Overview on Hardfacing Processes, Materials and Applications

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Abstract. Hardfacing alloys are mainly obtained through atomization of powders and by determining of alloying elements in pure form or ferro alloys. They are widely used materials as weld overlay to improve wear and corrosion resistance in applications such as agricultural, construction, mining, etc. Wear is an important factor that controls life of any component. Different types of wear such as corrosion, impact, abrasion, metallic, etc are responsible for worn out of components. Many researches have been done to either reduce the wear or improve the wear resistant of the existing materials. Among these, hardfacing technique has made many developments since last few years. As in nuclear reactors, hardfacing of the grid plate through Laser cladding and Plasma Transferred arc welding, to improve the life of the components and resistance from wear and corrosion. Hardfacing involves applying a consumable material with desired wear properties over a soft base metal to enhance resistance to different wear mechanism. Using Calphad technique for development of desired composition and application of Schaffler diagram has been attempted successfully. In this paper a review of hardfacing processes and materials, highlighting the use of Laser cladding and Plasma transfer arc for overlaying hardfacing alloys has been attempted.

1. Introduction

Hardfacing is a process or surfacing operation where harder or tougher material is applied to a base metal, to extend the service life of new components, or worn down surface of old components. Critical components of machineries used in mining, mineral processing, construction, agriculture and many industrial processes are subjected to severe wear in service.[2] Machine parts deteriorate and fracture early from their intended life not only because of poor operation but also because of wear and abrasion. Degradation of the component surface due to wear has lead to downtimes and increased production cost. Many types of wear exists, some of them are – Abrasion, Impact, Metallic, Heat, Corrosion etc. In agricultural tools, mining and earthmoving equipments the problem is same, where the tools have to work on the hard surface. Welding deposits can make a surface function and reclaim
the components by extending their service life. [6] Welding is a key technology to fulfill these requirements and to apply hardfacing alloys. [7]

Hardfacing is a method to improve surface properties of tools and components in which an alloy is homogeneously deposited onto the surface of a base material by different welding processes, with the purpose of increasing hardness and wear resistance. [8] Selection of the material is done on the basis of hardness, mechanical properties, microstructure and wear resistance. Hardfacing can be applied to a new component during its manufacturing or to restore a worn-down surface.

2. Hardfacing processes

Hardfacing is generally applied through welding processes; it is also better from other processes as it can be suitable for almost all alloys. The other methods include Thermal spraying and Cladding. The selection of the welding process depends on size and shape of component, nature of work to be hard-faced, application where it is going to be used and base metal composition. Thermal spraying processes are preferred for applications where thin and hard coatings are required with minimum thermal distortion of the component and good process control. Cladding processes are used to bond bulk materials to the substrate to provide good tribological properties. The cladding process is used for precise coating and where thermal spraying and welding are not possible. The welding processes can be grouped as follows:

- Arc welding: shielded metal arc welding (SMAW), submerged arc welding (SAW); [15-16]
- Gas welding: oxyacetylene gas welding (OGW);
- Combination of arc and gas: tungsten inert gas welding (TIG), gas metal arc welding (GMAW); [9]
- Powder spraying: flame spraying, high velocity oxyfuel process (HVOF), electric arc spraying and plasma transferred arc welding (PTAW); and laser hardfacing/laser cladding (LC). [10,11,13]

Some of the welding methods have been successfully used to apply hardfacings on substrates such as: gas tungsten arc welding (GTAW), plasma arc welding (PAW), laser beam welding, tungsten inert gas welding (TIG), gas welding, manual metal arc welding (MMAW), shielded metal arc welding (SMAW), and flux cored arc welding (FCAW). The rate of dilution depends on materials and on the welder’s skill.
Table 1: Comparison of welding processes used for hardfacing [2]

| Welding Process       | Auto/Manual     | Precautions            | Weld pool | Dilution   | Deposit rate |
|-----------------------|-----------------|------------------------|-----------|------------|--------------|
| Shielded metal arc    | Manual          | Electric arc baking    | Slag      | 15-30%     | 1-3 kg/h     |
| Submerged arc         | Automatic       | Flux baking            | Slag      | 30-50%     | 5-20kg/h     |
| Gas tungsten arc      | Manual/Automatic| Electric arc           | Gas       | 5-15%      | 0.5-1.5kg/h  |
| Gas shielded metal arc| Semi auto/Automatic| Electric arc         | Gas       | 15-35%     | 3-10kg/h     |

