Heat input (kJ/mm)	Corrosion Rate (g/m^2hr^{-1})	Heat input (kJ/mm)	Corrosion Rate (g/m^2hr^{-1})
1	0.462	164.57	0.394	209.98	0.512	207.22
2	0.501	173.11	0.409	315.91	0.554	233.94
3	0.558	179.98	0.479	271.09	0.725	326.94
4	0.562	156.49	0.497	168.86	0.622	146.88
5	0.608	168.69	0.563	245.57	0.731	101.94
6	0.661	150.38	0.585	154.12	0.792	161.08
7	0.677	174.38	0.605	184.97	0.597	153.09
8	0.716	155.59	0.734	212.72	0.673	143.92
9	0.797	156.16	0.864	241.75	0.855	123.09

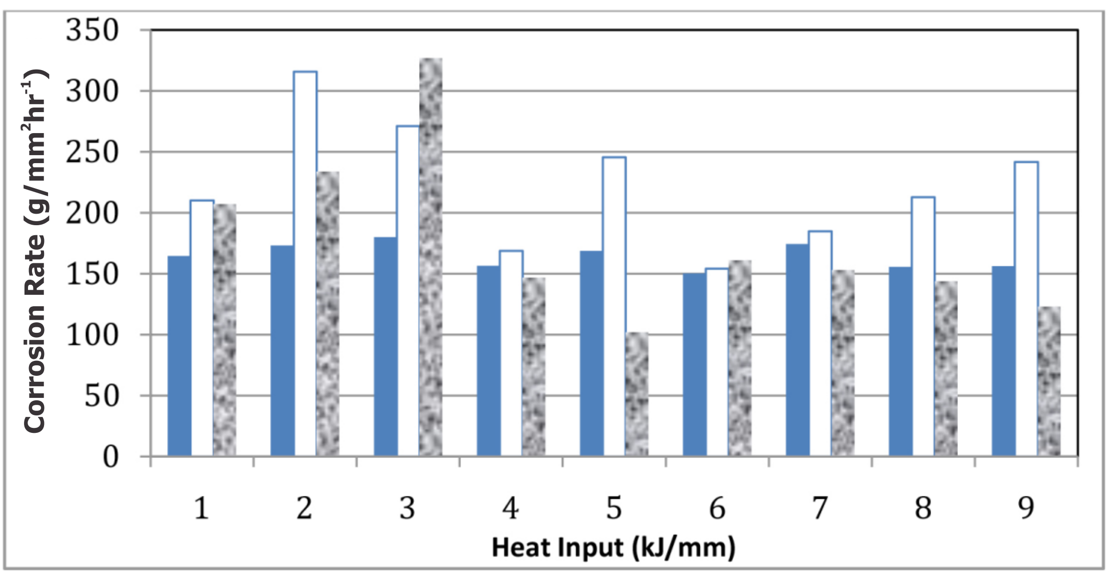


Fig. 06 : Bar chart of corrosion rate with heat input for Cu coated (blue), uncoated (yellow) and Ni coated (green) clad specimen

From the table it is observed that minimum corrosion rate occurs at 0.731 kJ/mm heat input for austenite stainless steel cladding using nickel buttering and it is almost one fourth of the corrosion rate that of base material. In each case corrosion rate decreases a lot than that of base material.

Values obtained from the **Table 05**, one bar chart is constructed and shown in **Fig. 06**. The blue bar, yellow bar and green bar represent corrosion rate of non-buttering cladding samples, Cu buttering cladding samples and Ni buttering cladding samples respectively. Each bar represents average corrosion rate of a particular cladding against a particular heat input.

From **Fig. 06**, it can be observed that except first three values of heat input (lower value) and sixth value of heat input, Austenitic stainless steel cladding using nickel buttering shows better corrosion resistance property in chloride atmosphere.

