Journal of Manufacturing Engineering, December, 2017, Vol. 12, Issue. 4, pp 208-213

EFFECT OF ARC CURRENT ON MICROSTRUCTURAL CHARACTERISTICS OF PLASMA TRANSFERRED ARC HARDFACED NICKEL ALLOY

***Gnanasekaran S[1], Padmanaban G[2], Balasubramanian V[3], Hamenth Kumar[4] and Shaju K Albert[5]**

[1]Research Scholar, [2]Assistant Professor, [3]Professor, Centre for Materials Joining & Research (CEMAJOR)
Department of Manufacturing Engineering, Annamalai University, Annamalainagar- 608002, Tamil Nadu
[4]Scientific officer –E, [5]Head, Material Technology Division, Indira Gandhi Center for Atomic Research (IGCAR)
Kalpakam-603102.

ABSTRACT

In this investigation, plasma transferred arc (PTA) hardfacing was done on AISI 316 LN austenitic stainless steel (ASS) plates using Nickel base alloy (Colmonoy 5 powder). ASS plate was preheated at 400^0C to avoid cracking. After hardfacing the samples are immersed in the vermiculite powder to confirm the moderate cooling and avoiding crack. The arc current was varied between 120A to 150A and other parameters such as, traverse speed, powder feed rate, standoff distance, torch oscillation width were kept constant. From this investigation, it is found that the microstructure of the PTA hardfaced deposit overwhelmingly comprises of the γ-Ni phase and the interdendritic eutectic mixture comprised of γ-nickel and nickel-rich borides. These investigation also exposed the presence of chromium-rich carbides and borides in a γ-Nickel matrix. Ni-based deposits showed superior hardness compared to the substrate.

Keywords: *Austenitic stainless steel, Plasma transferred arc hardfacing and Microstructure.*

1. Introduction

Atomic industry, numerous basic parts inside the reactor are under contact sliding, it reduces life time of the components. This parts should be hardfaced to beat distinctive sorts of wear like galling, sliding wear. Indian prototype fast breeder reactor (PFBR), type 316LN ASS has been picked as the basic material for segments working over 673 K. The fluid sodium coolant acts as a decreasing specialist and removes the defensive oxide film show on the ASS surface of the in-sodium parts. A large number of these parts would be in contact with each other or would have relative movement during operation, and their presentation at high working temperatures (normally 823 K) combined with high contact stresses causes the self-welding of the spotless metallic mating surfaces. Also, the relative development of the mating surfaces could prompt galling, a type of high-temperature wear, in which material exchange happens starting with one mating surface then onto the next because of rehashed self-welding and breaking at the contact points of the mating surfaces. Further increase in temperature increases the intensity of self welding [1].

Hardfacing of the matting of coupled surfaces has been broadly utilized in components of water-cooled and liquid-sodium cooled fast breeder reactors to escape from self-welding and galling [2,3]. It is notable that ASS have poor wear characteristics during sliding. Their wear rates are regularly high and they show a checked propensity to endure serious harm by galling and seizing [4]. To stay away from the issue of alloying, which is an outrageous type of adhesive wear, hardfacing techniques are generally utilized for mating and coupled surfaces. The determination of hardfaced material for nuclear-powered applications should address the issue of induced activity, notwithstanding the high-temperature wear resistance properties. Cobalt-base Stellite-6 and Stellite-12 alloys, which have magnificent imperviousness to wear at higher temperature and corrosion, are broadly utilized for hardfacing of nuclear power plant components, particularly in surfacing of valves. Notwithstanding, the utilization of cobalt-base alloys indications to induced action from the transformed Co^{60} isotope forms in the nuclear-powered reactor environment [5]. Keeping in mind the end goal to stay away from this trouble, without cobalt hardfacing alloys are being created and introduced. Ni-based hardfacing alloys have turned out to be progressively prevalent as of late inferable from their out standing enactment under

**Corresponding Author - E- mail: gnanasekaran1947@gmail.com*

environments of corrosion, abrasion and elevated temperature.

