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Investigating the Effect of Nickel Buttering on Corrosion Resistance

Santanu Das*, Manas Kumar Saha
Mechanical Engineering Department,Kalyani Govt. Engineering College, Kalyani, West Bengal, 741235, India
*Corresponding Author: sdas.me@gmail.com

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ABSTRACT

Cladding is usually employed for improving corrosion and/or abrasion resistance of a component but it may not yield desirable result due to loss of precious alloying elements present in cladding material due to dilution, vaporization, etc. Moreover, welding defects like cracks, porocity, etc. may be caused due to dissimilar welding as that of cladding. Buttering layer between clad layer and structural steel is also sometimes provided to promote bonding between the cladding and the substrate. The buttering layer may also give desired corrosion resistance. Nickel has FCC structure and can stabilize FCC austenite phase in steel, and it is often added by means of cladding, coating, buttering, etc. to enhance hardness and corrosion protection of steel. In the current investigation, 316-austenitic stainless steel is deposited over nickel plated medium carbon steel substrate with the help of metal active gas welding. Nickel is accumulated on medium carbon steel by electroplating to act as a buttering layer. Welding current and torch travel speed are varied with constant arc voltage to develop different values of heat input during clad layer deposition by welding with an objective of obtaining good corrosion resistance. Accelerated corrosion test in chloride atmosphere is done on ground and polished clad surface to judge and compare the corrosion resistance within the experimental runs. Heat input is found to have only marginal effect on corrosion rate. However, corrosion rate is observed to be decreased remarkably for all the clad samples relative to the base material along with almost no crack.

INTRODUCTION

Cladding is a few millimeter covering made by materials having high corrosion resistance and mechanical strength. It promotes medium carbon cheap structural steel by enhancing its corrosion resistance, abrasive erosion resistance and mechanical strength (Saha and Das, 2016, Smith, 2016). Cladding may be performed by different types of welding, rolling, etc. Gas metal arc welding is an accepted procedure for developing clad part. Weld bead formation during weld cladding plays important role for enhancing corrosion resistance properties and improving mechanical properties of clad parts. It requires lower penetration to keep dilution as low as possible.

Quality of gas metal arc welded bead profile could be improved (Shihab *et al.*, 2018) by means of maintaining process inputs. In one recent work, it was observed that bead geometry of 316 γ austenite stainless steel bead showed good correlation with heat input components, when analyzed by multiple regression method (Saha *et al.,* 2019a, Saha *et al.,* 2019b, Verma *et al.*, 2013, Khara *et al.*, 2016).

Performance of clad parts produced by GMAW was reported to depend intensely on heat input. Results from various experiments indicated increment in corrosion rate with increment in heat input, particularly in case of austenitic stainless steel (ASS) (Saha *et al*., 2018b) as well as duplex stainless steel (DSS) with different base materials up to a certain value (Saha *et al*., 2018c, Saha *et al*., 2018d). Results of one electroslag cladding process showed dilution to have decreased with increase in heat input (Jung *et al.,* 2017).

Stainless steels having different ratios of austenite (γ) and ferrite (δ) phase (from much more than 1, in case of ASS to nearly equal to 1, in case of DSS or super DSS) are becoming natural choice for cladding material due to their corrosion resistance properties. 316 austenite stainless steel was reported to have sufficient resistance against general corrosion due to the presence of molybdenum (Abdallah *et al.,* 2017). An experiment was conducted to observe pitting corrosion rate of nickel, 316 austenitic stainless steel and inconel against different Cl^- ion concentrations. Results revealed that at common Cl^- ions, accumulation per unit volume, pitting corrosion potential shifts towards larger noble values as per sequence below.

Highest ⟷ Lowest
(a) 316 Stainless Steel, (b) Incoloy 800, (c) Inconel, (d) 600 Ni

Nickel is an austenite stabilizer and increases protection from corrosion of the steel when it is present in steel. Nickel increases hardenability and impact strength of steel. In one recent work it is observed that presence of Ni increases stability of the austenite in elastic regime in case of high carbon bearing steel which affects further the wear resistance (Bedekar *et al.*, 2018). In general, alloying elements of cladding layer get diminished at the time of weld cladding due to dilution. Similarly, stainless steel (316) loses costly alloying elements, including Ni during cladding. Nickel amount could be compensated by mean of adding one buttering layer on low alloy substrate and by means of that it could enhance corrosion resistance property of cladding. Addition of nickel in low alloy steel caused (Wen *et al.,* 2016) enhancement of corrosion resistance of steel in saline water as well as at other wet/dry conditions.