Table 2: Comparison of Thermal spraying processes used for hardfacing

| Spraying Process      | Coating material form | Heat source      | Flame temperature °C | Gas velocity mm/s | Porosity % | Coating adhesion MPa |
|-----------------------|-----------------------|------------------|-----------------------|-------------------|------------|----------------------|
| Wire arc spray        | Wire                  | Electric arc     | 5000-6000             | <300              | 5-10       | 28-41                |
| Wire flame            | Wire                  | Oxy-fuel combustion | 3000                | <300              | 5-10       | 14-21                |
| Plasma spray          | Powder                | Plasma flame     | 12000-16000           | 500-600           | 2-5        | 40-70                |
| High Velocity Oxy-Fuel Laser cladding | Powder                | Laser            | Upto 30000            | 25-30             | 1-2        | >70                  |

3. Selection of Substrate material

The most common substrate material used for producing hardfaced parts are Steels. Substrates are chosen according to the application required such as high temperature application or abrasive wear environment, etc. Some of them are listed as follows:
(i) High carbon steels, (ii) Medium carbon steels, (iii) Low carbon steels, (iv) Low alloy steels, (v) High speed steels, (vi) Stainless steels, (vii) Manganese steels, (viii) Low nickel chrome steels, (ix) Cast iron (grey and white)
4. Hardness evaluation of hardfacing alloys

Hardness can be described as the resistance to plastic deformation by indentation, scratching or other frictional means. Dilution increases with an increasing welding current which leads to decrease in hardness, however, lower welding current increases the hardness of the hardfacing. The resultant hardness of some hardfacing alloy when deposited on substrate by various welding processes is shown in Table 3.

Table 3: Comparison of Hardfacing alloy, process, and substrate by various researchers

| Author          | Hardfacing alloy | Process                        | Substrate                        | Hardness          |
|-----------------|------------------|--------------------------------|----------------------------------|-------------------|
| Yuksel N. et. Al. | Fe-Cr-C          | Open arc welding               | AISI 1020 steel substrate       | 1450-1700HV[25]   |
| B. Maroli et al. | Fe-Cr-V-Ti-C-B   | Plasma transfer arc welding    | EN S235JR mild steel plate      | 60-61 HRC (600 HV)| [5]               |
| B.K. Sreedhar    | Stellite6*, Colomonoy5* | Vibratory cavitation equipment | 316L Austenitic stainless steel | 393 HV[27]        |
| Kown-yeong Lee et al. | Fe-Cr-C-Si | Gas tungsten arc welding | AISI 304 plate                  | 600 HV[24]        |
| J. Zeisig et al  | Fe-Cr-Mo-V-C     | Laser cladding                 | High performance tool steel (X155CrMo12-1) | 666 HV[26] |
| E. Badisch et al | Fe-Cr-C-B        | Gas metal arc welding          | M.S plate (DIN 1.0038)          | 175 HV[21]        |
| DashuangLi et al | Fe-Cr-Ti-C       | Self shielded metal cored arc welding | Mild steel                  | 54-64 HRC (420-560 HV) [22] |
| Wang Xin-hong et al | Fe-Ti-V-C | Shielded metal arc welding | 1045 steel substrate            | 60-62 HRC (570-610 HV) [23] |
| Agustin Gualco et al | Fe based | Flux cored arc welding         | AISI 1010 carbon steel plate    | 920 HV[28]        |

