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Effect of Auxiliary Preheating of the Filler Wire on Quality of Gas Metal Arc Stainless Steel Claddings

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Weld cladding is a process for producing surfaces with good corrosion resistant properties by means of depositing/laying of stainless steels on low-carbon steel components with an objective of achieving maximum economy and enhanced life. The aim of the work presented here was to investigate the effect of auxiliary preheating of the solid filler wire in mechanized gas metal arc welding (GMAW) process (by using a specially designed torch to preheat the filler wire independently, before its emergence from the torch) on the quality of the as-welded single layer stainless steel overlays. External preheating of the filler wire resulted in greater contribution of arc energy by resistive heating due to which significant drop in the main welding current values and hence low dilution levels were observed. Metallurgical aspects of the as welded overlays such as chemistry, ferrite content, and modes of solidification were studied to evaluate their suitability for service and it was found that claddings obtained through the preheating arrangement, besides higher ferrite content, possessed higher content of chromium, nickel, and molybdenum and lower content of carbon as compared to conventional GMAW claddings, thereby giving overlays with superior mechanical and corrosion resistance properties. The findings of this study not only establish the technical superiority of the new process, but also, owing to its productivity-enhanced features, justify its use for low-cost surfacing applications.

Keywords austenitic stainless steel, ferrite, preheated filler wire, UGMAW process, weld cladding

1. Introduction

Increasing productivity of any welding process while maintaining or even improving the weld quality has been the task of researchers in the field of development of welding processes. Previous predictive studies on gas metal arc welding (GMAW) process have had various purposes. Researchers have attempted to model GMAW process in different metal transfer modes and tried to optimize it using different techniques (Ref 1-3) apart from accounting for wire melting rate in this process (Ref 4-6).

1.1 Cladding

The term weld cladding usually denotes the application of a relatively thick layer (approximately 3 mm or 1/8th in.) of weld metal for the purpose of providing a corrosion-resistant surface (Ref 7). In modern industry, increasing use is being made of clad materials as a means of achieving the optimum balance of strength, special surface properties, and economy. Some of the typical base metal components that are weld-cladded include the internal surfaces of carbon and low-alloy steel pressure vessels, paper digestors, urea reactors, tube sheets, and nuclear reactor containment vessels. Among the various welding processes employed, GMAW process has become a cost-effective choice for cladding smaller- and medium-sized areas due to its superior quality, all position capability, and ease of mechanization. The characteristics and typical uses of various weld-surfacing processes are mentioned in Table 1.

1.2 Dilution

It is defined as the ratio of the cross section of weld metal below the original surface to the total area the weld bead measured on the cross section of the weld deposit (Ref 8).

Various combinations of procedural parameters like primary parameters viz. welding current, voltage, welding speed, and secondary parameters like polarity, electrode size, wire stickout, welding position/inclination, arc shielding, electrode oscillation, welding technique, additional filler metal etc., which affect dilution, can be incorporated into a procedure (Ref 9). Various processes like SAW, GTAW, PAW, GMAW, ESW, FCAW, Strip cladding, Explosive welding (Ref 10-13), etc., have been used for cladding operation with an aim of minimizing dilution to as low value as possible without sacrificing the joint integrity. This requires a thorough understanding and proper control over a number of variables, which affect dilution. Use of hot filler additions (Ref 14) in various conventional processes like TIG, Laser, Plasma arc, etc., have been reported which affect dilution to a significant extent.

1.3 Auxiliary Preheating Arrangement in GMAW Process (Universal Gas Metal Arc Welding Process)

This process makes use of a specially designed torch as shown in Fig. 1. It employs two contact tips and a secondary

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Table 1 Characteristics and typical uses of various weld-surfacing processes

Process	Approximate minimum deposit thickness, mm	Deposition rate, kg/h	Dilution of single layer, %	Typical uses
Oxy-acetylene (OA)	0.5	1	15	Small areas deposits on light sections
Powder weld (PW)	0.1	0.2-1	···	Small areas deposits on light sections
Manual metal arc (MMA)	3	1-4	15-30	Multilayer on heavier sections
Tungsten inert gas (TIG)	1.5	2	5-10	High quality low dilution work
Plasma transferred arc (PTA)	2	10	2-10	High quality low dilution work
Gas metal inert gas (GMAW)	2	3–6	15-30	Faster than MMA, no stub end loss, position work possible
Flux-cored arc (FCAW)	2	3–6	15-30	Similar to GMAW, mainly for iron-base alloys for high abrasion resistance
Submerged arc wire (SA)	3	10-30	15-30	Heavy section work, high-quality deposits
Submerged arc strip (SA)	4	10-40	10-25	Corrosion resistant cladding of large areas
Electroslag (strip) (ESW)	4	15-35	5-20	High-quality deposits at higher deposit rates than SAW, Limited alloy range

