Experimental Investigation of SS Buffer Layer on Carbon Steel for Stellite-6 Hard-facing

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Received: 25th May, 2026; **Revised:** 6th June, 2026; **Accepted:** 8th June, 2026; **Available Online:** 20th June, 2026

ABSTRACT
Hardfacing is the process of deposition of a thin layer of hard and wear-resistant materials on a surface of a worn or new component that is subjected to wear, impact, high pressure, high temperature and oxidation. It is also used to repair the worn-out part of a component, thereby enhancing its resilience and operating life. Valves are devices that stop, control, or regulate fluid flow. The seating surface of the valve seat ring and closure elements like disc or wedge are critical components of the valve, which are subjected to extremely very high pressure and temperature during its operating cycle. To withstand the specific operational conditions of high temperature and pressure of the steam, the seating surfaces are hard-faced with an enhanced procedure to improve the surface properties of a component or part to abrasion, impact, corrosion, and heat. The hard-facing process has certain inherent anomalies that lead to increased failure and high-cost factors. To overcome the problems associated with hard-facing, a SS Buffer layer is introduced into the seating surfaces of valve seat ring and the closure element. Buffer layers, which are intermediate metal deposits between the base material to be hardfaced and actual hard-facing weld material. The seating surfaces were modified, manufactured, and tested by studying the microstructure of the Heat-Affected Zone (HAZ) and weld deposits and their hardness. The HAZ is an area of the base material that has not melted completely, but its mechanical properties and microstructure are transformed by the intense heat of the welding process. A small and narrow HAZ is formed by depositing the buffer layer between the base metal and hard-facing material when compared with the direct deposition of the hard-facing material on the base metal. This also resulted in an improved and finer grain structure. The microstructure and hardness results were compared.
Keywords: Buffer, Cladding, E309, Hard-facing, Stellite-6.
How to cite this article: Singh RP, Ramaiyan TS, Mahendran S. Experimental Investigation of SS Buffer Layer on Carbon Steel for Stellite-6 Hard-facing. Int J Drug Deliv Technol. 2026;16(62s): 540-548. DOI: 10.25258/ijddt.16.62s.61
Source of support: Nil.
Conflict of interest: None.

INTRODUCTION

In power plants, valves play an important role in controlling the flow of fluids (Steam, Water, Flue gases, Slurry, Fuel, etc.) through pipes. Depending on the system requirements and design parameters, different types of valves are installed to stop or control the fluid flow. There have been instances of valve failure and fluid leakage through the valve, either due to gland packing failure or fluid passing through the closure element. The operation of power plant systems is affected by valve failure, which ultimately results in huge financial losses.

Stellite alloys (a trade name of Kennametal) are used as corrosion, wear, and temperature-resistant surface coatings on automotive valve seating surfaces, tools, gun barrels and steam turbine valve seating surfaces [1]. In recent years, the protection of the structural and expensive materials of various components, such as motor drives, cranes, crushers, bearing components, brakes, bushes, valves, and pipeline assemblies, against wear has become essential. Hence, metallurgical and mechanical engineers have conducted extensive research on wear and oxidation. Therefore, future research priorities in tribological studies are quite evident and a prominent topic in a large number.

Valves installed in power plants are critical components of power plants. The valve can be a Gate Valve, Globe Valve, Regulating Globe Valve, Safety Valve, Non-return Valve and Control Valve. Typically, all valves have a welded seat ring and closure elements such as discs, wedges and gates. As power plants operate at high pressure and high temperature, the valves are generally subjected to a temperature range of 540–600 °C (1000–1112 °F) [2]. The fluid flowing through the valves should be controlled under all conditions and at all times throughout the entire life of the power plant. To ensure the long life of these various types of valves with respect to the varying operating conditions of the power plant. The valve seating surfaces of the seat rings and closure elements should be wear- and corrosion-resistant.

For a valve with a bonnet, the closure element forms the pressure boundary, which is subjected to high pressure. When the closure element comes in contact with the seat ring, it seals off the fluid flow. The seating surfaces are a critical component of the valve, and they are hard-faced with stellite-6 to improve their wear and corrosion resistance properties. However, the direct hard-facing of the seating surfaces of the base metal results in surface defects and crack propagation, which leads to failure of the seating surface. These failures are either in terms of fluid passing through the valve or fluid passing through the gland packing. Valve leakage or passing leads to power plant shutdown and high financial losses.

