EXPERIMENTAL STUDIES OF STELLITE-6 HARDFACED LAYER ON FERROUS MATERIALS BY TIG SURFACING PROCESS

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Abstract: Hardfacing is the cheapest technique and it is the deposition of coatings of hard, wear resistant materials on a worn or new component that is subjected to wear, impact, high temperature, and oxidation. Weld hard facing is used to deposit thick layers of hard material by Tungsten Inert Gas (TIG) welding technique. This layer acts as a sacrificial layer at the point of impact and safeguards the base metal from wear out and corrosion. It is also used to fill the worn out part of a component there by increasing its durability and lifetime. A thick layer of stellite-6 of width 1 mm is deposited on the base metals (i.e mild steel and EN-8) varying the weld currents as 120A, 140A, 160A. Vicke rs Hardness testing machine is used to measure the hardness of the hardfaced components and the variation of the hardness with varying weld current for both substrates. The specimens are subjected to oxidation at elevated temperature of 973K by muffle furnace for 5, 10, 15 hours duration and to study the oxidation rate with respect to different processing currents. The microstructural analysis is performed using optical microscopy on hardfaced samples. The aim of the paper is to study the effect in rate of oxidation, hardness, and microstructure with respect to varying parameters in stellite-6 hardfacing on ferrous materials.

Keywords: Hardfacing layer, Morphology, Microstructural analysis, Oxidation process, TIG welding.

1. INTRODUCTION:
In recent day’s protection of the structural materials of different motor drive, cranes, crushers, bearing components, brakes, bushes, and pipeline assemblies against wear is very essential. Hence the metallurgical and mechanical engineers have carried out lot of research on wear. It became evident during the survey that wear of metals was a prominent topic in large number of the responses regarding some future priorities for research in tribological studies. Wear and oxidation are the most leading factors, which influence the life factor of the machine parts and assemblies. These hardfacing procedures can be applied in number of components like cranes, crushers, pump and fan impellers, crane wheels, turbine blades, pipeline assemblies, bucket teeth, screw conveyors, bulldozer teeth, blades, worn railway crossings, etc. MX Yao et al., have conducted study on wear, corrosion and cracking resistance of some W-or Mo-containing Stellite hardfacing alloys, and stated that the W-containing stellite alloys have better corrosion resistance in oxidizing acid. The Mo-containing Stellite alloys exhibit unusual combination of excellent wear and corrosion resistance in reducing environments[4]. Yucel Birol has investigated that the high temperature wear performance of Inconel 617 and Stellite-6 alloys and compared with that of the X32CrMoV33 hot work tool steel [12]. JL Otterloo and De Hosson have demonstrated that electron microscopy, pin-on-disc wear experiments and hardness measurements were carried out on a laser-coated cobalt based stellite alloy [9]. Buchely et al., have studied the microstructures of as-cast HS111 and as-SHShed Stellite-6 by SEM, XRD and EPMA [11]. Bingley and Schnee have studied that the abrasive...
resistance is related to carbon content and secondary effect is based on hardness and chromium percentage [1]. Lemaire and Calvar have proposed the influence of addition of Nb, Cr, Mo and C on wear behavior of nickel based alloy [8]. Fontalvo and Mitterer have projected that the Co-based alloy composition having a relatively small lanthanum addition and relatively large carbon content provided remarkable oxidation resistance and wear resistance at high temperatures [7]. Bortoleto et al., have developed high Cr and V based hardfacing alloy and found that the wear resistance of high Cr and V based hard facing alloy on pin on disc is on the level of standard of NiCrBSi + 60% fused tungsten carbides and 13 times better than that of Stellite-6[2]. The objective of the hardfacing technique is to make the critical components for longer life by depositing on them with metal alloys in order to resist scratching and indentations, corrosion, erosion, abrasion, wear, impact etc.

2. METHODOLOGY:

Hardfacing is a metalworking technique and it is resistance to wear, it is an application of build-up of deposits of special alloys on the surface of base metals [3]. TIG technique deposits can functionalize surfaces and reclaim components extending their durability. The service life of a part increases by hardfacing and thereby extend the effective, efficient utilization of machinery equipments viz. core components such as crushers, dozer blades, bearings are exposed to heavy wear and require efficient surface protection measures to avoid costly down times and to reduce cost for expensive spare parts.

3. EXPERIMENTATION:

Experimental Details and Procedure for Hardfacings

Hardfacing is one of ancient technique used to improve mechanical properties, majorly surface properties of contacting surfaces and reduces the internal stress [5]. Hardfacing is performed by a TIG welding setup [6]. It was operated at 15V and a processing current of 120A, 140A, and 160A (according to AWS welding handbook). The setup is schematically shown in Figure 1. Initially scales and dust are removed from the samples. Then the sample was fixed on a suitable fixture and the argon pressure of 5kg/cm² was adjusted. Hardfacing was performed at different welding speeds shown in Table.1, which were measured by means of stopwatch. Straight away after hardfacing, the plate was quenched in an oil. The details of hardfacing operation is listed in Table 1. EN 8 and mild steel is used as substrate material, having the dimension of 60x30x6mm³. Electrode for hardfacing was stellite-6. Samples sizes of 30X30mm² were cut from hardfaced plate whose hardfaced surface was prepared with fine finish. The composition of substrate materials is mentioned in table 2 and table 3.

