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Recent Advancements in Developing Metal Matrix Composites with Arc-Assisted Cladding Techniques: A Review

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Abstract

Cladding is one of the flagship technologies of improving the surface dependent properties of metals. Heat-assisted technique of reinforcing foreign precursor material into substrate such as tungsten inert gas cladding, laser cladding and plasma transferred arc cladding are reviewed and presented in this paper. A comprehensive study of the research work of the present era in this particular field is also discussed here. Selection of different types of substrate material, reinforcing metal powder, type of heat source, the method of preparing coating powder (in paste form) and impurity-free substrate material respectively prior to cladding is also detailed after thorough investigation of different research papers. The type of tests which has to be done after cladding to evaluate the surface dependent properties are also discussed in this paper.

Keywords: Cladding, Materials, Metal Matrix Composite, Properties of Metal, Review

1.0 Introduction

Composite materials are formed by combining two or more materials with different properties. In composites, one material remains in matrix phase and the other is reinforced into it. Composites are made by different methods such as powder blending and compaction, stir casting, physical and chemical vapor deposition methods, and by coating of hard ceramic particles on a metal substrate. Coating of precursor material on a metal substrate utilizing high energy heat source is known as cladding and is used for manufacturing of surface-alloyed metal matrix composites. The surface topography of the coated surface is far better than the substrate in terms of wear resistance, surface hardness and corrosion resistance. This technique of laying a thick layer of foreign material protects substrate material from surface damaging properties such as wear and corrosion. The thickness of cladded layer is up to a certain millimeter from the top towards the bottom of the substrate surface. The microstructure and chemical composition of coated layer depends upon the dilution rate of precursor in the molten state.

Among various techniques of surface alloying, the arc assisted technique produces high quality, high performance metal matrix composites (mmc's) due to the uniform dilution of the foreign particle into the soft substrate material. In this way, arc assisted cladding has emerged as an attractive research field for the development of non-abrasive, anti-wear surface coating on the substrate.

Kumar *et al.*[1] fabricated Ti-TiB_2 reinforced mmc's on AISI 304 SS substrate utilizing Tungsten Inert Gas (TIG) arc and achieved highly wear resistant coated layer. The minimum and maximum average wear rate of the coated samples were 11.049×10^{-9} g /N–m and 27.63×10^{-9}

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g /N–m whereas that of as-received steel substrate was found to be 88.414 $\times 10^{-9}$ g /N–m. Kilinc *et al.*[2] fabricated Fe-Nb-B reinforced mmc's on AISI 1020 substrate with TIG arc and found that the surface hardness of the metal matrix composite significantly improved due to the presence of boride phases such as Fe_2B, NbB_2, Nb-Fe-B in the coated layer. The hardness of alloyed layer was 1689±85$HV_{0.01}$ whereas that of base metal was 181±7 $HV_{0.01}$. Das *et al.*[3] developed Gas Tungsten Arc (GTA) cladded composite coating on AISI 1020 steel substrate by reinforcing TiC-Fe powder mixture in different proportions (by weight %). The Scanning Electron Microscopy (SEM) micrographs of the coated samples were examined and it was found that when (10 % TiC - 90 % Fe) powder mixture was used then TiC particles dissolved completely whereas coating powder accumulated over the substrate and the metallurgical bonding between the coating powder and substrate material was not satisfactory when (20 % TiC-10 % Fe) ceramic powder composition was deposited.

Iravani *et al.*[4] deposited pre-mixed powder layer of Cu-Sn-Ti-Diamond on AISI 1030 mild steel specimen by laser. The SEM images of the laser-cladded samples were analyzed and found that with increase of scanning speed and with decrease in laser power, the clad-substrate bonding achieved was very poor or no bonding achieved. At optimum levels of scan speed and Laser power, hard coated layer of diamond particles surrounded by the TiC particles in the cladded zone were obtained. Deng *et al.*[5] checked the influence of coating thickness on the surface hardness of coated layer. The research team examined the Vicker's micro-hardness test data of deposited thick and thin coatings (2.5 mm and 1 mm) and found that the hardness of thin coatings was lower by only 5.65% as compared to that of thick coatings. This small amount of degradation in hardness of thin coatings shows that after worn out of upper layer of coatings by around 50%, the surface hardness still remains unchanged.