5. Hardfacing alloy production methods

Methods of producing hardfacing powders include:
(i) Powder metallurgy, followed by pulverization, grinding and sieving of the sintered alloy [21,22].
(ii) Atomization, which produces powders in the range of few microns to 1 mm. Methods of atomizing liquid metal are by water atomization, gas/air atomization and centrifugal atomization[19].
(iii) Granulation, followed by grinding and sieving of the granules to obtain the alloy powder. The granulation process results in particle sizes of millimeter range sometimes greater than 10 mm [20].
6. Classification of Hardfacing and their applications

Hardfacing improves the properties of the surface of a component without influencing its bulk properties. It is used where the surface is subjected to wear, oxidation, and corrosion. Hardfacing alloys are mainly categorized as Iron-based, Cobalt-based and Nickel-based alloys.

The applications vary widely, ranging from rock crushing to those which minimize metal-to-metal wear such as control valves. Cobalt and nickel-based hardfacing alloys are used extensively at elevated temperatures and in corrosive environments. [31]

6.1 Iron based Hardfacing alloys

Large amount of Chromium and Molybdenum are present in high alloy irons which help in formation of carbides for resisting abrasion. The matrix may be austenitic, martensitic, pearlitic, ferrite or some combination of these phases. They show excellent low-stress abrasion resistance since they have a smaller volume fraction of brittle carbides. Martensitic irons which are cheaper show good high-stress abrasion resistance because of the high hardness of the martensitic matrix. Some of the Fe based hardfacing alloys available are mentioned below along with their composition and applications. [31]

- Work hardening Manganese alloys- (46-48 HRC)
  Chemical composition; C- 0.1-1%, Mn- 6-16%, Cr- 14-19%, Ni-9%
  Properties- High resistant to cracking, High rate of work hardening
  Application- Retouching of casting imperfections.

- Low and Medium alloys- (55-60 HRC)
  Chemical composition: C- 0.1-0.5%, Mn- 0.7-2%, Cr- 1-9.5%, Mo-0.2-0.7%, V- 0.3%
  App - Transmission shaft, rolls, Cams, raceways, press and transport screws.

- Heat Treated steels for tooling- (50-60HRC)
  Chemical composition: C- 0.2-1.1% Mn- 0.3-2% Cr- 2-10% Mo- 1.5-7% V- 0.6-1.1% Ti- 0.3
  App- Mill roll, hopper seats in blast furnace, Steam valves, press tooling, moulds and ceramic tiles,
  Milling cutters, knives, forging tooling.

- Anti abrasion- (61-67 HRC)
  Chemical composition: C- 0.5-5.5%, Mn- 0.2-2%, Cr- 10-27%, Mo-3-5%, Ni- 2% B- 2.2-4.5%
  App- Equipments used in agriculture, Quarrying, mining, Screw conveyers, mineral conveying equipment,
  vertical crushers, extractor fans, grinding mills.

- Ferritic and Martensitic stainless steels - (42-54 HRC)
  Chemical composition: C- 0.04-0.3%, Mn- 0.8-1.5%, Cr- 12-17%, Ni- 1.2-5% Mo-0.5-1.2%, V- 0.2-0.5%
  Co- 0.2%
App - Anti corrosion coating, valve seats, pump bodies and rotors, hydraulic rams, hot rolling mills, static brakes for railway.

6.2 Nickel-Based Hardfacing Alloys
Ni-based alloys are generally deposited to improve the wear resistance during service at high temperatures. Carbon containing alloys are popular as a replacement for cobalt-based alloys. Molybdenum and tungsten additions improve the hardness and high temperature strength. Boron containing Ni-based alloys is also available in which the presence of hard chromium borides provide exceptional abrasion resistance. They have poor impact resistance due to the large volume fraction of hard inter-metallic precipitates.

