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Evaluation of Wear, Mechanical and Metallurgical Properties of TIG Re-Melted Stellite 6 Cladded Over AISI-304 L Stainless Steel

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Abstract- Stellite 6 is a cobalt based super alloy with major percentage of cr (27-32%), w(4-6%), c (0.9-1.4%) and other alloying elements like ni, fe, si, mn and mo. it is used for the improvement of wear resistance and mechanical properties of stainless steel engineering components used in harsh environment. the use of shielded metal arc welding (smaw) process for cladding of stellite 6 on stainless steel is getting attention due to high deposition rate and low dilution. initially bead on plate experiments were performed to optimize the single pass cladding process parameters i.e. current, electrode manipulation (stringer and weaving technique) and speed. 80 amp current with weaving technique were found to be optimum parameter for cladding with minimum dilution and maximum hardness with finer microstructure were found. these parameters were then used for multi pass multilayer cladding of stellite 6 on aisi 304 l. further the comparative study was performed for seven layer seven pass (slsp) and five layer five pass tig remelted (flfptr)stellite 6 cladding. the aim of this work is to analysis the effect of tig re-melting on wear, metallurgical and mechanical properties of aisi 304 l cladded with stellite 6.

Keywords: Cladding, Stellite 6, Wear, Mechanical and Metallurgical properties.

I. INTRODUCTION

Stellite 6 is a most widely used Cobalt based super alloy in industries, due to its outstanding behavior against high temperature oxidation and excellent wear resistance. [1]. Kotecki explained surface engineering a methods for achieving the desired surface requirements and their behavior in service for engineering components. Engineering components must perform certain functions completely and effectively, under various conditions in aggressive environments. The wear causes hundred tons of material to be lost and thus loss in productivity that can never be recovered. This causes significant expenses to companies in the recovery or replacement of these worn out components [2]. The cladding process of stellite 6 is very effective for increasing wear resistance for the components subjected to large stresses under complex loading condition of impact, wear, fatigue etc [3]. Kirchgabner et al. had explained surfacing an application of build-up deposits of specialized alloys to resist abrasion, high temperature corrosion and impact. Such an alloy may be deposited on the surface, on an edge, or merely on the point of a part that is subjected to wear [4]. S. Kumar et al. had listed commonly used hardfacing techniques which include oxy-acetylene gas welding (OAW), gas tungsten arc welding (GTAW) or tungsten inert gas welding (TIG), submerged arc welding (SAW) and plasma transferred arc welding (PTA). The significant differences between these processes are the welding efficiency and the dilution ratio of cladded layers [5] Wang and Luer reported that coatings are used to protect the heat affected areas like tubes of fluidized bed combustor etc [6]. Hocking had explained the use of corrosion resistant alloys as coatings to protect substrate metals [7] Cladding is the most widely used technique to prepare composite structural parts providing required mechanical strength properties as well as inhibition of oxidation and other corrosive degradation processes[8]. Coating techniques are widely used for the protection of turbine engine and boiler tubes against high temperature corrosion attack power generation equipment, chemical process equipment, aircraft engines, pulp and paper processing equipment, bridges, rollers and concrete reinforcements, orthopedics and dental, land- based and marine turbines, ships [9-11]. Coatings show superior resistance at high working temperatures among the other cermets coatings. Therefore, these coatings are widely used in steam turbine blades and boiler tubes for power generation [12] Gugian Xu et al. had investigated the powder mixture of Stellite 6 and Tungsten Carbide (WC) deposited to mild steel with constant chemical composition multi-layer cladding (CCCMLC) and functionally gradient material multi-layer cladding (FGMMLC). They concluded that as the WC weight fraction had increased the eutectic structure due to more melted WC particles, the hardness near the substrate is low due to dilution and FGMMLC is an effective method for preventing cracks [13]. Luo et al. concluded that laser cladding have high rate of dilution as compared to supersonic laser deposition. The micro structure is refined with supersonic laser deposition whereas carbide dendrites form with laser cladding [14]. Meng and Ludema had examined that when two surface sliding in contact under pressure; asperities of both the surfaces interlock with each other and produce some kind of stresses. After the asperities of the given surface had moved over each other, the stresses are relived and cycle repeated. Thus the material of the hard metal near the surface undergoes cyclic stress. This loading and unloading conditions experienced by the material may induce the surface cracks which lead to its breakage and leaving large pits in the surface [15]. Madadi et al. did a comparison of constant and pulse current Tungsten inert gas cladding on microstructure and wear resistance of stellite 6. They found that the pulse current had improved the micro-structure with lower dilution levels and the increased current intensity levels resulted in higher dilution level with decrement in the hardness. They also concluded that higher WC volume of faceted dendrites impart excellent wear behavior [16]. Shin et al. had investigated the effect of varying molybdenum contents on the microstructure and wear resistance of Stellite 6 hardfacing on AISI 1045 carbon steel using plasma transferred arc welding (PTAW) process. They found that the volume of Chromium-rich carbides decrease in inter-dendritic region but that of M_6C type carbide increased at the interfaces of dendrites. The addition of Mo contents improved the hardness and wear properties of Stellite 6 coating. [17]. Kuzucu et al. studied the effect of Post Weld Heat Treatment (PWHT) of casted Stellite 6 having Mo alloy (6% by Weight). They found that a phase transformation from α phase with fcc structure to ε phase with hcp structure occurred in sample cooled in water whereas the amount of the ε phase and hardness increased in the sample cooled in liquid Nitrogen [18]. Zhong et al. evaluated the micro structure in high power laser cladding of stellite 6 + Tungsten carbide (WC) layers. The WC volume percentage were carried from (0-100%) with different feeding rates of stellite 6 and WC. They concluded that formation of dendrites and inter-dendrites eutectics from 0-36% of WC and other was faced dendrites in block, star, flower shapes from 45-100% of WC [19]. Sudha et al. had evaluated the Micro-Chemical and Microstructure modification that takes place during depositing Ni-Cr-Si-B alloy coating on AISI 304L using plasma transferred arc welding process. They concluded that the defect free coating of maximum 7mm thickness could be obtained by suitable selection of process parameters [20].The main objective of the present investigation is to find the optimum parameter by bead on plate experiment which resulted in minimum dilution without compromising on bond integrity. The best resulted parameters have been used for multi layer cladding of Stellite 6 on AISI 304 L. Further the comparison was done for as cladded and TIG remelted cladded Stellite 6 on AISI 304 L using SMAW process.