2.0 Requisites for Cladding

The fabrication of a cladded layer over a matrix material needs a lot of things such as substrate material, reinforcement material, suitable heat source, substrate and coating material preparation and proper method of applying cladding material on to the substrate.

2.1 Substrate Material

For enhancement of metal surface topography by cladding technique, the substrate materials used by different researchers are mainly low carbon steels, aluminum alloys and titanium alloys. Due to low cost, ease of weld ability and machinability; low and medium carbon steels are in demand for surface engineering applications. Sekhar *et al.*[6] stated that carbon steels have some drawbacks like poor tribological properties due to lack of carbon content and alloying element which arises the need of cladding.

Different AISI grades of low and medium carbon steels such as 1010 1020 and 1045 are used as substrate due to its low cost and ease of fabrication. Aluminum alloy such as 7005 is used as substrate due to its light weight. Some research groups selected Titanium alloys and Tool Steel as substrate material to improve its anti-corrosive and anti-wear applications.

2.2 Reinforcement Metal / Precursor/ Alloying Element/ Cladding Material

Reinforcement metal powders are generally hard ceramic particles i.e. oxides, carbides, nitrides and borides of different metallic elements. The metal compounds which is to be added on to the substrate as an alloying element is taken as a single entity or can be a mixture of two or more than two. Different types of hard ceramic particles were overlayed by utilizing different types of welding power sources.

When ceramic particles such as silicon carbide (SiC), Al_2O_3, titanium di boride (TiB_2) and titanium carbide (TiC) are used as a precursor material to make surface alloyed mmc's, the tribological property such as wear of the substrate's top surface has greatly improved[6,7].

In harsh service environments where chances of friction, wear, corrosion of parts are predominant; parts alloyed with single ceramic powders like WC, SiC, CrB_2, TiN, TiB_2, TiO_2 or a combination of two or more powders by mixing them in different proportions such as Cr-CrB_2, Al-Ni-TiB_2, TiB_2-Co, TiB_2-TiO_2, Ti-TiB_2, TiC-Fe, TiB_2-TiC-Al_2O_3, TiN-Co, SiC-B_4C to form a hard carbide layer improves the surface dependent properties of the coated layer. This precursor enriched hard top layer on the substrate acts as a thin protection film.

2.3 Heat Source

Heat source acts as an important parameter in order to control microstructure of newly formed metal compounds in the newly deposited layer onto the substrate material. The primary aim of using a heat source is to melt reinforcement particles just because it has to be diluted into the substrate. More the dilution, more the purpose of getting a hard, wear resistant layer onto the substrate surface is fulfilled. Different researchers utilized the energy of different type of welding arc such as TIG arc, plasma arc, laser beam, electron beam and High Velocity Oxy-Fuel (HVOF). The main benefit of using laser beam lies behind its property of localized heating and less heat affected zone. This unique property of laser beam pushed many researchers to use it for their different cladding purposes. Das *et al.*[8] fabricated surface-alloyed compositionally graded coatings on pure titanium matrix utilizing laser beam as a heat source.

2.4 Substrate and Coating Material Preparation

A homogenous thoroughly mixed coating material leads to proper distribution of it onto the substrate surface. Preparation of substrate material prior to cladding also puts a significant effect on the dilution rate of foreign metal powder in it. One important notable point is that, substrate material such as mild steel if used; it is very prone to dry corrosion. The dust free, polished mild steel if kept in open atmosphere; the chance of getting its surface attacked by atmospheric gases leading to corrosion is too much. So, it is better to prepare substrate material just before the coated tracks are to be deposited in case of carbon steel or the polished carbon steel substrate is to be stored in an enclosed space.

As received substrate material is first polished with the help of different grades of SiC emery paper starting from coarse to fine and then dipped into Acetone. Coating materials with different composition ratios is weighed and proper mixing is done. Into this mixture, Poly-Vinyl Alcohol (PVA) and distilled water is added to form semi-solid. This paste of coating material is preplaced as a layer on substrate. Now, the substrate covered with a thin layer of precursor is kept in oven for drying at least for few hours at elevated temperature to remove moisture content from it. Then, after oven- treatment, a suitable heat source is taken such as TIG- arc to melt the precursor and substrate material. Due to melting and solidification, new coated tracks are obtained in which the dilution of the precursor material into the substrate had taken place.