The microstructure of Ni-based hardfacing alloy deposits has been contemplated utilizing different alloy compositions and different substrates. In general, the structure consists of γ-Ni solid solution dendrites and interdendritic eutectics comprised of γ -Ni + Ni borides and silicide [6]. Furthermore, chromium borides and carbides and other phases dependent on composition have also been observed as distributions in the eutectics [7–8]. Su and Chen studied the effect of alloy composition on microstructure. They found niobium and molybdenum to be favorable by forming the particular carbides that reduce the coefficient of friction [9]. The hardfacing can be deposited through various welding processes. Plasma transferred arc (PTA) weld method is a recognized surfacing process to deposit nickel hardfacing alloys over stainless steel substrate with lowest dilution[10]. PTA process is favored on many events because of its better process control, convenience, high deposition rate and lower heat input. It attains smooth and thin deposits of hardfacing through the controlled powder feed rate. The resulting hardfacing are of outstanding wear, corrosion resistant and high temperature properties with excellent metallurgical bonding [11]. In this investigation, effect of arc current on microstructural and microhardness characteristics of nickel-based hardfacing alloy (corresponding to colmonoy-5) deposited on 316 LN substrate was analysed.

2. Experimental Work

2.1 Substrate (Base metal) and hardfaced powder (colmonoy-5) properties.

The 316 LN stainless steel substrate was used in this investigation.ASS is nuclear grade stainless steel extensively used in valves, valve cones, spindles etc. and it is a fine grain structural steel. The substrate metal chemical composition was obtained using a vacuum spectrometer. The substrate and powder, chemical composition is presented in Table 1 and 2. Rolled plates of 12 mm thickness was used as the substrate material. The substrate was preheated to 400 ^{o}C to release the internal stresses and also to moderate the cooling rate to escape the formation of cracks after deposit. The average deposited thickness was about 3-4 mm on the stainless steel. An automatic PTA hardfacing system has been engaged to conduct the experiments. The experiments were accompanied by forming a single layer with the electrode negative (DCEN). Pure argon (99.9%) gas has been used as a shielding and powder feeding gas.

PTA hardfacing process parameters used to carry out hardfacing are presented in Table 3. The deposits were fabricated using four different levels of main arc current. The other parameters such as, Traverse speed, powder feed rate, torch oscillation width, standoff distance were kept constant. The photographs of hardfaced samples are displayed in Fig. 1. After hardfacing, deposit was cut into small samples for the metallography study. A Vickers microhardness testing machine was used for quantifying the hardness across the hardfaced deposit cross section with load of 0.05 kg and dwell time of 15 s. The deposit for metallographic examination were sectioned to the required size and then polished using different grades of emery papers. A standard reagent made of 0.25 g picric acid, 20 ml ethanol and 1.25 ml HCL was used to reveal the microstructure of the specimens. Microstructural analysis was carried out using a light optical microscope (OM) incorporated with an image analyzing software (Metal Vision).

Table 1 Chemical composition wt% of 316LN

C	Ni	Cr	Mo	Si	Mn	Fe
0.020	12.55	17.27	2.35	0.29	1.69	**Bal**

Table 2 Chemical composition of hardfaced powder

C	Fe	Cr	Si	B	O	Ni
0.41	3.10	10.44	4.02	2.26	0.03	**Bal**

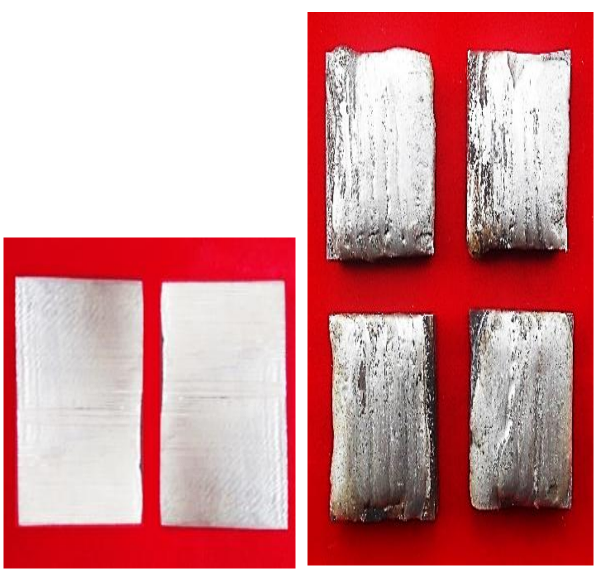
Table 3 PTA process parameters used for hardfacing