II. EXPERIMENTAL WORK

The chemical composition of AISI 304L (base material) and Stellite 6 (Overlaying material) is shown in Table 1. Prior to multilayer multipass cladding, bead on plate experiment with single bead were performed. The current range (80 Amp -110 Amp) was chosen as per the electrode burning characteristics and electrode manipulation (stringer, weaving technique) were utilized.

Based on bead on plate experiment, the results with minimum dilution and maximum hardness were chosen for multilayer multipass cladding. Further comparison was made for seven layer seven pass and five layer five pass TIG remelted Stellite 6 cladded over AISI 304L.

A. Materials

The base metal was in the form of rolled plate of (250×250×12mm) and surfacing material was flux coated electrode of stellite 6 of 3.15 mm diameter.

B. Preparation of base plate

The base plates of AISI 304 L were thoroughly cleaned mechanically and chemically before overlaying in order to avoid any source of contamination like oil, grease, dirt, rust etc. that could hinder welding and result into a possible weld defect.

C. Baking of electrodes

The electrodes of Stellite 6 were baked in an oven maintained at 300^0 C for 3 hour to remove any traces of moisture contents which may results in porosity in the weld overlay.

D. Bead on Plate Experimentation

The Stellite 6 was overlaid on AISI 304 L plate for bead on plate experiment with various techniques and at different current range as shown in Table 2. Based on these parametric techniques the satellite 6 was overlaid on the base plate as shown Fig. 1.

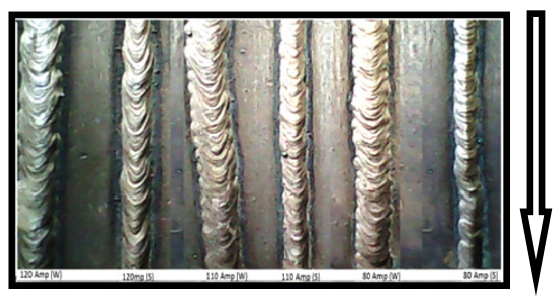

Fig. 1 Show the weld bead at (80, 110 and 120 Amp) and with stringer and full weaving technique.

