Recent Trends in Surface Cladding on AISI 1045 Steel Substrate: A Review

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Abstract. This paper gives the informative review and enlighten the important characteristics and development of different cladding techniques applied on AISI 1045 medium carbon steel substrate material. The paper focuses on the cladding methods used on AISI 1045 steel follows the way of surfacing via fusion. The cladding practice like wire feed, powder blown are taken into consideration. Different cladding methods such as Tungsten Inert Gas (TIG) Arc cladding, thermal spraying, laser cladding and electron beam cladding has been compared for better understanding. The application of various cladding powders by TIG cladding technique on AISI 1045 steel substrate material is presented by exhaustive critical review of various research papers of the era. The importance of TIG cladding process has been discussed.

Introduction

AISI 1045 steel is one of the most usable medium carbon steels with excellent mechanical properties that is widely used in the automotive industry. Forging camshafts and cams needs material characteristics such as hardness, wear resistance, and higher strength. In order to achieve desirable microstructures and excellent mechanical properties, manufacturing conditions such as alloy content and cooling rate were changed in industrial practise. As technology progressed, the demand for better surface properties grew in popularity. There have been many advances that may be classified as "surface engineering." Coating, also known as cladding, is the process of creating a modified or new surface phase in a solid substrate [1–4]. Cladding is commonly used to improve properties near the surface while leaving core characteristics unchanged. [5-7]. Metals can be resurfaced using a melting process in which an intense energy source is used to fuse the substrate's surface as well as the reinforcing particles. [8]. When the reinforcing particles and base material solidify, this results in a tight metallurgical bond. Injection of powder, pre-place, powder surfacing or wire feed methods may all be used to apply reinforcement to the substrate material's surface. [9-11]. Several common techniques for surfacing AISI 1045 substrates have been investigated, including tungsten inert gas cladding [3,9,10,12–19], laser cladding [1,2,4,20–23], electron beam cladding [24,25], and thermal spraying [5,8,9,26–36]. The TIG cladding process uses an electric arc to generate a heat arc between the electrode (tungsten) and the substrate surface. Shielding gases like hydrogen, helium, argon, and a mixture of both helium and argon are used to protect the molten layer from contamination during the melting process. Following the solidification of the melted sheet, a new micro-structure with altered hardness and wear performance is created. Laser cladding is a non-conventional technique that involves fusing another material to the substrate surface. The process involves depositing coating material onto a substrate using a laser heat source. As a result, laser cladding (coating) emerges as an alternative surfacing technique. The technique can create coating layers with low dilution, better solid metallurgical bonding, and lesser distortion with the substrate on a large variety of candidate materials [23, 24]. Low porosity and a homogeneous microstructure can be achieved using the laser cladding technique. Researchers suggested that the thickness of the film be monitored by adjusting the process parameters. In the electron beam cladding (EBC) process, a high velocity accelerated electrons is used to melt target metal. Thermionic emission occurs when cathode filament is heated in a negatively charged state, as a result electron are emitted. The beam of electrons bombarded into the surface of substrate at a speed of up to 0.7 times the speed of light. About 95% heat energy is generated by the kinetic energy of the electrons. The highest power density that could be achieved is 1010 Wm^{-2}. The electron beam has a diameter of between 0.3-0.8 mm. One of EBC's superior abilities is the ability to deep melt the surface layer due to its high-power density. This may be useful for coalescence of two metals, but the surface alteration does not need as much heat because the target focus is to reshape the top surface layer of the metal. [28] Another method known as thermal spraying that involves heating the coating material and depositing it on the substrate in individual particles. Sprayed reinforcing particles strike the ground, solidify, and form a laminar structure, resulting in a new/altered coating layer. [31-33].

