Surface Modification of Engineering Materials Using TIG Cladding Technique: A Review

Joydip Ray, Sanjib Kumar Acharyya, and Dipten Misra

Abstract High temperatures and pressure settings used in industries such as petrochemicals, power plants, and vehicles cause significant wear and corrosion to many components. Improving the corrosion and wear resistance of those components is therefore essential. To enhance a material's surface qualities, a variety of techniques are frequently employed, including thermal spraying, CVD, PVD, and laser cladding. Researchers have investigated the effectiveness of the TIG process for the cladding of superior materials, such as metal, ceramics, etc., on various ferrous and nonferrous substrate materials. So, the anti-corrosive, hardness, and wear resistance properties of different materials may be improved by the low-cost TIG cladding process for better service life and increment of the application area. The goal of this research study is to gather the literature on the TIG cladding technique and how it can enhance substrate attributes. The TIG welding procedure has been shown to be successful in cladding superior materials such as silicon carbide (SiC), titanium oxide (TiO_2), stainless steel powder (316 L), nickel-based alloys, and many more. Additionally, researchers have noted a sufficient improvement in different properties such as wear resistance, microhardness, and corrosion resistance of various grades of ferrous and nonferrous substrate materials. Observations also revealed that the performance and quality of TIG cladding are also dependent on various process factors, including substrate material and coating characteristics, as well as scan speed, current, and gas flow rate.

Keywords TIG cladding · Process parameters · Coating materials · Surface properties

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Y. Kumar et al. (eds.), *Recent Advances in Manufacturing Engineering*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-96-9768-7_14

1 Introduction

Researchers have investigated the influence of different cladding process parameters, like current, scanning speed, heat input, powder feed rate, particle size of powders, etc., on different ferrous and nonferrous materials. It might be possible to enhance surface characteristics such as corrosion resistance, wear resistance, and hardness [1] of the substrate surface with the addition of additive materials without changing its main properties.

TIG cladding is an additive manufacturing technology used in the agricultural, chemical, and engineering sectors for superior surface properties of different materials. Different processes of TIG cladding are available, with which alloy materials may be deposited on bulk material. TIG cladding is an appropriate method for the reduction of temperature gradients and stress in the clad area. TIG is a low-cost cladding method that deposits a coating layer on the surface of the substrate. Researchers have looked into TIG cladding using reinforced alloy materials on a variety of base materials, including CP-Titanium, AISI 1045 steel, and AISI 4340 steel. Additionally, it has been discovered that the reinforced coating with TIG cladding has better surface properties than the base metal [2]. However, due to the availability of high heat input, cracks and pores may generate on clad layers. To overcome the problems associated with it, process parameters have to be controlled within the proper limits for the achievement of the quality clad layer [3, 4].

Work on the current review is completed to find the effects of the TIG cladding technique on the mechanical characteristics of ferrous and nonferrous materials. It also emphasizes the effects of process parameters and coating materials on the mechanical characteristics of different engineering materials.

2 Comparative Analysis Between Different Coating Techniques

Table 1 represents a comparative study of different coating processes. Observations revealed that TIG cladding is one of the economical methods of surface treatment. With proper balancing of input process parameters, this process may produce good-quality clad upon the substrate surface.

3 Different TIG Cladding Techniques

TIG cladding process with preplaced powder is shown in Fig. 1. TIG surfacing with preplaced powder is an additive manufacturing process used for surface modification and protection of components by applying a coating of material onto the surface of the substrate. This simple technique is used for the development of good metallurgical

Table 1 Comparison between different coating techniques

Sl. no	Methods	Principle	Advantages	Disadvantages
1	Thermal spray	Using this technique, coating particles are heated for deposition on the substrate surface. As the reinforcing particles touch the substrate's surface, they harden and create a coating layer [5, 6]	This method may attain a high deposition rate. It needs low power input. This process applies less heat to the substrate, and, for the same reason, it can be used on thermally sensitive components such as electrical equipment [6–8]	This approach makes it harder to acquire higher coating thickness. The initial setup is expensive. Due to the high levels of dust and fumes, there are worries about health and safety. This method may suffer more porosity, oxide levels, and cracks than the other methods [7, 9]
2	Laser cladding	With laser cladding, a thin layer is deposited on the surface of the substrate using a heat source. The coating material is transferred into the melt pool using a nozzle and an inert gas [10, 11]	A highly focused heat source can be used to achieve precise cladding. Complete bonding between metals with minimum porosity. High energy efficiency combined with high consistency [10, 12, 13]	A very costly process because of the large setup expenses. Weld quality may suffer because of sporadic disruptions in the system [14, 15]
3	PVD	This procedure creates an extremely thin coating layer by first converting the solid material into a vapor phase in a chamber of vacuum and then depositing that material on the surface of substrate. Numerous processes, including evaporation, transit, reaction, and deposition, are involved in this process [16]	There is no surface degradation involved. This procedure works well for anti-chipping implementation. There is no decrease in the substrate's bending strength during this operation [7]	For mass production, this process is inappropriate. This procedure makes it harder to deposit material on side walls [16]
4	TIG Cladding	In this method, between the tungsten electrode and the substrate, heat is generated via an electric arc. Typically, inert gases like argon are utilized to prevent contamination and oxidation [7]	This process is simple to control. Costs for installation and maintenance are minimal. There is operational flexibility in this technique [17]	Powder reinforcement is wasted when shielding gas is blown over the melting pool. Powder paste preparation and application for a large sample is difficult [18]