Based on the bead on plate experimentation the overlaying (multilayer multipass) of the stellite 6 have been done.

One of the plate of AISI 304 L was overlaid with seven layer seven pass stellite 6 clad and another plate of AISI 304 L was cladded with five layer five pass with further TIG re-melting. In the present work based on minimum dilution by ensuring bond integrity, 80 Amp current and weaving techniques were used to fully clad AISI 304 L with stellite 6 using SMAW process as shown in Fig. 2 below

TABLE 1 CHEMICAL COMPOSITION OF AISI 304 L AND STELLITE 6

Material	Element	Co	Cr	Fe	Mn	P	S	Si	Ni	C	W	N	Mo
AISI 304 L	Wt (%) age	--	18-20	Bal.	2	.045	0.03	0.75	8-12	0.03	--	0.10	--
Stellite 6		Base	27–32	0.79	0.13	--	--	1.25	0.65	0.9-1.4	4–6	--	Bal

TABLE 2 SHOWING VARIOUS INPUT VARIABLES

Current (Amp)	80	80	110	110	120	120
Weaving technique	Stringer	Full	Stringer	Full	Stringer	Full

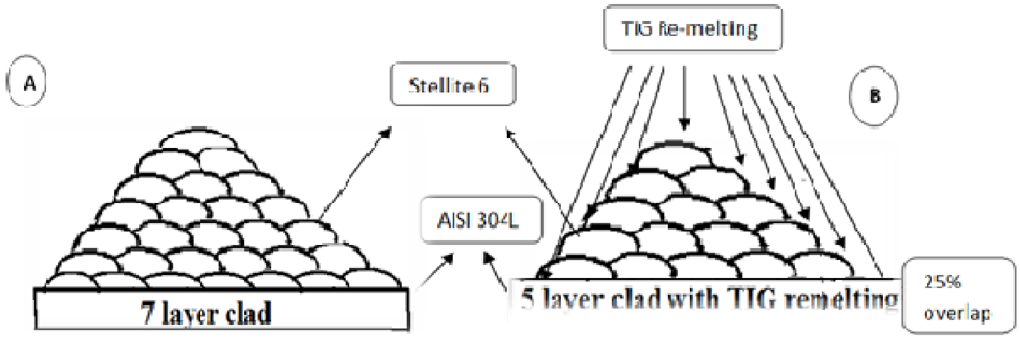

Figure. 2. (A) Cladding of stellite 6 alloy with 7 layers
(B) Cladding of stellite 6 with 5 layer and furher TIG re-melting

An overlap of 25% between the beads and inter pass temperature of 150 ^{0}C was maintained. Further on one cladded plate TIG remelting was done, to study the improvement in wear, metallurgical and mechanical properties.
The above cladding is abbreviated as follow:-

1. **SLSP**: - Seven layers seven pass
2. **FLFPTR**: - Five layers five pass TIG re-melted

III.RESULTS

A. Bead on Plate Experiment

It was found that by using low current range and weaving technique the hardness of the clad is improving. It is clear from bead on plate experiment that 80 Amp current and weaving techniques resulted in minimum dilution and for maximum micro-Hardness for cladding of stellite 6 using SMAW process.
Thus, the dilution and hardness of the clad can be improved by using low heat input. The further improvement can be done by using Weaving technique of electrode. The results are as tabulated in Table 3 below:

B. SLSP and FLFPTR Stellite 6 cladding:

The results of micro hardness, micro structure, ultimate tensile strength, fatigue and wear resistance for as cladded seven layer seven pass (SLSP) and TIG remelted five layer five pass (FLFPTR) Stellite 6 cladding are presented in the tabulated form in Table 4 below:-

TABLE 3 SHOWING RESULTS FOR BEAD ON PLATE EXPERIMENT

Current	Technique Used	Dilution %age	Micro-Hardness (VHN)		
			Base metal	HAZ	Weld Bead
80 Amp	Stringer	**47.44**	*180*	*280*	*320*
	Weaving	**30.81**	*201*	***380***	***405***
110 Amp	Stringer	**52.41**	*206*	*280*	*310*
	Weaving	**45.33**	***207***	*290*	*385*
120 Amp	Stringer	**55.44**	*172*	*260*	*308*
	Weaving	**52.46**	*204*	*310*	*339*