Chromium free nickel-iron buttering layer was used (Rathod *et al.,* 2017) in one dissimilar metal weld joining between ferrite steel pressure vessel and ASS pipeline used in nuclear power plant to minimize carbon diffusion causing good post weld heat treatment condition and high heat edged condition. This type of layer was stated to enhance metallurgical, structural and mechanical properties of weld joint produced by dissimilar materials like carbon steel and stainless steel. Ni rich inconel 182 was also joined with SA 508 as a dissimilar joint by GTAW and SMAW using Ni-Fe buttering layer to reduce carbon migration. In one experimental work, Ni rich (69.36%) buttering layer was deposited on dissimilar welding joint between 304 SS (10.50% Ni) and low carbon low alloy API 5L X65 steel by means of GTAW. Carbon diffusion got reduced and caused less martensitic layer formation in base metal.

Buttering layer was reported to have enhanced (Saffari *et al.,* 2020) ductility of the joint and reduced tensile strength. Hot wire and cold wire GTAW processes were used (Ming *et al.,* 2018) to deposit high Ni (59% approximately) buttering layer (MB52) on low alloy SA508 and 316LN austenitic stainless steel to make dissimilar joint to control carbon enrichment, or its elimination, successfully in its application in a power plant. When high Ni contained monel metal was joined with 316L austenite stainless steel by GTAW method using high nickel electrode, corrosion resistance was increased (Mani *et al.,* 2018) significantly. In high pressure sub-sea system, forged components are undergone cladding and overlaying to minimize corrosion problem. Buttering is done to make the dissimilar joint more reliable. Moreover, some additional characteristics may be introduced by adding alloying element in buttering layer. Residual stresses developed by cladding as well as buttering might be nearly eliminated (Javadi *et al.,* 2017) by post weld heat treatment. Nickel base micron level hard layer coating was deposited on 316L ASS by means of laser beam. Wear resistance property of the coated stainless steel could be enhanced (Jeyaprakash *et al.,* 2018) significantly. In one such previous experiment, 316 ASS was clad on low alloy steel plate having buttering layer made by copper produced by varying heat input, exhibited significantly enhanced corrosion resistance property (Saha *et al.,* 2018a). In one recent work, nickel based clad on γ steel (SS-304) showed excellent resistance to slurry erosion (Hebbale *et al.,* 2020). So, nickel can be introduced in austenitic clad layer by means of pre-coating of base plate with nickel as buttering layer with the help of electroplating method and that could lower corrosion rate of steel. If that could be achieved, it would be appreciated by several modern industrial sectors, such as paper and pulp, naval, chemical, oil refinery, nuclear, etc.

This work is done in view to explore cladding of medium carbon steel with 316 austenite stainless steel through MAG welding associated with a buttering layer of Nickel for getting crack free clad layer having good corrosion resistance. Also the influence of process parameters like heat input is investigated to get good anti-corrosive clad layer. In the present investigation, 50% overlapped single layer of stainless steel belongs to austenite category is deposited on nickel coated E350 structural steel using metal active gas welding process under nine different values of heat input. First, visual inspection and dye penetration tests are done, and then accelerated corrosion test is executed to find out anti-corrosion characteristics of clad part.

RESEARCH METHOD

316 grade stainless steel of austenite category is used to clad nickel coated low alloy steel (E350) substrate as a 50% overlapped single layer on with the application of metal active gas (MAG) welding. MAG uses carbon dioxide as the shielding gas. Two replicated experiments are carried out in this work. The substrate contains 0.15% carbon, 0.19% silicon, 0.41% manganese and other trace elements along with iron in wt.%. The wire electrode contains 0.07% carbon, 0.18% silicon, 0.342% copper, 1.102% manganese, 9.94% nickel, 15.05% chromium, other trace elements and iron. Small amount of niobium of 0.04% and vanadium of 0.002% are also present.

