DOI: 10.24906/isc/2023/v37/i3/223656

Search And Survey

Weld Cladding, ATIG Welding and Wire Arc Additive Manufacturing: Some Emerging Areas of Welding Research

Santanu Das†

Abstract

In this article, first, an outline on cladding processes, weld cladding and the use of a buttering layer to improve cladding performance is made. Next, the use of activating flux for having high productivity in GTAW or TIG Welding is highlighted. Lastly, a relatively new area of wire arc additive manufacturing and its opportunities are briefed. This article, in fine, makes an attempt to open up some of the immense possibilities of research in welding.

Keywords: Welding, Cladding, ATIG Welding, WAAM, Additive Manufacturing.

Introduction

Welding has emerged to be an important joining and fabrication process since last few decades, although it was considered not to be a reliable process even at around the middle of the last century. Welding, in majority of the applications, is used for joining metals and alloys permanently. However, it is also employed for joining of many non-metallic materials. Plastic packets are usually joined by a plastic welding method quite conveniently utilizing candle light, hot blade welding, etc. [1]. Among the welding practices, mostly fusion welding through establishing an electric arc is adopted worldwide.

In this paper, an overview on cladding processes, weld cladding methods and the utility of using a buttering layer is first made. Next, the use of activating flux is highlighted to improve high productivity in GTAW or TIG Welding. At the end, use of wire arc additive manufacturing using robotic arc welding and its application opportunities are outlined. This is an attempt to open up the immense possibilities of research in the area of welding before the readers as a truly multi-disciplinary area.

Introduction to Cladding

Cladding is a process where one material covers another. Here a material/ metal is bonded onto another under high pressure and temperature, or a protective or insulating layer is fixed to the outside of a structure. In contrast to cladding, coating is done in order of few microns of thickness. Unlike Coating, Cladding is done on a surface of few milimetre thickness of the clad layer. Cladding on a surface to done to improve resistance to wear as well as to enhance hardness, strength, etc. When the process is utilized to raise hardness and strength, it is known to be Hardfacing. Cladded parts are made to serve in hostile conditions to a prolonged time period thereby raising economy.

†Professor, Department of Mechanical Engineering, Kalyani Government Engineering College, Kalyani- 741235, West Bengal, India. Email: sdas.me@gmail.com
ORCID: Santanu Das: https://orcid.org/0000-0001-9085-3450

Hence, cladding is increasingly used nowadays in certain installations in chemical, naval, mining and agricultural sectors, power generation, industry for making tools, such as rollers, dies, jaws, etc. In Power Generation, extreme erosion, abrasion and temperature are prevalent throughout coal power generation processes. Cladding extends the time between maintenance cycles from months to years [2-8].

(a)

(b)

Fig. 1: Different clad components [a) Fan blade and housing, b) Conveyance pipe] [9]

Technology Used for Cladding

Different technologies employed [2-4] for cladding a component are listed below:

- Welding methods
  - Arc Welding Processes
    - ➢ Shielded or Manual Metal Arc Welding (SMAW/MMAW)
    - ➢ Gas Metal Arc Welding (GMAW)
    - ➢ Pulsed Gas Metal Arc Welding (P-GMAW)
    - ➢ Flux Cored Arc Welding (FCAW)
    - ➢ Gas Tungsten Arc Welding (GTAW)
    - ➢ Pulsed-Gas Tungsten Arc Welding (P-GTAW)
    - ➢ Submerged Arc Welding (SAW)
    - ➢ Plasma Arc Welding (PAW)
  - Electro Slag Welding (ESW)
  - Resistance Welding
  - Laser Beam Welding (LBM)
  - Some Hybrid Welding Processes, etc.
- Thermal spraying methods
- Metal forming methods
  - ➢ Hot Roll Bonding
  - ➢ Cold Roll Bonding
  - ➢ Explosive Bonding
  - ➢ Extrusion
  - ➢ Hot Isostatic Pressing (HIP)
- Some other processes
  - ➢ Centrifugal Casting
  - ➢ Brazing

Weld Bead Geometry

Welding process makes a permanent joint by making a weld bead or coalescence that is a metallurgical bond at the faying surfaces between the materials to join. There are three parameters of bead geometry, namely height of reinforcement, bead width and depth of penetration as indicated in Fig. 2. For making a sound weld joint, depth of penetration should be high, however, for weld cladding, there should be shallow penetration with low mixing volume of the clad material and substrate material although bond strength should be good [2-4, 8-12].