Further comparative investigations have been carried out on the microstructures and corrosion properties of hardfacing cobalt based alloys by different methods [4], in which the study applies three different welding methods, namely tungsten inert gas (TIG) welding, laser welding, and plasma arc welding, were used to perform cobalt alloy surfacing on austenitic stainless-steel substrates, and their microstructure and corrosion properties were compared. The results obtained using all three methods exhibited excellent metallurgical bonding between the austenitic stainless-steel substrate and cobalt alloy surfacing layer, with no observed defects such as cracks, pores, or inclusions. This study offers valuable insights into the selection of cobalt alloy surfacing welding methods on austenitic stainless-steel substrates and the evaluation of the corrosion properties of the cobalt alloy surfacing layer, providing essential guidance for engineering practices in power plant valves.

The Impact Wear Resistance of Stellite 6 Hard-faced Valve Seats with Laser Cladding was investigated, and the results exhibited superior impact wear resistance of the valve seat [5]. A cobalt-based alloy, Stellite 6, was deposited on the seat face using a laser cladding process. For comparison with conventional hard-facing techniques, a plasma transferred arc (PTA) method was selected for parallel experiments in this study. The laser-cladded layers, which consisted of refined solidification structures, were characterized by increased hardness and impact toughness compared to the PTA overlays. The laser-cladded valve seats displayed improved impact wear resistance, that is, resistance to impact cracking at higher loads, when compared with the PTA-cladded valve seats. Additionally, the PTA-cladded specimen exhibited the microcracks along the interface of eutectics and carbides, but the laser-cladded specimen had lesser extent of microcracks.

The refined solidification microstructure produced by laser cladding led to significant improvements in hardness and impact toughness compared with PTA-deposited overlays. As a result, the laser-cladded valve seats exhibited superior resistance to impact wear, particularly against impact-induced cracking under severe loading conditions. In addition, microstructural examination revealed fewer microcracks along the eutectic–carbide interfaces in the laser-cladded specimens, whereas the PTA-cladded specimens showed a higher propensity for interfacial microcrack formation. However, the cost implications have affected the use of Laser Cladding over the PTA.

In a study, E309-16L stainless steel was deposited as a buffer layer on Grade 91 (9Cr–1Mo) alloy steel using various process such as SMAW (shielded metal arc welding), GTAW (gas tungsten arc welding), and FCAW (flux-cored arc welding). Later, Stellite 6 (Co–Cr alloy) coatings were applied over the E309-16L buffer layer through either SMAW, GTAW or PTAW (plasma transferred arc welding) processes. The deposited Stellite 6 coatings were then assessed in terms of their microstructural characteristics by means of optical microscopy and optical emission spectroscopy (OES) and mechanical characteristics by means of Vickers hardness testing, The flux-cored arc weld deposit has a narrow heat-affected zone and improved and uniform hardness than the SMAW and GTAW deposits. The stainless-steel (E309-16L) buffer layer decreases the development of surface cracks and hardfaced weld delamination near the weldment fusion zones. The microstructure of Stellite 6 consists of dendrites of a Co solid solution and carbide secretion in the interdendrites of the Co and Cr matrices [7].

In another study, wear-resistant surface coatings of Stellite 6 were deposited on the base metal stainless steel 316 substrate by depositing an intermediate buffer layer of Inconel 625 with varying Linear Heat Inputs (LHI). The mechanical and microstructural properties of Stellite 6 coatings were examined to evaluate the outcome of the SS 316 buffer layer. The surface defects, microstructure properties, micro-hardness and wear resistance properties of Stellite 6 clads with a buffer layer were examined and compared with direct-deposited Stellite 6 properties. The results showed an increase in hardfaced weld height of 30% and 9% at lower and higher linear heat inputs (LHIs) respectively. The deposition (with and without buffer layer) of

Stellite 6 was free from surface and internal cracks. The weldment dilution was less by 25% and 10%, whereas the enhanced microhardness displayed an of 12% and 5%, respectively, with the addition of the buffer layer. Furthermore, a fine-grained microstructure was observed in the buffer layer clads at the interface zone. Moreover, the investigations demonstrated wear rate improvements of 14% and 3%, respectively, with a reduced coefficient of friction (COF) in buffer-layer-deposited coatings. These improvements were accredited to the collective effects of increased microhardness and microstructural refinement. Accordingly, laser cladding of Stellite 6 under low laser heat input (LHI) conditions with the incorporation of a buffer layer resulted in enhanced mechanical properties and a superior microstructural framework. [6].