AutoK 400 MIG/MAG machine made by ESAB India is used for cladding. A motor driven vehicle that is capable of speed alteration and can be driven along a straight guide rail is made use of. With the help of an indigenously made fixture, welding gun is held at 75º with the guide rail (Fig. 1). 50% overlap setting is done by providing manual cross feed.

Properly cleaned low alloy steel plates (E350) of size 55mm x 45mm x 25mm (the cathode) are coated with Nickel by means of electroplating process. Small high purity nickel pieces loaded in titanium basket are made anode.

Process parameters are selected in such manner that 9 values of heat input will be generated for performing cladding. Gas flow remains constant at 15 l/min during the experiment. Table 1 shows parameters selected for conducting the experiment.

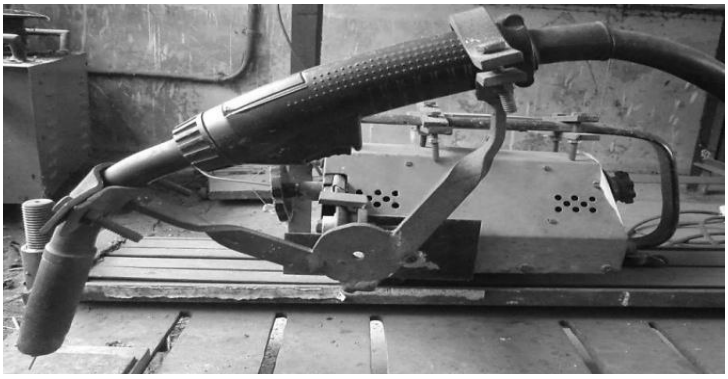


Figure 1. Torch holding fixture connected with a vehicle

Table 1. Process parameters chosen for cladding experiment

Sl. No.	Arc voltage (V)	Welding current (A)	Arc travel speed, S (mm/min)	Heat Input (kJ/mm)	Gas flow rate (l/min)	Replication
1	32	140	420	0.512	15	Twice
2	32	140	388	0.554		
3	32	170	360	0.725		
4	32	170	420	0.622		
5	32	200	420	0.731		
6	32	200	388	0.792		
7	32	140	360	0.597		
8	32	170	388	0.673		
9	32	200	360	0.853		

Tests performed: Dye-penetration (DP) test is conducted on clad parts to observe presence of any subsurface cracks in the samples. Colorless cleaner, red dye and white absorbent are applied on cladding layer one by one. Red colored die when appears from the absorbent, it indicates presence of open surface cracks in welding.

Samples having size of 10mm x 10mm x 20mm are cut from clad specimens. Surfaces of the test piece to be exposed to corrosive medium are made ground finished. All samples are marked with letter punch at the rear side. The corrosion solution, which is used in this experiment, is a mixture of ferric chloride (29%), hydrochloric acid (24.67%), and distilled water. The surfaces to remain unexposed to corroding solution are covered with teflon tape. The test pieces are exposed to the corrosive media for 24 hours. Samples are withdrawn from the corrosive solution, washed with running water and dried quickly. Weight of the each sample is taken in pre-corrosion test and post-corrosion test by a sensitive weighing machine. Corrosion rate is found by weight loss per unit area per hour.

Some other test pieces are cut, belt grinded, disc grinded and polished using different grades of emery papers and then buffed using alumina paste on the disc polisher. Polished test samples are etched with 10% oxalic acid to observe microstructures of top of clad layer, middle of clad layer and at the interface under a microscope at 400x magnification.

RESULTS AND DISCUSSION

Under all the experimental conditions, uniform cladding with no detectable flaw except presence of small spatters has been noticed under visual observation. No open surface crack is revealed through DP test as well.

