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MICROSTRUCTURE AND PROPERTIES OF FRICTION SURFACED STAINLESS STEEL AND TOOL STEEL COATINGS

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Abstract. Friction surfacing is a novel solid state surface coating process with several advantages over conventional fusion welding based surfacing processes. In this work, austenitic stainless steel (AISI 310) and tool steel (H13) coatings were friction deposited on mild steel substrates for corrosion and wear protection, respectively. Microstructural studies were carried out by using optical and scanning electron microscopy. Shear tests and bend tests (ASTM A264) were conducted to assess the integrity of the coatings. This study brings out the microstructural features across the coating/substrate interface and its mechanical properties, showing good metallurgical bonding between stainless steel and tool steel coating over mild steel.

Introduction

Surface coatings are often used in engineering components for wear and corrosion protection. Friction surfacing is an emerging surface engineering technique for wear and corrosion applications. This is a solid state process which can deposit layers without dilution. The deposition is made possible by leaving a plasticized layer of metal when a rotating consumable rod called mechtrode fed against a laterally moving substrate under the influence of an axial force. The end of the rod which is in contact with the substrate undergoes severe plastic deformation by the combined effect of axial force and the frictional heat generated at the interface. Schematic representation of friction surfacing process is shown in Fig 1. Compared to thermal spraying and welding based coating processes, this process has got several advantages. In thermal spraying the bonding is realised by mechanical bonding and employed for thin coatings(upto 500 microns). The welding based processes suffers the problems like hotcracking, porosity and dilution. The solid state bonding mechanism in friction surfacing addresses this problems. Another distinct feature of this process is its ability to deposit dissimilar metal combinations. Since it is machine tool controlled process, thickness of the layers can be precisely controlled for a given set of parameters with fairly good repeatability.

Although the concept of friction surfacing is known for a long time[1], it is only recently that the process is considered for commercialization [2]. Materials like mild steel, aluminum, stainless steel, inconel, monel, stellite, and aluminum MMCs were successfully coated over substrates of mild steel, aluminum and stainless steel [3-8]. Previous studies on friction surfacing foccus on parameter optimisation and feasibility studies[3-12]. Eventhough these studies thoroughly demonstrates the potential of this process to emerge as an important surface engineering technique, not much is known about the microstructural and mechanical property characteristics.

Studies in this direction are much needed to enhance the suitability of friction surfacing for a wide range of commercial applications like industrial knives for food, pharmacuetical and packaging industries, hardfacing of valve seats, repair and manufacture of parts for the gas turbine industry especially for turbine blades and for various types of tooling such as punches, drills and agricultural equipments[5]. Studies reveal that it is possible to deposit stainless steel and tool steel over mild steel with suitable combinations of parameters[6]. The objective of the present study is to examine microstructural features of the deposit - substrate interface and to ascertain the integrity of friction surfaced deposits of austenitic stainless steel and tool steel over mild steel.

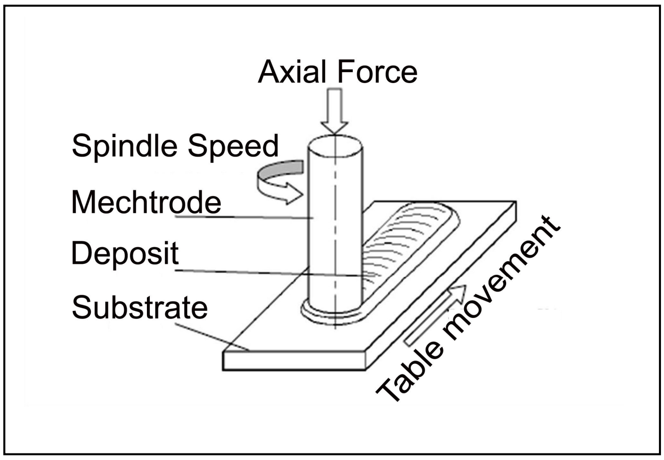

Fig.1. Schematic of friction surfacing.