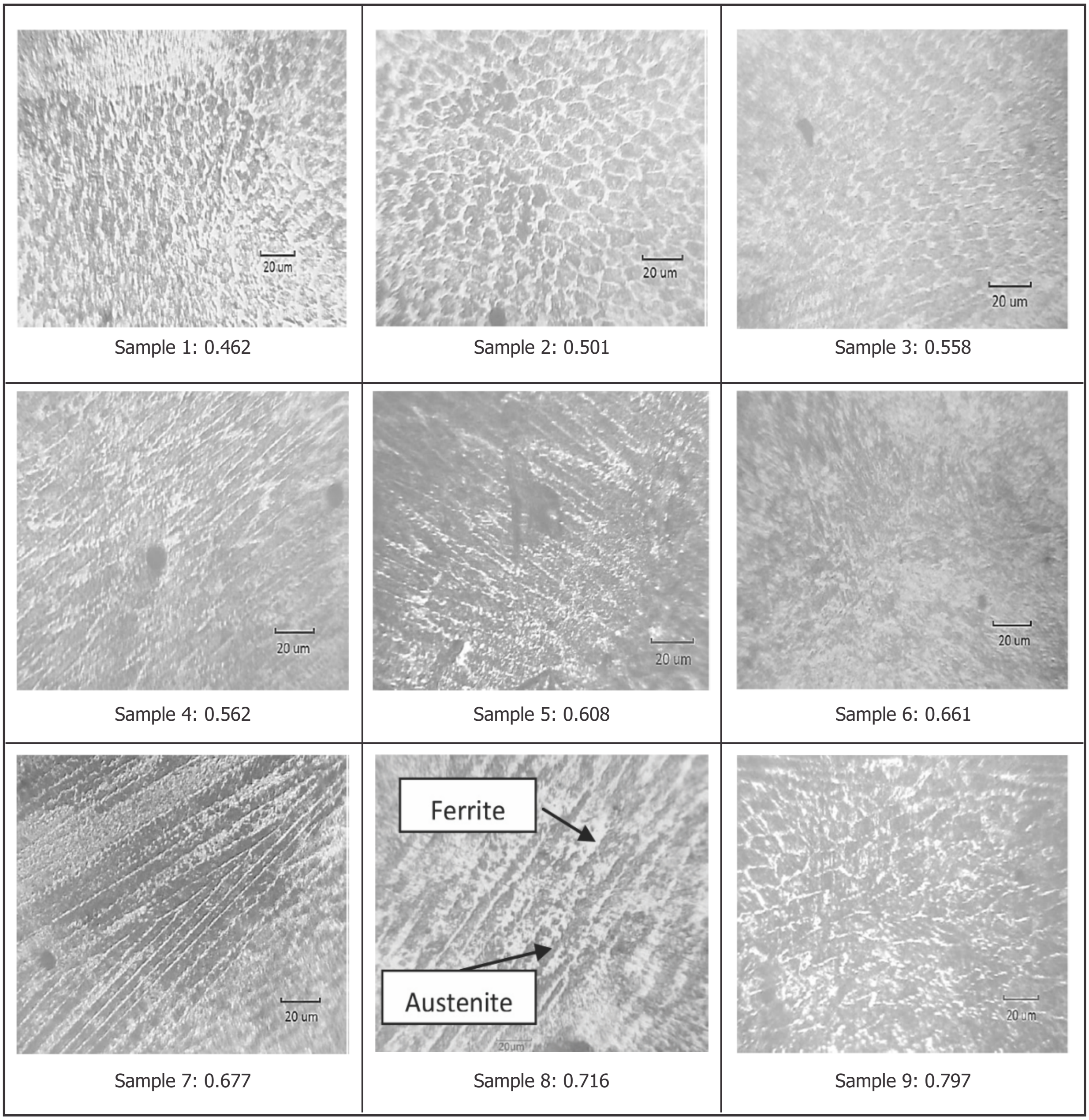


Fig. 07 : Microstructure of 316 ASS cladding over non-coated E350 low carbon steel [18]

Fig. 07 shows the microstructure of clad surface of -SS cladding on non-coated E350 steel. Heat input of each sample in kJ/mm is shown in each case accordingly. **Fig. 07** show the cellular and epitaxial growth of austenite with intercellular ferrite and form primary austenite with second phase ferrite (AF) microstructure of austenitic stainless steel cladded test samples. Various intermetallic phases are also found in the microstructures.

