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A Review of Surface Modification Techniques in Enhancing the Erosion Resistance of Engineering Components

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Abstract
Material loss due to wear in various industries of engineering components is significantly high. Surface modification techniques are used to enhance the service life of several engineering components by improving their wear resistance. 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, and Thermal Spraying.

I. Introduction

Surface modification techniques such as hardfacing and surface coating can improve the corrosion, erosion and wear resistance of materials. In well-designed tribological systems, the removal of material is usually a very slow process but it is very steady and continuous [1]. The modes or different types of wear are: abrasion, erosion, corrosion, adhesion, impact and 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, as 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 different surface modification techniques such as hardfacing and surface coatings are discussed.

II. 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 [2]. The deterioration of surfaces is a very real problem in many industries. It occurs due to impact, erosion, metal-to-metal contact, abrasion, oxidation, and corrosion, or a combination of these different modes of wear.

Solid particle erosion is a result of the impact of a solid particle A, with the solid surface B, resulting in part of the surface B been removed, which is known as erosion of materials or components. fig. 1 shows the solid particle erosion mechanism.

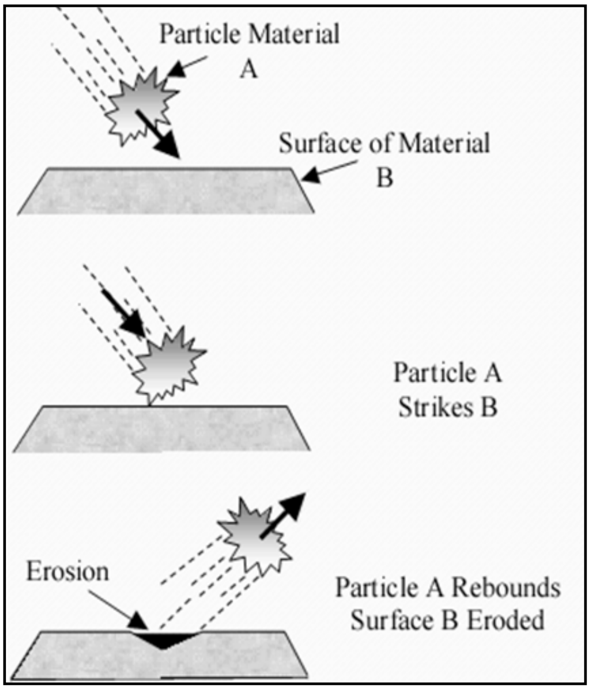

Fig. 1: Schematic of Erosive Wear

III. Surface Modification Techniques

Serviceable engineering components not only rely on their bulk material properties but also on the design and characteristics of their surface [3]. 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 [4]:

- 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, therefore 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 [5].

IV. 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 [6]. 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 [7]. 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. Manual Metal Arc Welding (MMAW) process is commonly selected for hardfacing applications, as it is highly versatile and most economical [8].

V. Hardfacing Processes

There are various processes for hardfacing. They can be grouped in the following ways [9]:

A. Hardfacing by Arc Welding

Shielded Metal Arc Welding [Amado et al., (2008)], Flux Cored Arc Welding [Coronado et al., (2009)], Submerged Arc Welding [Chang et al., (2003)].

B. Hardfacing by Gas Welding

Deposition by Oxy-Acetylene Gas Welding [Buchely et al., (2005)].

C. Hardfacing by Combination of Arc and Gas

Tungsten Inert Gas Welding [Kashani et al., (2007)], Gas Metal Arc Welding [Fouilland et al., (2009)].

D. Powder Spraying

Flame Spraying [Navas et al., (2006)], High Velocity Oxy-Fuel Process [Lin et al., (2006)], Electric Arc Spraying [Buchanan, (2009)], Plasma Transferred Arc [Oliveira et al., (2002)] etc.

E Laser Hardfacing

Laser hardfacing (Laser Cladding) [Ming et al., (1998)

VI. Hardfacing Alloys

Different types of hard-facing alloys are available and they fall into four general categories [9]:

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

VII. 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 [9]:

- 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.

VIII. Manual Metal Arc Welding

Welding with stick electrodes is called Manual Metal Arc Welding (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 5000°C permits it to supply a large amount of heat. Among the arc processes, manual metal arc welding 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. From the arc welding group, Manual Metal Arc Welding (MMAW), or stick welding is the most common and versatile process, although it does not provide the highest deposition rate.

IX. Benefits of Hardfacing

Hardfacing is the most versatile process to improve the life of the worn out component. It is the best chosen process these days for reducing the cost of replacement. It reduces downtime because parts last longer and fewer shutdowns are required to replace them. Fewer replacements of parts are needed when parts are hardfaced. Hardfacing can be done on any steel material using wide variety of welding processes. Different alloying elements can be introduced into the base metal in the form of weld consumables to achieve any desired property like hardness, wear resistance, abrasive resistance, crack resistance etc. Upon improving wear life, this contributes to the equipment working and producing more per hour. This increases the productivity and profits. 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. 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.

X. Some Applications of Hardfacing

Hardfacing is widely used in Agriculture, Mining, Metallic, Pulp & Paper, Dredging, Foundry, Petroleum, Metal Production, Cement /Concrete, Glass, Railroad, Plastic, Steel Making, Metal Forming, Brick/Clay, 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 now a day its use in making new components is also increasing.