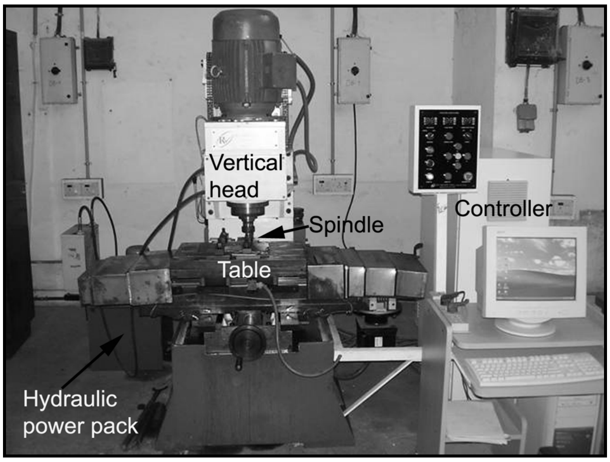

Fig.2. Friction surfacing equipment

Experimental procedures

A dedicated fully automatic friction surfacing machine(axial load capacity: 12kN, spindle speed range: 450- 3000 rpm, feed rate: steps of 0.1mm/s.) was used to carry out the experiments. The experimental set up is shown in Fig 2. As the mechtrode got consumed, the vertical head moves downwards by the virtue of axial load through a ball screw supported on either sides by friction free linear guide ways. This ensures an uninterrupted formation of bead. The details of friction surfacing operations are reported else where [6].

A 10mm thick mild steel plate (0.12 C, 0.4 Mn, 0.02 P, 0.01 S and balance Fe) was surfaced with stainless steel (AISI 310) and tool steel (H 13). The stainless steel (0.05 C, 25.15 Cr, 19.11 Ni, 1.3 Mn, 0.85 Si, balance Fe) and tool steel (0.37 C, 0.37 Mn, 0.27 Ni, 0.3 V, 5.56 Cr , balance Fe) were taken as rods of 18mm diameter and 100mm length. The surface scales of as received mild steel plates were first removed by milling and then surface grinded to 0.2μm Ra. Before surfacing the substrate was thoroughly cleaned with acetone. The end of the rod was faced and surface grinded to maintain perpendicularity.The parameters used in this work is given in Table1. These parameters were taken from an earlier work done by the same authors where Taguchi design of experiments was used for optimisation of parameters for getting 1 mm thick coating.

Table 1. Parameters used.

Parameter	Mechtrode speed [rpm]	Axial contact pressure [kN]	Feed rate [mm/s]
Coating			
Stainless steel	2000	5	2.4
Tool steel	800	10	4

Microstructural observations were performed by optical microscopy and scanning electron microscopy. Mild steel was etched with 2% Nital and tool steel was etched with 4% Nital. Electrolytic etching was carried out for stainless steel in a solution of 10% oxalic acid and 90% water with a power supply set to 6V for about 60 s. The specimens were observed in a Leica make optical microscope and FEI make scanning electron microscope equipped with an EDAX system.

Micro hardness measurement on cross sectional samples was carried out across the interface, from the top surface of deposit and ending at the base metal region of the substrate. During the test a load of 300 g was applied to the intender for 15 s. Three point bend tests and shear tests (ASTM A-264) were carried out to assess bond integrity of the coatings.

Results and Discussion

Microstructures. Microstructural observations on both stainless steel and tool steel coatings confirmed good coating/substrate bonding across the coating width except at the deposit edges. This lack of bonding at the deposit edges is known to be due to hot plasticized material rolling over as the mechtrode moves along the substrate surface[8]. A typical friction surfaced coating is shown in Fig.3. The top surface of the coating is characterised by the formation of ripples. The ripple formation is attributed to the mechanism of material transfer from the mechtrode. Discrete circular layers of plasticised metal get detached from the mechtrode due to the shear force experienced at the interface by relative motion of the table. This discrete layers get deposited one after another to form a continous bead. Examination of specimen cross section (Fig. 4) revealed a distinct heat affected zone (HAZ) just beneath the deposit with a transition zone (TS) which seperates HAZ from the unaffected base metal. Fig. 5a shows an irregular intact interface indicating a good metallurgical bonding. However unbonded regions can be noticed at the deposited edges (Fig. 5b).

