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Surface Modification of Metals by Using Laser Surface Engineering and Physical Vapor Deposition – A Review

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Abstract:

Metal matrix composite is a new class of material that exhibits a good wear and erosion resistance properties, higher stiffness and hardness at a lower density as compared to the matrix. However, presence of the ceramic particles in metallic matrix makes the matrix brittle. In this regard, it may however be noted that wear is a surface dependent degradation which may be improved by a suitable modification of surface microstructure and/or composition. Hence, instead of bulk reinforcement if the ceramic particles would be added on the surface, it could improve the wear and erosion resistance without sacrificing the bulk toughness. Dispersion of ceramic particles on metallic substrate surface and the control of its distribution are difficult to achieve by conventional surface treatment. On the other hand, a high power laser beam and PVD may be used as a source of heat to melt the metallic substrate and ceramic particles may be fed externally on to the molten metal to form a metal-matrix composite. Studies on the related work are presented in this paper.

Keywords:

Physical vapor deposition, laser surface engineering, composites,

1. Introduction:

FAILURE of engineering materials due to fatigue friction, abrasion or corrosion is most likely to initiate at the surface because

1. Intensity of stress is often highest at surface and
2. Expose surface are or prone to environmental degradation.

The engineering solution to surface initiated failures is to provide component in use with surface properties different from those of bulk [1]. Differential properties between surface and the interior may be achieved by special treatments known as surface treatment [1]. Broadly surface treatments evolved either change in both surface composition and microstructure, are only microstructure modification of the near surface region of the component concerned. Wear and erosion are surface dependent degradation which involves progressive loss of material from the operating surface of a solid occurring as a result of relative motion between two surfaces [2]. Metal matrix composites are a new class of materials that exhibit good wear and erosion resistance properties, higher stiffness and hardness at a lower density as compared to the matrix [3]. However, the presence of the ceramic particles in the metallic matrix makes the matrix brittle [3]. Hence, instead of bulk reinforcement, if the ceramic particles would be added to the surface, it could improve the wear and erosion resistance without sacrificing the bulk properties [2]. Dispersion of ceramic particles on metallic substrate surface and the control of its distribution are difficult to achieve by conventional surface treatments [2]. In the present study, related research have been studied on the development of ceramic/intermetallic dispersed metal-matrix composite layer on the surface of commercially metals and Alloys to improve mechanical and chemical properties.

1.1 Surface Engineering:

Surface Engineering is almost as old as structural materials used by man.

From the beginnings of time until the early 70s of our century, mankind has worked on the development of surface engineering, although not aware ofthe concept. The term of surface engineering, in use in the world for over tenyears, remained undefined and its topical scope is still the subject of discussions [3].

The processes by which a component can be surfaced modified may be divided into three basic groups

1. The first group consists of processes which modify the existing surface in some way **without** a change in composition, such as shot peening, transformation hardening and surface remelting.
2. The second group consists of processes which modify the existing surface in some way, **with** a change in composition of the surface engineered layer being a critical feature of the process.
3. The third group consists of processes which apply a new material to the surface, generally referred to as coating processes.

1.2. Composite surfacing:

The surface characteristics of a component/structure can be changed without changing the bulk material properties by use of surface coating. The surface is modified by incorporation of metal powders, alloy powders and ceramic particles. The coating which is done by using ceramic particles develops a composite on the surface. Composite coatings have enormous commercial potential for applications, such as high-temperature coatings for turbine blades, conductive and erosion-resistant coatings for arc heaters, and protective and wear-resistant coatings for machine and tools. An ideal coating could possibly be identified by its properties, such as high hardness, high-temperature strength, wear and erosion resistance, oxidation and corrosion resistance, and strong adherence to the substrate. Such coatings enable the use of the structure/component even in aggressive environments.

2. Techniques employed for the formation of Composite coatings on the surface of the metals:

There are several methods which are used in surface modification by developing composite layers. They are described below.

2.1Physical vapour deposition:

Physical vapour deposition (PVD) is fundamentally a vaporisation coating technique, involving transfer of material on an atomic level. It is an alternative process to electroplating. The process is similar to chemical vapour deposition (CVD) except that the raw materials/precursors, i.e. the material that is going to be deposited starts out in solid form, whereas in CVD, the precursors are introduced to the reaction chamber in the gaseous state. It incorporates processes such as sputter coating and pulsed laser deposition (PLD).