Table 1: - Surface alteration approaches

Methods	Tungsten Inert Gas (TIG Arc) cladding	Electron beam (EB) cladding	Laser cladding (LC)	Thermal spraying (TS)
Fundamentals	A negatively charged tungsten electrode and positively charged metal substrate produces electric arc, hence heat is generated. Argon gas works as a shielding agent to prevent contamination and oxidation.	An electron beam is a high kinetic energy accelerated beam, when an electron beam is bombarded with a substrate material, the kinetic energy of the electrons is changed into heat, causes the fusion.	Laser cladding is an unconventional technique that involves melting one material to a substrate's surface. With a pre-set spot size, the laser beam is directed at the substrate. An inert gas transports the powder coating content into the melt pool using a nozzle	The cladding substance is sprayed on surface of substrate then heated. The sprayed particles collide with the surface of substrate, melting and solidifying to create a modified/new coating layer.
Advantages	There is no need for flux since inert gas shielding is used, so there is no inclusion or slag, high surface characteristics, ease of operation, lesser installation & maintenance costs, and a wider range of materials can be used. Less distortion is caused by small fires or sparks.	Since the process is carried out in vacuum, there is no scattering of electrons, and the surface quality is excellent, even on materials with higher thickness. Less distortion & shrinkage due to a more reliable and repeatable process, as well as a better regulated process.	Because of the concentrated heat source, coating can be accurately positioned, resulting in complete metallurgical bonding with low porosity and voids, high regularity, and a broader variety of products that are more energy efficient	The highest rate of deposition is up to 15 kg/h, and there is a wide variety of cladding materials that are easy to use and need little input power, and they can be used on heat sensitive substrates that need less heat, such as electronic components.

Disadvantages	Rate of dilution is high. Because of the limited heat sources, it is not ideal for thicker materials or sluggish processes.	X-rays produced during the operation. Due to the limited size of the vacuum set-up, installation costs are high and are dependent on the vacuum chamber.	Due to random disruption in the system, sensitive process may lead to poor quality weld. Comparatively higher cost.	Higher oxide and porosity levels comparatively; hard to achieve thicker coating; high installation cost; more dust and fumes produced; therefore, health and safety issues; higher oxide & porosity comparatively.

Surface cladding trends on AISI 1045

The material's surface property is critical for extending the existence of mechanical components. To achieve the surface alteration, ceramic particles were added to the matrix material's surface using different techniques to improve the material's surface properties. Surface composites are processed using molten phase processing at elevated temperatures. Matrix and the reinforcement form an interfacial reaction, and the chances of any harmful phases forming are strong. Ceramic particles were applied to the matrix surface and treated with TIG arc, EB irradiation, LC, and TS techniques in order to improve the material's surface characteristics. Areley et al. [1] used a 2.5 kW CO2 laser to deposit TiC on an AISI 1045 substrate. The existence of undissolved TiC particles was found to have increased the surface hardness. According to Wang et al. [3] TIG heating deposits coating layer of a mixture of powders containing (FeBrBSi, graphite and ferro-titanium on AISI 1045 steel. The findings revealed that during the TIG welding process, a metallic bonding of graphite and ferro-titanium and graphite can produce TiC grains. The cladded composite surface achieved has a significant improvement resistance against wear and micro-hardness because of development of titanium carbide grains. Similarly, Xinhong et al. [10] used a TIG process to deposit Fe-based self-fluxing, ferro-titanium, graphite and FeCrBSi powder to the substrate of C-45 steel grade, resulting in an in-situ system coating to manufacture an iron based composite surface with titanium carbide grains. TiC particles in the range of 3-5m were synthesised from graphite and ferrotitanium powder and uniformly spread in the matrix. TiC particles having higher hardness in the matrix enhanced the composite coating's hardness and wear resistance. On an AISI 1045 steel substrate, Zhao et al. [19] used tungsten inert gas cladding to deposit an in-situ synthesised $(Ti\text{-}Cr\text{-}Nb\text{-}Mo)_x\ C_y$ grains ceramic coating reinforcement. Closed packed grains, no cracks, and porosity characterise the coatings. The cladding's contact with the AISI 1045 steel substrate appeared to be seamless, reliable, and free of flaws. The substrate and the coating may have a strong metallurgical bond. Dark ceramic particles are mixed with a white Ni alloy binder to create the coating. Ceramic particle size and quantity vary from the root to the peak of the cladding grew in the proportion and amount in a gradient pattern. 5 times higher hardness value was achieved in comparison to AISI 1045 steel substrate. On an AISI 1045 steel substrate, Zhao et al. [18] used a TIG arc to create a cermet cladding layer based on (Ti, W) C. Close packed grains, no cracks, and porosity make up the cladding layers. Uniformity, continuous, and almost without defect cladding layer's is achieved at interface with the AISI 1045 steel substrate. It is possible to achieve fairly good metallurgical bond between the cermet and AISI 1045. Dark ceramic particles are bonded together by a white Ni alloy binder in the cladding layer. The peak

