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Review

Friction surfacing—A review

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ABSTRACT

Friction surfacing (FS) is a solid state technology with increasing applications in the context of localized surface engineering. FS has been investigated mainly for producing fine grained coatings, which exhibit superior wear and corrosion properties. Since no bulk melting takes place, this process allows dissimilar joining of materials that would be otherwise incompatible or difficult to deposit by fusion based methods. Several studies also emphasize its energy efficiency and low environmental impact as key advantages when compared with other alternative technologies. Main applications include repair of worn or damaged surfaces through building up or crack sealing. It has also been applied to enhance surface properties at specific areas in the manufacturing of parts and tools. A wide range of material combinations have been deposited by FS, mainly alloy and stainless steels. Aluminium, magnesium and titanium alloys have also been investigated, including the production of metal matrix composites.

Starting with a brief introduction, this review presents a detailed description of the thermo-mechanical and microstructural transformations as well as process modelling approaches. The material combinations investigated so far and the effect of process parameters are also addressed. An overview of the main technologic and equipment advances is presented, including: computational optimization models, surface preparation, gas protection, post-processing methods, pre-heating and cooling. An assessment of the material deposition rate and the specific energy consumption is also provided, comparing friction surfacing to mainstream electric arc, laser and thermal spraying based processes. Based on current process advantages and disadvantages, an outlook on future research and development is provided.

Friction surfacing has a significant potential for further industrial applications and is being developed as a practicable alternative to mainstream coating processes. The present review paper provides a broad overview throughout the fundamentals of FS and the most relevant technology developments, establishing both a theoretical and technical basis for new researchers and industrial practitioners searching for new coating alternatives.

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1. Introduction

Friction surfacing (FS) is a solid state coating process based on the plastic deformation of a metallic consumable rod. As depicted in Fig. 1a, a rotating rod is pressed against the substrate under an applied axial load (Fig. 1b). Frictional heat generates a viscoplastic boundary layer at the rod tip. The pressure and temperature conditions lead to an inter diffusion process resulting in a metallic bond between the plasticized material and the substrate. Heat conduction into the substrate enables this layer to consolidate near the bonded interface, and as such, the viscoplastic shearing interface is formed between the rotating consumable rod and the deposited layer. With the on-going heat conduction, this viscoplastic shearing interface moves away from the substrate surface, increasing the thickness of the layer (Fig. 1c). By applying a travelling movement, the viscoplastic material is deposited onto the substrate surface in a continuous process (Fig. 1d). Note that FS relies solely on interfacial friction and plastic deformation for heat source, allowing to process materials at temperatures below fusion. Giving the thermo-mechanical process experienced, a continuous layer of fine grained microstructures is deposited, from the progressive consumption of the rod. The process is also known by the generation of a revolving flash of material at the rod tip, giving it a characteristic mushroom-shaped geometry.

Considered as a variant of friction welding by Nicholas (1993), the original FS concept was first mentioned in a patent by Klopstock and Neelands (1941). Although some reports summarized by Bishop (1960) indicate that the process was also developed during the 50s in the USSR, research addressing FS remained relatively dormant in the following decades. Since the late 80s, a new focus was drawn onto the process, following the growing interest on friction-based solid state processes (Nicholas, 2003). In a search for superior coating solutions, FS has been investigated mainly for producing homogeneous fine grained coatings, which exhibit superior wear or corrosion properties (Nicholas, 1993). First application case studies addressed the rehabilitation of worn or damaged parts through building up or crack sealing in localized areas, as proposed by Dunkerton and Thomas (1984).

The process allows the deposition of materials containing hard phases, which cannot be easily formed such as tool steels and Co-basis alloys. Nicholas (2003) emphasized that since no bulk melting takes place during the coating process, it is possible to join dissimilar materials that would be otherwise incompatible or difficult to deposit by fusion based methods. Similar to other friction-based joining and processing technologies, the lower heat input reduces the heat affection of the base material microstructures, avoiding the degradation of material properties (Thomas et al., 2002). As stated by Bedford and Richards (1985), the absence of melting also results in the absence of dilution as well as lower residual stress levels since solidification shrinkage does not occur. A wide range of materials combinations has been deposited by FS, mainly tool steels, stainless steels, mild steel, copper and nickel-based alloys. Alloys such as aluminium, magnesium and titanium have also been investigated as well as metal matrix composites.

Although FS is not considered as a new technology, the demand for superior coating solutions drives the on-going interest from the scientific community, making it a still emerging alternative process.

2. Thermo-mechanical process

FS involves a high complexity of transformations, combining both hot-working and joining principles. As other friction based manufacturing technologies, a viscoplasticized solid state region is generated and processed into a new shape and metallurgical condition. Although this region remains in solid state, it presents a three-dimensional material flow pattern that enables the joining between different materials. This phenomenon is generally referred to as the “third-body region” concept, as described by Thomas (2009b). This “third-body region” is characterized by a relatively low flow stress and temperatures above the recrystallization temperature but below the melting temperature of the material. Being driven exclusively by the introduction of mechanical energy, the heat is generated by friction dissipation during deformation at contacting interfaces and internally by the consumable rod material flow.

Because the heat generated by friction dissipation tends to zero as the material gets near the fusion temperature the maximum temperature achieved within processed zone is physically limited by the fusion temperature and thus all the deformation is restricted to solid state condition. Therefore a metal cannot reach fusion solely by plastic deformation on its own.