S.No	Main parameters	values
1	Main arc current (Amps)	120, 130, 140, 150
2	Traverse speed (mm/min)	160
3	Powder feed rate (grams/min)	35
4	Torch oscillation width (mm)	10
5	Preheating temperature (^{o}C)	400

2.2 Dilution

Normally, for hardfacing and cladding applications the welding process are used, in that which produces minimum dilution is preferred. Dilution is defined as the percentage of substrate in deposit. If the dilution is higher, then the percentage of substrate metal in the deposit will be higher. Hardfacing is primarily done to enhance the surface properties of substrate and hardfacing materials normally shows better wear, corrosion and oxidation resistance compared to substrate. At higher dilution, the surface properties are not enhanced to the estimated level because of the existence of higher amount of substrate material. In this section, an experimental examination has been carried out to compare the dilution level of different power level. After hardfacing, the specimens have been extracted by sectioning at the middle of the deposit. Metallographic procedures have been followed to polish the specimen surface and specimens were etched using 2% nital. Bead profile and bead geometries as shown in Fig. 2 it has been visualized and recorded using the scanner at high resolution. Dilution has been calculated using the following expression [4]. Percentage of dilution in different power levels presented in Table 4.

Percentage of Dilution = $\frac{B}{A+B} x100$ %



(a) Before hardfacing and (b) After hardfacing

Fig. 1 Photograph of hardfaced specimens

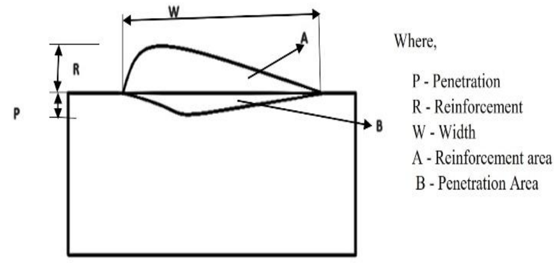


Fig. 2 Bead profile and bead geometries.

3. Results and Discussion

The macrostructure of the hardfaced deposits are shown in the Fig. 3. At higher transferred arc current, the heat generation is higher and additional heat to melt the substrate material after melting the powder. Further, the higher heat generation increases the arc forces and subsequently increases the penetration depth in the substrate material (Ref Fig. 3 Exp. No.4). Deeper penetration will generally lead to higher percentage of dilution and this may be the reason for the increase in percentage of dilution when transferred arc current is increases (Ref table. 4). At lower arc current, the heat generation is inferior and most of the heat is used to melt the powder and less heat is available to melt the substrate material after melting powder.

Expt No	Arc current	Macro structure
1	120	 2.5 mm
2	130	 2.5 mm
3	140	 2.5 mm
4	150	 2.5 mm

Fig. 3 Optical macrographs of cross-section of PTA deposit.