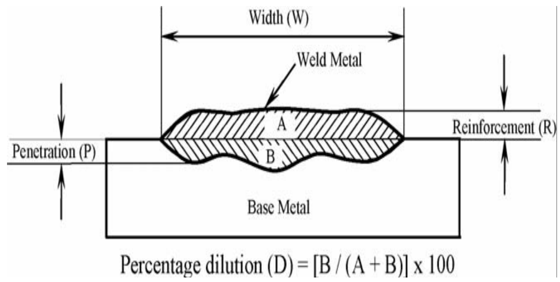

Fig. 2: Bead geometry parameters [2]

Mechanical properties of weld clad material is influenced not only by the type of metallic materias, but also by the geometry of weld bead [2-4, 13, 14]. Desired weld bead geometry can be obtained by appropriate welding current, gas flow rate, wire feed rate, welding speed, torch angle, nozzle-tip distance, etc. Heat Input to welding zone is quite important and it is dependent on weld current, weld voltage and weld torch travel speed. Hence, the importance to establish the relation between input process parameters and bead geometry parameters. Suitable optimization algorithm may be employed to establish this relationship and to evolve optimal bead and the corresponding input conditions. With the condition derived for depositing optimal weld bead needed for cladding, cladding experiments can be performed to serve the desired purpose [2-4, 8-12].

Outline of the Experiments Done on Cladding

Series of experimental investigations were performed [13-33] on weld cladding by austenitic stainless steel (code: 316) and duplex stainless steel (code: E2209T0-1) on low carbon steel popularly known as mild steel (MS) using Gas Metal Arc Welding (GMAW), commonly known as MIG/MAG welding. MIG is Metal Inert Gas welding when inert shielding gas is used to put a protective cover around the weld region to prevent atmospheric contamination through chemical reaction. In case carbon di-oxide gas is used as the shielding gas, the process becomes Metal Active Gas (MAG) welding. Particularly for steel welding, MAG is most widely used for certain benefits. Weld cladding experiments were first started at the Welding Technology Centre of Jadavpur University, Kolkata and then continued at Kalyani Govt. Engineering College, Kalyani.

Fig. 3 shows a single layer cladding with 50% overlap of successive weld beads. In this way, there can be multiple clad layers depending upon the requirement.

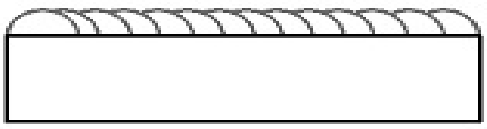

Fig. 3: 50% Overlap Single Layer Cladding [24]

Fig. 4: Microstructure of a typical test sample showing the interface between austenitic stainless steel weld cladding and the MS substrate (dark region) [25]

Wire Electrode of 1.2mm Diameter was used for GMAW using a ESAB made AutoK400 GMAW Machine. Welding Speed was typically set at 420 mm/min. 100% CO_2 Gas Shield was employed with a Gas Flow Rate of 16 l/min. After a single layer cladding, the specimen is readied to observe its microstructure. Microstructure of a typical test sample as shown in Fig. 4 indicates the interface between austenitic stainless steel weld cladding and the mild steel (MS) substrate. The interface indicates strong metallurgical bond existing. The lower dark region corresponds to mild steel while the top region is with white ferrite portion and the grey tree branch like austenitic structure [25].

Accelerated Corrosion Test was performed on cut clad specimens of size of 15x15 x25 mm^3 by dipping it in a chloride medium (29% wt. of $FeCl_3$, 24.67% wt. of HCl and distilled water) for up to 24 hours. Each specimen is coated with Teflon tape, leaving only the surface area of clad layer exposed. Fig. 5 [25] and Fig. 6 [9] show typical plots of corrosion Rate of Austenitic Stainless Steel and duplex stainless steel Cladding with variation of heat input respectively. In both the cases, increase in heat input is observed to have caused hike in the rate of corrosion. Therefore, somewhat low heat input may be recommended for use in practice. Corroded Surfaces with and without Cladding are shown in Fig. 7 [3, 13]. Large black colored cavities can be seen in the unclad surface under the corrosive atmosphere when the extent of corrosion pits are found to be of remarkable less area corresponding to the clad surface. This definitely shows improvement in corrosion resistance by putting a clad layer.

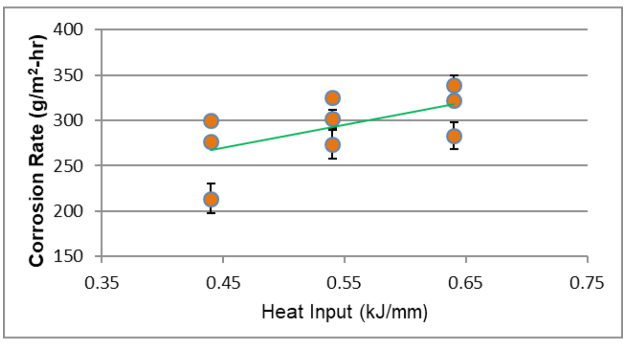

Fig. 5: Typical plot of corrosion rate of austenitic stainless steel cladding with variation of heat input [25]

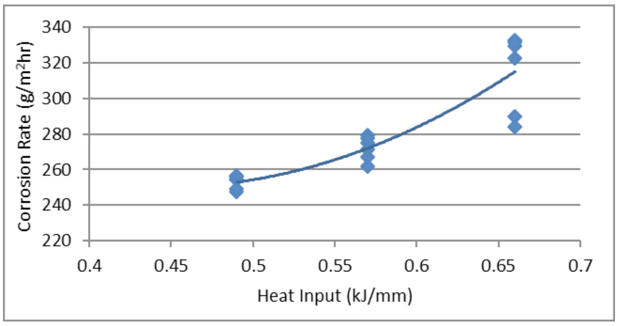

Fig. 6: Typical plot of corrosion rate of duplex stainless steel cladding with variation of heat input [9]