When the valve is closed, the fluid should not pass through the valve seat ring and wedge. If fluid passing occurs, it cannot be easily controlled. It requires a complete overhaul of the valve, which takes a lot of time to repair. Occasionally, power plants need to be shut down to carry out repair/service activities. The passing of valves mainly occurs due to the damage of hard-facing material welded on the base metal, which is required to withstand high pressure and high temperature. The hard-faced seat ring and disc can be repaired by re-lapping, but this is only a temporary solution to the issue.

In Fig. 1 the seating surfaces are locally repaired with overlay by welding of hard-facing material and machined surface is shown.

		
Cracks observed in seating surface	Local repair by overlay	Preparing the surface for Machining/Lapping

Fig.1 Seat ring – local repair of peeled-off hard facing material

Presently many issues have been reported regarding Hard-facing (Stellite-6) peeling off from the base metal (Carbon Steel) while operating at its rated and elevated parameter. Sometime, depending on the power plant system, the power plant has to shut down due non-availability of alternate or bypass pipe line, leading to loss in business methodologies.

As per the feedback received from various Power Plants, the prolong operation of valves, under various operating parameters of pressure and temperature, leads to failure of hard-faced seats of seat rings and the closure elements like disc/wedge. The surface defects failures in general are:

(a) Crack on the hard-faced surface
(b) Peeling of the hard-faced material
(c) Insufficient hardness
(d) Inappropriate post weld heat treatment.

Due to the occurrence of these failures, operating parameters are not achieved in the power plant and huge loss occurs.

Hard Facing:

Different categories of wear exist, but the most typical wears are – Abrasion, Impact, Metallic (metal to metal), Heat, Corrosion etc. The failure of engineering components is rarely attributed to a single wear mechanism; instead, it generally results from the collaborative action of multiple wear modes, such as abrasion and impact. To address this challenge, significant researches are in progress for the development of new wear-resistant materials and the enhancement of existing materials through the incorporation of wear-resistant alloying elements and advanced surface engineering techniques.

There are four types of surfacing namely hard-facing, build-up, weld cladding, and buttering. Among these a weld hard-facing is a relatively thin/thick layer of filler metal applied to a base metal for the purpose of providing a corrosion-resistant layer. Various materials like cobalt-based alloys, nickel-based alloys, and chromium carbide alloys are used for hard facing.

Hard-facing is a technique used to enhance surface properties of a metallic component as a specially designed alloy is surface welded in order to achieve specific wear properties. The performance, microstructural characteristics, and quality of the deposited surface are significantly affected by both the alloy system and the deposition process utilized.

Hard-facing alloys, are a special material applied on the base metallic surface of a component for the basic purpose of reducing wear, are generally classified into three categories: iron-based, nickel-based, and cobalt-based alloys. Among the hardfacing materials employed in the power generation industry, Stellite 6 (S6) is one of the most widely used cobalt-based alloys, has been widely used for decades [1]. SS E309, is often used as a buffer layer (also referred to as a butter layer) between the steel substrate and S6 to bridge the thermal expansion mismatch.

Hard-Facing for Wear Resistance

Hard-facing is a surface engineering technique where a wear-resistant material is applied to a carbon or low carbon and alloy steels component to enhance its durability and lifespan. This process is crucial for industries dealing with high wear, impact, or corrosion, as it significantly reduces maintenance costs and downtime. In Hard-facing process, a metal alloy coating is bonded to a second metal substrate that is vulnerable to corrosion and wear. Hard-facing involves the preparation of a thick metallurgically bonded coating between two different metal alloys. Hard-facing is the application of build-up of deposits of specialized alloys by means of welding process to resist abrasion, corrosion, high temperature, or impact. Such alloys can be deposited onto surfaces, edges, or localized regions of components that are susceptible to wear. Welding-based deposits enhance surface functionality and enable the restoration of worn components, thereby extending their service life. Welding is a significant technology to full-fill the hardfacing requirements by appling hard-facing alloys. Hardfacing material may be applied to a new part during its production, or it may be applied to restore a worn-out surface. Hardfacing enhances the service life of components, thereby effectively extending the operational lifespan of machinery and equipment.