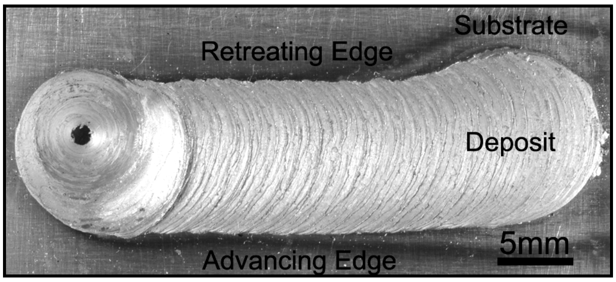

Fig.3 Typical friction surfaced bead

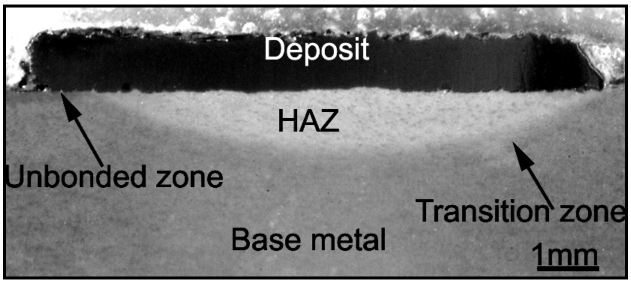

Fig.4 Low magnification picture showing interface characteristics.

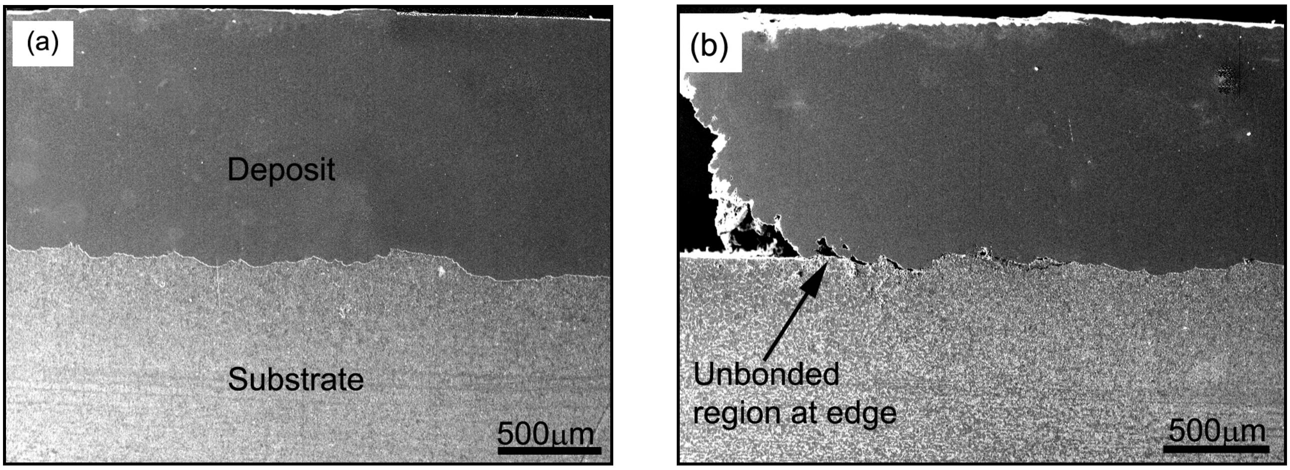

Fig. 5. a) Good bonding at the interface b) Unbonded region at the edge of the coating

