Particulate Composite Protective Coating Using Conventional Melting Approach

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Introduction

The term protective coating or surface engineering means modifying or engineering the surface of material to increase protection against wear and corrosion properties along with other properties. Among the processes employed for protective coating, incorporation of ceramic particles to produce composite protective coating or layer by melting is gaining popularity (Maleque *et al.*, 2017). High energy laser cladding (Zhou *et al.*, 2016; Yang *et al.*, 2016; Qunshuang *et al.*, 2017) and electron beam melting technique (Peng *et al.*, 2011; Lienert *et al.*, 1993) are commonly used for processing such composite protective coating which are reported to significantly increase wear and corrosion resistance of engineering component surfaces. Electron beam welding (EBW) for composite surface coating was developed starting in the late of 1950s. In that method, the electrons are accelerated and kinetic energy is used as the heat input for melting of the substrate material. A negatively-charged cathode filament is heated up to its thermionic emission temperature where electrons are generated. The substrate surface is bombarded with the electron beam at 70% of speed of light. The heat comes from approximately 95% of the electron's kinetic energy. The diameters of the electron beam are between 0.3 and 0.8 mm. Due to its high power density, one of the superior abilities of EBW is the capability of deep melting of the surface layer (Sun and Karppi, 1996).

The composite protective coating of materials can be performed by melting process where high energy source is applied to melt the surface of the substrate together with the reinforcing particles (Sathiya *et al.*, 2009; Lailatul and Maleque, 2017). This resulted in a strong metallurgical bonding upon solidification between the reinforcing particles and the substrate material. The melting process is commonly utilized for ceramic particles for reinforcement due to their superior hardness and thermal stability. In other work, the composite coated layer obtained through laser cladding technique showed low porosity, with homogenous microstructure with proper control of thickness by manipulating the process parameters (Fernández *et al.*, 2014).

The reinforcement can be fed onto the surface of the substrate material using either powder blown, wire feed or pre-place powder surfacing method (Fernández *et al.*, 2014; Folkes, 1994). Powder injection or blown method applied a stream of gas which are usually argon, CO_2 or oxygen to carry the reinforcing powders. The reinforcing powders are delivered using coaxial or lateral feed method. The flow of the carrier gas is maintained properly to have uniform distribution of reinforcement and good quality of melt pool layer. The use of higher gas flow rate in this method can easily decrease the melting temperature of the substrate and hence, less dissolution of particles. On the other hand, the flowability of the reinforcing ceramic particles is reduced with the use of lower gas flow rate and hence, fewer amounts of particles reach the melting area.

Wire feed method is an approach where composite protective coating of metallic materials is performed using filler material. The spool containing filler material is directly fed through a nozzle and onto the substrate. To have a good quality of melt structure, the wire feed used to carry the reinforced particulate material should be free from defects which can affect the flow consistency. When the wire used is bent, the filler material could have deviated from reaching the center of the melt pool. According to Kou (2003), this technique does not waste any filler material compared to the powder injection method. However, some extent of reinforced particles may not reach the center of the melt pool at a certain heat input because of the use of slower wire feed rate. The quality of the melt structure is strongly affected by the wire feed rate. Among the composite surface coating methods, particulate preplacement method is the cheapest, and a simple, flexible way of composite protective coating of metallic alloys with good metallurgical bonding and decent melt pool structure (Maleque *et al.*, 2018). A binder solution such as polyvinyl acetate (PVA) is used to preplace the particulate on the substrate material so that the particulate is not blown away by the shielding gases during the melting process. However, the excessive use of binder could lead to porosity that comes from escaped gas during solidification. The particulate preplacement process is followed by the application of high heat energy to melt the surface layer. Upon solidification, the melted reinforced particle together with the melted surface of the substrate can bond and develop a new microstructure with modified physical, mechanical and tribological properties (Adeleke and Maleque, 2014).

Overall, all the composite protective surfacing techniques mentioned earlier such as powder (particulate) blown or injection method, wire feed method and pre-place particulate method have their own mechanism to supply the reinforcing particulate material onto the surface of the substrate during the melting process. Each of the method has its own sensitive parameters that affect the end quality of the produced melt structure. For instance, powder blown technique heavily relies on the gas flow rate for consistency of the feeding of reinforcing particulates. Generally, pre-place particulate method is beneficial compared to the others because it is the cheapest, simple and flexible way with the ability to produce a good melt microstructure.

However, particulate protective coatings using those techniques have a limited application because of the expensive establishment and precision control of the system. An alternative and novel method was developed using conventional melting (surfacing) technique by TIG torch melting for composite protective coating which is suitable for high temperature application as

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