(continued)

Table 1 (continued)

Sl. no	Methods	Principle	Advantages	Disadvantages
5	CVD	The fundamental idea behind this process is the partial decomposition of vapor-phase particles, which results in subsequent thin film deposition on the substrate surface. The coating material is transported in vapor form [19]	The high deposition rate makes this process appropriate for large-scale manufacturing. For mass production, this technique is suitable [19, 20]	This process can deteriorate the quality of the film that is deposited on the substrate. This method also uses highly toxic and corrosive gases [16]

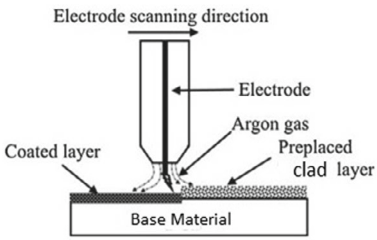

Fig. 1 TIG cladding process with preplaced powder [2]

bonds with a low dilution rate. In this process, powdered material is combined with a binder, for example, polyvinyl alcohol and polyvinyl acetate, and forms a solution of pasty material. Then, the substrate surface is primed with the paste solution [21, 22]. Findings show that excessive use of binder material may form porosity due to the generation of gas during the cladding process. For the same reason, the use of binders has to be restricted for better metallurgical properties [23].

Figure 2 shows TIG cladding with a wire feeding system with the help of which filler material is directly dispensed from a nozzle onto a substrate's surface using a reel. The feeding technique with the help of a wire has few advantages over the powder-based method, such as increased material efficiency, higher deposition rate, and lower wire material preparation cost [25].

4 Impact of Process Parameters of TIG on Surface Properties

Figure 3a depicts that at elevated current (90A), the magnitude of surface hardness is low, whereas at low current (50A), the magnitude of the same is comparatively high. This is because of the heat input. As the heat supplied is directly proportional to input current, with an increment of current, extreme decomposition and dilution

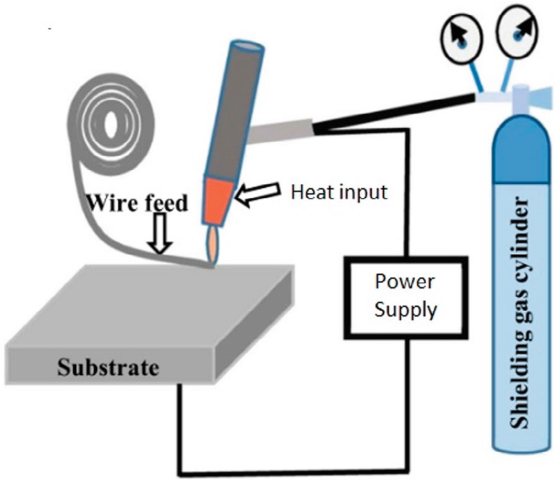

Fig. 2 TIG cladding process with wire feeding system [24]

of clad material also take place, which reduces the hardness of the clad zone [26, 27]. The relationship between heat input and process parameters can be given as heat input = {(0.48 × voltage × current)/scan speed} [2, 28].

Observations on Fig. 3b revealed that microhardness values improved with a faster scan speed (270 mm/min) and decreased with a decrease in scan speed (180 mm/min). This is because the scan speed and the amount of heat applied to the preplaced layer are inversely related [3]. A high amount of heat is supplied at a low speed, which results in high decomposition and dilution of coating material and lower hardness.