Hard-Facing Application Process

1.Hot-wire TIG surfacing.

Hot-wire TIG surfacing was developed for hard-facing of Cast steel / Alloy Steel valve seats and disc / wedges. Resistance heating of the Stainless-steel wire employed and deposition of the wire on to component is carried out by TIG process.

2.Stelliting

Hard facing of Stellite components subjected to high temperature service and trim material in valves are generally done by cobalt base alloys (Stellite). The quality requirements of these services are stringent. The surfaces should be free from porosity and inclusion as surface and under bead cracks are undesirable. Apart from the above, the control of dilution is a predominant factor considered before choosing right process for Stelliting. Plasma arc welding for surfacing of it may be used to restore a worn-down surface. Hard-facing increases the service life large components by using special cobalt-based filler material in the form of continuous wire.

AIM & OBJECTIVE

The aim of this project is to perform a comparative study on the microstructure and mechanical properties of the hard-faced specimens and investigate the bonding strength of the hard-facing material (Stellite-6) with the base metal mainly carbon steel (SA515 Gr.70) and another specimen hard faced with Stellite-6 on a SS buffer layer with the base metal carbon steel (SA515 Gr.70).

This study results shall be used to find the difference between two types of hard-facing and establish the requirements of SS buffer layer for stellate-6 deposition which will be used to enhancing the durability of the hard facing.

MATERIAL AND METHODS

MATERIAL

1. Base Material (SA515 Gr.70)

The base plate used in this project is very commonly used in boilers and power plants for various applications where working fluid is water and steam systems. This is specially modified and heat treated to perform well at elevated temperatures in the power plant. SA515 Gr.70 is a plate form of Carbon Steel and the basic chemical composition and mechanical properties are given **in Table 1 and Table 2** respectively. The test specimen is prepared for testing.

Table 1 Chemical Composition (mass %) of SA515 Gr.70 Material

C	Mn	P	S	Si
0.31	1.2	0.025	0.025	0.15-0.4

Source: ASME SA515

Table 2 Mechanical properties of SA515 Gr.70 Material

Material	Heat Treatment	Yield Strength MPa	Ultimate Tensile Strength MPa	Elongation	Hardness HV
SA515 Gr.70	Normalising	260	485-620	21%	140-200

Source: ASME SA515

2.

Hard-facing Material (Stellite-6)

Stellite 6 is a cobalt-based alloy that is extensively used as a hardfacing coating material because of its excellent wear resistance, corrosion resistance, and high-temperature performance, which are attributed to its alloying elements. Chromium being the major alloying element of Stellite 6 provides better corrosion resistance properties and formation of M_7C_3, $M_{23}C_6$ carbides contributes for increasing the strength. Furthermore, it acts as a strengthening element by promoting the formation of a solid solution within the alloy. The presence of tungsten (W) and molybdenum (Mo) enhances the strength of the alloy through precipitation hardening, resulting in the formation of (Mo-W) carbides that exhibit high density along with adequate ductility. Therefore, to produce such a functionally higher graded coatings of Stellite-6, efforts were made using several techniques like TIG welding, Oxyacetylene, SMAW, Thermal Spray, Plasma Spray, Laser cladding, etc. Each of these processes possesses distinct advantages and limitations. For instance, conventional welding techniques introduce a significant amount of heat into the substrate, resulting in increased dilution and thermal distortion. A variety of thermal processes produce mechanical bonding with the substrate that propagate delamination or insufficient coating strength with the substrate [3].

Stellite 6 alloy has exceptional wear resistance, oxidation resistance and corrosion resistance properties along with some general complications in traditional manufacturing and processing limits its wider application. Recent advancements in additive manufacturing technology are anticipated to provide an innovative method for the fabrication and processing of Stellite-6 alloy [8].

The most used Hard-facing material is Stellite-6, and the requirement-based parameters control the selection of Hard-facing material. Stellite 6 is a cobalt-based alloy named best for its exceptional wear resistance, particularly at elevated temperatures and in corrosive environments. It's a versatile material, widely used in various industrial applications where resistance to wear, galling, and corrosion is crucial. Stellite-6 is considered the industry standard for general-purpose wear resistance.