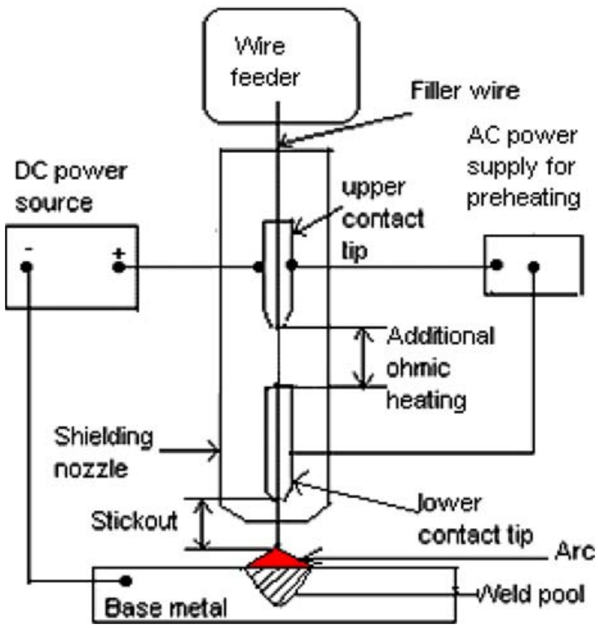

Fig. 1 Schematics of GMAW process with preheating arrangement (Ref 15)

power source to preheat the filler wire prior to its emergence from the welding torch, thereby providing an additional and independent power source. In this arrangement, the major role of welding current is dissipation of sufficient heat to support the arc, to melt the surface of the base plate, and to fuse the hot incoming wire. The main difference between conventional GMAW and this arrangement, in terms of heating, is that the preheated wire further experiences I^2R heating after it leaves the lower contact tip. This allows breaking of the fixed relationship between welding current, wire stickout, and the deposition rate, which often limits conventional GMAW process. The use of the independent secondary power source enables the heat content of the filler wire to be independently controlled, thus providing the ability to weld at a desired deposition rate while reducing the welding current,the wire stickout, the arc force, and the heat input (Ref 16).

2. Experimental Work

2.1 Base Material and Filler Used

The popularly used structural steel, which was cut down to suitable sizes of $200 \times 150 \times 12$ mm plates each, was used as the substrate material for the present investigation and the solid filler wire used was 316L (extra low-carbon grade) of 1.14 mm diameter, which because of higher molybdenum content has a higher corrosion and creep resistance, thus making it a suitable choice for chemical, pulp handling, photographic, and food equipment. The chemical composition of the base and the filler metal is given in Table 2.

2.2 Trial Runs

Trial runs were conducted for establishing the working range of the input parameters viz., wire feed rate, open circuit voltage, welding speed, electrode stickout, and preheat current to the filler wire. Weld quality was considered to be acceptable when the input parametric combination resulted in beads which were free from various visual defects like macrocracking, non-uniform ripples on the bead, excessive convexity and spatter, surface porosity, geometrical inconsistency, etc. Welding was done in the mechanized mode using the model Power Wave-355 from Lincoln Electric Co., with constant voltage system, which facilitated the variation of wire feed rate and voltage in steps of 0.05 m/min and 0.1 V, respectively. Owing to the high resistivity of the filler wire it could withstand a maximum preheat current of 110 A only, which was provided using a transformer (Table 3). Other secondary process parameters used for the final beads were:

Torch angle = 90°
Shielding gas used = industrially pure Argon
Shielding gas flow rate = 20 L/min
Electrode polarity = Reverse
Cladding position = Flat

2.3 Quantitative Comparisons of GMAW and Preheated Filler GMAW Process as Regards Chemical Composition in Single Layer Cladding

This included weld overlaying in the mechanized mode, of austenitic stainless steel 316L filler wire of 1.14 mm diameter

Table 2 Chemical composition of the base and filler wire (wt.% age) with Fe as balance