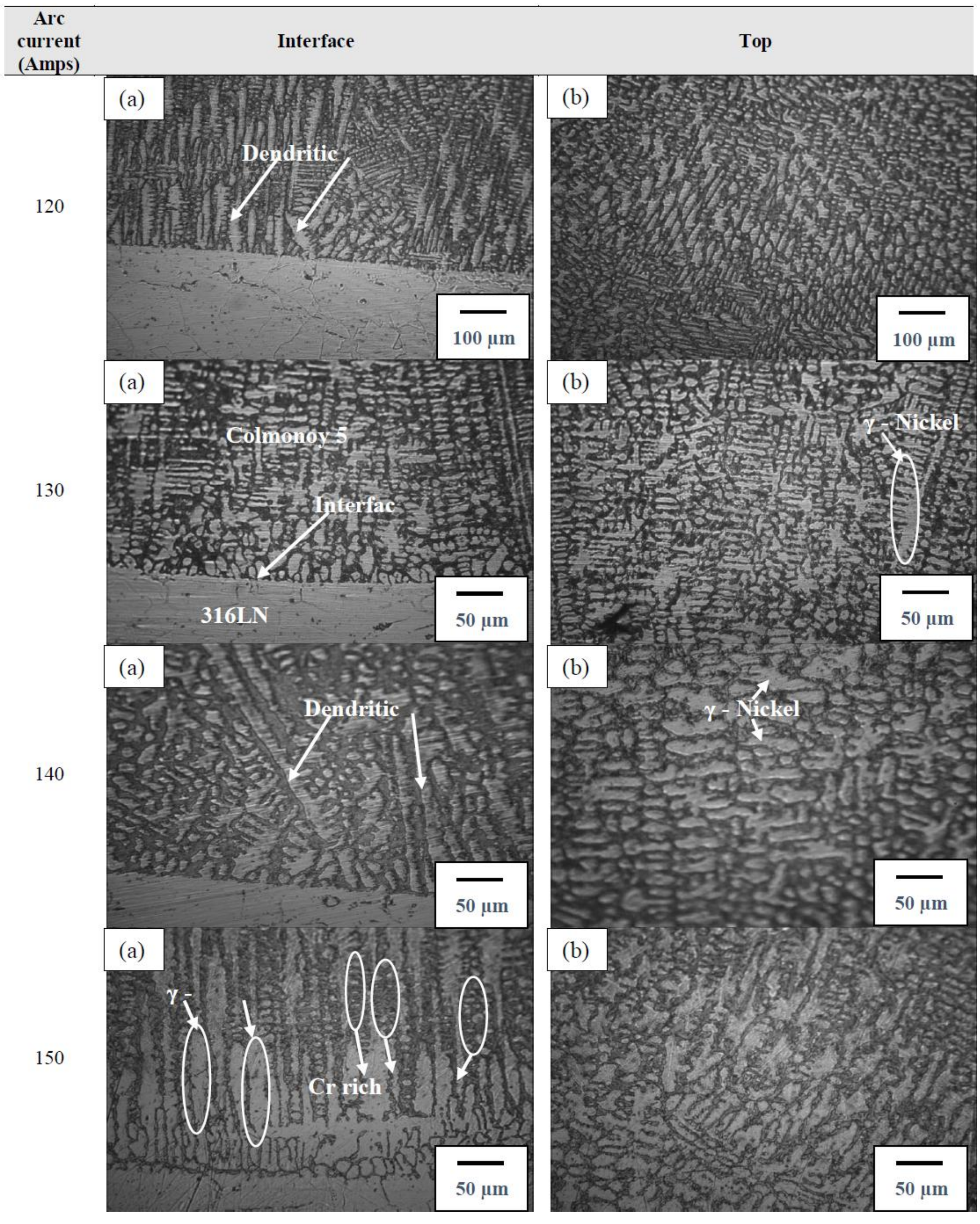


Fig. 4 Optical micrographs (a) hardfaced deposit (b) Interface.