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TABLE 4 RESULTS COMPARISON OF SLSP AND FLFPTR STELLITE 6 CLADDING

PROCEDUER	Micro-Hardness			Tensile (ultimate strength point)	Micro-Structure	Fatigue cycles	Wear Resistance		
	Base metal	HAZ	Weld Bead				2 kg load	3.5 kg load	5 kg load
SL SP	*206*	*320*	*603*	50.85 kN	Not - fine	6.50 - 7.60	14.72	5.35	4.91
FLFP TR	*204*	*323*	*622*	60.12 kN	Refin ed	7.00- 7.80	19.63	29.45	58.8

IV. DISCUSSION

A. Micro-Structure and micro-hardness studies

In order to study the effect of TIG remelting on stellite 6 cladded on AISI 304 L overlays, micro hardness studies were carried out on base metal, HAZ and cladded metal. It is observed that the micro hardness of TIG re-melted stellite 6 shows an increasing trend which could be attributed to the fact of TIG Re- melting (as shown graphically in Fig. 3) and refine the micro- structure with finer grains as shown in Fig. 4 and 5 below:

The Micro-structural pictures shown above clearly describe the grains of SLSP and FLFPTR. The Crack propagation of SLSP was due to long grain size whereas the grain size of FLTR is finer and small. The porosity of the clad is also removed by the TIG remelting. The size of the grains for SLSP is large and not similar with one another but in case of FLFPTR the size of grains is smaller, finer and similar to each other.

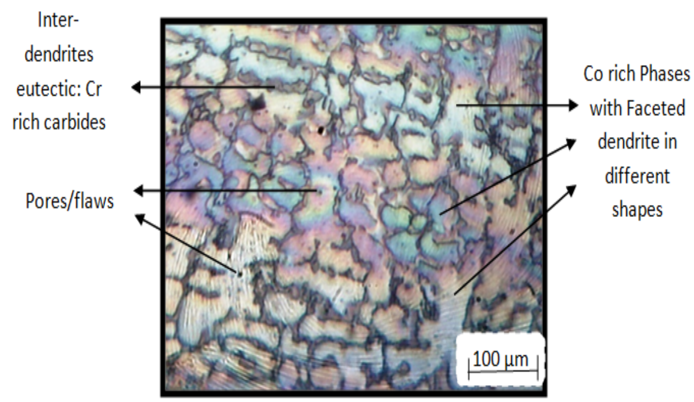

Fig. 5 Micro structure for SLSP Stellite6 clad

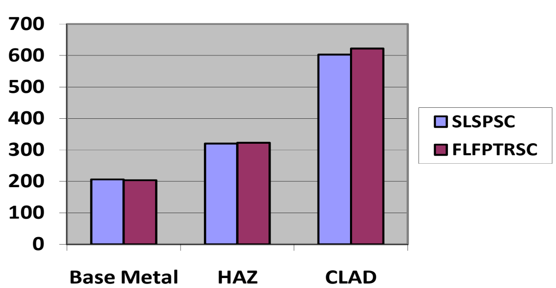

Fig: 3 Showing the Vickers hardness of cladding

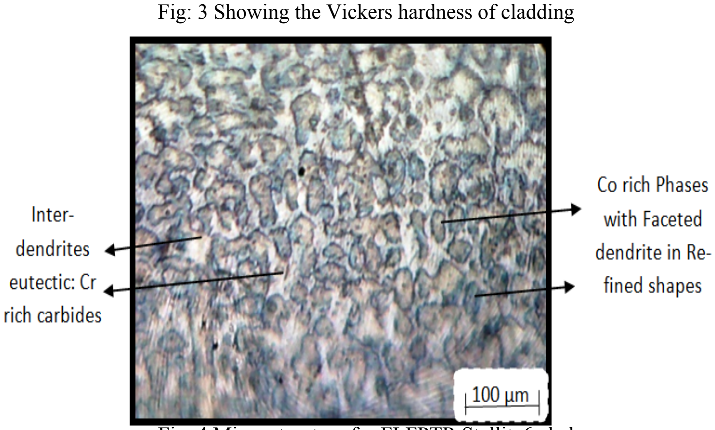

Fig. 4 Micro structure for FLFPTR Stellite6 clad

B. Mechanical properties

In order to confirm the bond integrity of overlays 180^0 U-bend test was performed according to ASTM standard A264. No visible cracking was observed which indicate that stellite 6 overlays processed good bond integrity throughout the overlay. The comparison between ultimate tensile strength of TIG remelted and as cladded showed that ultimate tensile strength of TIG remelted was more than as cladded overlay as shown in Table 5 below. This could be due to the finer micro structure.