Material	C	Mn	Si	Cr	Ni	Mo	Cu	S	P
Base metal	0.295	···	0.18	0.25	···	0.50	···	0.018	0.027
Filler wire	0.019	1.61	0.37	19.12	12.47	2.83	0.10	0.014	0.019

Table 3 Different welding conditions used with recorded responses

Sr. No.	Wire feed rate, m/min	Open circuit voltage, V	Welding speed, cm/min	Electrode stick-out, mm	Process	Dilution, %
1	10	34	30	30	GMAW	33.33
2	10	34	30	30	UGMAW	24.18
3	6	34	30	30	GMAW	27.20
4	6	34	30	30	UGMAW	12.45
5	7	40	30	30	GMAW	32.54
6	7	40	30	30	UGMAW	22.48
7	7	28	30	30	GMAW	23.22
8	7	28	30	30	UGMAW	15.12
9	7	34	40	30	GMAW	22.90
10	7	34	40	30	UGMAW	13.18
11	7	34	20	30	GMAW	22.25
12	7	34	20	30	UGMAW	13.67
13	7	34	30	42	GMAW	23.45
14	7	34	30	42	UGMAW	13.34
15	7	34	30	18	GMAW	33.65
16	7	34	30	18	UGMAW	24.72
17	8	34	30	30	GMAW	23.14
18	8	34	30	30	UGMAW	13.90

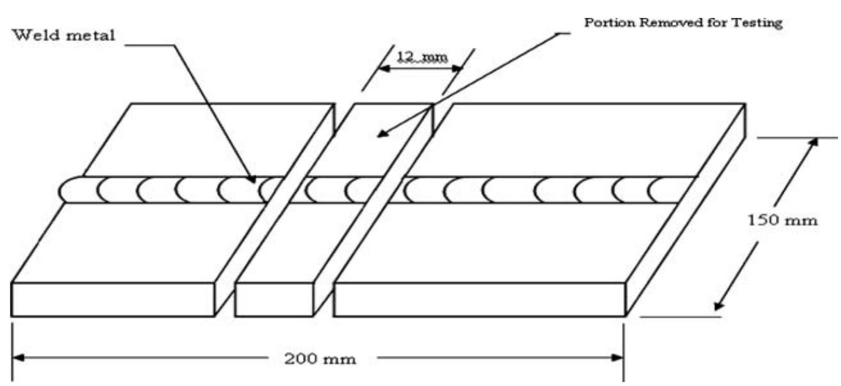

Fig. 2 Specimen cutting plan

on 12 mm thick low-carbon steel (IS: 2062 Grade 1 which is used as general structural steel) with the objective of producing a high-alloy fully austenitic surface in one weld layer. Figure 2 and 3, respectively, show the specimen cutting plan and the cross sections of the weld bead profiles.

Figure 3 shows the cross sections of the bead profiles obtained using GMAW and Preheated filler-GMAW process.

Welding parameters used were those which would give the optimum dilution conditions (Ref 17):

Wire feed rate = 6 m/min, Open circuit voltage = 30 V, Welding Speed = 20 cm/min, Electrode stickout = 30 mm, Preheat current = 110 A (preheating resulted in 36 A of drop in the main welding current).

Table 3 shows the variation of dilution with respect to different input parametric combinations in GMAW and UGMAW process.

Table 4 represents the relative comparisons of various weld bead geometry parameters.

After laying down single overlays, the chemical composition, at a distance of 2 mm from the top of the weld bead was checked and is mentioned in Table 5.

Table 6 shows the input parametric combinations for GMAW and UGMAW process, yielding the same level of dilution i.e. 33%. This comparison shows the capability of UGMAW process in giving higher deposition rate than GMAW process (which is one of the main objectives of cladding operation).

2.4 Effect of Buttering Layer

In order to compensate for increased dilution (Table 6), generally, use is made of the buttering layer, which is generally high-chrome filler like 309L filler. First layer of solid filler 309L was laid which was followed by the second layer of 316L layer with an inter-pass temperature of 150 °C using GMAW process with other welding conditions remaining constant as used above (Table 7).

3. Microstructural Studies

Standard metallurgical procedures like sectioning, grinding, polishing, and etching (etchants used were 2% Nital for the base metal and 10 g oxalic acid in 100 mL of distilled water for the weld metal 316L) were employed to prepare the samples taken for this study (those using UGMAW process owing to its low dilution capability). Photomicrographs in Fig 4(a) shows characteristic primary solidification structures as they appear in different zones of a weld bead of austenitic stainless steel overlay with normal cooling in air. The solidification structure was found to be mainly cellular or cellular-dendritic. Narrow zones of planar growth were, however, found along the fusion line in claddings surfaced with UGMAW process. Furthermore, no equiaxed grains were found in the weld metal.