Stellite 6 is available in powder and wire forms for various processes like welding, laser cladding, and thermal spraying. It can be applied using processes like PTAW (Plasma Transferred Arc Welding), laser cladding, and HVOF (High-Velocity Oxygen Fuel) and it can be machined using carbide tooling. The basic chemical composition and mechanical properties are given in **Table 3**

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Table 3 : Nominal Composition (mass %) and physical properties of Stellite-6

CO	Cr	W	C	Mo	Fe	Ni	Si	Mn	P	Hardness
Base	29.8	4.75	1.31	0.25	2.48	2.2	1.26	0.17	0.012	402 HV

Source: ASME BPVC IIC SFA 5.21 ERCoCr-A

3. Buffer Material (E309)

E309 is a standard buffer material commonly used for buffering (cladding) or surfacing carbon, low carbon steel and low alloy steel. As per ASME SFA-5.4 / AWS A5.4. The Chemical Composition Requirements of buffer material E309 are given in **Table 4.**

Table 4 : Chemical Composition (mass %) of E309 Material

C	Cr	Ni	Mn	Si	Mo	P	S	Cu	Hardness HV

0.15	22-25	12-14	0.5-2.5	0.9	0.75	0.04	.03	0.75	180-240

Source: ASME SFA-5.4 E309-16,

METHODS

During a welding process, the filler material is fused between two joining metals. The fused material is deposited by number of passes in line with the weld bead requirement. This builds the strength of the weld joint and enhance its mechanical properties. This process of welding generates heat and the adjacent area of the base metal are called the heat affected zone. A typical welding technique is represented in Fig.2.

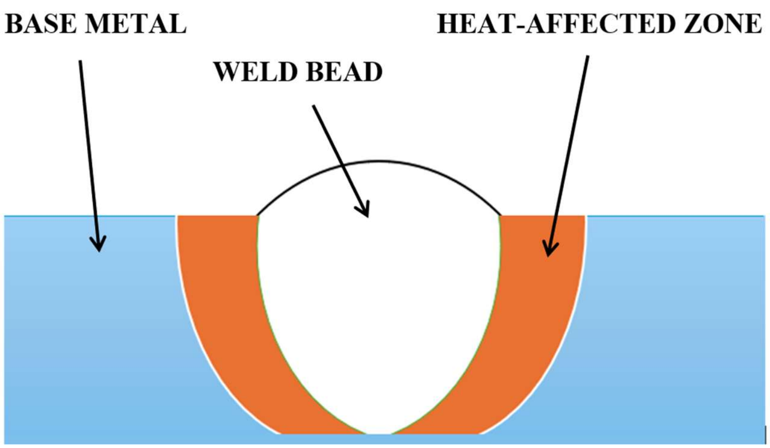
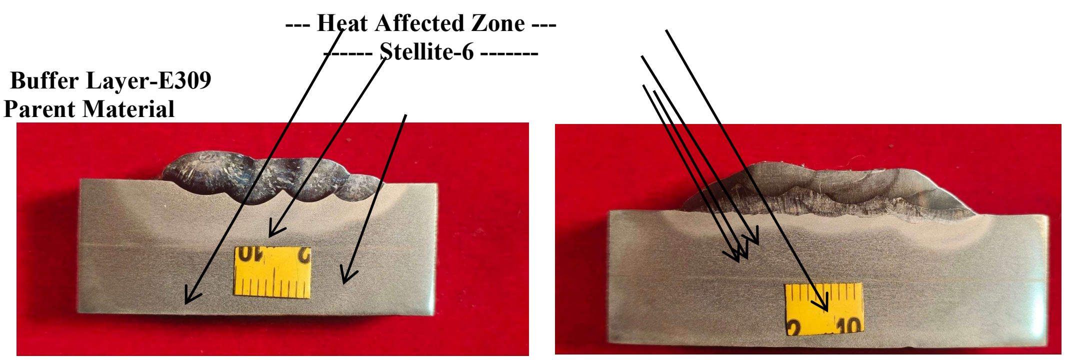


Fig.2 Representation of Hard-facing by Welding technique

Two sample specimens as shown in Fig.3, Specimen-A and specimen-B are prepared by machining for hard-facing. The specimen is prepared as per AWS B4.0M:2000 and ASTM E8/E8M standard. On Specimen-A, the hard facing material Stellite-6 is welded on the base metal directly and on Specimen-B, buffer layer of E309 is welded before welding the hard facing material Stellite-6. Fig.3 depicts the Hard facing with Stellite-6 with and without buffer layer E309.