E350 low alloy steel sample shows a high corrosion rate of 544 $gm.m^{-2}hr^{-1}$ in the corrosive medium of chloride solution undertaken. Also cladding of 316 grade stainless steel of austenite category on E350 low alloy steel substrate was reported (Saha *et al.*, 2018) to have corrosion rate of 198 $gm.m^{-2}hr^{-1}$ or higher up to 329 $gm.m^{-2}hr^{-1}$ in the same chloride corrosive medium. It indicates that by providing Ni buttering layer corrosion resistance has much improved. A somewhat low corrosion rate of less than 120 $gm.m^{-2}hr^{-1}$ is achieved using Ni buttering layer compared to that without buttering. Results of corrosion tests of both the replicated experiments and their average values are expressed in tabular form in Table 2. There are considerable variations noticed within the replicated test results.

Table 2. Observation of corrosion rate on cladding

Sample No.	Welding voltage (V)	Arc current (A)	Torch travel speed (mm/min)	Heat Input (kJ/mm)	Corrosion rate ($gm.m^{-2}hr^{-1}$)		
					1st Replication	2nd Replication	Average
1	32	140	420	0.512	207.22	129.46	168.34
2	32	140	388	0.5542	233.93	156.89	195.41
7	32	140	360	0.5973	326.94	228.77	277.86
4	32	170	420	0.6217	146.88	174.92	160.9
8	32	170	388	0.673	101.94	133.33	117.64
3	32	170	360	0.7253	161.08	112.36	136.72
9	32	200	420	0.7314	153.09	251.12	202.11
5	32	200	388	0.7918	143.92	188.01	165.96
6	32	200	360	0.8533	123.09	104.49	113.79

Based on the results obtained as seen in Table 2, change in corrosion rate against the variation of heat input is represented in Fig. 2. An 'M' like pattern can be seen in the plot. Initially, during increase in heat input from its value of 0.512 kJ/mm, corrosion rate increases, reaches a maximum at 0.5973 kJ/mm heat input. After this, there is a decline in corrosion rate and it becomes the least at 0.673 kJ/mm heat input. Beyond this heat input, corrosion rate again increases up to 0.731 kJ/mm heat input and beyond that, there is a declining tendency in the corrosion rate. At 0.673 kJ/mm as well as 0.8533 kJ/mm heat input, corrosion rate is found (Table 2 and Fig. 2) to be minimum in one of the two replicated experiments. At these two heat input values, corrosion rate is also the minimum considering the average value of the corrosion rate among the two replicated experiments. Therefore, it can be stated that for industrial practice, a heat input of 0.673 kJ/mm can be used that gives a low corrosion rate of 117.64 $gm.m^{-2}hr^{-1}$. At a high heat input of 0.8533kJ/mm also, low corrosion rate is observed, however, this may not be recommended as high heat input may cause some detrimental effects on mechanical properties of the weldment.

On the other hand, under 0.5973 kJ/mm heat input, that is obtained through 32 V arc voltage, 140 A current and 360 mm/min torch travel speed, corrosion rate becomes quite high. Corrosion rate is also high at the 2nd replicated experiment with 0.7314 kJ/mm heat input. However, in all the cases of cladding with a buttering layer of nickel, corrosion rate is found out to be substantially lower than that with unclad E350 low alloy steels under chloride solution environment.

Fig. 3 shows 3D contour plot of corrosion rate with change of both current and torch travel speed. It can be observed that corrosion rate is high at low weld current and torch travel speed within this experimental domain. Relatively low corrosion rate occurs at medium to high weld current over wide range of torch travel speed. It is the fact that heat input increases with increase in current and voltage and with decrease in torch travel speed, and in this experimental work, no clear trend of the variation of corrosion rate with heat input is observed. It can be stated that on the whole, 316 austenitic stainless steel cladding on the E350 low carbon steel samples with nickel buttering layer gives less corrosion rate compared with unclad specimens and also that of 316 cladding without any buttering layer.