3.0 Tests to Evaluate Surface-Dependent Properties

Tests are conducted after the coated tracks are deposited. Tests help in evaluating the surface properties in a more concrete way. The first test that has to be conducted after the coated tracks are being deposited is Vicker's micro- hardness test. After that, SEM, X-ray Diffraction (XRD), Energy Dispersive Spectroscopy (EDS) and Wear test (by pin-on-disk tribometer) has to be done. The reason behind performing the micro-hardness test first is that if it is known from the micro-hardness test results that surface hardness of the coated specimen is improved as compared to the surface hardness of the as received substrate material, then performing other tests for material characterization, microstructural study of the newly formed metal-compounds if any in the newly deposited layer will become meaningful. On the other hand, if micro-hardness test results reflect that the surface hardness of the coated tracks are poor than that of the substrate material, then it is almost meaningless to perform the other tests such as SEM, XRD or wear test of the coated tracks. Material characterization of the coated tracks is done by examining the test reports of XRD, SEM and optical microscopy respectively[8,9].

4.0 TIG -Arc Assisted Cladding

For surface cladding of materials like low and medium carbon steels, aluminum alloys; TIG arc is utilized successfully by different research groups in a number of ways by altering different process parameters such as scanning speed, current level and polarity[10]. While cladding with TIG-arc, a non-consumable tungsten-electrode is used inside the TIG-torch whereas inert gas like argon and helium flows continuously providing a protection shield to the coating environment[11].

Surface alloying taking the advantage of constricted TIG-arc has been widely used to develop low cost, ceramic particle reinforced metal and alloy matrix composites. In this way, the surface dependent properties such as

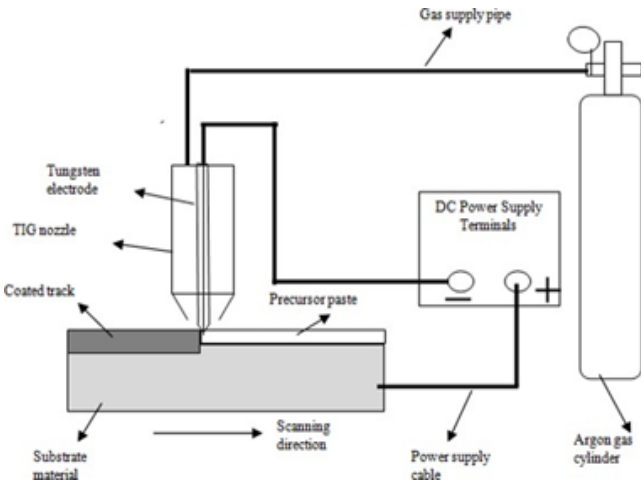


Figure 1. TIG –arc assisted coating track deposition technique over a substrate material.

hardness, oxidation, corrosion etc., are greatly improved. Properties like wear, coefficient of friction of the cladded layer are also far better than that of as received substrate material. This technique involves dilution of surface alloying foreign particle into the substrate material by applying a high energy heat source such as TIG arc resulting creation of thin protection film over the substrate after solidification[12,13].

Kumar *et al.*[12] fabricated AISI 1020 steel matrix composites by depositing a layer of TiB_2-CO coating material with TIG-arc. After coating, SEM of the coated specimens conducted to examine the micro structural changes. XRD is performed to examine the composition of the newly deposited layer i.e. whether formation of new metal compounds if any in the coated layer happened or not. Vickers micro hardness test of the coated surface is performed to check the degree of improvement in surface hardness of the newly formed layer on the substrate material. Finally, wear test on pin-on-disc Tribometer set-up is done to check improvement (if any) in terms of wear resistance. Kumar *et al.*[13] fabricated TiB_2-TiO_2 alloyed AISI 1020 matrix composites utilizing the energy of TIG arc. It was observed that the maximum micro-hardness of the coated tracks was near about 568 VHN which was 3.5 times greater than that of as received substrate material (157 VHN). Wear test of coated pins and as-received 1020 substrate done on pin-on-disc tribometer and the wear test results depict that the former (coated pins) have 2.5 times lower wear rate to that of later one. Das *et al.*[3] fabricated TiC-Fe reinforced TIG cladded 1020 steel matrix composites. After examining the Vicker's micro hardness test reports, it was concluded that the hardness value of coated tracks varies linearly with increasing TIG current levels and also with amount of reinforcement particle addition (by weight percent) in cladded zone. Experimental setup of TIG-arc assisted surface alloying techniques shown in Figure 1.