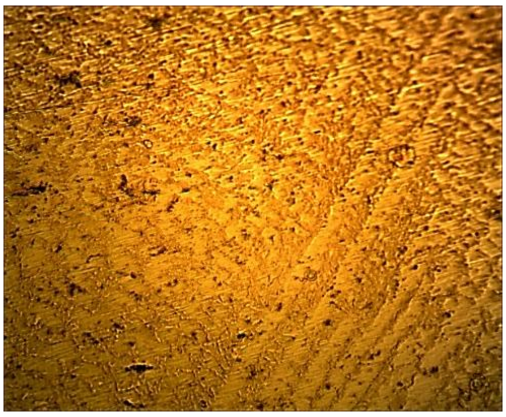


Fig. 5 Optical micrographs of carbides

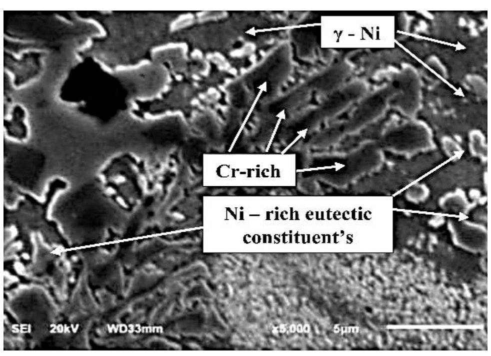


Fig. 6 Scanning electron micrograph - Cr-rich precipitates.

Moreover, the arc force is also less in this condition and subsequently there is a decrease in depth of penetration and produces shallow penetration. The cross-section of the hardfaced deposits with etching as shown in Fig. 4 (1a) indicates that there is a good adherence of the deposit to the substrate without any defects. At higher magnification, dendritic growth of the γ-nickel was observed almost perpendicular to the interface of the deposits (Fig.4-1b). Microstructure of the deposits consists of dendrites of γ-nickel with interdendritic carbide precipitates. The microstructure of the deposit at near interface is somewhat different from the top of the deposit. The volume fraction of the chromium rich precipitates is very low near the interface (Fig.4-4b), whereas the volume fraction of these precipitates increases with increasing distance from the interface. Murakami's reagent used at between 80 and 100 ^{0}C to reveal the carbides in austenitic grain boundary. Fig.5 shows the carbide precipitates reveled in the hardfaced region.

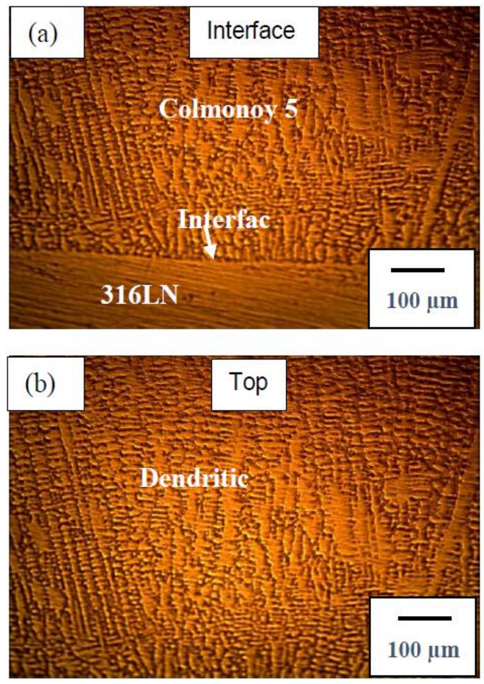
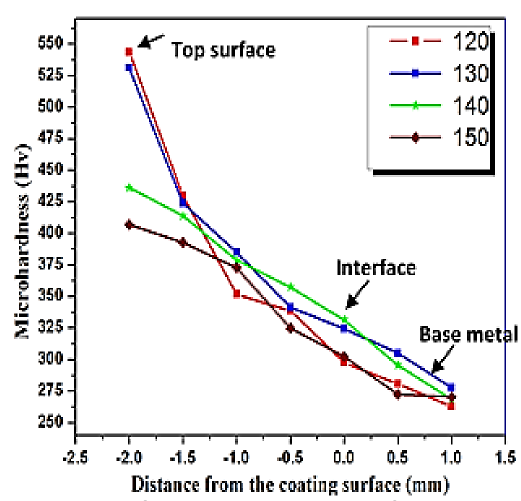


Fig. 7 Optical micrographs without etching (a)



hardfaced deposit (b) interface

Fig. 8 Microhardness survey

Scanning electron micrograph (SEM) image (shown in Fig. 6) consists of dendrites of the γ-nickel solid solution phase and the eutectic mixture as interdendritic constituents. The interdendritic eutectic mixture is comprised of γ -nickel and nickel-rich borides.