Hard facing with Stellite-6 without buffer layer | Hard facing with Stellite-6 with buffer layer E309

Fig.3 Hard facing with Stellite-6 with and without buffer layer E309

RESULT AND DISCUSSION

Hardness Measurement:

Micro Indention Hardness measurement is performed across the specimen to obtain the hardness profiles in the base metal, heat affected zone, buffer layer and the stellite-6 hard-face. The results of hardness test obtained are tabulated in Table 5 and Table 6.

Table 5 : Hardness Measurement of sample-A

(Hard-facing on Parent Metal without buffer layer)

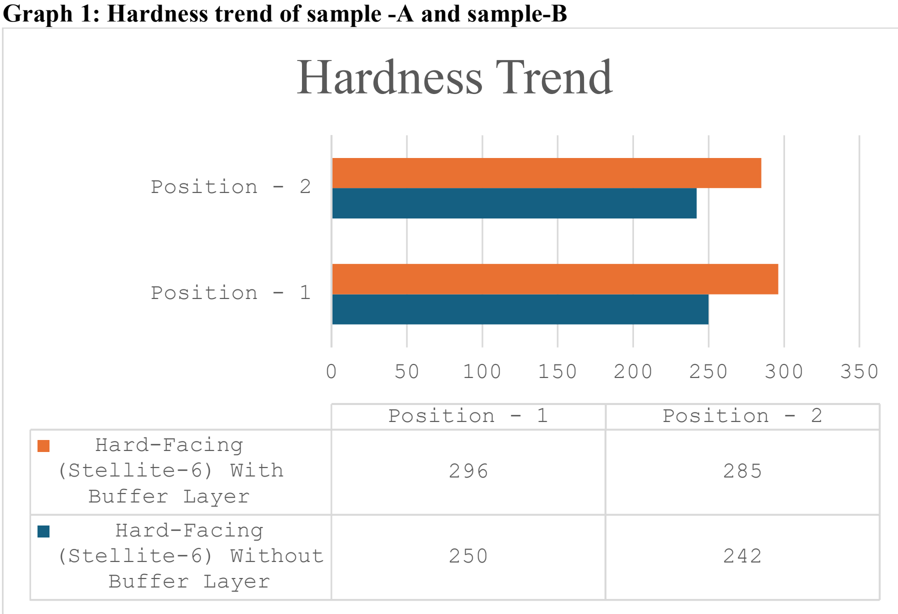
	Parent Metal	HAZ	Hard-Facing (Stellite-6)
Position - 1	154	168	250
Position - 2	152	166	242

Table 6 : Hardness Measurement of sample-B
(Hard-facing on Parent Metal with buffer layer E309)

	Parent Metal	HAZ	Buffer Layer (E309)	Hard-Facing (Stellite-6)
Position – 1	152	165	193	296
Position - 2	154	164	187	285

A graphical representation of Hardness trend of both samples A and B is shown to understand the mechanical properties and further the data obtained can be utilised for design and manufacturing process of various hardfaced components for improved life cycle of hardfacing material.

Graph 1: Hardness trend of sample -A and sample-B



Microstructure Test:

Microstructure test is conducted by optical microscope at different focal length to find out the microstructure present in the weld metal, HAZ, weld interface, Root interface and base metal.

Metallography procedure is used to study the microstructure of base metal, weld metal, heat affected zone and the microstructure changes, which are recorded under the metallurgical microscope are very effective way to analyse as shown through the Fig. 4(a) to Fig. 4(g).

