A review studies on hard-facing of inconel 718 on stainless steel 321 and 347 grades for the nuclear reactor components

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KEYWORDS

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Gas Metal Arc Welding (GMAW),
Dilution,
Process Parameters.

ABSTRACT

Corrosion and wear have been a major challenge in most of the industries. There are various surface modification techniques are need to make the desired layer on the substrate such as laser hardfacing, thermal spraying, and Arc welding process because of availability and economical considerations. Arc welds pool are used. Particularly gas metal arc welding (GMAW) having a good deposition. This process has various parameters like welding current, torch speed, filler wire speed, filler metal deposition rate, shielding gas flow rate and types of shielding gases. A lot of attempts were made by the researcher to get low dilution, which usually comprises the essential corrosion resistance and wears. These results will help the researchers in selecting the best suitable welding process and materials used in hardfacing technology. This paper will give guidelines to the researchers to focus on the future scope of hardfacing technology.

1. Introduction

In engineering applications there are various surface improvement techniques are available to enhance the surface properties of the components. Hardfacing is most suitable techniques used to improve the properties of the surface of the mechanical component in such a way that the life of the component especially which are subjected to wear and corrosion can enhance.

A layer of suitable material at the surface is developed on the substrate to improve surface properties [1]. The outcomes were studied by adjusting the various input parameters. Hardfacing by arc welding processes such as plasma arc welding (PAW) [2], gas tungsten arc welding (GTAW) [3], gas metal arc welding (GMAW) [4], submerged arc welding (SAW) [5], and shielded metal arc welding (SMAW) [6] are analyzed by various process parameters [2-6]. Among all the hardfacing, the GMAW process has a lot of advantages such as low cost, low dilution, good weld appearance, high quality of the weld, easy to handle and suitable for surfacing most of the engineering components [7].

In this paper, the various hardfacing techniques used in the GMAW process are focused on. Based on the detail literature review hardfacing by the arc welding process, GMAW parameter and outcomes are discussed. This review paper will give a clear idea about the research gap for the new beginners in hardfacing by GMAW process. This work is important because till date hardfacing of GMAW process is giving suitable outcomes.

The stainless steel is used as a substrate because its high-alloy have high corrosion resistance. Stainless steel of 321 and 347 grades has excellent welding features[8]. Inconel 718 is a nickel-base superalloy having good mechanical properties in combination with excellent corrosion resistance [9].

2. Methods

The classification of the coating process by welding is shown in Fig.1. This research paper is aimed to review the various surface modification techniques.

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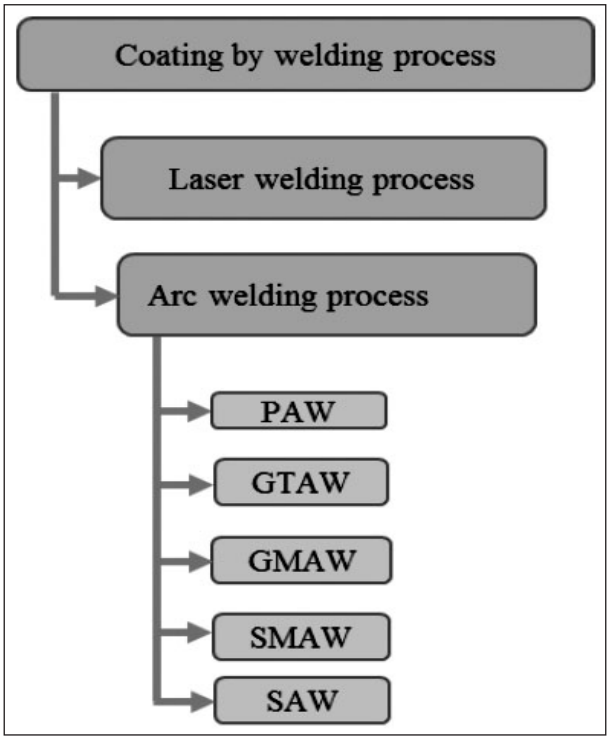

Fig. 1. Classification of the coating by the welding process.