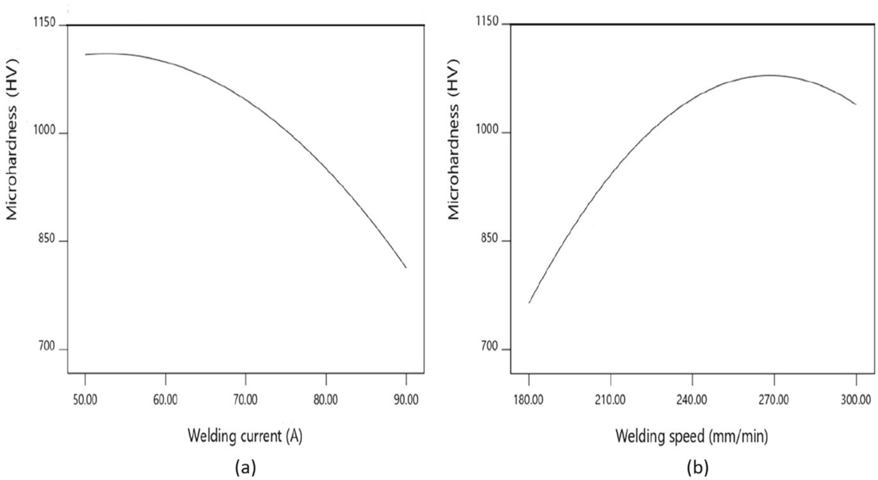

Fig. 3 Effect of current and scan speed on hardness [26]

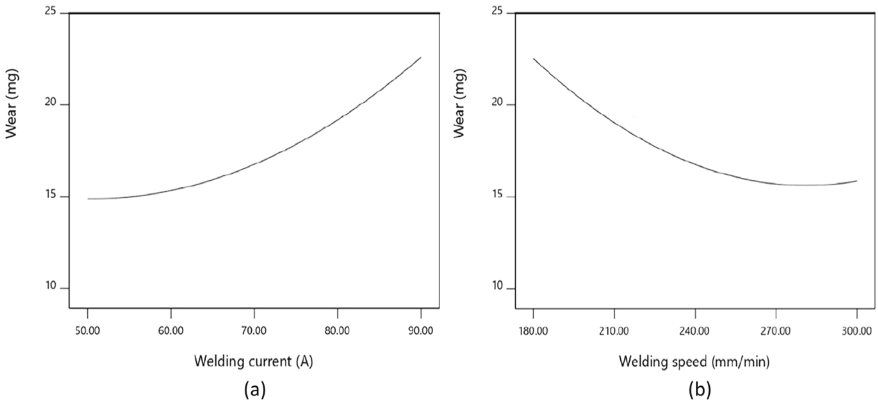

Fig. 4 Effect of current and scan speed on wear [26]

Heat input to the preplaced layer drops at high speeds, which results in low dilution, a greater number of partially melted clad powder particles, and high hardness [26].

Observations on Fig. 4a revealed that the loss of weight is minimal at low current, whereas the loss of weight attains the highest value at high current. This is because the amount of heat applied to the preplaced layer is directly proportional to the welding current. At low current (50 A), due to the generation of low heat input, a large amount of partially melted clad material could be expected to be present in the cladding, and therefore wear is also less; at high current (90 A), wear is maximum due to maximum dissolution and dilution of clad material.

Observations on Fig. 4b depict variations in the cladding's abrasive wear in relation to welding speed. The workpiece processed at high speed (300 mm/min) shows higher wear resistance as compared to the workpiece processed at low speed (180 mm/min). At lower velocities, the amount of heat transferred to the preplaced layer rises due to the longer duration of interaction between the arc and the preplaced layer. This causes greater dissolution of coating materials into the matrix and poor wear resistance [26].

5 Effect of Cladding Material on Surface Properties

Table 2 clearly shows that coating materials have a significant effect on the surface properties of the parent metal. Maximization of surface characteristics, such as hardness, wear resistance, corrosion resistance, etc., may be achieved by controlling and optimizing input characteristics.

Table 2 Effect of cladding material on surface properties

Sl. no	Material name	Property improvement	References
1	Cr powder	Wear resistance property increases, corrosion resistance property increases with nickel	[29, 30]
2	Ni powder	Corrosion resistance property increases with Cr	[30]
3	Inconel 625 powder	Corrosion resistance property increases	[31]
4	Ni–Ti wire	Corrosion resistance property increased	[32, 33]
5	TiO_2 powder	Improves wear resistance and fracture toughness and reduces tendency of cracking	[34]
6	TiB_2 powder	Hardness and wear resistance increases	[27]
7	Silicon carbide powder	Hardness increases	[35]
8	Stellite 6 powder	Hardness increases	[36]
9	TiC powder	Hardness increases	[21]
10	Stainless steel powder (316 L)	Corrosion resistance property increased	[37–39]
11	2205 duplex stainless steel	Corrosion resistance property increased	[40]

6 Investigations on Surface Properties with Different Coating Materials

Metallurgical properties play a significant role in the selection of a material for industry applications. Depending upon metallurgical properties, such as grain size, microstructure, etc., the mechanical properties of a material vary, and depending upon the mechanical properties, a material's manufacturing application varies. Researchers used laser cladding techniques on different ferrous and nonferrous materials for investigation of metallurgical properties.