The precipitate phases also be noticeably seen in the light micrographs in unetched condition (shown in Fig.7). The chromium-rich precipitates indicated by arrows in Fig.. 6. The hardness profile across the deposit, interface and substrate is shown in Fig. 8. Average hardness of the deposit is around 485 HV, which is maintained down to a distance of 1 mm from the interface. Average base metal harness is around 230HV. An average of 2-fold increase in the hardness of the PTA hardfaced nickel deposit was observed when compared to the substrate. The improved hardness of the deposits is attributed to the existence of uniformly distributed mixture of complex carbides, and borides precipitates.

4. Conclusions

- Nickel based Colmonoy 5 powder was effectively deposited using the PTA process on austenitic stainless steel substrate up to a thickness of 4 mm.
- It is found that the arc current is having directly proportional relationship with dilution. If the arc current increases the dilution is also increasing. This is mainly due to increase in heat input to melt the powder and base metal.
- An average of 2-fold increase in the hardness on the deposit was observed compared to the substrate. The higher hardness of the deposits is attributed to the existence of homogeneously distributed mixture of complex carbides precipitates.
- The predominant microstructural constituent is the γ -Ni solid solution phase as dendrite in the deposit. The interdendritic constituent consists of γ -Ni and other phases among which current study has been identified as to be Ni-rich borides. The microstructure also reveals the presence of a large number of precipitate particles including chromium-rich carbides.

Acknowledgments

The authors are thankful to UGC-DAE consortium for providing financial assistance to carry out this investigation (Project No. CSR-KN/CRS-56/2013-14/656 dated 04.09.13). Authors wish to express their sincere thanks to M/s. Omplas systems, Chennai, provide PTA hardfacing facility. Authors also express their sincere thanks to The Director, IGCAR, Kalpakkam for the base metal supply.

References

1. *Yoshida E, Hirakawa Y, Kano S and I Nihei (1988), "In-sodium tribological study on cobalt–free hard facing materials for contact and sliding parts of FBR components, Proc. Conf. on Liquid Metal Technology Avignon, Societe Francaised' Energie Atomique Paris, Vol. 502, 1–10.*

2. *Douty R A, Schwartzbart H (1972), "Surfacing of 304 stainless steel for liquid sodium service" Weld. J., Vol. 51, 406s-416s.*

3. *Lemaire E and Le Calvar M (2001), "Evidence of tribocorrosion wear in pressurized water reactors", Wear, Volume 249 (5–6), 338–344.*

4. *Hsu K L, Ahn T M (1980), "Friction, wear and microstructure of unlubricated austenitic stainless steels", Wear, Vol. 60, 13–37.*

5. *Persson D H E, Jacobsen S and Hogmark S (2003), "Effect of temperature on friction and galling of laser processed Norem 02 and Stellite 21, 14th int. conf. on Wear of Materials, Volume 255 (1-6), 498-503.*

6. *Ming Q, Lim L C and Chen Z D (1998), "Laser cladding of nickel-based hardfacing alloys", Surface and Coatings Technology, Vol. 106, 174–182.*

7. *Lim L C, Ming Q and Chen Z D (1998), "Microstructures of laser-clad nickel-based hardfacing alloys", Surface and Coatings Technology, Vol. 106, 183–192.*

8. *Haemers T A M, Rickerby D G, Lanza F, Geiger F, Mittmeijer E J (2000), "Hardfacing of stainless steel with laser melted colmonoy", Journal of Materials Science, Vol. 35, 5691–5698.*

9. *Su Y L, Chen K Y and Su (1997), "Effect of Alloy Additions on Wear Resistance of Nickel in Pulsed GMAW", Welding Journal, Vol. 76, 143s-150s.*

10. *Kesavan D, Kamaraj M (2010), "The microstructure and high temperature wear performance of a nickel base hardfaced coating", Surface & Coatings Technology, Vol. 204, 4034–4043.*

11. *Siva K, Murugan N (2013), "A Study on the Influence of PTAW Process Parameters on Pitting Corrosion Resistance of Nickel Based Overlays", Procedia Engineering, Vol. 64, 1147 – 1156.*