Generation of frictional heat and heat concentration at the contact end during friction surfacing causes reduction in flow stress of mechtrode and resulted in severe plastic deformation. Noticeable deformation has not developed in the substrate. However the effect of frictional heating was prominent. Fig. 6a shows martensitic microstructural features in HAZ and Fig. 6b shows transition zone with a mixture of pearlite and ferrite. The substrate region just near to the interface (HAZ) experiences a temperature well into the austenising range and cools down at a rapid rate. It has been reported that the temperature at near HAZ region was experimentally determined as 1020^{0}C and cooling rate higher than 400^{0}C/s [8]. Because of this , there will be a phase change resulting in the transformation of martensite. Martensitic transformation does not occur in transition zone but severe change in microstructure occurs when compared to the base metal. This is because of the lesser heat experienced at this region with a relatively lower cooling rate. Similar substrate microstructural features were observed in the case of tool steel coating as well.

Fig.7 and Fig.8 shows the optical micrographs of stainless steel deposit and tool steel deposit respectively. Fine equiaxed grains were observed in stainless steel deposit microstructure indicative of recrystallisation. No undesirable phases like sigma phase or delta ferrite were observed in the deposit microstructure. The tool steel deposit microstructure shows fine grained ferrite matrix with homogenously distributed carbide particles. However detailed studies are required to understand the morphology of carbides and its effect on the wear characterisitics of tool steel friction surfaced deposits.

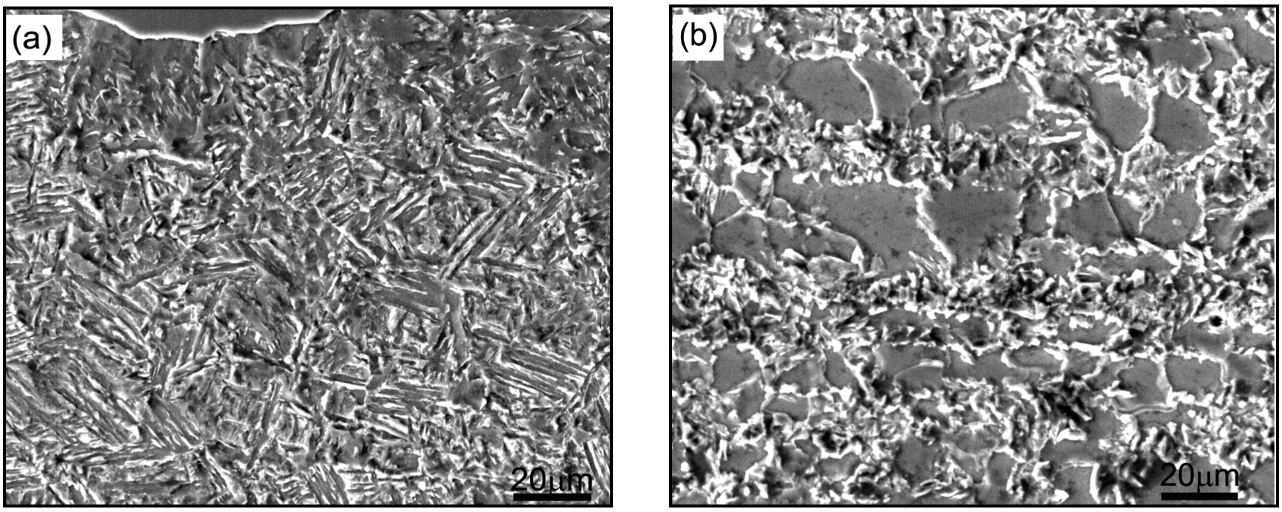

Fig.6. SEM images (SE mode) in transverse direction a) HAZ. b) Transition zone.