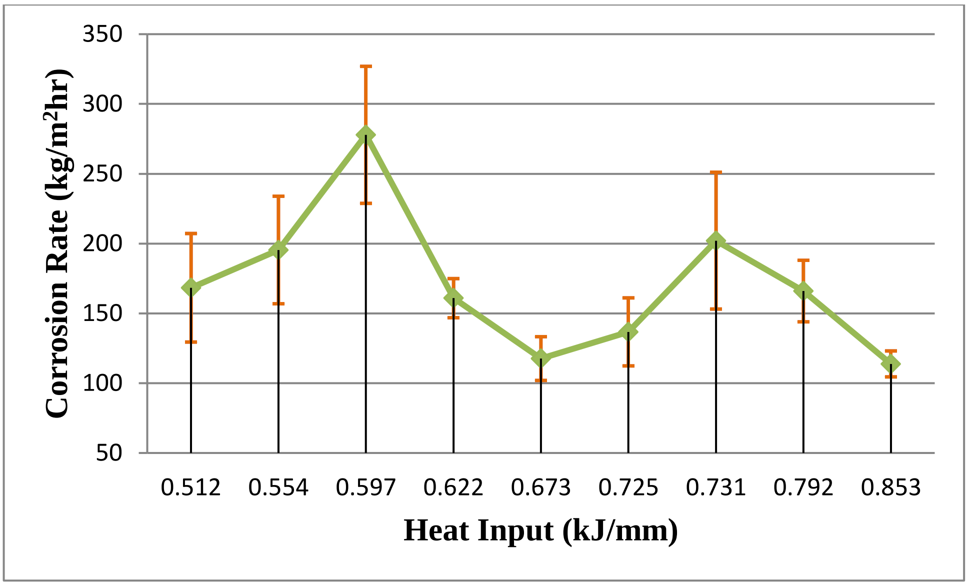


Figure 2. Plot of corrosion rate against heat input

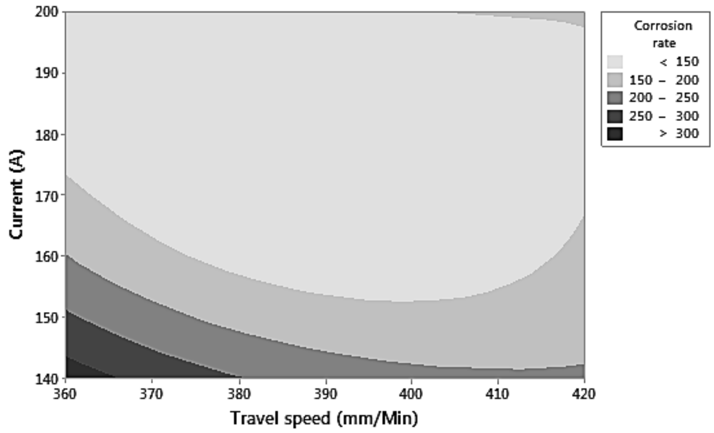


Figure 3. 3D Contour plot of corrosion rate with change of both current and torch travel speed

Microstructures are observed at three positions of each clad sample of 1st replication, such as at the interface of cladding and base material, at the middle position of clad layer and at the top of the cladding layer. Microstructures of cladding-base metal interface of nine samples of 1st replication as obtained from metallographic test are shown in Fig. 4. The figures of the microstructures are placed corresponding to the ascending values of heat input. Microstructures of middle portion of all nine samples of 1st replication arranged in ascending heat input are shown in Fig. 5, whereas microstructures of every sample of 1st replication at top portion of clad layer are arranged in accordance with low to high values of heat input and are shown in Fig. 6.

Microstructures of cladding samples at cladding layer-base material interface zone show (Fig. 4) an incomplete dendritic structure almost in all the cases. Some directional solidifications can be seen in some samples. Both austenite (γ) and ferrite (δ) phases are present in all the samples at different proportions. γ and δ phases are present in microstructures in whitish and darkish colour respectively under the oxalic acid solution based etching process as was reported by Nelson *et al.* (1985). With the increase in heat input, no remarkable change in the blackish portion representing ferrite phase can be observed in Fig. 4. *Nickel has FCC structure and can stabilize FCC austenite phase in steel*

