Combating Wear by Surface Modification Techniques

Vineet Shibe and Vikas Chawla

Abstract Surface modification techniques are used to enhance the service life of several engineering components by combating wear. Material loss due to wear in various industries is significantly high. Surfacing is a cost-effective and proven method of depositing protective coating. Research is going on over years to reduce the corrosion, erosion, and wear either in the form of using a new corrosion-, erosion-, and wear-resistant material or by improving these properties in the existing material by using surface modification techniques such as hardfacing and surface coating. The economic success of the hardfacing process depends on selective application of hardfacing material and its chemical composition for a particular application. In this paper, an attempt has been made to discuss the various types of surface modification techniques such as hardfacing and surface coating used for combating wear. Surface protection by different hardfacing techniques and surface coatings employed on the substrate surface of material by different methods and their advantages have been discussed.

Keywords Wear · Hardfacing · Surface coatings · Thermal spraying

1 Introduction

In well-designed tribological systems, the removal of material is usually a very slow process, but it is very steady and continuous (Archard 1980). The modes or different types of wear are abrasion, erosion, corrosion, adhesion, impact, and

V. Shibe (✉)
Department of Mechanical Engineering, Punjab Technical University, Jalandhar, Punjab, India
e-mail: shibevineet@gmail.com

V. Chawla
D.A.V. College of Engineering and Technology, Kanina, Mohindergarh, Haryana, India
e-mail: vikkydmt@gmail.com

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surface fatigue. The surface characteristics of engineering materials have a significant effect on the serviceability and life of a component thus cannot be neglected in design. Surface engineering can be defined as the branch of science that deals with methods for achieving the desired surface requirements and their behavior in service for engineering components. The surface of any component may be selected on the basis of texture and color, but engineering components generally demand a lot more than this. Engineering components must perform certain functions completely and effectively, under various conditions in aggressive environments. Engineering environments are normally complex, combining loading with chemical and physical degradation to the surface of the component.

Surface wear is a phenomenon, which effects how a component will last in service. Surface coatings can help to deal with the circumstances such as component working in an aggressive environment. In wear-resistant components, their surface must perform many engineering functions in a variety of complex environments. The behavior of a material is therefore greatly dependent on the surface of a material and the environment under which the material must operate. The surface of these components may require treatment to enhance the surface characteristics. Surface modification techniques such as hardfacing and surface coating may be used enhance the wear resistance. In this paper, surface protection by hardfacing techniques, manual metal arc welding (MMAW) process, and applications of hardfacing are discussed.

2 Wear

Wear is a process of removal of material from one or both of two solid surfaces in solid-state contact, occurring when two solid surfaces are in sliding or rolling motion together (Bhushan and Gupta 1991). The deterioration of surfaces is a very real problem in many industries. Wear is the result of impact, erosion, metal-to-metal contact, abrasion, oxidation, and corrosion, or a combination of these. Figure 1 shows the five main categories of wear and the specific wear mechanisms that occur in each category (Stokes 2008) (Figs. 2, 3, 4, 5).

3 Surface Protection by Surface Modification Techniques

Serviceable engineering components not only rely on their bulk material properties but also on the design and characteristics of their surface (Stokes 2008). Although considerable attention has already been paid by the researchers to develop modern techniques to prevent and control the problems resulting from wear; still, there is a need for further research to reduce the losses incurred. These wear- and corrosion-related problems can be minimized mainly by following two methods (Arulmani and Sunil 2003):