Figure 4(b) shows the cellular and cellular-dendritic structure of fully austenitic phase solidified in 316L stainless steel overlay surfaced with preheated filler-GMAW process.

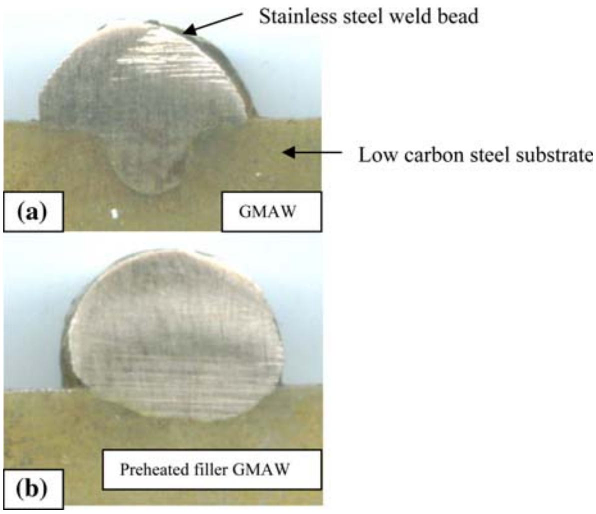

Fig. 3 Cross sections of weld bead profiles, as obtained with GMAW process (a) 182 A arc and preheated filler-GMAW (b) 146 A arc-observe significant decrease in the penetration in (b) and peaky bead appearance

Table 4 Relative differences of weld bead geometry parameters in GMAW and UGMAW (preheatied filler GMAW) process

Parameter	GMAW process	UGMAW process	Relative difference
Height, mm	4.24	4.96	14.51% increase
Width, mm	9.0	7.5	16.67% decrease
Penetration, mm	3.36	1.24	63% decrease
Dilution, %	20.32	11.35	44.14% decrease

Table 5 Chemical composition of single layer claddings using GMAW and UGMAW processes

Process	C	Cr	Ni	Mo
GMAW	0.050	13.92	9.02	1.76
UGMAW	0.040	16.86	10.80	2.14

4. Ferrite Studies

Since weld microstructure is greatly influenced by chemical composition, a number of empirical relationships and constitutional diagrams like Schaeffler's diagram, Delong diagram, WRC 1992 diagram (Ref 18-20), and even the latest prediction models that account for cooling rate effects (Ref 21-23) have been developed to predict microstructures based on actual or approximated composition.

Various constitutional diagrams and empirical relationships were used in order to predict the ferrite content in the clad metal because the importance of this study lies in the fact that in order to avoid hot cracking or microfissuring in austenitic stainless steels a minimum of 4% ferrite is necessary. The following formulas were used using different constitution diagrams for predicting the ferrite content of weld metals.

1. Schaeffler Chromium Equivalent = (%Cr + %Mo + 1.5% Si + 0.5%Nb) Schaeffler Nickel Equivalent = (%Ni + 30%C + 0.5%Mn)
2. Delong Chromium Equivalent = (%Cr + %Mo + 1.5% Si + 0.5% Nb) Delong Nickel Equivalent = (%Ni + 30%C + 30%N + 0.5%Mn)
3. WRC-1992 Chromium Equivalent = (%Cr + %Mo + 0.7%Nb) WRC-1992 Nickel Equivalent = (%Ni + 35%C + 20%N + 0.25%Cu)
4. Hammer and Svensson Chromium Equivalent = (%Cr + 1.37%Mo + 1.5%Si + 2%Nb + 3%Ti) Hammer and Svensson Nickel Equivalent = (%Ni + 22%C + 1.31%Mn + 14.2%N + %Cu)

Table 7 Chemical composition of GMAW claddings using buttering layer of solid filler 309L

C	Cr	Ni	Mo
0.050	17.97	11.02	1.55

Table 6 Comparison of GMAW and UGMAW process in terms of dilution

Process	Wire feed rate, m/min	Open circuit voltage, V	Welding speed, cm/min	Nozzle-to-plate distance, mm	Welding current, A	Heat input/weld length, kJ/mm	Dilution, %	Deposition rate, kg/h
GMAW	4	28	28	20	162	0.826	33	3.242
UGMAW	8	36	42	16	214	0.902	33	4.230