Fundamentals of physical vapour deposition:

The PVD coating process involves deposition of the coating on an atom by atom basis from the vapour phase. There are four important stages as shown in Figure 1.

- Production of the vapour flux by a physical process (evaporation orsputtering).
- Transfer of the coating atoms from target to components through thegas phase.
- Deposition of the coating elements on the component surface.
- Incorporation of coating atoms into the layer.

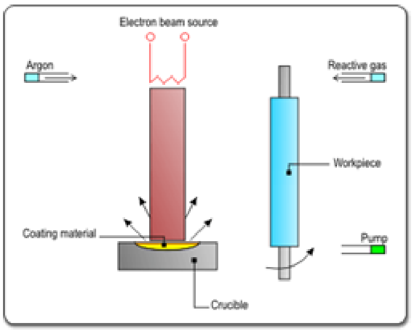

Figure 1 - Physical Vapour Deposition

Development of Composite surfacing by Physical Vapour Deposition Technique:

Due to the increasing importance of lightweight engineering and design driven by ecological and economic reasons, advanced composite coatings are needed to improve the surface properties of machine elements and system components made of light metals and their alloys, like magnesium and aluminum. Light metals in general exhibit very poor tribological properties in unlubricated condition resulting in severe seizing and wear. The application of thin solid lubricant coatings by PVD improves the tribological behavior significantly, but in many cases these coatings fail under high surface loading due to the low Young's modulus of the light metal substrate and the mechanical incompatibility of thin solid film and substrate. In addition, the damage tolerance of the coatings is unsatisfying.

Hollstein et al [4]presented relevant mechanical and chemical properties of various PVD-coatings on high purity (hp) AZ31 magnesium alloy specimens. The industrially very important layer systems TiN, CrN, TiAlN, NbN-(TiAl)N, CrN-TiCN and the multi-layer composite AlN/TiN are discussed in detail. Furthermore, the protective effect of CrN/NbNsuperlattices has been studied. All of these coatings were deposited by d.c. magnetron sputtering. The sputtering processes have been performed by two different coating devices-PLS 500 (laboratory scale) and HTC 1000y4 ABS (industrial scale). Both the mechanical behaviour and the corrosion resistance of the specimens have been studied after coating. The chemical composition of the thin films was analysed by GDOES. A special emphasis of the investigation was laid on searching for appropriate stripping procedures due to the fact that the substrate material is very reactive.The effects of thermal exposure on the microstructure, properties and failure of electron beam physical vapor deposited Al_2O_3–yttria stabilized zirconia (YSZ) gradient thermal barrier coatings (GTBCs) were studied**by Guo et al [5]**. The GTBCs, with lifetimes of more than 500 h for 1-h cycles and 13 h for 0.25-h cycles at 1100 8C, exhibited a better thermal shock resistance than two-layered-TBCs consisting of a NiCoCrAlY bond coat and a YSZ topcoat. The GTBCs also showed a relatively low oxidation rate under cyclic exposure, due to the formation of a pre-deposited Al_2O_3film on the bond coat. The oxidation of the bond coat is dominated by the selective oxidation of aluminum. The values of hardness and modulus for the Al_2O_3 –YSZ graded layer are in the range of 2.0–3 and 170–230 GPa, respectively, whereas after 500 h exposure a considerable reduction in the mechanical properties occurred in a rich Al_2 O_3 area of the graded layer. Micro-cracks initiated and propagated in the rich Al_2O_3area, and finally resulted in the spallation failure of the coating. The thermal conductivity of a GTBC was found to be 1.7 W/mK, which was marginally lower than that of the two-layered-TBC at 2.2 W/mK. However, the value of thermal conductivity increased up to 2.0 W/mK after 500 h exposure.