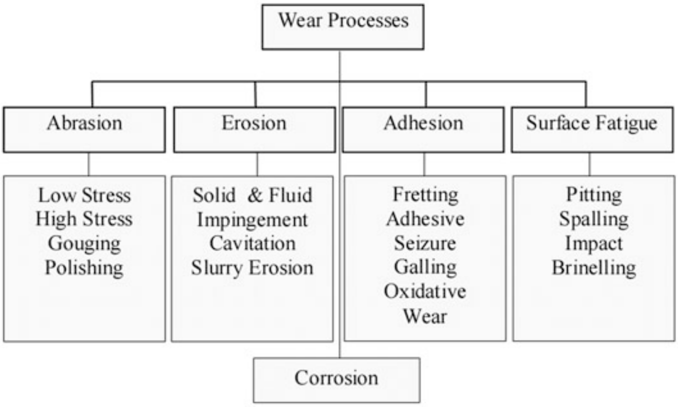


Fig. 1 Flowchart of various wear mechanisms

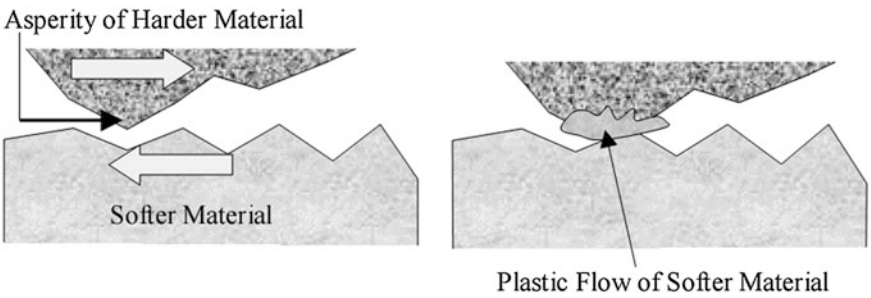
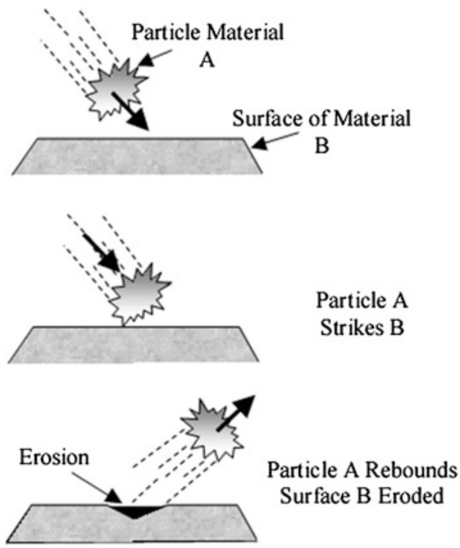


Fig. 2 Abrasion mechanism

- By using high-cost wear-resistant alloys/metals better than the existing low-cost ones.
- By improving the wear resistance of the existing metals and alloys by applying certain modifications to the surface.

Individuals and industry tend to focus on the wearing surface that has the greatest impact on their own economic situation. As the wear is a surface phenomenon and occurs mostly at outer/mating surfaces, it is more appropriate and economical to use the latter method of making surface modifications than using the former one which will not only involve very high cost of the operation but also involve longer time as compared to the second technique. To this end, a host of surface modification techniques can be used such as hardfacing by welding or thermal spraying in which a layer of strong and hard alloys is fused onto the surface of the component for improving its wear resistance (Winkelmann and Badisch 2009).

Fig. 3 Schematic of erosive wear



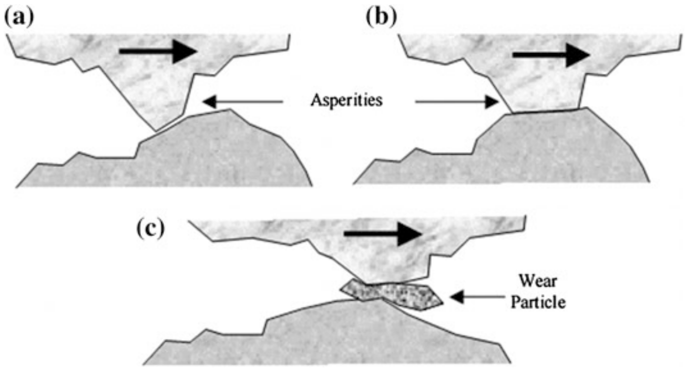
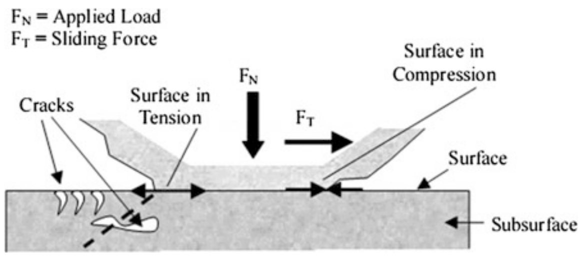