Fig. 08 represents the microstructure of ASS cladding on Cu buttering layer over E350 grade steel. Different patterns of austenitic phase are observed in the microstructure. Austenitic phase observed in sample No. 1, 2, 3 are long and narrow in shape. The shape of austenitic phase in sample 4, 5, 6 are also long but relatively wide. In case of sample 7, 8, and 9 the grains become shortened and thick. In all the cases the grain boundaries are prominent.

In case of 316 ASS cladding on Ni buttering layer over E350 grade steel, microstructure are taken I three layers. represents the microstructure of clad samples at E350-γ-SS interface with ascending order of heat input. Heat input of each sample in kJ/mm is shown in each case accordingly. **Fig. 10** and **Fig. 11** represent the microstructure of clad samples at middle portion of cladding and top portion of cladding respectively with ascending order of heat input.

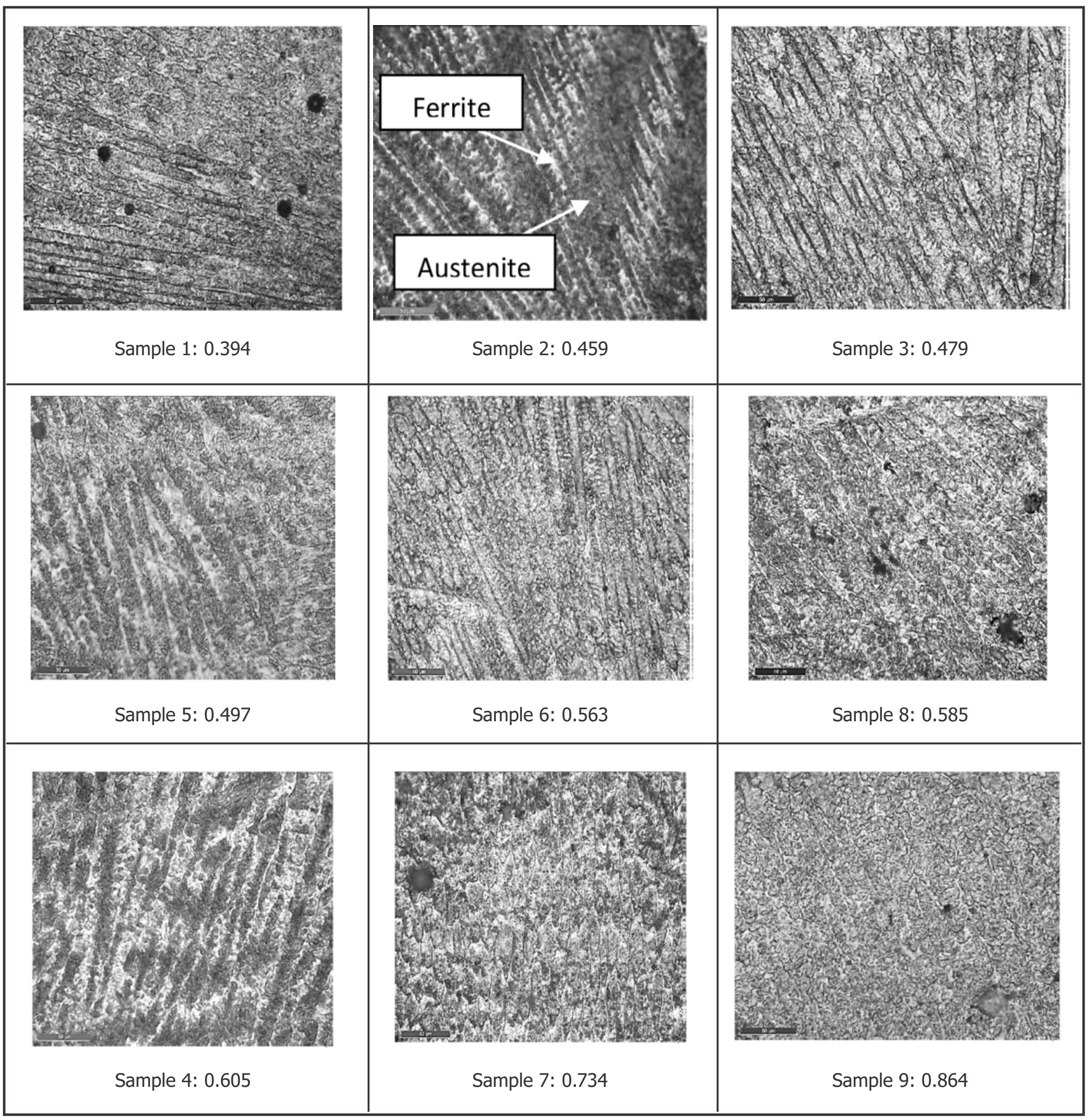


Fig. 08 : Microstructure of 316 ASS cladding over Cu buttering layer deposited on E350 steel [19].

Microstructures of cladding samples at 316 γ-SS and E350 material interface zone show incomplete dendritic structure almost in all test specimens. Grain size gets coarse mostly as cooling rate is the slowest relative to other two cases. Both γ and δ phases are present in all samples at different proportions. γ and δ phases are present in microstructures in darkish and whitish colour. As heat input increases blackish portion, or in other words, austenite phase increases. In general addition of nickel by means of buttering layer causes an increase in ferrite phase in every sample.

Microstructure of middle portion of the cladding layer asdepicted in **Fig. 10** shows coarse grains with not well defined grain boundaries. Blackish austenitic phase increases in microstructures along with increase in heat input. Ferrite phase is responsible for resisting corrosion, particularly pitting corrosion. It indicates that it is capable of resisting corrosion at higher heat input. Results from corrosion test agree with this logic.