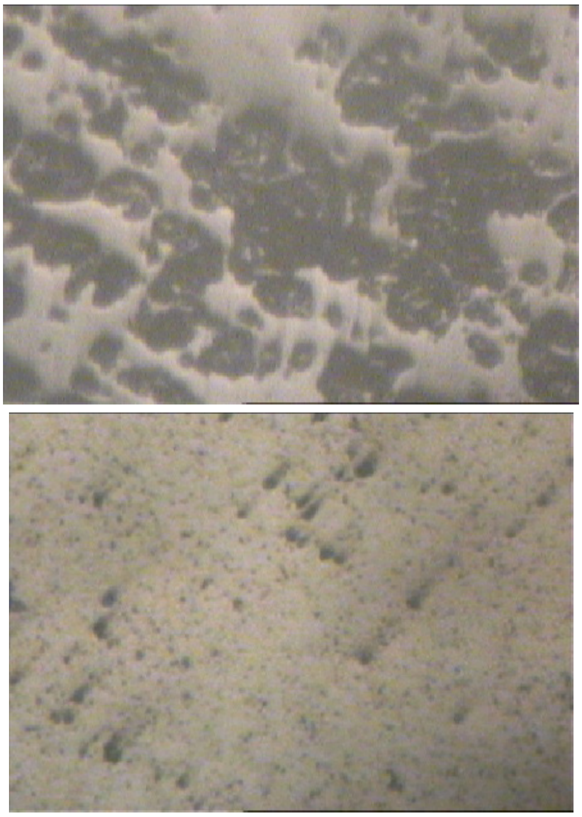

Fig. 7: View of typical corroded surface (200X) [a) MS surface, (b) clad surface] [3, 12]

Enhancing Corrosion Resistance of Cladding through a Buttering Layer of Nickel or Copper

In another set of experimental investigation, 316 austenite stainless steel cladding was performed on Nickel [33] or Copper [27] coated low carbon steel by means of GMAW using 100% CO_2 as shielding gas. Nickel, or Copper, was deposited on low carbon steel by electroplating method to act as a buttering layer. Welding current and torch travel speed were changed to vary heat input. Similar accelerated corrosion test in chloride atmosphere was done on clad surfaces. Results indicated significant decrease in corrosion rate of clad samples with the buttering layer relative to that without buttering layer. Fig. 8 shows a copper coated sample on which cladding was done later.

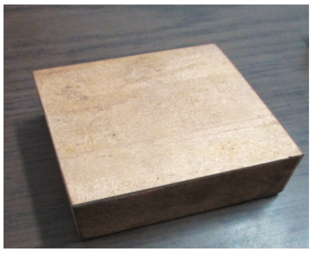

Fig. 8: Copper coated MS sample ready for cladding [27]

Activated Tungsten Inert Gas (A-TIG) Welding

Following are typical characteristics of GTAW or TIG welding process [1, 35].

Advantages of TIG Welding:

- Suitable for high quality welding of thin sheets (as small as 0.125 mm)
- Clean, uniform, aesthetically good looking
- Suitable for nonferrous metals, specifically aluminium and its alloys and stainless steels

Disadvantages of TIG Welding:

- Slow process giving low productivity (GMAW Process can give high productivity of 3 kg/h or more, while GTAW gives only about 1 kg/h)

To overcome the shortcoming of TIG welding with regard to its low productivity, many ways and means were attempted in the past. Activating Flux TIG, in short, A-TIG, welding is a simple alternative to improve productivity of TIG welding by improving depth of penetration. In A-TIG welding, activating flux used is usually a mixture of flux powders (usually oxides, halides, etc.), or an oxide/ a halide, etc., suspended in a solvent, like acetone, ethanol, etc. The technique is quite simple. A coating of this activating flux is put on the faying surfaces to weld by a brush or by spraying and then TIG welding is carried out [35].

Different persons tested various fluxes such as TiO_2, Cr_2O_3, $MgCO_3$, MgO, MnO_2, CaO, Al_2O_3, ZrO_2, etc., OR, a homogeneous mixture of these two or more fluxes in different proportions. Flux provides thermal insulation to the region adjacent to the faying surfaces [35-43].

Mechanism behind Deep Penetration in A-TIG Welding

In TIG Welding, heat flow occurs parallel to the top surface of the material away from the arc. However, in A-TIG Welding, heat flows towards the bottom of work material making penetration higher. The effect of Arc Constriction and Reverse Marangoni Flow that happen in A-TIG welding are stated to be the main reasons behind the achievement of deep penetration. Fig. 9 clearly indicates the nature of arc pattern leading to deep penetration in A-TIG welding whereas Reverse Marangoni Flow is clearly indicated in the schematic diagram as shown in Fig. 10 [35-43].