Fig. 4 Schematic of generation of wear particle as a result of adhesive wear

Fig. 5 Schematic of fatigue wear



4 Hardfacing

Hardfacing is one of the versatile techniques that can produce the hard and wear-resistant surface layer of various metals and alloys on metallic substrate. It not only helps them withstand wear, but also helps to prevent corrosion and high-temperature oxidation (Wang and Han 2008). Hardfacing is a commonly employed method to improve surface properties of agricultural tools, components for mining operation, soil preparation equipments, and others. An alloy is homogeneously deposited onto the surface of a soft material (usually low- or medium-carbon steels) by welding with the purpose of increasing hardness and wear resistance without significant loss in ductility and toughness of the substrate (Buchely and Gutierrez 2005). The hardfacing technique has in the mean time grown into a well-accepted industrial technology. Due to continuous rise in the cost of materials as well as increased material requirements, the hardfacing has been into prominence in the last few decades. MMAW process is commonly selected for hardfacing applications, as it is highly versatile and most economical (Selvi et al. 2008).

5 Hardfacing Deposition Techniques

The various types of hardfacing deposition techniques are as under:

- Thermal spraying
- Cladding
- Welding.

5.1 Thermal Spraying

These processes are preferred for applications requiring thin, hard coatings applied with minimal thermal distortion of the work piece and with good process control. These processes are most commonly used the coating material in the powder form, and almost any material capable of being melted without decomposition, vaporization, sublimation, or dissociation can be thermally sprayed.

5.2 Cladding

These processes are used to bond bulk materials in foil, sheet, or plate form to the substrate to provide tribological properties. The cladding processes are used either where coatings by thermal spraying and welding cannot be applied or for applications which require surfaces with bulk-like properties. Since relatively thick sheets can be readily clad to substrate, increased wear protection may be possible compared to thermal spraying and welding. If the coating material is available in sheet form, then cladding may be cheaper alternative to surface protection. It is difficult to clad parts having complex shapes and extremely large sizes.

5.3 Welding

Welding is preferred for applications requiring dense relatively thick coatings (due to extremely deposition rates) with high bond strength. Welding coatings can be applied to substrate which can withstand high temperatures (typically 7,900 °C). Welding processes most commonly use the coating material in the rod or wire form. Thus, materials that can be easily cast in rods or drawn into wires are commonly deposited. In arc welding, the substrate and the coating material must be electrically conductive. Welding processes are most commonly used to deposit primarily various metals and alloys on metallic substrates.

Hardfacing by arc welding is performed using all of the common processes and equipment. From the arc welding group, MMAW or stick welding is the most common and versatile process, although it does not provide the highest deposition rate.

6 Hardfacing Processes

There are various processes for hardfacing. They can be grouped in the following ways (Pradeep et al. 2010):

6.1 Hardfacing by Arc Welding

Shielded metal arc welding, flux-cored arc welding, and submerged arc welding.

6.2 Hardfacing by Gas Welding

Deposition by oxy-acetylene gas welding.

6.3 Hardfacing by Combination of Arc and Gas

Tungsten inert gas welding and gas metal arc welding.

6.4 Powder Spraying

Flame spraying, high-velocity oxy-fuel process, electric arc spraying, and plasma transferred arc.

6.5 Laser Hardfacing

Laser hardfacing (Laser Cladding).

7 Hardfacing Alloys

Different types of hard-facing alloys are available, and they fall into four general categories (Pradeep et al. 2010):

- Low-alloy iron-base alloys,
- High-alloy iron-base alloys,
- The cobalt-base and nickel-base alloys,
- Tungsten carbide materials.

8 Base Materials

Almost 85 % of the metal produced and used is steel. The term steel encompasses many types of metals made principally of iron. The various types of steels used in the industry for making different components for different applications are grouped into the following types (Pradeep et al. 2010):

- Low-carbon steels and low-alloy steels
- Medium-carbon steels
- High-carbon steels
- Other steels are low-nickel chrome steels, low-manganese steels, low-alloy chromium steels, and the electric furnace steels.