- Nickel based- (200-250 HB) (as welded)

Chemical composition: C- 0.05-0.06%, Mn- 0.2-1%, Cr- 13-16%, Fe- 2.2-5% Mo- 6-16%, W- 0.8-4.5%
Co- 2.3-11.5% Ti- 3%
App- High speed forging tools, tube extrusion mandrels, pumps and valves for chemical and petrochemical industries

6.3 Cobalt-Based Hardfacing Alloys
Cobalt-based hard-facing alloys have been used widely for over 50 years because of their good wear, oxidation, and corrosion resistance combined with high hot hardness at temperatures sometimes approaching 980°C. The most commonly used Co-based hardfacing alloys are of the "Stellite" variety, with a nominal composition of Co-28Cr-4.0W-1.1C (wt%).

- Cobalt based- (40-47HRC)

Chemical composition: C- 0.15-2.3%, Mn- 1-1.5%, Cr- 2-30%, Fe- 4% Mo- 5.50%, W- 4.5-14% Ni- 3-9.5%
App- Vertical mill rolls, forging dies, hot shearing blades, Petrochemical and industrial valves, Valve seats for marine engines, wood and paper industries, rubber kneaders.

General Discussion:

Various methods of Alloy development have been adopted to get the required composition, for example Calphad method, Thermocale software, Schaffler diagram, etc. In the CALPHAD method, one collects and assesses all available experimental and theoretical information available on phase equilibria and thermo chemical properties in a system. The thermodynamic properties of each phase are then described through the Gibbs free energy, applying a mathematical model containing adjustable parameters. These parameters are evaluated by optimizing the fit of the model to all the assessed information, also involving coexisting phases. Following this it is possible to recalculate the phase diagram, as well as the thermodynamic properties of all the phases and the system as a whole. The CALPHAD method is used to obtain a consistent description of the phase diagram and the thermodynamic properties, to reliably predict the set of stable phases and their thermodynamic properties in regions without experimental information. It is also used for predicting metastable states.
during simulations of phase transformations. Thermocale is widely used for a variety of calculations including calculating Stable and meta-stable heterogeneous phase equilibrium, amounts of phases and their compositions, phase diagrams (binary, ternary and multi-component), Thermodynamic properties of chemical reactions, etc.

A Schaeffler diagram is used to represent the effect of the proportion of two elements (and therefore the composition of the alloy) on the structure obtained.

The current trend is toward the use of semiautomatic and automatic welding processes using FCAW and GMAW. GMAW uses either a solid wire or metal-cored welding wire, requires a gas shield, whereas FCAW uses welding wires that are used open-arc or gasless, as well as with a gas shield. SMAW with flux-coated electrodes is still popular for field on-site hardfacing applications, because the equipment is inexpensive and portable.

Laser cladding and Plasma transfer arc welding though being costly processes are very popular in terms of low dilution rates and higher power density, which are useful for powder metallurgy route.

**Conclusion:**

Hardfacing is the most versatile and economical process these days for reducing the cost of replacement and improving the life of worn out components. Wide variety of welding processes can be done on steel materials by hardfacing. Different alloying elements can be introduced in to the base metal in the form of weld consumables like tube rod, wire electrode or powder to achieve the desired properties like hardness, wear resistance, abrasive resistance, corrosion resistance, crack resistance etc.

- Melting of alloy followed by atomization or granulation, grinding and sieving are the process routes to achieving homogeneous hardfacing consumable powder with fine carbides in the microstructure.
- High hardness of carbides of carbide forming elements has direct relationship with their wear resistance for example Chromium. The smaller the carbide particles in the microstructure , better is the wear resistance.
- Both traditional and sophisticated welding methods can be used for hardfacing; however, dilution must be kept as low as possible to obtain optimal properties.
- Laser cladding and PTAW gives the lowest dilution rates which are used for Powder metallurgy routes only.
- Hardness of hardfacings vary with the welding method, this may be due to variation in dilution, which increases with increasing current or heat input and vice versa.
- Hardfaced parts reduce downtime, resulting in reduced maintenance cost, increased plant availability and improved organizational productivity.
- Hardfacing can be carried out as many times as possible and component can be reused before the wear gets to the substrate.
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