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Characterization of D2 tool steel friction surfaced coatings over low carbon steel

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ABSTRACT

In this work D2 tool steel coating is produced over a low carbon steel substrate using friction surfacing process. The process parameters are optimized to get a defect free coating. Microstructural characterization is carried out using optical microscopy, scanning electron microscopy and X-ray diffraction. Infrared thermography is used to measure the thermal profile during friction surfacing of D2 steel. Wear performance of the coating is studied using Pin-on-Disk wear tests. A lower rotational speed of the consumable rod and higher translational speed of the substrate is found to result in thinner coatings. Friction surfaced D2 steel coating showed fine-grained martensitic microstructure compared to the as-received consumable rod which showed predominantly ferrite microstructure. Refinement of carbides in the coating is observed due to the stirring action of the process. The infrared thermography studies showed the peak temperature attained by the D2 coating to be about 1200 °C. The combined effect of martensitic microstructure and refined carbides resulted in higher hardness and wear resistance of the coating.

1. Introduction

Friction surfacing gained significant attention in the recent years as a solid state hardfacing technique to produce wear and corrosion resistant coatings. The ability to produce coatings without any melting makes this process distinct from other conventional coating processes. The process was patented as a metal-coating process by Klopstock and Neelands in 1941 [1]. The underlying principle of friction surfacing is similar to that of friction welding [2]. Severe plastic deformation due to combined action of frictional heating and axial pressure forms the basis of the processes. A rotating cylindrical rod, which is the coating material, is rubbed against a metallic substrate, with applied pressure such that the rubbing surface of the cylindrical rod gets sufficiently heated up by friction and gets softened due to severely plastic deformation. The softened/plasticized material then begins to flow (during the translation of the substrate) and gets deposited over the substrate. Here, only the rubbing surface of the cylindrical rod gets preferentially softened due to the difference in energy balance between the rod and the substrate. A schematic of friction surfacing is shown in Fig. 1.

Friction surfacing can be considered for wide range of applications where wear and corrosion becomes a major concern. Earlier studies on friction surfacing clearly demonstrated the suitability of the process in applying wear resistant [3–8] and corrosion resistant coatings [9,10]. Another important area where this process can be considered is for repair and reclamation of worn-out engineering components [11] such as dies and related tooling which might have developed surface cracks by thermal fatigue [12]. Fusion welding is frequently adopted to rebuild these cracked surfaces. Unfortunately, fusion welding techniques are characterized by high temperature gradients, which results in the build-up of high thermal stresses, and a rapid solidification, which gives rise to the occurrence of segregation phenomena and the presence of non-equilibrium phases [13]. To deal with these issues, the parts are often subjected to pre-heating and post-weld heating procedures. Being a solid state process, friction surfacing is free from the above stated problems. Hence, by using friction surfacing to fill the cracked region, the heat treatment procedures can be eliminated. This will considerably reduce the processing time and more importantly results in improved metallurgical properties of the tools.

D2 steels are commonly used in applications such as blanking dies, mill rolls, punches etc. Any effort to extend the life of these components will be beneficial to improve the productivity. This steel is high in carbon and chromium for the purpose of forming large volumes of secondary carbides as a result of the precipitation of carbides during tempering processes. By cladding D2 steel on a softer metallic surface like mild steel or rebuilding a worn D2 steel component by depositing D2 steel coating can extend the life of a component with improved properties. Considering the deleterious effect of conventional fusion based techniques, applying friction surfacing as a means to provide D2 steel coatings, could be a better

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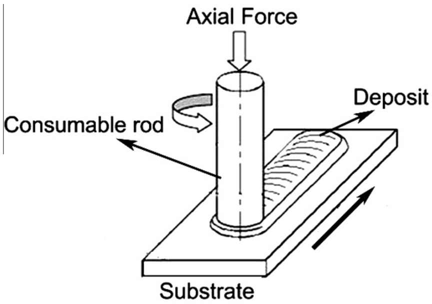

Fig. 1. Schematic of Friction surfacing process.

option. Keeping this in view, this study is focused on the microstructural and performance characteristics of D2 steel coated over low carbon steel by friction surfacing. Process parameters were optimized and the microstructural features of the coatings were investigated. Performance characteristics of D2 steel coatings were studied by conducting wear test.