The detailed review of hardfacing by arc welding processes and literature is discussed below. In this research the standard outputs like bead geometry, microhardness, microstructure, tensile strength, and bending, etc. are focused respective to the materials. The detailed review of the arc welding process parameter and literature are discussed below.

2.1 Laser Hardfacing

Laser hardfacing is commonly referred to as the laser cladding, it little differs from traditional hardfacing techniques. The primary difference is the use of high energy laser beam heat source rather than an arc or gas flame. Laser beams offer potential is applying thin overlayer. Cobalt, nickel, and tungsten carbide-based hardfacing alloys are the usual cladding material for the laser hardfacing.

The hardfacing material selection depends on its hardness and strength better than the base metal [12]. The hardfacing alloy is melted by a laser beam and allowed to spread freely and freeze over the substrate. The beam also melts a thin layer of the substrate, which combined with the liquid weld metal in the list extent necessaries and solidifies to form a strong metallurgical bond. A good fusion bond is achieved with a dilution zone that is only 10µm thick.

2.2 Plasma Arc Welding (PAW)

PAW is an advance version of the GTAW process. It also used the tungsten electrode and inert gas for shielding a molten metal. Low-velocity plasma coupled the diffused arc is generated in the GTAW welding while in case of PAW very high velocity and coherent plasma are generated. The large surface area of the arc exposed to ambient air in the case of GTAW welding causes greater heat losses than PAW. This method can produce a hard layer of coatings and good metallurgically bonded to the substrate [2]. Therefore, GTAW arc burns at a temperature lower than the plasma arc welding.

Kesavan and Kamara Examined the effect of microstructure on high temperature, wear behaviour of nickel-base hard-faced coating [13]. Results showed that the wear resistance of coating improved with an increase in temperature. Hou et al Examined the effects of Mo addition on the microhardness and Mo coated particles and coated particles can increase the wear resistance [14]. Balasubramanian et al Studied the substrate, stainless-steel hard-faced surface is four times better than that of the carbon steel using PAW [15].

2.3 Gas Tungsten Arc Welding (GTAW)

The GTAW process is used when high-quality weld and good weld appearance are required. Shari et al Investigated to Fe-TiC-Al_20_3 the coating on the substrate of the steel of grades 1045 by GTAW process, and find that the hardness value is increased, which enhance the wear resistance of the substrate [16]. Sadeghi et al Studied the microhardness tests the hardness values increased by the addition of niobium (Nb) and titanium (Ti) contents [17].

Abed et al Studied weld layers and heat input and the results show that hardness of layers was increased by increasing the number of layers or by decreasing the heat input [18]. Chang et al Evaluated the hardness value is increased by added chromium content and also improve the corrosion resistance of the material [19].

2.4 Gas Metal Arc Welding (GMAW)

Gas metal arc (GMAW) welding, a consumable electrode is used. In GMAW process wire can

be deposited in either spray arc or short arc method. The filler metal and workpiece surface are protected by shielding gas such as argon (Ar), Helium (Hi) and CO_2. Yangfan et al considered the effect of welding speed on the properties of manufactured specimens [20].

The average microhardness of the specimens slightly enhanced by increased in torch travel speed. The travel speed of the torch is directly proportional to the microhardness. Cold Metal Transfer (CMT) is an advanced process of Metal Inert Gas Welding (MIG) [21].

The welding of dissimilar metals such as aluminium and steel gives the best results that have been possible with CMT welding [22]. It producing minimum defect and different metals with low heat input and low dilution [23]. The schematic representation of the GMAW process shown in Fig. 2. Kirchgaßner et al Evaluated wear resistance of the different Fe-based hardfacing alloys [24]. The hardness value is depending on the grain size and grain structure are essential for wear.

2.5 Submerged Arc Welding (SAW)

Submerged is a welding procedure wherein the area between the electrode and the workpiece shielded by a granular flux material. During welding granular flux is protected the weld pool contaminants from the atmosphere. SAW is known as high current welding process that is mostly used for joining thick plate. It is the most commonly used welding process because of its simplicity and high deposition productivity [25] chromium carbide overlay (CCO. It is an effective hardfacing method for welding on worn metal surfaces with repeated depositions [26].