2.3 Laser Surface Engineering:

The development of high lasers with power densities of about 10^5 to 10^7 W/cm^2 has made the surface engineering practices of metallic materials truly versatile and precise. During laser surface engineering, the surface is heated locally at an extremely rapid rate (10^4 to 10^9 K/s)[6]. Due to a relative displacement of the sample with respect to the laser beam, the heated region is cooled at a rapid rate. The microstructures obtained are correspondingly fine and often possess unique features. The process may or may not involve surface melting is unavoidable if the surface composition needs to be altered, as in surface alloying(Figure 2)

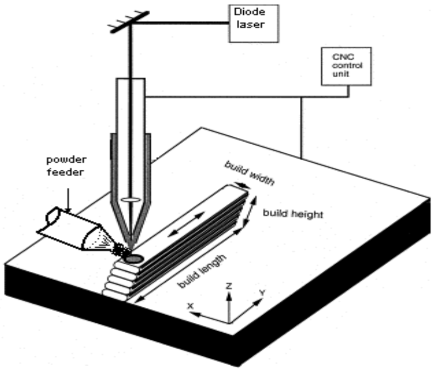

Fig. 2. Schematic diagram of Direct Laser Deposition (DLD) process

Development of Composite coating on Ferrous materials by Laser processing:

Cerriet al [7] developed a WC and TiC which are mixed with metallic alloys are deposited on a low alloy steel AISI 4140 using laser cladding. The coated layers obtained have been characterized by metallurgical examination. They show low dilution, absence of cracks, and high abrasion resistance. Gasser et al [8] investigated the densification of surface coatings by remelting with continuous wave CO_2 laser radiation as a function of the processing variables. The surface coatings (molybdenum, niobium, titanium and WC-Co) under investigation have been prepared on steel surfaces by plasma and flame spraying.

The remelting with laser radiation yields surface layers of high density and improved adherence, which only just influence the underlying steel substrates. HOSSON, et al [9] developed a coating by mixing Cr_20_3 and Fe powder on Duplex steel SAF 2205 using laser beam. Transmission electron microscopy observations indicated a proper bonding between substrate and coating consisting of a spinel structure around the composition $FeCr_20_4$ near the interface. In addition, particles with a spinel structure have been observed in the b.c.c, substrate. Crystallographic orientation relationships have been identified for the interfaces of the spinel structure with the b.c.c, matrix using electron diffraction. Axen et al [10] produced a TiC-steel composite clad layers containing about 50 vol.% TiC of 3 or 30 micron size on the tool steel 90MnCrV8 using a 3.5 kW CO_2 laser. The hardness and the volume fraction of retained austenite of the martensitic matrix were varied by heat treatments. The abrasive wear resistance was markedly influenced by the size of reinforcing TiC particles, matrix hardness, retained austenite and abrasive grit size. Incorporation of TiC particles enhanced the wear resistance by a factor of up to about 6 compared with the unreinforced steel after equal heat treatment. Pantelis et al [11] laser surface alloyed 4140 and high speed M2 tool steels with tungsten carbide injection and obtained a significantly higher hardness (900 HV 50 gf and 1200 HV 50 gf) as compared with those of the substrates (300 HV 50 gf and 250 HV 50 gf respectively). Friction and wear tests (using a plane-ring experimental device), revealed that the laser surface coatings on both steels present wear resistances considerably higher than that of a conventional plasma-sprayed coating.Fang [12] produced a TiC-WC coating on W18Cr4V steel by laser surface alloyed using a 2 kW CW-CO_2 laser under optimum processing condition. The microhardness and the wear resistance were found to increase due to the formation of special microstructures, i.e. a fine carbide network on a martensitic matrix (in the alloyed zone), a special martensite and a M_6C, M_4C carbide (in the heat-affected zone). The attritional wear resistance is strengthened greatly by laser alloying but the adhesive wear resistance is not improved.

3.CONCLUSION:

The conclusions which can be made from the review paper are, In this regard, it may be pointed out that though physical vapor deposition is capable of developing a thin and ceramic dispersed composite layer on the surface, however, limitations of coating thickness and week bonding (van-der-walls) at the interface are the problems associated with physical vapor deposition. Hence, the hard coating though is applicable for low stress abrasion, however, cannot be used under high stress abrasion and gauging abrasion. On the other hand, the unique advantages of the LSA technique for surface modification are now well recognized and include the possibility of localized treatment, refinement of the grain size because of rapid quench rates and the generation of meta-stable structures with novel properties that are not achievable by other methods.

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