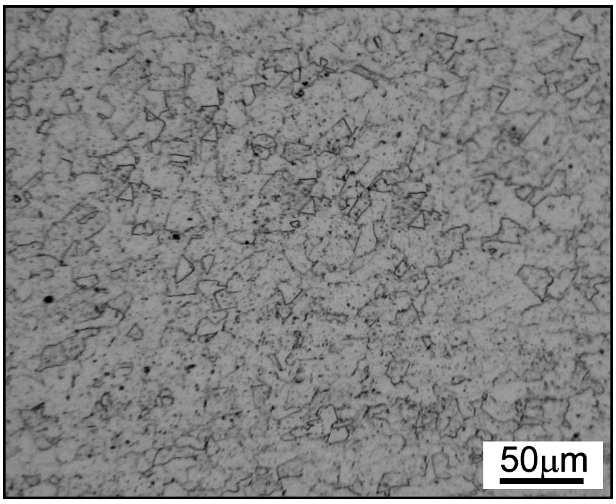

Fig.7 Stainless steel deposit microstructure

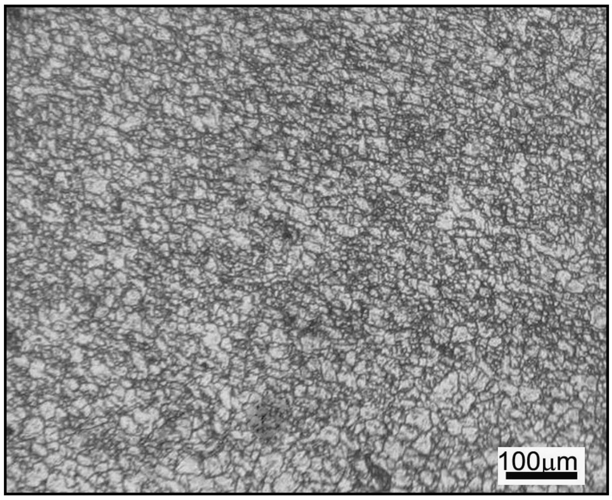

Fig.8 Tool steel deposit microstructure

Hardness. The results presented in Fig 9 and Fig. 10 illustrates the variation in hardness across the interface for stainless steel coating and tool steel coating respectively. As can be seen, the near HAZ hardness shows a higher value due to martensite formation. Since martensitic hardness is a function of carbon content, only moderate increase in hardness can be expected in mild steel substrate with 0.12% C. As the distance from the interface increases reduction in hardness can be anticipated within the HAZ region as martensitic volume fraction decreases. This reduction in hardness continued in transition zone and become steady once it reached the base metal. Similar trend in hardness variation can be seen in the mild steel substrate on which the tool steel was deposited. Not much variation is observed in hardness values of tool steel deposit when compared to the base metal (780Hv) which indicates that severe plastic deformation during friction surfacing process has only moderate effect in carbide distribution.