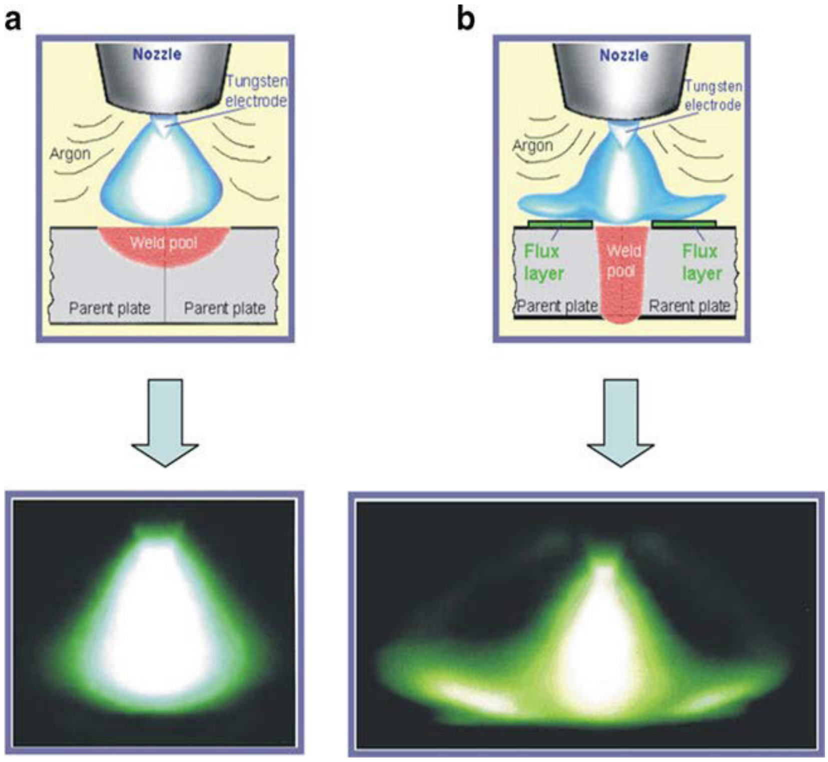

Fig. 9: Schematics and photographs of the arc (a) without & (b) with flux [35, 45]

Some experimental investigations were and are being made [44-51] at Kalyani Govt. Engineering College, Kalyani. Both bead-on-plate and butt joining were conducted using TIG as well as A-TIG welding with Work Material being 6 mm thick stainless steel (grade 316L and other) plates. The set up is shown in Fig. 11. Filler Material used was the same grade of stainless steel wire. AC and DCEN polarity were used. Activating Fluxes employed were TiO_2, Cr_2O_3 and Fe_2O_3 and also some mixtures of some fluxes. Fig. 12 shows the use of milky white TiO_2 flux on 316L austenitic stainless steel specimens for A-TIG welding and a typical A-TIG welded joint [47].

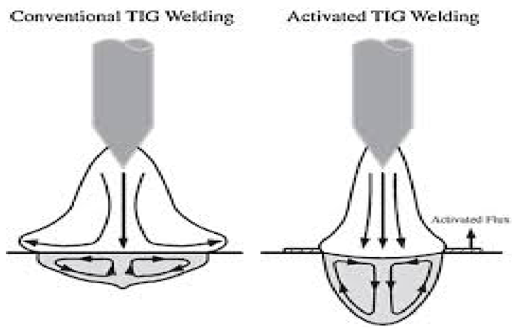

Fig. 10: Effect of Reverse Marangoni Flow in A-TIG Welding [35, 37, 45, 46]

Variation of depth of penetration with heat input during bead-on-plate welding of 316L austenitic stainless steel specimens under different activating flux and without using a flux is depicted in Fig. 13. Similar plots showing the variation of depth of penetration with heat input during welding joints of 316L austenitic stainless steel specimens with or without applying different activating fluxes are indicated in Fig. 14 [47].

Fig. 11: The GTAW Set up [44-51]

a) White portion is TiO_2 Layer   b) A-TIG welded butt joint

Fig. 12: The Use of TiO2 flux for A-TIG welding [47]

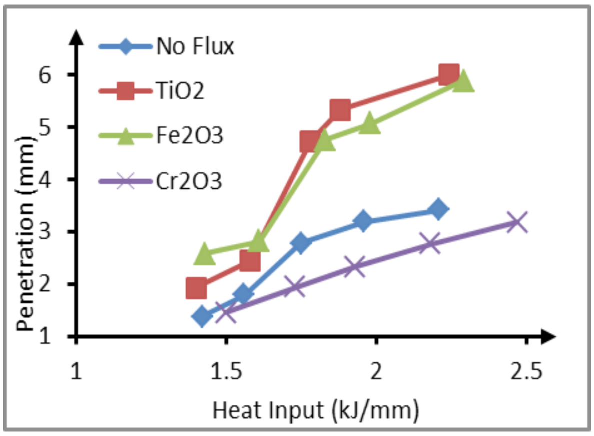

Fig. 13: Change in depth of penetration with heat input during bead-on-plate welding [47]