Kahraman Studied the effect of adding a carbon, manganese, and chromium in the welding wire and find that the wear resistance properties improved [5]. Zahiri et al Investigated the amount of heat input, do effect on the microstructure [27]. Sadeghi et al Considered the effect of microhardness and properties of hardfacing coatings produced using SAW [17]. The results show that hypereutectic performed better than the hypo-eutectic. Karaoğlu and Seçgin Investigated the effect of input parameters such as welding current, welding voltage and welding speed on output parameters like Bead width, height and penetration of the weld bead [28]. These inputs parameters play an important role in the quality of weld bead geometry.

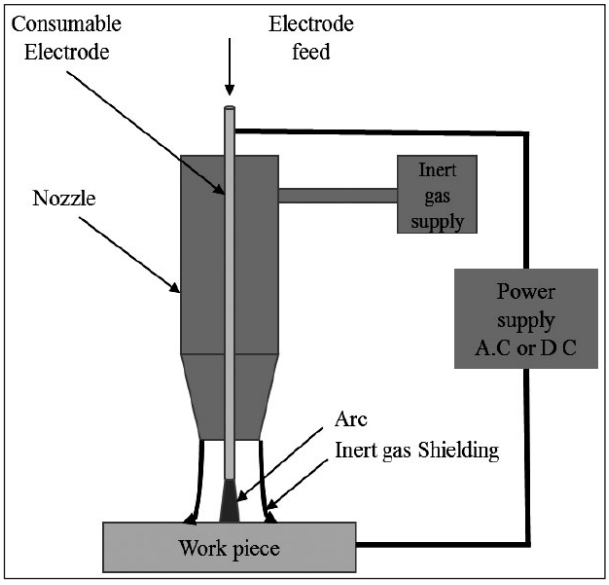

Fig. 2. Schematic representation of the GMAW.

2.6 Shielded Metal Arc Welding (SMAW)

This process is commonly used for welding of the metal which is comparatively less sensitive to the atmospheric gasses. Wang et al Examined the outcome of the deposition of wear resistance materials by SMAW using hardfacing alloys possess higher hardness value and wear resistance are observed [29]. Yang et al Investigated that the carbide precipitation of the Fe-Cr13-C-Nb hardfacing alloy was determined by Ti addition showed the better wear resistance [30].

Xu et al., Examined the effect of hardfacing alloy on microstructure and wear properties, the hardness increases rapidly with boron content increases up to 1% by weight [31]. Buchely et al considered the various hardfacing electrodes and their effect on the microstructure [32]. The results show that the wear resistance of the material is determined by the size, shape, distribution and chemical composition of the carbides, as well as by the matrix microstructure. Liu et al studied the consequence of hard-faced material content on microstructure and wear properties of the substrate and find that boron enhances the wear resistance properties of the substrate [33]. Singla et al Investigated the effect of adding rare earth (RE) iron-based hardfacing alloys and observed the consequence of wear properties and the result shows it exhibited an improvement in microhardness [34].

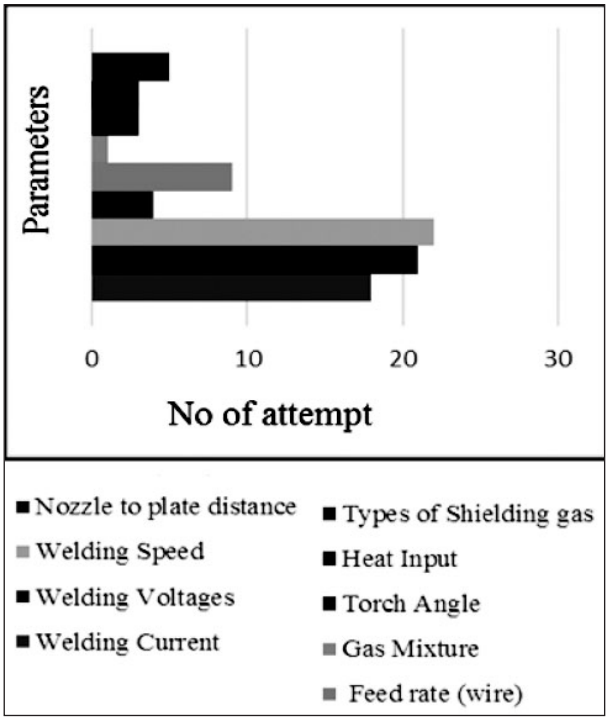

Fig. 3. The contribution of various parameters used in hardfacing process.