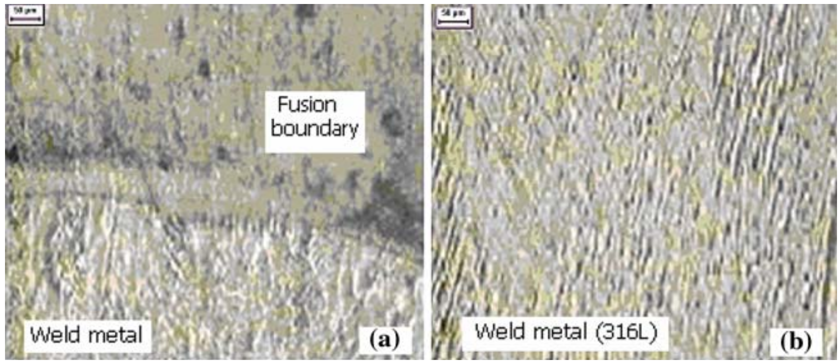

Fig. 4 (a) and (b) Microscopic view of the weldment (100×)

Table 8 Chromium and nickel equivalents (in percentage) of claddings

Process	Schaeffler-Cr equiv.	Schaeffler-Ni equiv.	Delong-Cr equiv.	Delong-Ni equiv	WRC-1992-Cr equiv.	WRC-1992-Ni equiv.	Hammer & Svensson-Cr equiv.	Hammer & Svensson-Ni equiv.
GMAW	16.175	11.34	16.175	12.343	15.75	12.397	16.826	13.5
Preheated filler-GMAW	19.495	12.84	19.495	13.825	19.07	13.827	20.186	15.126

Table 9 Comparison of predicted ferrite content (in percent) of the welds and predicted modes of solidification

Process	Schaeffler	Delong	WRC-1992	Hammer & Svensson
GMAW	Nil (A+M)	Nil (Below A+M line)	Not applicable due to low Cr content	1.24 (A/AF)
UGMAW	1 (A+F)	2.75 (A+F)	1.2 (AF)	1.33 (A/AF)

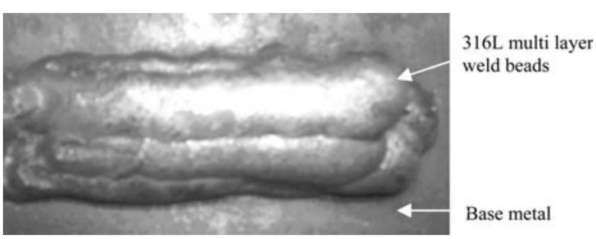

Fig. 5 Multilayer stainless steel overlays

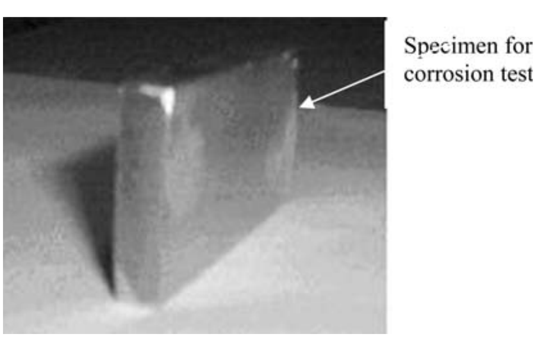

Fig. 6 Stainless steel specimen for corrosion testing

Predicted ferrite from Seferian equation = $3(Cr_{equivalent} - 0.93Ni_{equivalent} - 6.7)$, where Cr_{equiv} and Ni_{equiv} are defined by Schaeffler and = 2.56 both for GMAW and UGMAW process.

Table 8 shows the tabulated values of various equivalents using the formulas as mentioned above.

The predicted solidification modes are represented in the brackets as mentioned in Table 9 whose notation is as given below:

A + M indicates austenitic and martensitic mode
A + F is austenitic and ferritic mode
AF is austenitic-ferritic mode
A/AF is austenitic and austenitic-ferritic mode

5. Corrosion Test

5.1 Specimen Preparation

In order to evaluate the suitability of the claddings for nitric acid environment, three layers of 316L were overlaid on the low-carbon substrate using preheated filler-GMAW process as shown in Fig. 5.