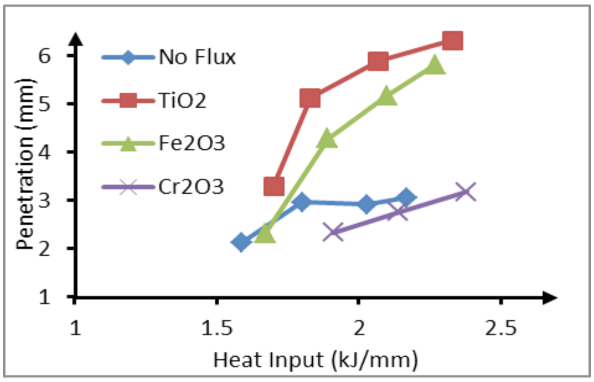

Fig. 14: Change in depth of penetration with heat input during weld joining [47]

At low heat input, penetration achieved for TIG and A-TIG welding is similar whereas at higher heat input, TiO_2 and Fe_2O_3 flux based A-TIG welding indicates remarkable hike in penetration. Full penetration of 6mm is achieved by using only TiO_2 flux [47]. Different other fluxes can be tried to evolve more effective A-TIG welding to have further improvement in productivity. Many industries are using this using imported costly flux; however, an industry can easily develop its flux needed and achieve good penetration and productivity economically [44-51].

Wire Arc Additive Manufacturing Techniques

Introduction

Additive Manufacturing enables manufacture of end-use parts directly from CAD data by depositing layer by layer material to make a 3D object thereby eliminating the need of complex intermediate tool. It significantly reduces production cycle and allows greater design freedom and development of quite complex shapes [52, 53].

Additive Manufacturing can well be done using Arc welding employing GMAW Wire electrode, etc. Then it is called Wire Arc Additive Manufacturing (WAAM). A typical scheme of WAAM is shown in Fig. 15 [55]. Depending upon the size of the component to be manufactured, the WAAM system can reduce fabrication time by 40–60%, and also post-machining time by 15–20% compared to traditional subtractive manufacturing.

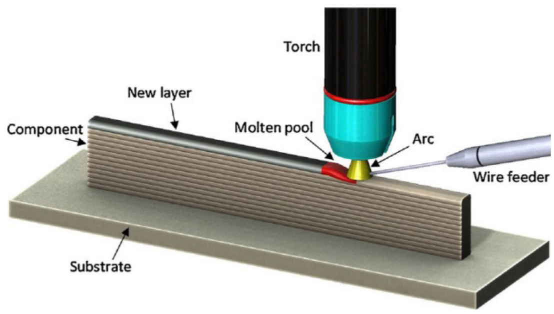

Fig. 15: A typical WAAM shown schematically [55]

WAAM processes may be (a) GMAW based, (b) GTAW based and (c) plasma arc welding (PAW) based. Metals used in WAAM process may be titanium alloys, nickel-based superalloys, steels, aluminium alloys, copper alloys, etc. [53, 54].

Some experimental investigations involving WAAM techniques were and are being carried out in collaboration with CSIR-CMERI, Durgapur [55-57]. The set up of WAAM is shown in Fig. 16.

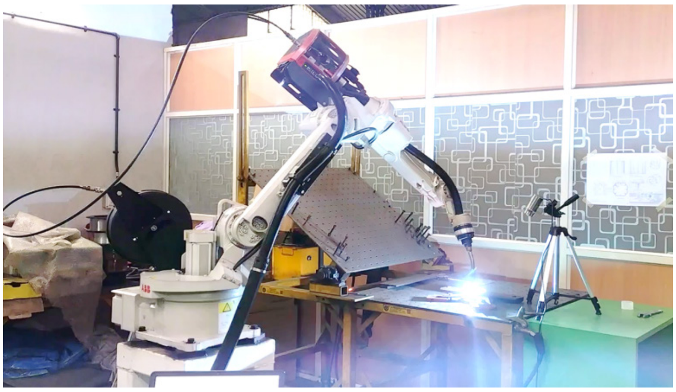

Fig. 16: The WAAM set up used [55-57]

Variation in process parameters, heat dissipation rate, and size of previous layer(s) usually result in uncertainties to the WAAM process. It may make the actual layer height deviated from the step height, giving rise to a change in the nozzle to the top layer distance. With the increase in the number of layers, distance between the nozzle to the top layer may vary widely, resulting in too long or too short arc length resulting in uneven surface profile. WAAM-fabricated components may experience some common defects such as deformation, residual stress, transverse crack, delamination of successive layers, porosity, etc. Residual stress can lead to fatigue failure also. A typical deformation of substrate after fabrication by WAAM is shown in Fig. 17. In case of WAAM, clear understanding of the material characteristics and effect of process parameters on the process should be known through in-depth investigation [54, 56]. Banerjee et al. tried to take the image of the WAAM part to subject these images to analyze using different image analysis techniques to detect different defects.