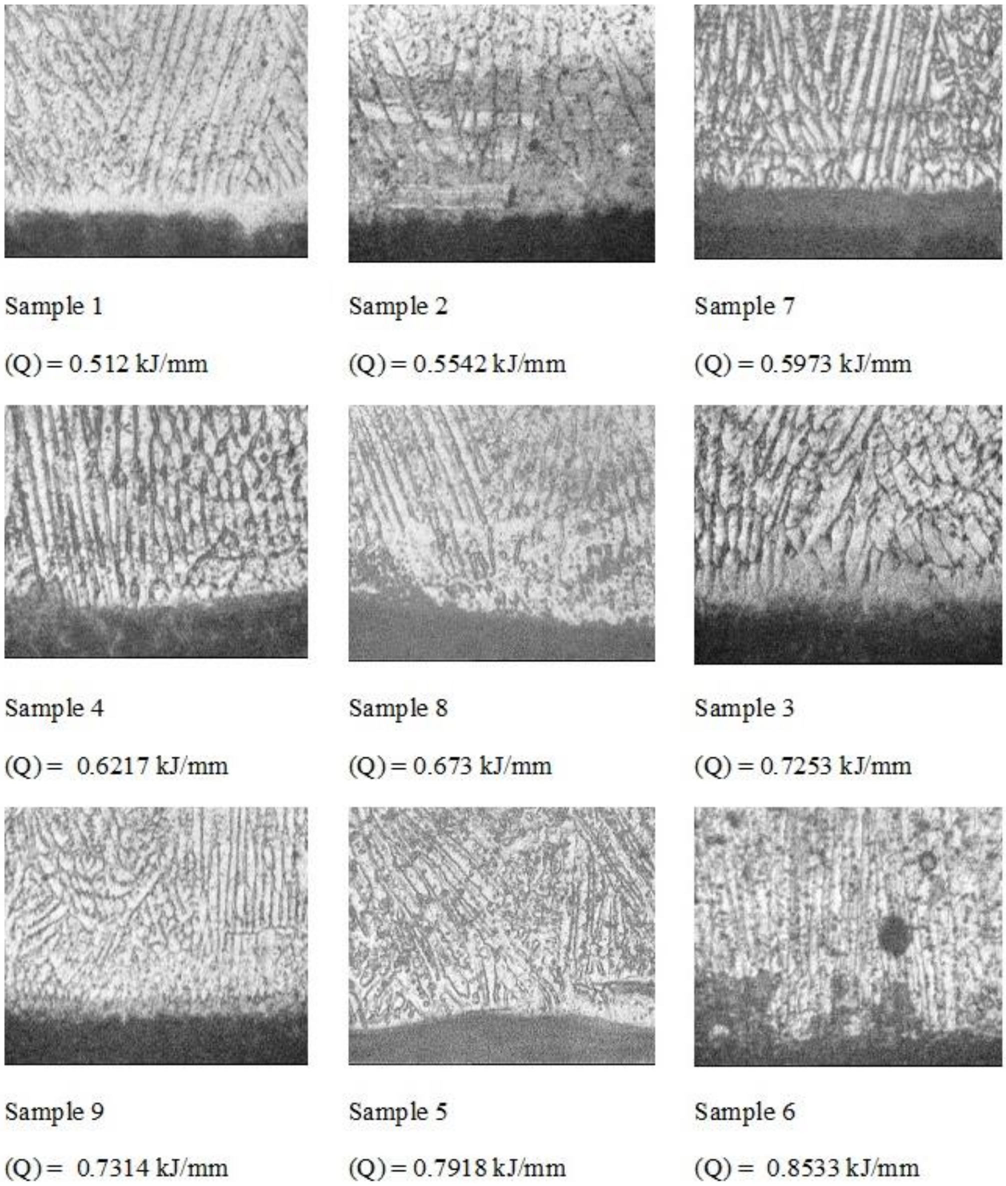
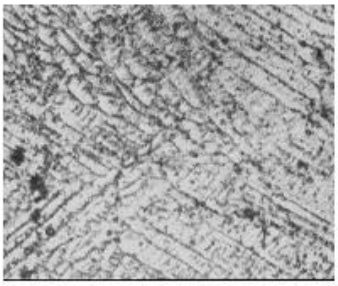


Figure 4. Microstructures at cladding-base metal interface with ascending order of heat input with x200 magnification

Microstructures of the middle portion of cladding layer, shown in Fig. 5, depict slightly coarser grains as they gets relatively more time to grain growth due to slower cooling rate. Blackish ferritic phase shows a slight increase on the whole in the microstructure as heat input increases.