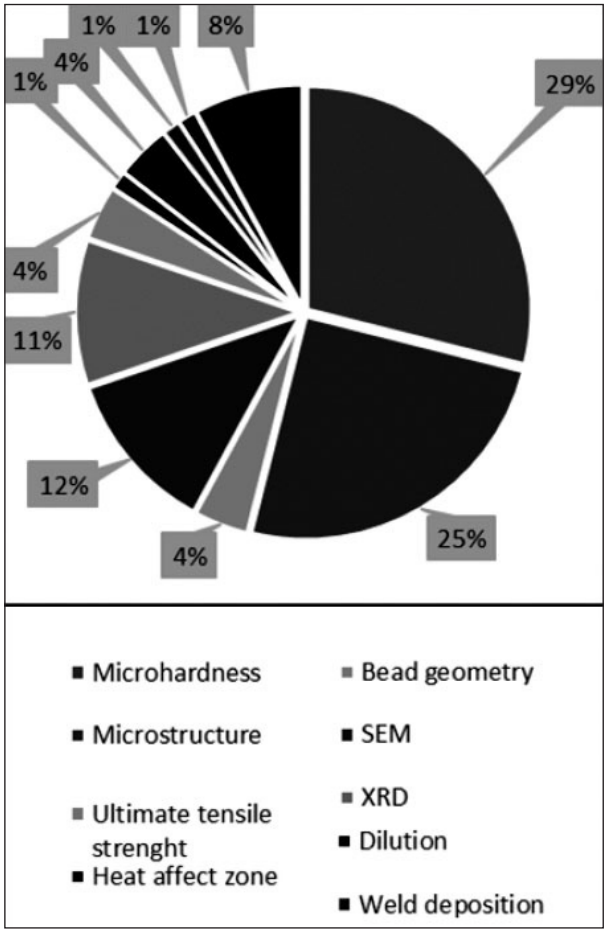

Fig. 4. Response obtained from hardfacing process.

3. Discussion

The literature survey was supported out in the field of hardfacing techniques of the arc welding process and based on the following results is made. This chapter mainly focuses on the effect of inputs parameters on the microhardness and microstructure. From the above literature, it is clear that the GMAW process is repeatedly used by most of the researchers.

3.1 Process parameter

The hardfacing by arc welding process has a countable number of parameters as mention in the abstract. All the parameters are studied by the researcher, some parameters are repeatedly chosen concerning the expected output.

The graph is drawn for the parameters with the relation to their attempt made by researchers. Fig. 3 shown the relation between the no of parameters and their attempts. welding speed, welding voltages, and welding current are repeatedly selected. Because controlling these parameters is very easy in the arc welding process. These parameters also control the dilution which is very important for hardfacing of the equipment.

3.2 Response studies

The outcomes studied by various researchers are shown in Fig. 4. Most of the literature indicates that the microhardness and microstructure of the specimen being studied. Because finding the hardness value and bead geometry is basic forhard-faced samples. In future researchers can move towards new goals.

4. Conclusion

In this paper, various hardfacing techniques used by an arc welding process is discussed. Form the relationship between input parameters and outcomes. Following conclusions are made;

- The widely used hardfacing techniques for coating process so GMAW are identified through the literature. The contributions of each process parameters are identified. The graph shown in Fig. 3 indicates that welding speed, voltages, and currents are the most predominant parameters.
- The output studied is shown in Fig. 4 by

most of the researchers are microhardness and microstructure. The other outcomes like corrosion, fatigue analysis, and the effect of HAZ studies are needed more attention.

In future studying, the fatigue analysis will be giving some interesting outcomes. The new hardfacing techniques may also give better results.