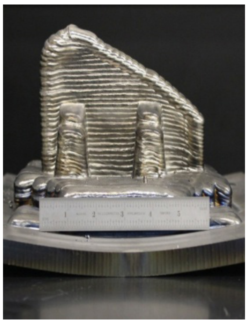

Fig. 17: Deformation of substrate after WAAM fabrication [54, 56]

On the other hand, Datta et al. [55, 57] employed different linear and spiral path strategies on bulk deposition of inconel 625 by wire arc directed energy deposition to find the effect of these varying path strategies. They used finite element analysis to carry out the analysis, and found out an optimal path strategy. Several other investigations are being performed worldwide to explore the WAAM to suite specific applications for varying materials.

Conclusion

- It can be stated that ample scope remains to find out better corrosion resistant system using suitable stainless steel, etc. with or without a buttering layer so that higher service life and economy can be achieved.
- Different activating fluxes can be explored to find out indigenous flux to apply to industries without relying upon foreign patented costly flux that is being used widely nowadays.
- Different strategies of Wire Arc Additive Manufacturing strategies are to be explored to develop indigenous technology to apply to critical component manufacturing industries.

References

1. O P Khanna, A Text Book of Welding Technology, Dhanpat Rai Publications, New Delhi, 2010.
2. M K Saha, A Mondal, R Hazra and S Das, An overview on cladding through gas metal arc welding, Proceedings of the National Welding Seminar, Jamshedpur, India, 2015.
3. M K Saha and S Das, A review on different cladding techniques employed to resist corrosion, Journal of the Association of Engineers, India, Vol 86, No 1&2, page 51-63, 2016.
4. M K Saha and S Das, Gas metal arc weld cladding and its anti-corrosive performance- a brief review, Athens Journal of Technology and Engineering, Vol 5, No 2, page 155-174, 2018.
5. W Lucas, Arc surfacing and cladding processes to enhance performance in service and to repair worn components, Welding and Metal Fabrication, Vol 62, No 2, page 55-60, 1994.
6. A Gualco, H G Svoboda, E S Surian and L A de Vedia, Effect of welding procedure on wear behaviour of a modified martensitic tool steel hardfacing deposit, Materials & Design, Vol 31, No 9, page 4165–4173, 2010.
7. N V Rao, G M Reddy and S Nagarjuna, Weld

overlay cladding of high strength low alloy steel with austenitic stainless steel- structure and properties, Materials and Design, Vol 32, page 2496–2506, 2011.

8. P Sreeraj and T Kannan, Modelling and prediction of stainless steel clad bead geometry deposited by GMAW using regression and artificial neural network models, Advances in Mechanical Engineering, Vol 2012, page 1-12, 2012.
9. S Das, Cladding: applications, advances and some research experience- Engineer Soumitra Kumar De Memorial Lecture, Proceedings of Weld 2019, Kolkata, 2019.
10. A Mondal, M K Saha, R Hazra and S Das, Influence of heat input on weld bead geometry using duplex stainless steel wire electrode on low alloy steel specimens, Cogent Engineering, Vol 3, No 1, page 1143598/1-14, 2016.
11. M K Saha, R Hazra, A Mondal and S Das, Effect of heat input on geometry of austenitic stainless steel weld bead on low carbon steel, Journal of Institute of Engineers India: Series C, Vol 100, No 4, page 607-615, 2019.
12. M K Saha, L N Dhara and S Das, Variation of bead geometry of 316 austenitic stainless steel weld with varying heat input using metal active gas welding, Proceedings of the Conference on Leveraging Simulation & Optimization Techniques for Manufacturing Excellence and Productivity Enhancement, Tata Steel, Jamshedpur, India, 13 February 2018.
13. M K Saha, A Mondal, R Hazra and S Das, Effect of process parameters on hardness values of duplex stainless steel cladding onto low alloy steel by GMAW, Proceedings of the National Welding Seminar, Kolkata, India, 2016.
14. M K Saha, A Mondal, R Hazra and S Das, On the variation of hardness of duplex stainless steel clad layer deposited by flux-cored arc welding, Reason- A Technical Journal, Vol 16, page 1-6, 2016.
15. B Chakrabarti, S Das, H Das and T K Pal, Effect of process parameters on clad quality of duplex stainless steel using GMAW process, Transactions of the Indian Institute of Metals, Vol 66, No 3, page 221-230, 2013.
16. A K Verma, B C Biswas, P Roy, S De, S Saren and S Das, Explaining austenite stainless steel clad layer obtained by MAG welding, Indian Science Cruiser, Vol 27, No 4, page 24-29, 2013.
17. A K Verma, B C Biswas, P Roy, S De, S Saren and S Das, On the effectiveness of duplex stainless steel cladding deposited by gas metal arc welding, e-Proceeding of International Conference of the International Institute of Welding, Seoul, Korea, 2014.
18. A K Verma, B C Biswas, P Roy, S De, S Saren and S Das, An investigation on the anti-corrosion characteristics of austenitic stainless steel cladding, Indian Welding Journal, Vol 50, No 3, page 52-63, 2016.
19. B Khara, N D Mondal, A Sarkar and S Das, Weld cladding with austenitic stainless steel for imparting corrosion resistance, Indian Welding Journal, Vol 49, No 1, page 75-81, 2016.
20. M K Saha, J Mondal, A Mondal and S Das, Influence of process parameters on corrosion resistance of duplex stainless steel cladding done on low alloy steel specimens, Proceedings of the National Welding Seminar, Kolkata, India, 2016.
21. M K Saha, R Hazra, A Mondal and S Das, Effect of process parameters on corrosion resistance of austenitic stainless steel cladding done on low alloy steel specimens, Proceedings of the National Welding Seminar, Kolkata, India, 2016.
22. M K Saha, J Mondal, A Mondal and S Das, Influence of heat input on corrosion resistance property of duplex stainless steel cladding using flux cored arc welding on low alloy steel specimens, Proceedings of the International Congress 2017 (IC2017), page 18, Chennai, India, 2017.
23. M K Saha, M Kumar and S Das, Effect of heat input on pitting corrosion rate of duplex stainless steel cladding over low alloy steel by flux cored arc welding, Proceedings of the International Conference in Mechanical Engineering (INCOM-2018), Jadavpur University, Kolkata, page 393-396, 2018.
24. M K Saha, A Mondal, R Hazra and S Das, Anticorrosion performance of FCAW cladding with regard to the influence of heat input, Journal of Welding and Joining, Vol 36, No 5, page 61-69, 2018.
25. M K Saha, R Hazra, A Mondal and S Das, On corrosion resistance of austenitic stainless steel