2. Materials and methods

D2 steel in annealed condition was used as coating material and low carbon steel was used as the substrate material to perform friction surfacing. The chemical compositions of D2 steel and low carbon steel are given in Table 1. Coating material was taken in the form of rods of 18 mm diameter and 100 mm length. Low carbon steel substrate was machined to dimensions of 300 mm × 200 mm × 10 mm. A rotary friction welding machine and a friction surfacing machine were used to carry out the experiments. The friction welding machine was used to get a preliminary understanding on how the D2 steel behaves with different rotational speeds and loads. The friction welding machine was capable of applying 200 kN force and spindle speed of 2500 rpm. A custom made friction surfacing machine capable of delivering 10 kN axial force, 3000 rpm spindle speed, and traverse speed variations in steps of 0.1 mm/s was used to produce the coatings. At first the experiments were carried out in the rotary friction welding machine with different combinations of axial pressure (40 MPa, 60 MPa and 80 MPa) and spindle speed (600 rpm, 800 rpm, 1200 rpm and 1600 rpm) to understand the plasticizing conditions for tool steel. The consumable rod (D2 steel) was held on the rotating side and a larger diameter low carbon steel rod was kept on the stationary side. To get the material deposited on the mating surface of the larger diameter rod and to avoid the rods to get welded, the upset loading phase on the friction welding cycle was abandoned and the rotating consumable rod was retracted before the rotation stops.

Once the condition for sufficient plasticization was achieved from the experiments carried out in friction welding machine, further experiments were carried out in the friction surfacing machine where the substrate can be moved at different speeds. The substrate surfaces were ground by surface grinding to remove the scale or rust formed on the surface. The surfaces were then cleaned with acetone to remove the dust and grease, which could affect the process by interfering with friction co-efficient or bond formation.

Infrared thermography was used to measure the thermal profile during friction surfacing of D2 steel. An IR camera with a mean noise equivalent temperature difference of 20 mK was used to measure the surface temperature of the coatings. The CEDIP JADE mercury cadmium telluride IR camera (M/S. Flir System, Croissy-Beaubourg, France) is operated in the long wave infrared band (7.9–9.7 μm) with a focal plane array of 320 × 240 detectors (each detector is a pixel of size is 25 μm) and a pixel pitch of 30 μm.

Microstructural characterization was carried out by taking transverse cross-section containing both coating and substrate. The specimens were prepared with standard metallographic specimen preparation procedures. The samples were etched with 2% Nital for interface characterization. For characterization of the coating, samples were etched with 4% Nital. SEM images were taken with both secondary electron image mode and back scattered electron image mode at 30 kV. The electron microscopy of samples was performed using FEI Quanta 200, Quanta 400F and Inspect F scanning electron microscopes. XRD analysis was done on the coating to get the phase information. The phases were identified with commercially available X'PERT HIGH SCORE software.

Vicker's microhardness survey was taken across the coating/substrate interface with a load of 200 gm and dwell time of 15 s. To determine the bulk hardness, Rockwell hardness measurements were carried out at the top surface of the coating with a load of 150 using diamond indenter.

Wear performance of the coating was studied using Pin-on-Disk (ASTM: G99-05(2010)) wear testing method. Pins of 6 mm diameter and 12 mm length were extracted from the D2 steel coating. Coating was subjected to stress relieving treatment to avoid any cracking during machining. Disks of 12 mm thick and 50 mm diameter were machined out from D2 steel bar stocks and heat treated to hardness of about 62 HRC. The bulk hardness of the pin extracted from D2 steel coating was about 61 HRC. Wear tests were conducted at 5.6 kg load (normalized pressure 10^{-3}), 1 m/s sliding velocity (normalized velocity 0.5×10^3) for a total distance of 1000 m. To ensure the reproducibility of the results, tests were repeated twice. Weight loss measurements were carried out at a precision of 10^{-4} g to estimate the wear loss.

3. Results and discussion

3.1. Process parameters

The initial optimization studies carried out with the friction welding machine resulted in a parameter set with an axial pressure of 40 MPa and a spindle speed of 800 rpm. Tool steel buttons of various thicknesses were obtained on the mating surface of the larger diameter low carbon steel rod held at the stationary side of the friction welding machine. Fig. 2 shows the transverse cross-sectional view of buttons produced at different spindle rotational speeds and at an axial pressure of 40 MPa. It was observed that with a higher spindle rotational speed more material forms as flash which is not desirable in terms of material usage. In addition, higher spindle rotational speed can input more heat which may affect the microstructural characteristics. At the same time, enough speed was required to generate sufficient heat and to avoid the materials from getting welded. Experimental runs showed that a minimum rotational speed of 650 rpm was required to plasticize

Table 1
Chemical composition of consumable rod and substrate material (wt%).

	C	Mn	S	P	Cr	Mo	V	W
AISI D2 consumable rod	1.49	0.24	0.012	0.02	11.83	0.83	0.85	0.29
Low carbon steel substrate	0.13	0.48	0.05	0.05	–	–	–	–