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hardness of 1365 HV was obtained, nearly 600% harder than substrate. The cladded layers have excellent abrasion resistance. AISI 1045 steel substrate cladded by TIG arc with a placeable coating of ferro-titanium powder, the by the change in amount of nitrogen as shielding gas and their effects were studied by Hojjatzadeh et al. [12]. As the shielding gas's nitrogen content increases, an increment in penetration depth and area of cross section is observed in cladded surfaces. Two major microstructures emerged with the varying content of nitrogen: 1. Titanium-Nitride nano-structure spread in an alpha phase ferrite Fe_3C matrix is achieved with the increment of nitrogen, & 2. Ti (C_xN_y) in an alpha phase ferrite–Fe_2Ti matrix at a lower nitrogen content. In a crystal dissolved under pure argon, titanium carbide in a matrix of alpha ferrite, eutectic composition of alpha phase ferrite, and Fe2Ti was discovered. Tian et al. [29] used Fe-based cored wires as and spray device HAS-02, On the surface of AISI 1045 steel, FeNiCrAlBRE coatings were sprayed. The following were the wire arc spray system's parameters: The spray voltage is 30-34 V, the current is 14-160 A, pressure is 600 kPa (compressed air), and the gap is 200 millimetres. The arc sprayed FeNiCrAlBRE coatings undergo surface remelting, which results in a changed structure with reduced porosity, increased structure dispersion, and material homogenization, all of which led to improved wear resistance. Depending on how much heat was added to the coating after remelting, the Al_2O_3 form from an uneven block to a streamlined strip. Atoms diffused between both the layer of oxide and the surface matrix. There are no gaps or pores evident in the cladding layer after remelt. This layer has a smaller abraded volume, width, weight, and penetration than the spraying cladding. TIG is a popular and cost-effective method of improving the properties of arc-sprayed coatings. Tian et al. [30] produced as-sprayed coatings on AISI 1045 steel by using 2 mm diameter Fe–Ni–Cr–Al cored wire. The transformation Fe-Fe occurs as a result of the remelting treatment. Coated specimens have a much higher wear resistance than uncoated specimens. Separation of oxide into layers is the root cause of wear in sprayed coatings, according to thin flakes and energy dispersive spectroscopic analysis. The key abrasive wear mechanisms of remelted coatings are cutting and ploughing. Using cladding via laser and cladding by hybrid-laser induction, Zhou et al. [2] developed NiCrBSi powdered by 50% weight WC composite cladding on substrate of steel using LIHC. Prior to dry sliding wear, SEM and diffraction by X ray were used to investigate the micro-structure and phase constituents in composite coatings also XRD for wear. The height of cladding with LC was significantly more than LIHC with same laser processing conditions, while the heat affected zone, width of cladding, dilution, and efficiency of powder utilisation were significantly lower in LC. Sharifitabar [16] used a TIG coating process to coat AISI 1045 steel with Fe–TiC–Al_2O_3 coatings. Cladding precursors were $3TiO_2$-4Al-4.5C–1.71Fe. Using a TIG arc cladding process, substrate and mixture were melted together. The precursor was used to create a composite with 20 vol. percent reinforcing phases. Separately or on Al_2O_3 particles in a four-step process, in front of the molten pool, TiC is formed in Fe particles, when Fe grains enters molten pool, titanium carbide re-precipitated during solidification and TiC dissolution into the melt. Due to partially dissolution of few titanium carbide grains, TiC-Al_2O_3 territories formed in the cladded bead. Cladding micro-hardness improved and attained a maximum value 830 HV, increasing the resistance against abrasion of AISI 1045. Li et al. [35] are a group of researchers who came up with a novel approach an 800 μm thick coating layer was created spraying through plasma and arc remelting using on a steel substrate AISI 1045. Before and after TIG remelting, the NiCrBSi coating's microstructure and phase composition were investigated. The modulus of elasticity, fracture-toughness micro-hardness and resistance against wear of the material