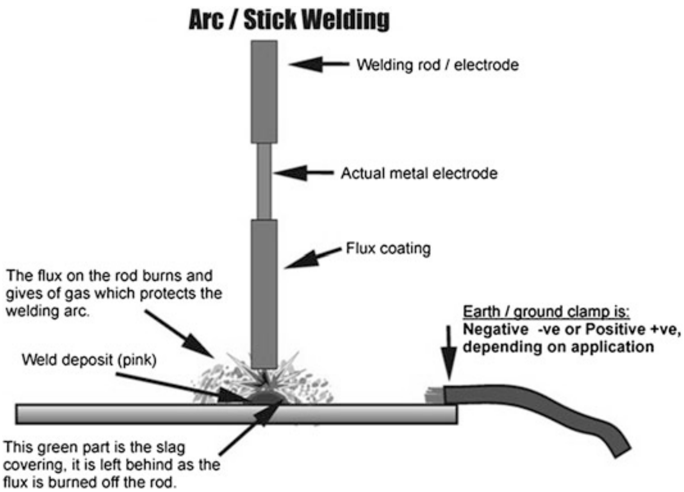


Fig. 6 Manual metal arc welding (MMAW) process

9 Manual Metal Arc Welding (MMAW)

Welding with stick electrodes is called MMAW. In this process, heat required for fusion is generated by the electric arc formed between a metallic electrode and the base metal. The electrode is consumed in the arc and provides the filler metal on the substrate. The extremely high arc temperature of over 5,000 °C permits it to supply a large amount of heat. Among the arc processes, MMAW is the most common, versatile, inexpensive one and has advantages in areas of restricted access and accounts for over 60 % of the total welding in advance countries and over 90 % of the total welding in India (Fig. 6).

10 Benefits of Hardfacing

1. *Most versatile*: Hardfacing is the most versatile process to improve the life of the worn-out component.
2. *Best chosen*: Hardfacing is the best chosen process these days for reducing the cost of replacement.
3. *Reduces downtime*: Hardfacing reduces downtime because parts last longer and fewer shutdowns are required to replace them.
4. *Any steel material*: Hardfacing can be done on any steel material using wide variety of welding processes.

5. *Desired property*: Different alloying elements can be introduced into the base metal in the form of weld consumables to achieve any desired properties such as hardness, wear resistance, abrasive resistance, and crack resistance.
6. *Longer service life*: Fewer replacements of parts are needed when parts are hard faced.
7. *Higher productivity*: Upon improving wear life, this contributes to the equipment working and producing more per hour. This increases the productivity and profits.
8. *Less downtime*: Greater availability of machine, a longer service life means that you will spend less time replacing the tips. This contributes to a reduction in operating costs.
9. *Reduced cost*: As wear resistance and hardness are the required at surface, one can deposit the superior material on the substrate to enhance the surface characteristics at less cost.

11 Some Industrial Applications of Hardfacing

Hardfacing is widely used in agriculture, mining, metallic, pulp and paper, dredging, foundry, petroleum, metal production, cement/concrete, glass, railroad, plastic, steel making, metal forming, brick/clay, and crushing/sizing industry. There are many different items that could potentially benefit from hardfacing on the farm. Primarily, hardfacing was used to restore worn pats, but nowadays, its use in making new components is also increasing.

12 Surface Coating Methods

Surface coating methods are classified as under:

- Thermal spraying (Metal Spraying)
- Chemical vapor deposition (CVD)
- Physical vapor deposition (PVD).