clad layer on a low alloy steel, Indian Science Cruiser, Vol 32, No 3, page 20-25, 2018.

26. Saha M K, Mondal J., Mondal A., Das S, Influence of heat input on corrosion resistance of duplex stainless steel cladding using flux cored arc welding on low alloy steel flats, Indian Welding Journal, Vol 51, No 3, page 66-72, 2018.

27. M K Saha, S Das and G L Datta, Corrosion behaviour of 316 austenitic stainless steel cladding on copper coated low alloy steel by gas metal arc welding, Indian Welding Journal, Vol 51, No 4, page 73-81, 2018.

28. M K Saha, R Hazra, A Mondal and S Das, Influence of heat input on corrosion resistance of 316 austenitic stainless steel cladding on E350 low alloy steel by active metal gas welding, Proceedings of the Conference on Leveraging Simulation & Optimization Techniques for Manufacturing Excellence and Productivity Enhancement, Tata Steel, Jamshedpur, India, 13 February 2018.

29. M K Saha, L N Dhara and S Das, Influence of heat input and shielding gas mixture on shear strength and macro-hardness of 316 austenitic stainless steel cladding onto E250 low alloy steel by GMAW process, Proceedings of the National Conference on Advanced Materials, Manufacturing and Metrology (NCAMMM-2018), CSIR-CMERI, Durgapur, India, page 72, 2018.

30. J Mondal, M K Saha and S Das, Corrosion resistance property of austenitic stainless steel cladding layer on low alloy steel, Proceedings of the National Welding Seminar, Cochi, India, 2018.

31. M K Saha, A Mondal, R Hazra and S Das, Influence of heat input on corrosion resistance of duplex stainless steel cladding on low alloy steel by FCAW, Advances in Micro and Nano Manufacturing and Surface Engineering in the Series: Lecture Notes on Multidisciplinary Industrial Engineering, Chapter 51, page 571-581, 2019.

32. S Bose and S Das, Experimental investigation on bead-on-plate welding and cladding using pulsed GTAW process, Indian Welding Journal, Vol 54, No 1, page 64-76, 2021.

33. S Das and M K Saha, Investigating the effect of nickel buttering on corrosion resistance, Spektrum Industri, Vol 20, No 2, page 57-68, 2022.

34. M K Saha, M Kumar and S Das, Cladding with duplex stainless steel to retard corrosion, Journal of Production Systems & Manufacturing Science, Accepted for publication, 2022.

35. S Das and S Acharya, Effect of activating flux in gas tungsten arc welding, WeldFab Tech Times, Vol 4, No 3, page 12-21, 2021.

36. S M Gurevich, V N Zamkov and N A Kushnirenko, Improving the penetration of titanium alloys when they are welded by argon tungsten arc process, Avtomatich Svarka, Vol 9, No 4, 1965.

37. D S Howse and W Lucas, Investigation into arc constriction by active fluxes for tungsten inert gas welding; Science and Technology of Welding and Joining, Vol 5, No 3, page 189-193, 2000.

38. J J Lowke, M Tanaka and M Ushio, Mechanisms giving increased weld depth due to a flux, Journal of Physics D: Applied Physics, Vol 38, No 18, 2005.

39. H S Lin and T M Wu, Effects of activating flux on weld bead geometry of inconel 718 alloy TIG welds, Materials & Manufacturing Processes, Vol 27, page 1457-1461, 2012.