Thereafter corrosion test specimen was prepared in accordance with ASTM Practice A-262 for corrosion testing (Ref 24). The stainless steel overlay was machined out so as to make it free from the base material. Then it was machined and ground to the suitable size as shown in Fig. 6.

5.2 Performing Nitric Acid Test (HUEY Test)

The test solution used was 65 ± 0.2 wt.% nitric acid. The solution was prepared by adding distilled water to concentrated

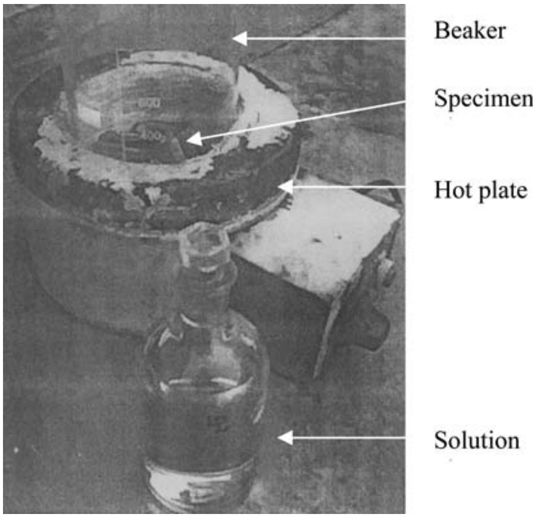

Fig. 7 Corrosion testing apparatus

nitric acid (reagent i.e., HNO_3, sp. gr. 1.42) at the rate of 108 mL of distilled water per liter of concentrated nitric acid.

As shown in Fig. 7 the stainless steel specimen was put in the boiling nitric acid for 24 h and the weight loss was determined.

Corrosion rate which is generally reported in in. /month or mils /year was calculated as follows:

$$\text{Inches per month} = (287 \times w)/(A \times d \times t),$$

where t = time of exposure, h; A = Total surface area, cm^2; w = weight loss, g; and d = density of the sample, g/cm^3.

Observed data was t = 24 h, A = 42.86 cm^2, W = 0.08 g, and d = 7.99 g/cm^3.

2.793×10^{-3} in. per month or 33.51 mils per year (using conversion factor of inches per month $\times$ 12,000 = mils per year).

6. Results and Discussion

Auxiliary preheating of the filler wire reduces dilution significantly which is due to the fact that for any given set of welding conditions the heat content of the filler wire is partially controlled by the preheating current (I^2R heating) whereas remaining energy required for melting the wire is provided by the main welding current. Since reduction in arc force and the heat transmitted to the weld pool are directly related to welding current, any decrease in welding current will result in decreased dilution. Hence the reason for obtaining significant reductions in the penetration and consequently dilution values due to the auxiliary preheated filler wire. Although the single layer claddings obtained both by the GMAW and preheated filler-GMAW process did not meet the fully austenitic composition, but new arrangement, besides capable of giving claddings with superior mechanical and corrosion resistance properties, certainly has an upper edge over its conventional counterpart GMAW in meeting the needs of low-cost surfacing applications. This is evident from the preheated filler-GMAW claddings which possess higher content of expensive materials namely chromium, nickel, and molybdenum and lower content of carbon besides having relatively higher ferrite content as compared to conventional GMAW claddings.

7. Conclusions

From the study undertaken, as above, the following conclusions can be drawn:

1. Dilution achieved in preheated filler-GMAW cladding is significantly lower as compared to GMAW cladding because preheating of the filler wire reduces base metal penetration, apart from relatively smaller variations in other bead geometry parameters, due to significant drop in the main welding current.
2. Owing to lesser arc force, finger-like penetration was absent in preheated filler-GMAW process and the weld beads obtained were peaky as compared to GMAW weld beads.
3. Preheated filler-GMAW claddings possessed higher contents of chromium, nickel, and molybdenum than GMAW claddings indicating the productivity-enhanced feature of the new process, i.e., by way of cutting costs due to lesser amount of clad metal build-up required for achieving fully austenitic composition.
4. New process is capable of substituting buttering layer to a significant extent thus resulting in considerable savings of high-chrome filler 309L.
5. For the same value of dilution higher deposition rate (more than 30%) is given by UGMAW process than GMAW process.
6. Higher ferrite content was present in preheated filler-GMAW claddings as compared to GMAW which shows its capability to give claddings having lesser tendency to hot-cracking.

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