XI. Surface Coating Methods

Surface coating methods are classified as under:

- Thermal Spraying (Metal Spraying)
- Chemical Vapor Deposition (CVD)
- Physical Vapor Deposition (PVD)

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A. Thermal Spraying

Thermal or Metal spraying 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, they cool and build up, splat by splat, into a laminar structure forming the thermal spray coating.

Thermal spraying has emerged as a suitable and effective surface engineering technology and is widely used to apply wear, erosion and corrosion protective coatings for various kinds of industrial applications. Cr_3C_2-based coatings have been applied to a wide range of industrial components. Cr_3C_2–NiCr coatings offer greater corrosion and oxidation resistance, also having a high melting point and maintaining high hardness, strength and wear resistance up to a maximum operating temperature of 900 °C [10].

Fig. 2 shows that coating material in the form of wire or powder is heated and accelerated towards the substrate to form a coating.

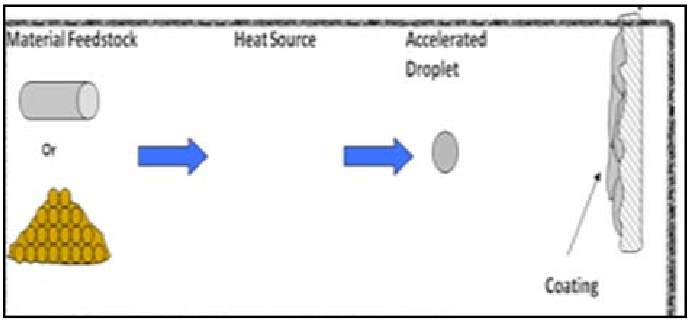

Fig. 2: Thermal Spray Process

Fig. 3 shows that the chemical energy of combustion of the fuel gas in oxygen is used to generate a hot flame. Feedstock material in the form of a wire or powder is melted or softened by flame or electricity and propelled onto the work piece to form a coating.

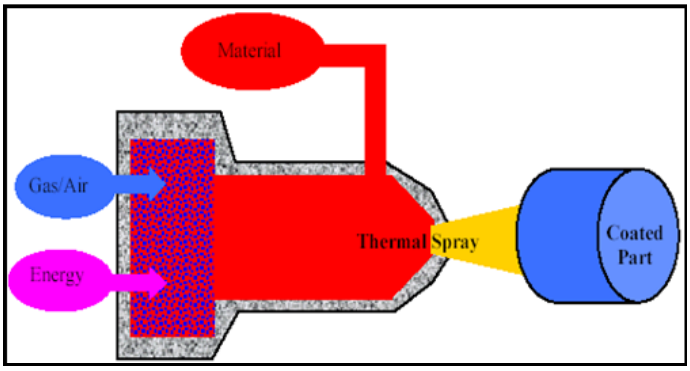

Fig. 3: Schematic of Thermal Spray

Thermal spray processes may be categorized as either combustion or electric processes. The combustion processes include low velocity flame spraying (wire or powder) and high velocity Detonation gun, High-velocity oxy-fuel (HVOF) & High-velocity Air Fuel (HVAF) thermal spraying. The Electric processes include Electric Arc Spraying and Plasma Spraying. Plasma Spraying is further classified as Atmospheric Plasma Spraying (APS), Vacuum Plasma Spraying (VPS) or Low Pressure Plasma Spraying (LPPS) and Controlled-Atmosphere Plasma Spraying (CAPS).

Fig. 4 shows the various types of thermal spray processes.

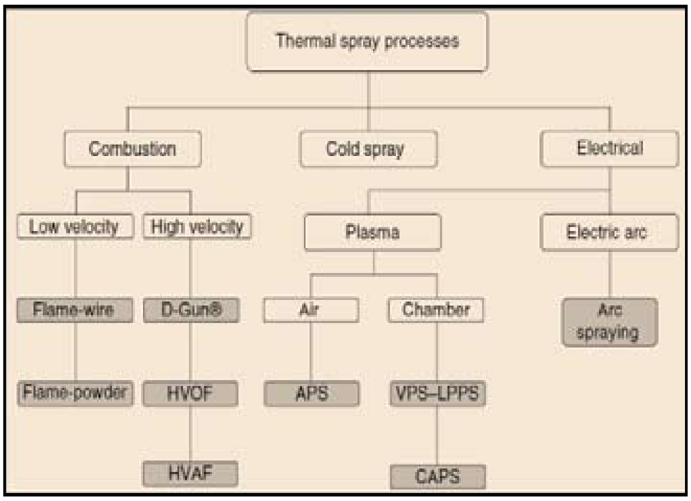

Fig. 4: Types of Thermal Spray Processes

B. Chemical Vapor Deposition (CVD)

It involves the dissociation and/or chemical reactions of gaseous reactants in a activated (heat, light, 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.

C. 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 source. Chemical reactions can exist on main material surface too colder than CVD coating (50500 °C); however such a reaction formation is no necessary. It is more interesting that PVD operation is performed in relatively lower temperatures. In addition, after completion of coating micro structure and properties of main material are not affected. PVD Method is carried out by three methods called as evaporating, dispersion and ionic coating.

XII. Conclusion

Surface modification techniques improve the life of the worn out engineering components and reduces their cost of replacement. It reduces downtime by extending the service life and hence few shutdowns are required to replace them. Hardfacing and surface coating can improve the corrosion, erosion and wear resistance of materials. Surfacing 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 depend 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. The various commercially viable coating techniques are thermal spraying, Chemical Vapor Deposition (CVD) and physical vapor deposition (PVD) methods.

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