40. K H Tseng, Development and application of oxide-based flux powder for tungsten inert gas welding of austenitic stainless steels, Powder Techno, Vol 233, page 72-79, 2013.

41. H C Dey, S K Albert, A K Bhaduri and U K Mudali, Activated flux TIG welding of titanium, Welding in the World, Vol 57, No 6, page 903–912, 2013.

42. G Magudeeswaran, S R Nair, L Sundar and N Harikannan, Optimization of process parameters of the activated tungsten inert gas welding for aspect ratio of UNS S32205 duplex stainless steel welds; Defence Technology, Vol 10, No 3, page 251–260, 2014.

43. A Babbar, A Kumar, V Jain and D Gupta, Enhancement of activated tig welding using multi component TiO_2-SiO_2-Al_2O_3 hybrid flux, Measurement, Vol 148, Mo December, 2019.

44. S Roy, S Samaddar, Md N Uddin, A Hoque, S Mishra and S Das, Effect of activating flux on penetration in ATIG welding of 316 stainless steel, Indian Welding Journal, Vol 50, No 4, page 72-80, 2017.

45. S Saha, Investigation on the effect of activating flux on tungsten inert gas welding of austenitic

stainless steel, Masters Dissertation submitted to Kalyani Govt. Engg. College, 2016.

46. B C Paul, Investigation on the effect of activating flux on tungsten inert gas welding of 316 stainless steel, Masters Dissertation submitted to Kalyani Govt. Engineering College, 2017.

47. S Saha and S Das, Investigation on the effect of activating flux on tungsten inert gas welding of austenitic stainless steel using AC polarity, Indian Welding Journal, Vol 51, No 2, page 84-92, 2018.

48. S Saha and S Das, Application of activated tungsten inert gas (A-TIG) welding towards improved weld bead morphology in stainless steel specimens, Annual Technical Volume of Production Division Board, The Institution of Engineers (India), Vol IV, page 13-23, 2019.

49. S Saha and S Das, Effect of polarity and oxide fluxes on weld-bead geometry in activated tungsten inert gas (A-TIG) welding, Journal of Welding and Joining, Vol 38, No 4, page 380-388, 2020.

50. S Saha, B C Paul and S Das, Productivity improvement in butt joining of thick stainless steel plates through the usage of activated TIG welding; SN Applied Sciences, Vol 3, No 416, page 416/1-10, 2021.

51. S Ray and S Das, Investigation on the effect of binary flux mixture on activated tungsten inert gas welding of stainless steel, Proceedings of the National Welding Seminar, Baroda, India, 2021.

52. J Liu, Y Xu, Y Ge, Z Hou and S Chen, Wire and arc additive manufacturing of metal components: a review of recent research developments, The International Journal of Advanced Manufacturing Technology, Vol 111, No 1, page 149-198, 2020.

53. T Goswami, S Biswas, S Das and M Mukherjee, An overview of wire arc additive manufacturing (WAAM) technique with different alloys in modern manufacturing industries, CRC Book Series on Advances in Manufacturing Design and Computational Intelligence Techniques, in Hybrid Metal Additive Manufacturing: Technology and Applications, 2023.

54. A Banerjee, M Mukherjee, S Das and S Dutta, Prediction of bead profile in GMAW based wire arc additive manufacturing using image processing techniques, Proceedings of the National Conference cum Industry meet on Foundry 4.0: Opportunities and Challenges, 24-25 February 2022, Durgapur, India, page 76-82, 2022.

55. A Datta, M Mukherjee and S Das, Optimization path strategies for bulk deposition using finite element analysis, Proceedings of WELD 2022: Seminar on Recent Trends & Innovations in Welding, Kolkata, 22 April 2022.

56. A Banerjee, M Mukherjee, S Das and S Dutta, Bead profile prediction in wire arc additive manufacturing with image processing techniques, Proceedings of the National Welding Seminar (NWS 2022) , Chennai, 19-21 January 2023.

57. A Datta, M Mukherjee, S Das, Chandrasekar E and Y Tiwari, Effect of linear and spiral path strategies on bulk deposition of inconel 625 by wire arc directed energy deposition using finite element analysis, Proceedings of WELD 2023: Seminar on Welding Technology: Present Status and Way Forward, Kolkata, 11-12 March 2023, page 68, 2023.

Acknowledgement

The author thanks the authority of Kalyani Govt. Engineering College, Kalyani for providing necessary funding for the experimental work on cladding and ATIG Welding. He also acknowledges Welding Technology Centre of Jadavpur University, Kolkata set up by Prof. Tapan Kumar Pal where the first work on cladding was done. He also thanks CSIR- Central Mechanical Engineering Research Institute (CMERI), Durgapur where collaborative works on wire arc additive manufacturing has been taken up and is going on under the leadership of Dr. Manidipto Mukherjee. The author specially mentions Mr. Sagar Roy, a B.Tech student, who first explored ATIG welding at Kalyani Govt. Engineering College, Kalyani.

This article is based on the Invited Lecture delivered by the author during the celebration of National Science Day 2022 organised by Institute of Science, Education and Culture on February 28 2022.