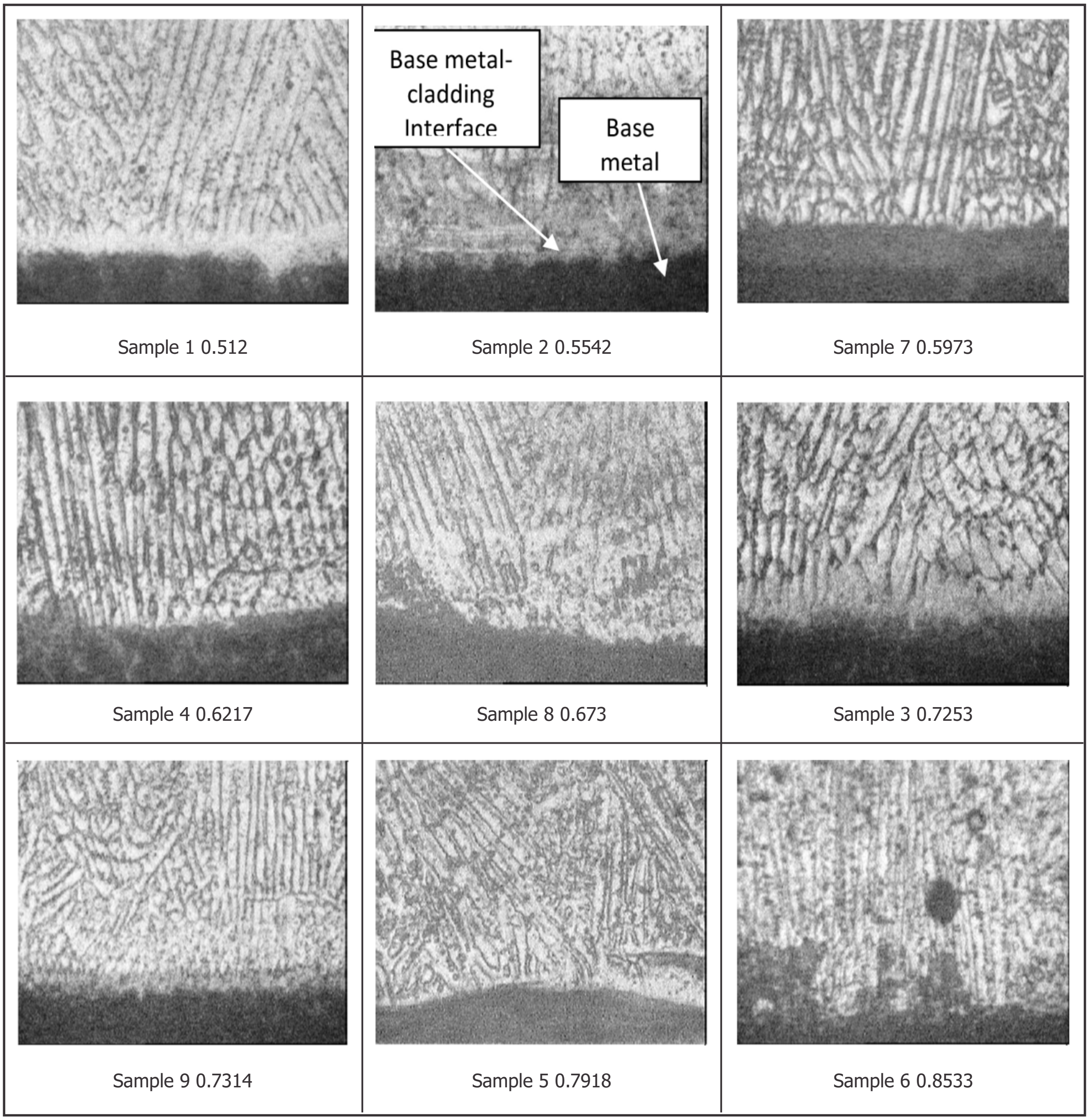


Fig. 09 : Microstructure at cladding-base metal interface with ascending order of Heat input [27]