The microstructures of outermost cladding layer are depicted in Fig. 6. Due to rapid cooling, particularly at higher heat input, finer grains are formed with more blackish ferrites. Ferrite phase is known to be responsible for resisting corrosion, particularly pitting corrosion, in a slightly better way than the austenite phase. On the other hand, in every case, Nickel having fcc structure promotes stability of fcc austenite phase in each of the clad layer that also enhances wear resistance property. Thus, slight increase in corrosion resistance of clad layer at higher input is found.

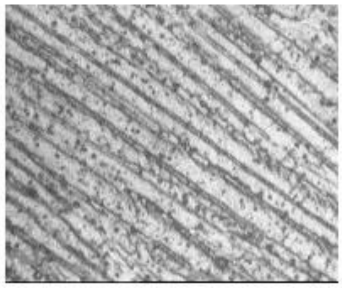


Sample 1

(Q) = 0.512 kJ/mm

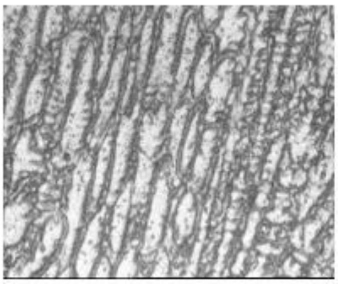
Sample 2

(Q) = 0.5542 kJ/mm



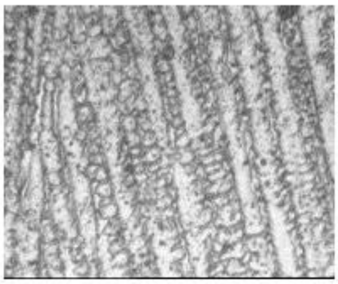
Sample 7

(Q) = 0.5973 kJ/mm



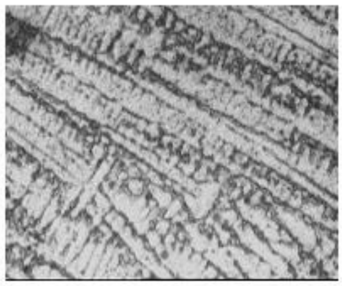
Sample 4

(Q) = 0.6217 kJ/mm



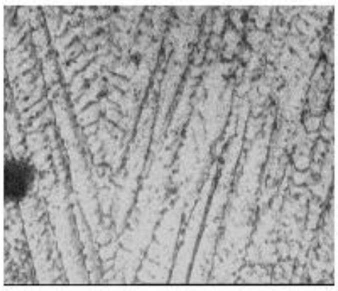
Sample 8

(Q) = 0.673 kJ/mm



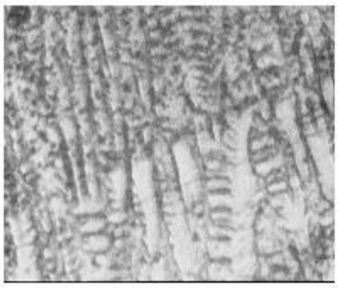
Sample 3

(Q) = 0.7253 kJ/mm



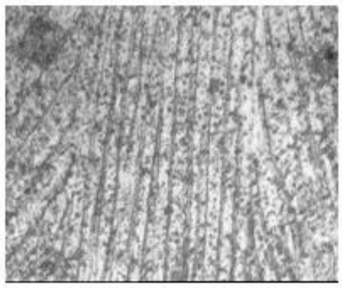
Sample 9

(Q) = 0.7314 kJ/mm



Sample 5

(Q) = 0.7918 kJ/mm



Sample 6

(Q) = 0.8533 kJ/mm

Figure 5. Microstructure at middle portion of cladding with ascending order of heat input with x200 magnification