5.0 Laser Cladding

Laser cladding is a new and advanced coating technology due to its several advantages over conventional cladding processes. The unique features of laser cladding process are rapid transformation of carbon in carbide form, low dilution rate of coating powder into substrate, fine and uniformly distributed grains and small heat affected zone. This is due to the fact that laser beam is a type of high energy heat source which acts on the substrate for a very small period of time[14]. The feature of laser beams such as localized heating leads to curing of desirable areas of substrate material by controlling the different laser parameters such as laser beam power, scanning speed and shielding gas flow rate[15].

Masanta *et al.*[16] executed comparative study of wear characteristics between coatings developed on SS 304 and 1020 mild steel. Both the substrate specimens are coated with a mixture of TiB_2, TiC and Al_2O_3 ceramic powders in a proportionate amount. After examining the test reports, the author(s) found less wear rate and high hardness value of SS304 matrix mmc's as compared to that of 1020 carbon steel matrix mmc's. Majumdar *et al.*[17] investigated laser cladded, SiC reinforced mild steel matrix composites. It was observed from the test reports that micro hardness of the coated tracks was in the range of near about 600 VHN as compared to 190 VHN of as received substrate material. Mahmoud *et al.*[14] investigated the effect of 316L stainless steel powder reinforcement through Laser cladding on mild steel substrate. From SEM micrographs, it was evident that as laser power decreases; depth of fusion zone decreases accordingly. The maximum hardness value achieved at the clad-substrate interface zone. Oliviera *et al.*[18] deposited (Co–Cr–W–C)-Stellite 6 coating on AISI 304 SS substrate with Plasma Transferred Arc (PTA) cladding and laser cladding. From test results,

it was found that the laser cladded samples exhibit higher hardness than PTA cladded samples keeping other process parameters remaining same.

6.0 Plasma-Transferred Arc (PTA Cladding System)

The energy evolved by burning of inert gases like Argonin the plasma state is utilized by different researchers for cladding purposes. This high energy plasma arc produces intense heating of materials at elevated temperature and therefore is a suitable candidate for the surface treatment of substrate materials to convert them into mmc's[19]. Surface treatment using plasma arc has gained much popularity in this decade as it produces defect -free alloyed–surface with good inter metallic bonding[20,21].

In PTA-cladding, plasma gas flows inside through the inner cone of the nozzle whereas the shielding gas flows through the outer cone of the nozzle. In case of DC welding power source; The circuit is at first established between the non-consumable tungsten electrode (2% thoriated) and the torch body itself and is known as non-transferred mode of plasma arc. In Transferred mode, the circuit is established between the electrode and the substrate material. When cladding starts, Pilot arc initiates first and then within no time, the machine changes from non-transferred to transferred mode and the main arc comes into picture.

Cheng *et al.* selected plasma arc as a heat source for developing TiC–TiB_2 reinforced Alloy Matrix Composites (AMC's). After coating, test reports of coated tracks were examined. Further the research group concluded that harness and wear resistance of the coated tracks varies linearly with the amount of addition of ceramic particles into High Entropy Alloy (HEA) matrix. Zhu *et al.*[19] fabricated plasma arc treated coatings on alloy matrix (HEA) by reinforcing TiN and Al_2O_3 into it in powder form. Tests results depict considerable improvement in surface hardness of coated tracks as compared to as-received HEA substrate.

Oliviera *et al.* used PTA-cladding technique to deposit 3 mm thick tungsten carbide (WC) -Fe enriched composite coating on AISI 1020 steel substrate without substrate preheating. Two combinations of powder (5%WC and 95% Fe) and (35%WC and 65% Fe) were used for coating. From Vicker's micro-hardness test results, it was found that surface hardness of coated tracks significantly improved in comparison to as received substrate. It was also concluded that increase in amount of tungsten carbide after a certain limit does not improve the surface hardness of the coated layer significantly since test results depict that 35 wt. % WC reinforced coated samples resulted similar hardness to that of 5 wt. % WC reinforced coated samples.

7.0 Conclusion

In the present review, hard coating layers of different metal powders deposited on different substrate materials by TIG cladding, Laser cladding and PTA cladding processes are thoroughly investigated. It was found that the newly deposited layer on the substrate material remains far better in terms of surface characteristics. This is due to dilution of precursor material into the substrate top surface at elevated temperature. The removal of dust, dirt or any type of unwanted particles from the substrate specimen also enhances the dilution rate of reinforcement into it.

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