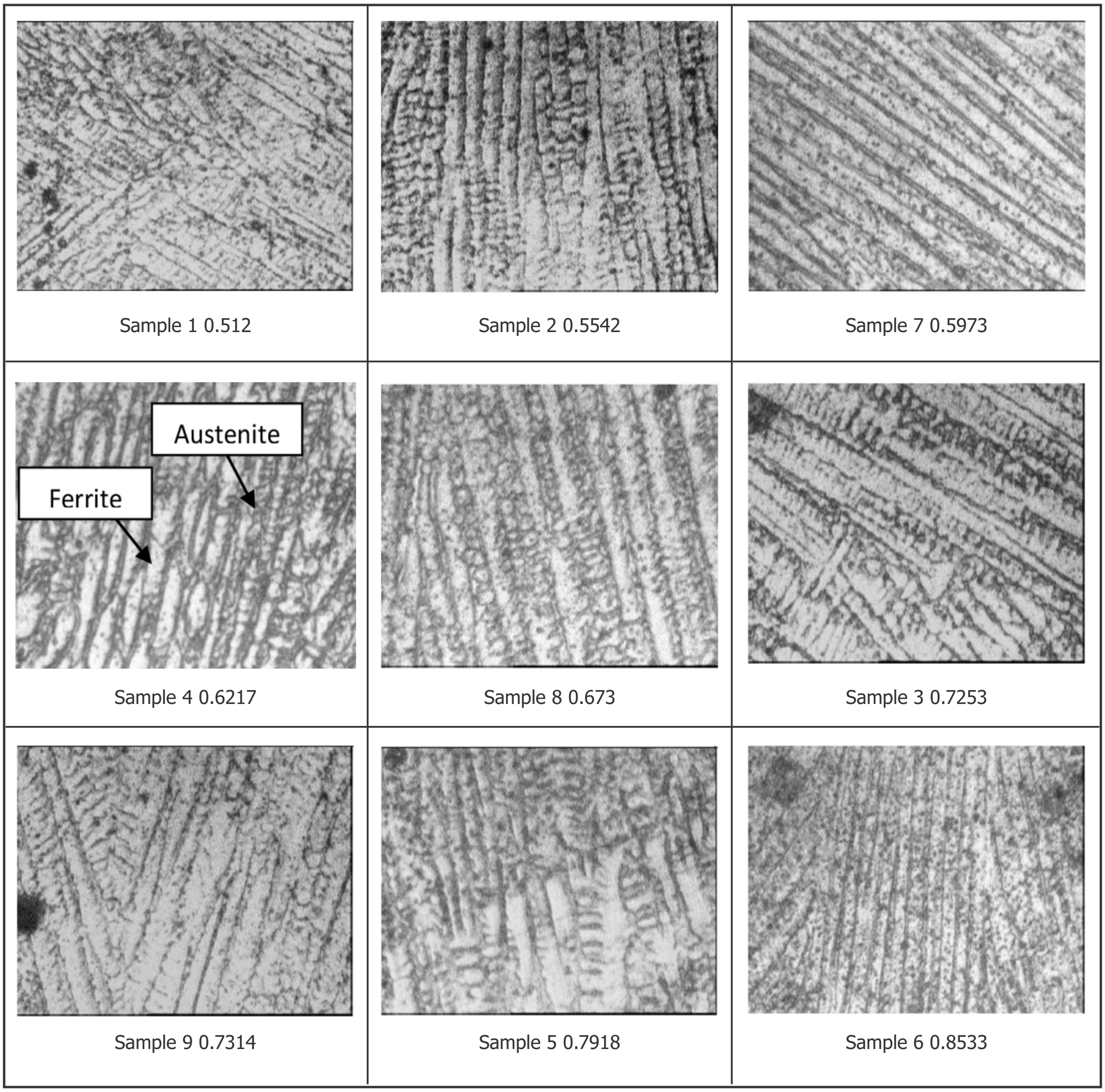


Fig. 10 : Microstructures at middle portion of cladding- with ascending order of Heat input [27]

Fig. 11 represents the microstructure of outermost cladding layer that are subjected to exchange heat to the surrounding atmosphere rapidly. Due to this rapid cooling, fine grains are formed. The grain boundaries are not well defined due to shortage in time for grain formation. Blackish ferrite forms more and more as heat input increases and thus it increases the corrosion resistance property of clad layer at the top portion also.

5.0 CONCLUSION

From the current experiment, conclusions may be drawn as follows:

- E316 austenitic stainless steel is successfully cladded on both copper & nickel buttering layer over E350 low alloy steel by GMAW process using only CO_2 as shielding gas.
- Copper coated E350 Steel cladded by 316 ASS did not show any great improvement in corrosion resistance than that of 316 AAS cladding onto plain E350 steel in chloride atmosphere.