Fig.1 TIG Welding setup

![Fig.1 TIG welding set-up](image-url)
Table.1 Hard-facing conditions

| Parameter                  | Value          |
|---------------------------|----------------|
| Applied voltage (V)       | 15             |
| Applied current (A)       | 120, 140, and 160 |
| Weld speed (mm/s)         | 2.25, 2.43, 2.63 |
| Gas (argon) pressure (kg/cm²) | 5             |
| Heat input (kJ/mm)        | 0.8, 0.864, 0.912 |

Table.2 Material composition of EN-8

| Element | Composition (%) |
|---------|-----------------|
| C       | 0.34-0.40       |
| Mn      | 0.60-1.0        |
| P       | 0.05            |
| S       | 0.005           |
| Si      | 0.10-0.40       |

Table.3 Material composition of mild-steel

| Element | Composition (%) |
|---------|-----------------|
| C       | 0.23            |
| S       | 0.55            |
| Mn      | 1.00            |
| P       | 0.40            |
| Si      | 0.35            |

Deposition of stellite layers on base metals:
The hardfacing alloy (i.e Stellite-6 rod) is shown in Fig.4 and which is deposited on two selected base materials i.e EN-8 and mild steel) by TIG welding process and the hardfaced samples of substrate are given in Fig.2 and Fig.3. The material composition of stellite-6 as shown in Table.4.
4. RESULTS AND DISCUSSION:

4.1. Hardness Test
The Vickers hardness test was performed at Mechanical Engineering department, Vardhaman Engineering College, Hyderabad. The Micro hardness test procedure as per ASTM E-384 and specified a range of light loads using a diamond intender to make an indentation, which is measured and converted to a hardness value [10].

Table 4 Material Composition of Stellite-6

| Element      | Composition (%) |
|--------------|-----------------|
| Chromium     | 30 %            |
| Tungsten     | 4-5 %           |
| Carbon       | 1.2 %           |
| Nickel       | < 3 %           |
| Molybdenum   | < 1 %           |
| Iron         | < 3 %           |
| Silicon      | < 2 %           |
| Cobalt       | Balance         |

Fig. 4 Stellite rods of (dia 3.2mm)

Table 5 Hardness of Mild-Steel

| Current (A) | Hardness number |
|-------------|-----------------|
| 120         | 310             |
| 140         | 353             |
| 160         | 361             |

Table 6 Hardness of EN-8

| Current (A) | Hardness number |
|-------------|-----------------|
| 120         | 331             |
| 140         | 365             |
| 160         | 371             |

Fig. 5 Comparison of hardness for mild-steel and EN-8 material
4.2. Oxidation Test at Elevated Temperature

The prepared samples are coated with the alumina on all the sides, except one side so that which enable to measure the oxidation of its hardfaced layer. These coated samples are weighed before oxidation test. The oxidation test is performed by Muffle furnace at Vardhaman College of Engineering, Hyderabad. The three samples are kept in furnace, and then heated to 700°C and the soaking time is maintained in furnace for 5hours duration at 700°C. Repeat the same process for 10 and 15hours of soaking time at constant temperature of 700°C. The respective samples were taken-out from furnace after cooling and weighed them. Determined the oxidation rate of alumina coated samples as per formula given in above Table 7. It is found that the oxidation

**Table 7 Test details**

| Sample size | 15x15x6mm | Coating  | Alumina |
|-------------|-----------|---------|---------|
| Test time   | 5,10,15hours |
| Test temperature | 700°C (973°K) |

Oxidation rate = Weight gain (g)/surface area (mm²)

Weight gain = Wt. before oxidation ($w_1$) - Wt after oxidation ($w_2$)

Surface area = 15x15mm²

**Table 8 Oxidation rates of mild steel for 5hours**

| Current (A) | Oxidation rate (gm/mm²) |
|-------------|-------------------------|
| 120         | 0.002692                |
| 140         | 0.002580                |
| 160         | 0.002237                |

**Table 9 Oxidation rates of EN-8 for 5hours**

| Current (A) | Oxidation rate (gm/mm²) |
|-------------|-------------------------|
| 120         | 0.002603                |
| 140         | 0.002296                |
| 160         | 0.002163                |
rate of mild steel is decreased from 0.002692 gm/mm$^2$ to 0.002580 gm/mm$^2$ if welding current is varies from 120A to 140A and the oxidation rate is decreased from 0.002580 gm/mm$^2$ to 0.002237 gm/mm$^2$ when welding current is varies from 140A to 160A shown in table.8. It is also observed that oxidation rate for EN-8 decreases from 0.002603 gm/mm$^2$ to 0.002296 gm/mm$^2$ and decreased from 0.002296 gm/mm$^2$ to 0.002163 gm/mm$^2$ for corresponding welding currents vary from 120A to 140A as shown in table.9.