Researchers developed a composite coating of TiB_2-TiO_2 on a mild steel substrate for the improvement of wear resistance and hardness properties. Observations revealed that the presence of TiO_2 lessens after clad crack formation. TiO_2 improves wear resistance properties, and by improving the fluidity of molten metal during cladding, it also improves bonding between clad material and substrate surface [41]. Titanium alloy was coated with a Ni–Ti clad layer for the improvement of wear resistance and hardness properties. Observations revealed that the surface roughness value was inversely proportional to the overlapping ratio [42].

Researchers have investigated the metallurgical effects of the water-cooled TIG cladding process using nano-vanadium carbide powder on low carbon steel substrate and compared the same with air-cooled TIG cladding powder. Observations revealed that different surface characteristics, such as wear resistance, hardness, and corrosion resistance properties, increase in the water-cooled process than that of the air-cooled TIG cladding process [43].

Low-carbon steel workpiece was coated with an amorphous Fe-based composite coating material using TIG cladding material for the improvement of surface properties. Analysis of microstructure revealed the generation of nano-crystallized and amorphous phases in the cladded structure. Investigations revealed that nano-crystallized grains possess higher microhardness compared to amorphous phase [44].

For the reduction of dilution rate and improvement of surface properties, AISI 304 steel was coated with powders of WC, CO, and Cr with a predetermined percentage. Metallographic observations revealed that with an increment of standoff distance and gas flow rate, moderate wear resistance and hardness properties were achieved. The preplaced powder layer receives less heat when the standoff distance and argon flow rate are higher, which results in the high hardness and wear resistance of the cladding [14].

For improvement of surface properties of ferrous alloy, researchers have investigated the effects of SiC powder with variable input parameters on different substrate materials, such as mild steel, SKD61 die steel, SAE 1020 steel, and micro alloyed steel. Observations revealed that the hardness of all substrate surfaces improved by incorporation of silicon carbide powder [45–49].

Using the TIG cladding method, a composite coating containing various rare earth oxides has been applied to improve the surface characteristics of the titanium alloy. With WC and Ni powder, three distinct rare earth oxides, CeO_2, La_2O_3, and Y_2O_3, were combined pairwise for experimentation. Based on the experimental results, coatings primarily contained hard phases such as NiTi and $AlTi_2C$. Observations revealed that cladding made with CeO_2 and La_2O_3 has the maximum wear resistance (COF of 0.22) and microhardness (870 Hv0.5) [50].

The above metallographic observations on ferrous and nonferrous materials with a TIG coating process revealed that clad microstructure and mechanical characteristics such as hardness, wear resistance, and corrosion resistance properties are greatly dependent on the properties of alloying elements and process parameters. In all cases, after cladding, properties increased the base material.

7 Conclusion

Observations by researchers revealed that TIG cladding is one of the most popular arc-based cladding methods that can generate coating layers of hard ceramic particles with reinforcement to enhance the substrate material's surface qualities. The overall aim of this review is to achieve a deep and broad understanding of the TIG cladding process with a view to enabling the eventual realization of a fully controlled manufacturing process. The following can be used to summarize the above discussion:

- TIG cladding performance is determined by process parameters that control the amount of heat input during cladding, such as current, scan speed, gas flow rate, etc. The surface characteristics and response surface characterization of the clad layer are further determined by input parameters.
- The TIG cladding process improves surface characteristics, including hardness and wear resistance. By applying a suitable material surface layer, the TIG cladding technique is found to be effective in improving the characteristics of low-grade material. It facilitates the use of these inferior materials in more industries with harsh environmental requirements.
- TIG cladding is one of the most affordable and efficient ways to enhance the substrate surface qualities.

8 Future Scope

Minimum research work has been carried out on engineering materials for the improvement of their surface properties (wear resistance, hardness, and corrosion resistance) together. Thorough investigations also revealed that studies on the effect of gas flow rate on surface properties of engineering materials are minimal. Therefore, it is suggested to conduct in-depth research to effectively address these challenges and develop a practical and affordable TIG cladding process that can be applied in the industry to improve the substrate surface qualities.

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