have all been tested. The results clearly show the improvement in the above-mentioned characteristics by the application of plasma sprayed and TIG remelting method. A similar study is carried out by Li et al. [26] confirms the feasibility of this method and found to have an improvement in the dense Ni based plasma sprayed coating's microstructure and interfacial properties. Dong et al. [32] fabricated Ni based coating on a AISI 1045 steel grade by the method of plasma spray and TIG remelting. Results confirms the feasibility of TIG remelting for the coating and the microstructure of coated substrate enhanced with a significant improvement in corrosion resistance. Dong et al. [31] uses the methodology of coating with plasma spray and then remelting by TIG arc for the cladding layer of FeCrBSi on AISI 1045 steel, results shows that the feasibility of coating is very high and found to have a good characteristics of wear resistance. Yuan et al. [36] Used plasma sprayed coating then remelting of the layer by TIG arc technique for NiCr-Cr_3C_2 coating on a substrate made of AISI 1045 plate. The experiment was carried out to see how remelt by TIG affect the micro-structure and resistance against wear characteristics of NiCr-Cr_3C_2 coatings. Cladding of NiCr-Cr_3C_2 results in a significant improvement in microstructure, mechanical, and wear characteristics, as anticipated. Hao Liu et al. [23] and Jian Liu et al. [22]. The surface properties of AISI 1045 steel were improved by coating it with a high-entropy alloy (HEA), Al- CoCrFeNiTi. A good metallurgical bonding between coated alloy and substrate is achieved. As compared to substrate excellent wear and corrosion resistance shown by coatings. 4.5 times higher microhardness (865 HV) is achieved with respect to AISI 1045. Coating showed the best corrosion resistance. Jing Liu et al. [4] Deposited composite coatings of γ-Niss/Mo_2Ni_3Si on AISI 1045 plate by CO_2 laser (10.6 μm) wavelength. SEM with an attachment of EDS and XRD was used for phase constitution and microstructure study. Various mechanical properties e.g., microhardness, dry sliding wear behaviour and toughness of the coated plate were analysed. The result depicts that a much higher improvement in wear characteristics of coated alloy with respect to the substrate. Dong et al. [5] Coated NiCrBSiNb on a steel ring made of C 45 grade by the method of plasma spray and induction remelting. After coating microstructure were analysed, hardness test and wear test has been conducted. The result indicates that spray coating defects has been nullified almost and a great metallurgical bond between NiCrBSiNb and AISI 1045 was achieved. There is an efficient & significant improvement by the plasma sprayed coatings and induction heating for remelting in microstructure and wear resistance. Li et al. [27] Prepared NiCr-Cr_3C_2 cladding with plasma spray followed by remelting through tungsten inert gas arc on AISI 1045. A comparative study has been carried out before and after remelting of the NiCr-Cr_3C_2 coatings at different temperatures namely 25 ^{0}C, 200 ^{0}C, 400 ^{0}C, and 600 ^{0}C at each temperature microstructure, hardness and the wear test has been done. The outcome reveals that coating's internal structure appeared dense, there is a large reduction in defects. Also, there is an increase of 13.3% hardness on cladding surface after remelting and the surface was found to be uniform. The NiCr-Cr_3C_2 coating has been shown to greatly improve wear resistance, and the microstructure can be improved by tungsten inert gas arc remelting.

Summary and Future Outlook

In this review article a comprehensive review on surface modification through various surfacing methods is presented. The mechanical properties such as tensile strength, hardness & flexural strength is increased due to formation of intermetallic phases. The tribological, mechanical and corrosive properties of modified composite surface is improved due to uniform mixing of reinforcement particles with matrix. TIG arc method is a straightforward and movable method in comparison with conventional heat treatment methods hence, it is convenient method for altering the selective region.

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