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References

1. Olson, D. L., Anon & Siewert, T.A. (Ed.). (1993). *ASM International, Volume 6: Welding, Brazing and Soldering.* ASM International.
2. Cao, H., Dong, X., Chen, S., Dutka, M. & Pei, Y. (2017) Microstructure evolutions of graded high-vanadium tool steel composite coating in-situ fabricated via atmospheric plasma beam alloying. *Journal of Alloys and Compounds.* 720, 169–181.
3. Lin, C., Chang, C., Chen, J., Hsieh, C., & Wu, W. (2010). Surface & coatings technology microstructure and wear characteristics of high-carbon Cr-based alloy claddings formed by gas tungsten arc welding (GTAW). *Surface and Coating Technologies.*205 (7), 2590–2595.
4. Mendez, Patricio & Barnes, Nairn & Bell, Kurtis & Borle, Steven & Gajapathi, Satya & Guest, Stuart & Izadi, Hossein & Kamyabi-Gol, Ata & Wood, Gentry. (2014). Welding processes for wear resistant overlays. *Journal of Manufacturing Processes*. 16 (1), 4–25. 10.1016/j.jmapro.2013.06.011.
5. Gülenç, B., & Kahraman, N. (2003). Wear behaviour of bulldozer rollers welded using a submerged arc welding process. *Materials & Design*. 24(7), 537-542.
6. Sitthipong, Siva., Towatana, P., Sitticharoenchai, A., & Meengam, C. (2017). Abrasive wear behavior of surface hardfacing on propeller shaftsAISI 4140Alloy steel. *Materials Today: Proceedings.* 4(2), 1492-1499. 10.1016/j.matpr.2017.01.171.
7. Dutra, Jair., Silva, Régis., Marques, Cleber & Viviani, Alberto. (2016). A new approach for MIG/MAG cladding with Inconel 625. *Welding in the World*. 60, 1201-1209. 10.1007/s40194-016-0371-3.
8. Govindasamy, Sayiram & N, Arivazhagan. (2015). Microstructural characterization of dissimilar welds between Incoloy 800H and 321 Austenitic Stainless Steel. *Materials Characterization*. 102, 180-188. 10.1016/j.matchar.2015.03.006.
9. Ye, Xin., Zhang, Peilei., Zhao, Jian & Ma, Pan. (2018). Effect of macro- and micro-segregation on hot cracking of Inconel 718 superalloy argon-arc multilayer cladding. *Journal of Materials Processing* Technology. 258, 251-258. 10.1016/j.jmatprotec.2018.04.004.
10. Kaishu, Guan., Xiaodong, Xu., Hong, Xu., & Zhiwen, Wang. (2005). Effect of aging at 700 deg. C on precipitation and toughness of AISI 321 and AISI 347 austenitic stainless steel welds. *Nuclear Engineering and Design.* 235(23), 2485-2494.
11. Hong, J.K., Park, J. H., Park, N. K ., Eom, I.S., Kim, M.B. & Kang, C.Y. (2008). Microstructures and mechanical properties of Inconel 718 welds by CO2 laser welding. J*ournal of Materials Processing Technology*. 201(1-3), 515-520. 10.1016/j.jmatprotec.2007.11.224.
12. Shepeleva, L. & Medres, B. & Kaplan, Wayne & Weisheit, A. (2000). Laser cladding of turbine blades. *Surface and Coatings Technology.* 125(1-3), 45-48. 10.1016/S0257-8972(99)00603-9.
13. Kesavan, D.& Kamaraj, M. (2010). The microstructure and high temperature wear performance of a nickel base hardfaced coating. *Surface and Coatings Technology.*204(24), 4034–4043
14. Hou, Q.Y. (2013). Influence of molybdenum on the microstructure and properties of a FeCrBSi alloy coating deposited by plasma transferred arc hardfacing. *Surface and Coatings Technology* **.** 225**,** 11–20.
15. Balasubramanian, V., Varahamoorthy, R., Ramachandran, C. S., & Babu, S. (2008). Abrasive slurry wear behavior of stainless

steel surface produced by plasma transferred arc hardfacing process. *Surface and Coatings Technology.* 202 (16) 3903–3912