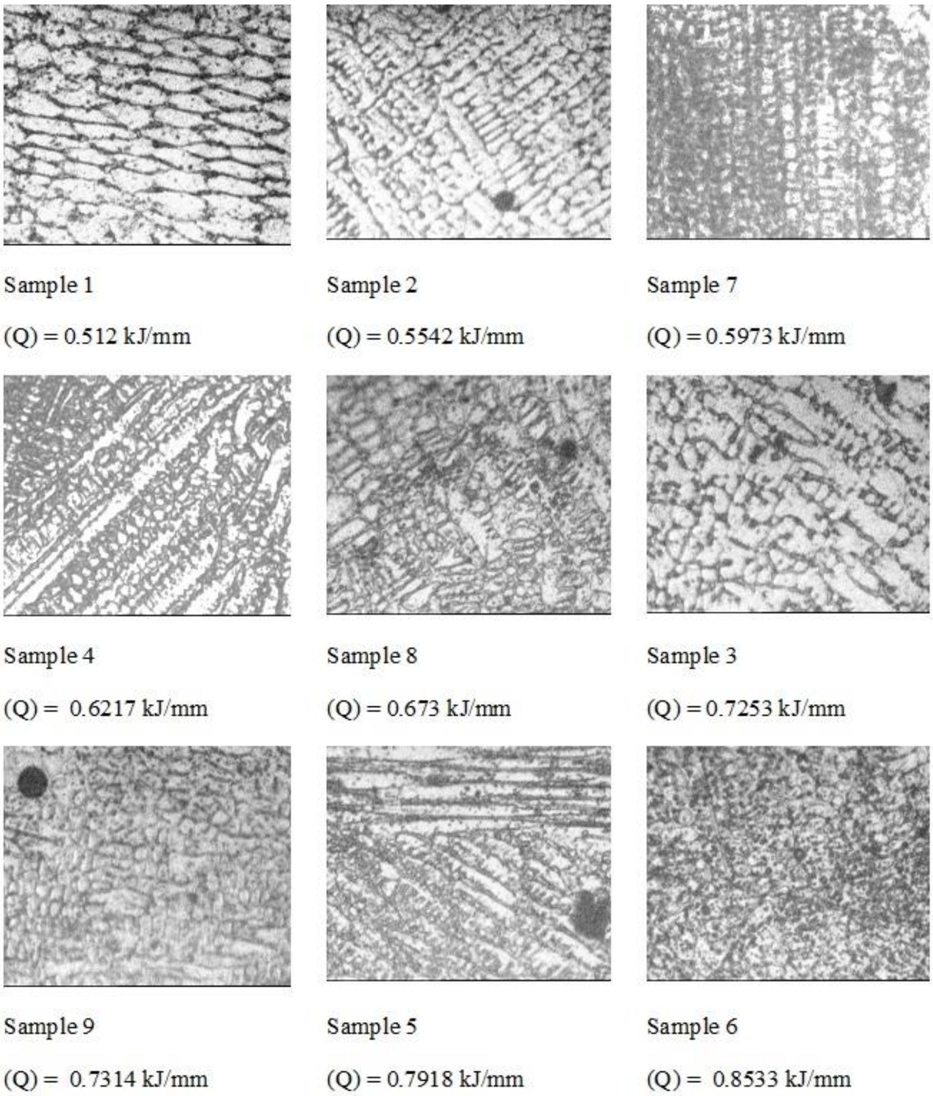


Figure 6. Microstructure at top portion of cladding with increasing heat input with x200 magnification.

CONCLUSION

Based on the results obtained from different tests, it may be stated that 316 austenitic stainless steel can be easily cladded on nickel buttering layer made on E350 steel base plate by metal active gas welding process. Corrosion rate in cladded samples with nickel buttering layer is much less compared to that of the base plate and that of ordinary cladding made without the nickel buttering layer although there is no clear trend of corrosion rate observed against an increment in heat input. Addition of nickel proves to be beneficiary to some extent and may be practiced. Ni buttering layer may be recommended for generating crack-free anti-corrosive clad layer of 316 austenite stainless steel onto low carbon steel.

Further investigation may be done to try to obtain presence of any clear trend of corrosion resistance of clad layer. Works may also be done using different cladding material combinations using buttering layer.

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