12.1 Thermal Spraying

It is a group of processes wherein a feedstock material is heated and propelled as individual particles or droplets onto a surface. Sprayed particles impinge upon the surface, and they cool and build up, splat by splat, into a laminar structure forming the thermal spray coating. A detonation gun unit mainly consists of a double-walled barrel, a combustion chamber, a powder feeder, and control panels to regulate gas flows and gas operation. The setup also includes an appropriate manipulator to hold the work piece and control its movements. A barrel is filled with a small amount of powder and an explosive oxygen–acetylene mixture. With the use of a spark plug, the mixture is ignited. After ignition, a detonation wave accelerates and heats the entrained powder particles. Instead of a continuous combustion process, it uses an intermittent series of explosions to melt and propel the particles onto the substrate. After each detonation, the barrel is purged with nitrogen. This step is essential to remove all remaining “hot” powder particles from the chamber; otherwise, these can detonate the explosive mixture in an irregular fashion. With this, one detonation cycle is completed. The above procedure is repeated at a particular frequency until the required thickness of coating is deposited. The process produces noise levels that can exceed 140 dB and requires special sound and explosion proof rooms. Depending upon the ratio of the combustion gases, the temperature of the hot gas stream can go up to 3,890 °C and the velocity of the shock wave can reach 3,500 m/s. Depending on the required coating thickness and the type of coating material, the detonation spraying cycle can be repeated at the rate of 1–10 shots per second.

12.2 Chemical Vapor Deposition (CVD)

It involves the dissociation and/or chemical reactions of gaseous reactants in an activated (heat, light, and plasma) environment, followed by the formation of a stable solid product. The deposition involves homogeneous gas-phase reactions, which occur in the gas phase, and/or heterogeneous chemical reactions, which occur on/near the vicinity of a heated surface leading to the formation of powders or films, respectively.

12.3 Physical Vapor Decomposition (PVD)

It is based on separating atoms from surfaces and accumulating (atomic or ionic) them to sub-material surface to be coated, by evaporating or sloping materials under vacuum. Coating material, in PVD method, is transmitted to surface in atomic, molecular, or ionic form, obtaining it not chemically but physically from solid, liquid, and gas sources. Chemical reactions can exist on main material surface too colder than CVD coating (50,500 °C); however, such a reaction formation is not necessary. It is more interesting that PVD operation is performed in relatively lower temperatures. In addition, after completion of coating, microstructure and properties of main material are not affected. PVD method is carried out by three methods called as evaporating, dispersion, and ionic coating.

13 Conclusion

Surface modification techniques improve the life of the worn-out component and reduce the cost of replacement. These techniques reduce downtime by extending the service life, and hence, few shutdowns are required to replace them. The purpose of surface technology is to produce functionally effective surfaces. Hardfacing and surface coating can improve the corrosion, erosion, and wear resistance of materials. Surfacing by hardfacing is an economical tool which can be used to increase the service life of the components used in various types of industries. The economic success of the surface modification techniques depends on selective application of material and its chemical composition for a particular application. Effort should be made for the right selection of surfacing materials and the process to achieve the full advantage of these techniques.

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References

Archard JF (1980) In: Peterson MB, Winer WO (eds) Wear theory and mechanisms. Wear control handbook. ASME, New York

Arulmani R, Sunil P (2003) Surfacing through plasma enhanced shielded metal arc welding. In: International welding symposium, pp 61–68

Bhushan B, Gupta BK (1991) Material coating and surface treatments. McGraw-Hill, New York

Buchely MF, Gutierrez JC (2005) The effect of microstructure on abrasive wear of hardfacing alloys. Wear 259:52–61

Pradeep GRC, Ramesh A, Durga Prasad B (2010) A review paper on hardfacing processes and materials. Int J Eng, Sci Technol 2(11):6507–6510

Selvi S, Sankaran SP, Srivatsavan R (2008) Comparative study of hardfacing of valve seat ring using MMAW process. Elsevier, J Mater Process Technol 207:356–362

Stokes J (2008) Theory and application of the high velocity oxy-fuel (HVOF), Thermal spray process. Dublin City University, ISBN 1-87232-753-2, ISSN 1649-8232

Wang X, Han F (2008) Microstructure and wear properties of the Fe–Ti–V–Mo–C hardfacing alloy. Wear 265:583–589

Winkelmann H, Badisch E (2009) Wear mechanisms at high temperatures part-1: wear mechanisms of different Fe-based alloys at elevated temperatures. Springer, Tribol Lett, pp 155–166