With an aim to predict the surface life fatigue testing was performed on a rotating bending type high cycle fatigue testing machine.

TABLE 5 SHOWING TENSILE TEST READINGS FOR BOTH CLAD

Description	SLSP	FLFPTR
Yield Point	35.75 kN	42.81 kN
Ultimate Strength point	50.85 kN	60.12 kN
Breaking point	46.62 kN	59.62 kN

It could be clearly seen that TIG remelted processed higher fatigue life that as cladded overlay the results are tabulated in Table 6 below.

TABLE 6 SHOWING FATIGUE TEST READINGS FOR BOTH CLAD

Bending Stresses	**No of cycles to failures (×10^5)**	
	SLSP	**FLSCTR**
200 MPa	07.60	07.80
250 MPa	06.50	07.00

4.3 Wear Properties

With an aim to study the wear properties pin on disc wear test were performed, wire cut EDM was used for extraction of pins from the cladded plates. In this test a pin is made to rotate on a moving disc. Mass of pin is calculated before and after the test. The mass loss from the pin during the test was used to calculate the wear performance.
The track Radius (R) and speed (N) was kept constant as 80 mm and 500 r.p.m respectively with varying load. TIG remelted cladding showed remarkable improvement in the wear behavior and as the load was increased the wear behavior of TIG remelted pins showed more wear resistance than that of as cladded stellite 6.

The wear resistance shown by Cladded and TIG remelted pins are as shown graphically below in Fig. 6 and tabulated below in Table: 7.

Where, Wear Volume = Weight loss / weight density (8.44 gm/cm^3)
Wear Rate = Wear Volume / Sliding Distance (V × time); where (V = $2\pi RN$ / 60)
Wear resistance = 1 / Wear Rate

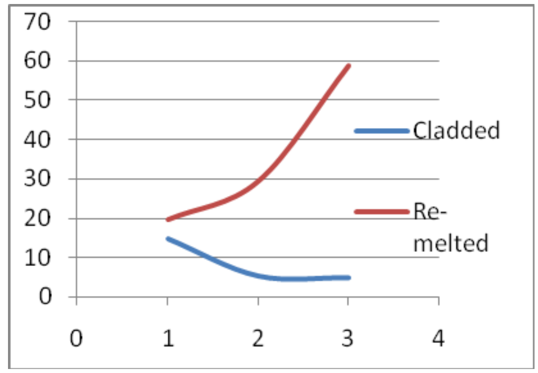

Fig. 6 Wear performance of both the cladding

TABLE 7 WEAR PERFORMANCE

Load (W)	**Sample NAME**	**Initial weight (w1) gm**	**Final weight (w2) gm**	**Weight loss (w1-w2=w) gm**	**Weight loss (w) mg**	**wear volume cm^3**	**Wear Rate cm^2**	**Wear Resistance ×10^8 (cm^2)**
2	Clad 1	7.2332	7.2328	0.0004	0.4	0.473933649	0.67920427	14.72311111
3.5	Clad 2	6.3386	6.3375	0.0011	1.1	1.303317536	1.86781175	5.353858586
5	Clad 3	6.6384	6.6372	0.0012	1.2	1.421800948	2.03761282	4.907703704
2	Remelt1	6.0637	6.0634	0.0003	0.3	0.355450237	0.50940321	19.63081481
3.5	Remelt2	6.6494	6.6492	0.0002	0.2	0.236966825	0.33960214	29.44622222
5	Remelt3	5.8225	5.8224	0.0001	0.1	0.118483412	0.16980107	58.89244444

V. CONCLUSION

1. The bead productivity can be increased by using low heat input and can be further improved with electrode manipulation. 80 Amp current with weaving technique led to minimum dilution without compromising on bond integrity.
2. TIG remelting reduced the inter connected porosity in the cladding which probably have a beneficial effect on tensile, fatigue and wear resistance performance of stellite 6 cladding.
3. The TIG remelted samples exhibits finer micro structure which improved the micro hardness of the coating which further increased the wear resistance properties.
4. TIG remelting has a beneficial effect in the improvement of various properties with lesser metal deposition.

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