Table.10 Oxidation rates of mild steel for 10hours Table.11 Oxidation rates of EN-8 for 10hours

| Current(A) | Oxidation rate (gm/mm$^2$) | Current(A) | Oxidation rate (gm/mm$^2$) |
|------------|-----------------|------------|-----------------|
| 120        | 0.005384        | 120        | 0.005206        |
| 140        | 0.005156        | 140        | 0.004592        |
| 160        | 0.004474        | 160        | 0.004326        |

Oxidation rate is decreased from 0.005384 gm/mm$^2$ to 0.005156 gm/mm$^2$ to 0.004474 gm/mm$^2$ if welding current vary from 120A to 140A to 160A as given in table.10. The rate of oxidation is recorded as 0.005206, 0.004592 and 0.004326 gm/mm$^2$ for the corresponding welding currents (i.e 120A, 140A and 160A) and the oxidation rate is decreasing as shown in table.11. It is observed that the same trend is followed as the oxidation rates of mild-steel and EN-8 are decreasing for varying welding currents as tabulated in table.12 and table.13.

Table.12 Oxidation rates of mild steel for 15hours Table.13 Oxidation rates of EN-8 for 15hours

| Current(A) | Oxidation rate (gm/mm$^2$) | Current(A) | Oxidation rate (gm/mm$^2$) |
|------------|-----------------|------------|-----------------|
| 120        | 0.008076        | 120        | 0.007809        |
| 140        | 0.007740        | 140        | 0.006888        |
| 160        | 0.006711        | 160        | 0.006489        |
Fig. 8 shows the comparison of oxidation rates of mild steel and EN-8 for different times in hours. Rate of oxidation of mild steel is moderate at 5 hours, slightly more at 10 hours and very high at 15 hours of soaking compared with EN-8. Thus oxidation rate is directly proportional to soaking time duration of samples in furnace at constant temperature (i.e. 700°C).

4.3 Micro-structural Analysis

The microstructure of each sample is captured using optical microscope with a magnification of 100X at the weld interface. Each sample was checked for complete fusion, freedom of cracks, porosities and other linear defects. There complete fusion of metals in each sample and defects were not found on the surface examined.

**Etchant:** Oxalic acid, **Specimen orientation:** Cross section, **Magnification:** 100X, **Material:** EN-8

| Microstructure of EN-8 | Observations                                                                 |
|------------------------|-----------------------------------------------------------------------------|
| ![Image](120A)          | The fine grain particles are formed. The fine grain possess low strength at high temperatures because of more grain boundaries and at high temperatures grain boundary atoms break bonds easily and slide over the other grain atom which is a cause for low strength. |
| ![Image](140A)          | Both coarse and fine grain particles are formed. The fine grains possess low strength and coarse grain particles possess high strength at high temperatures. As both coarse and fine grains are formed, its strength lies in between 120A and 160A specimens. |
The coarse grain particles are formed. The coarse grain possess high strength at high temperatures because of less grain boundaries and no sliding deformation takes place.

**Fig. 9 Microstructures of EN-8 Material with different processing currents**

**Etchant: Oxalic acid, Specimen orientation: Cross section, Magnification: 100X, Material: mild-steel**

| Microstructure of mild steel | Observations |
|-----------------------------|--------------|
| 120A                        | The fine grain particles are formed. These are formed due to fast cooling rate. It possess low strength at high temperatures because of more grain boundaries and at high temperatures boundary atoms breaks bonds easily and slide over the other grain atoms which is a cause for low strength. |
| 140A                        | Both coarse and fine grain particles are formed. The fine grains possess low strength and coarse grain particles possess high strength at high temperatures. As both both coarse and fine grains are formed, its strength lies in between 120A and 160A specimens. |
| 160A                        | The coarse grain particles are formed. These are formed due to slow cooling rate. The coarse grain possess high strength at high temperatures because of less grain boundaries and no sliding deformation takes place. |

**Fig. 10 Microstructures of mild steel Material with different processing currents**

5. **CONCLUSION:**

The hardness of the hardfaced component is greater than the hardness of the base metal. Hardness of hardfaced EN-8 material is higher in comparison with hardfaced mild-steel material. The oxidation rate of hardfaced component increases with increase in soaking time. The oxidation rate is decreasing as processing weld current increases. Hardfaced EN-8 material has good oxidation resistance in comparison with hardfaced mild-steel material. Micro-examination of the surface of the components shown complete fusion and freedom from cracks, porosities and other linear defects.
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