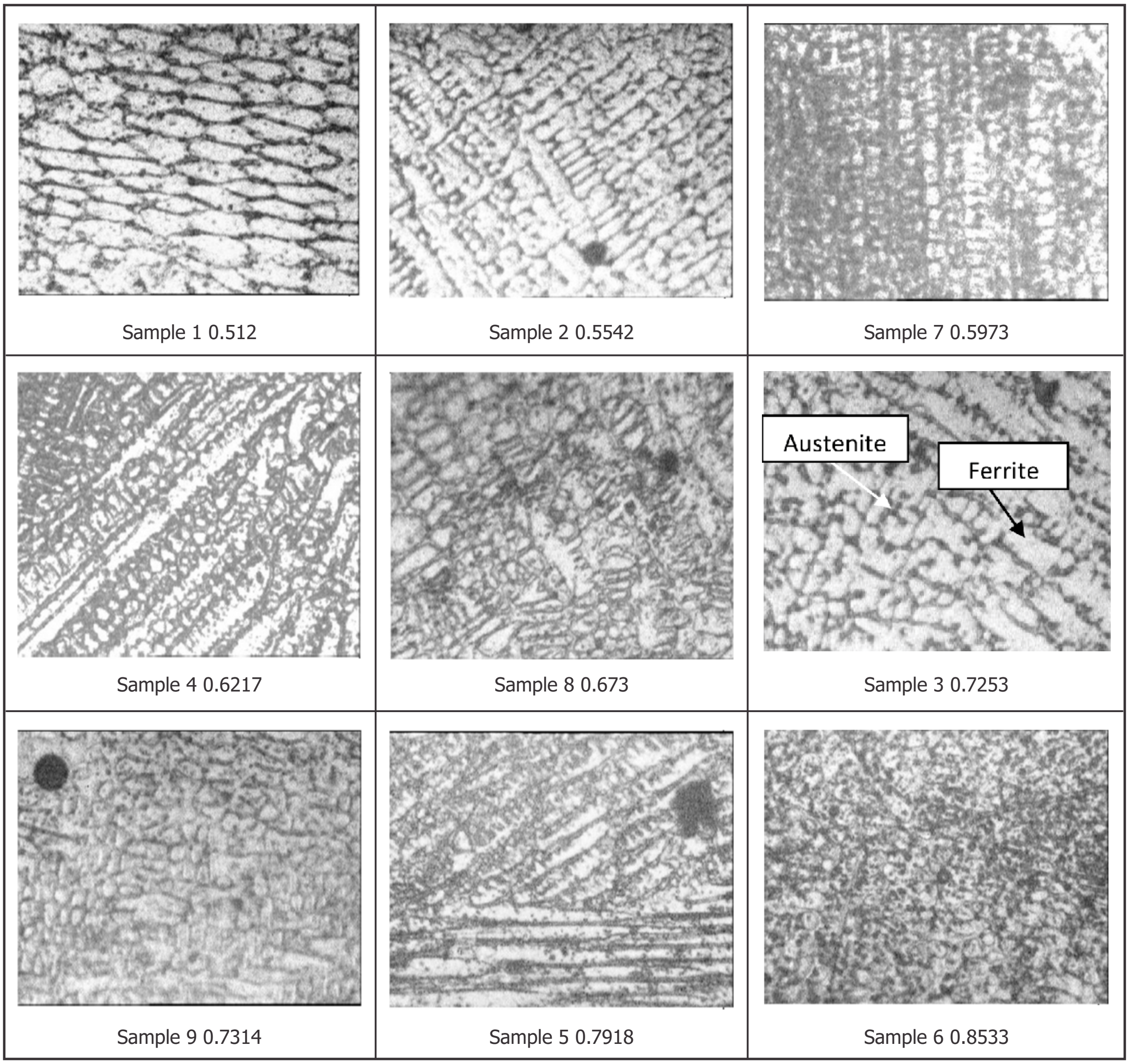


Fig. 11 : Microstructure at top portion of cladding with ascending order of Heat input [27]

- The corrosion rate of every clad sample is much less than that of base metal separately. The corrosion rate is also less than that of ordinary cladding by (316) austenitic stainless steel on E350 low alloy steel. Addition of nickel proves to be beneficiary.
- Corrosion rate shows no such significant relationship with heat input.

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