16. Sharifitabar, Mahmood & Khaki, J. & Haddad Sabzevar, Mohsen. (2015). Microstructure and wear resistance of in-situ TiC–Al2O3 particles reinforced Fe-based coatings produced by gas tungsten arc cladding. *Surface and Coatings Technology*. 285, 47-56. 10.1016/j. surfcoat.2015.11.019.
17. Sadeghi, F., Naja, H., & Abbasi, A. (2017). The effect of Ta substitution for Nb on the microstructure and wear resistance of an Fe-Cr-C hardfacing alloy. *Surface & Coatings Technology*. 324, 85–91.
18. Abed, H., Ghaini F. M., & Shahverdi, H. R. (2018). Characterization of Fe49Cr18Mo7B16C4Nb6 high-entropy hardfacing layers produced by gas tungsten arc welding (GTAW) process. *Surface & Coatings Technology. 352, 360-369.*
19. Chang, C., Chen, Y., & Wu, W. (2010) Microstructural and abrasive characteristics of high carbon Fe – Cr – C hardfacing alloy. *Tribiology International.* 43(5-6) 929–934.
20. Yangfan, W., Xizhang, C., & Chuanchu, S. (2019). Microstructure and mechanical properties of Inconel 625 fabricated by wire-arc additive manufacturing. *Surface & Coatings Technologies.*374 116–123.
21. Varghese, P., Vetrivendan, E., Dash M. K., Ningshen, S., Kamaraj, M., & Kamachi Mudali, U. (2019). Weld overlay coating of Inconel 617 M on type 316 L stainless steel by cold metal transfer process. *Surface & Coatings Technologies.*357 1004–1013
22. Selvi, S., Vishvaksenan, A., & Rajasekar, E. (2018). Cold metal transfer (CMT) technology - An overview. *Defence Technology.*14(1), 28–44.
23. Hu, S., Zhang, H., Wang, Z., Liang, Y., & Liu, Y. (2016). The arc characteristics of cold metal transfer welding with AZ31 magnesium alloy wire*. Journal of Manufacturing Processes.* 24(1). 298–306.
24. Kirchgaßner, M., Badisch, E., & Franek, F. (2008). Behaviour of iron-based hardfacing alloys under abrasion and impact. *Wear.* 265(5-6), 772–779.
25. Carvalho, M.C., Wang, Y., Souza, J. A. S., Braga, E. M., & Li, L. (2016). Characterization of phases and defects in chromium carbide overlays deposited by SAW process. *Engineering Failure Analysis.* 60, 374–382.
26. Tarng, Y. S., Juang, S. C., & Chang, C. H. (2002). The use of grey-based Taguchi methods to determine submerged arc welding process parameters in hardfacing *Journal of Materials Processing. Technology.*128(1–3), 1-6.
27. Zahiri, R., Sundaramoorthy, R., Lysz, P. & Subramanian, C. (2014). Surface & Coatings Technology Hardfacing using ferro-alloy powder mixtures by submerged arc welding *Surface & Coating Technology.*260, 220–229
28. Karaoğlu, S., & Seçgin, A. (2008). Sensitivity analysis of submerged arc welding process parameters. *Journal of Materials Processing. Technology.*202(1-3), 500–507.
29. Wang, X., Han, F., Liu, X., Qu, S., & Zou, Z. (2008). Microstructure and wear properties of the Fe-Ti-V-Mo-C hardfacing alloy. *Wear.* 265(5-6) 583–589.
30. Yang, K., Gao,Y., Yang, K., Bao, Y., & Jiang, Y. (2017). Microstructure and wear resistance of Fe-Cr13-C-Nb hardfacing alloy with Ti addition. *Wear.* 376–377(B), 1091–1096.
31. Xu, G., Kutsuna, M., Liu, Z., & Zhang, H. (2006) Characteristics of Ni-based coating layer formed by laser and plasma cladding processes. *Materials Science & Engineering: A*. 417(1-2), 63–72.
32. Buchely, M. F., Gutierrez, J. C., León, L.M. & Toro, A. (2005). The effect of microstructure on abrasive wear of hardfacing alloys . *Wear.* 259(1-6), 52–61.
33. Liu, D., Liu, R., Wei, Y., Ma, Y., & Zhu, K. (2013). Applied Surface Science Microstructure and wear properties of Fe – 15Cr – 2 . 5Ti – 2C – x B wt .% hardfacing alloys. *Applied Surface Sciences.* 271, 253–259.
34. Singla Y K, Arora N and Dwivedi D K 2017 crossmark 105, 229–40

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