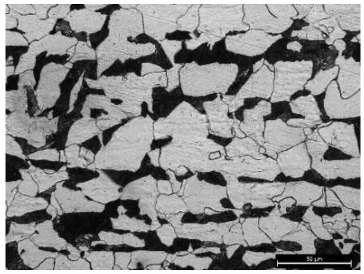


Fig. 4(a) – Parent Material

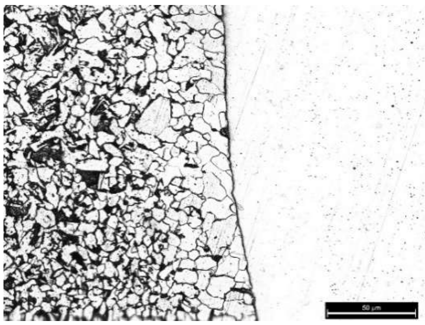


Fig. 4(b) – HAZ + Stellite-6

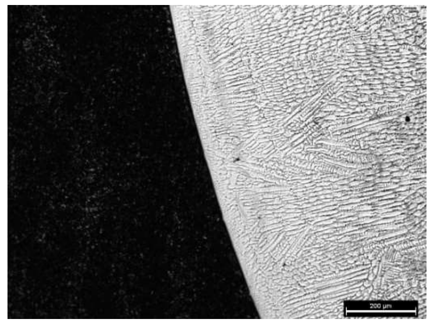


Fig. 4(c) – HAZ + Stellite-6 (Itched)

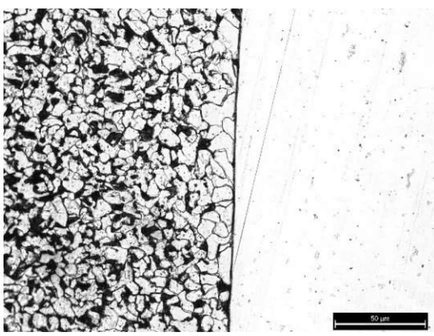


Fig. 4(d)– HAZ + E309

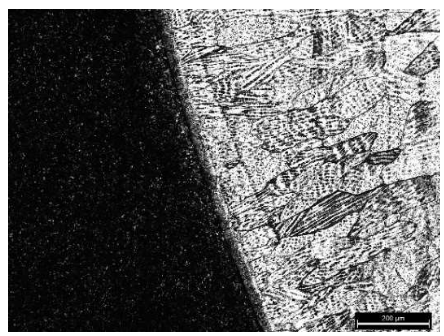


Fig. 4(e)– HAZ + E309 (Itched)

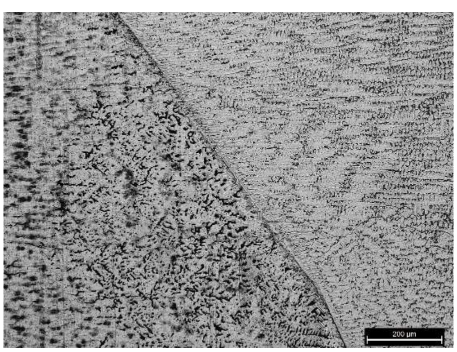


Fig. 4(f)– E309 + Stellite-6

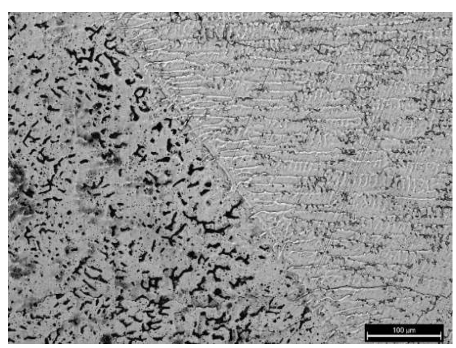


Fig. 4(g) – E309 + Stellite-6

Fig. 4(a) to Fig. 4(g). Microstructure Study of parent metal, hard-facing material, buffer material and HAZ.

CONCLUSION

The results obtained from the experimental analysis and feedback from various power plant sites; it is understood that the direct Stellite-6 hard-facing on the carbon steel for high pressure and high temperature application is not suitable for prolong period and the occurrence of defects such as crack and peeling off of hard-facing material are quite common in nature are due to wider heat affected zone with low hardness value.

Thus, as a solution to this problem, an experimental investigation has been studied by providing SS buffer layer on carbon steel before hard-facing with Stellite-6. The process of introducing a buffer layer on the carbon steel prior to deposition of hard-facing material stellite-6 significantly narrows down the heat affected zone with improved hardness requirement, as shown in Graph 1.

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