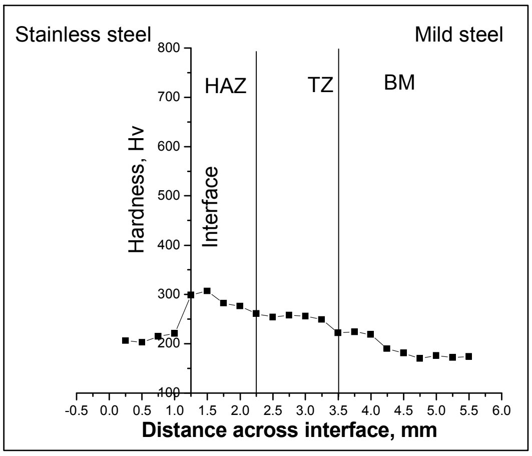

Fig.9 Hardness across the interface of Stainless steel/Mild steel coating

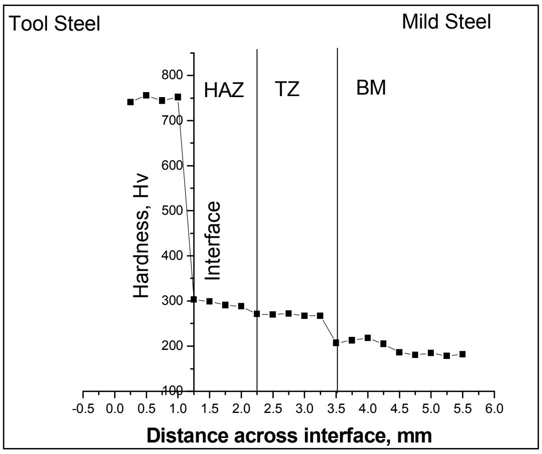

Fig.10 Hardness across the interface of Tool steel/Mild steel coating

Bend and shear tests. The ductility of the coating as well as the bond integrity was analyzed by a three point bend test. A bend angle of 90 degree could be achieved in the stainless steel coating without having a hairline crack. On the other hand, cracks started appearing in tool steel coating immediately after 5 degree of bending. This is because of the inherent brittleness associated with tool steel. Continued bending was performed till cracks started forming in the substrate. No spalling or delamination was observed which indicates that strong bonding exists between the coating and the substrate. Fig.11 and Fig.12 shows the bend tested specimens of stainless steel and tool steel coatings respectively.

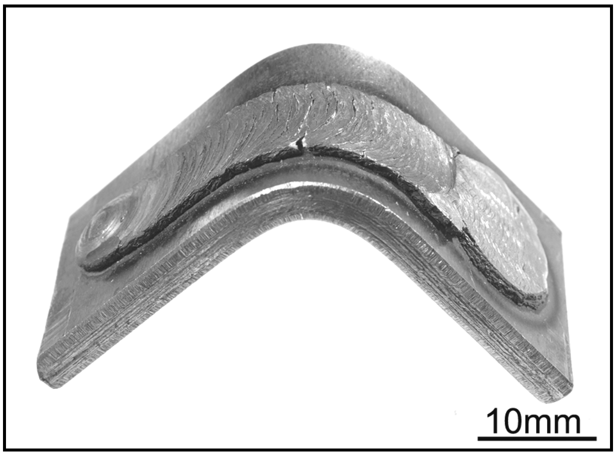

Fig.11. Stainless steel coating after bend testing.

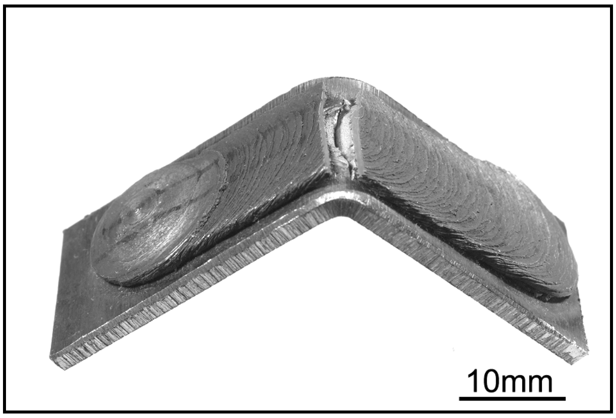

Fig.12. Tool steel coating after bend testing.

In order to ascertain bond integrity of the coatings, three specimens each from stainless steel coating and tool steel coating were shear tested. The average shear strength for stainless steel coating was 340 MPa and for tool steel was 223 MPa, showing good bonding between the coating and substrate. This result is also consistent with the bend test results. Lower value of shear strength obtained in the case of tool steel coatings may be because of some micro cracks formed at the interface due to its brittle nature. Apart from good metallurgical bonding the shear strength could also be influenced by irregular nature of the interface.

Summary

1. Stainless steel (AISI 310) and Tool steel (H13) can be readily friction surfaced over mild steel with good metallurgical bonding.
2. The substrate surface undergoes phase changes due to thermal cycling but will not hamper the bond integrity.
3. Tensile, shear strength values shows the soundness of the coating indicating its suitability for different loading conditions.

References

[1] H. Klopstock and R. A. Neelands: *An improved method of joining or welding metals,* British Patent Specification 572789, 1941
[2] G.M. Bedford. *Friction surfacing for wear applications*, Met. Mater., Vol. 6 (1990) 702-705
[3] A.W. Batchelor, S. Jana, C.P. Koh, C.S. Tan, *The effect of metal type and multi-layering on friction surfacing*, Journal of Materials Processing Technology, Vol. 57 (1996) 172 -181.
[4] M. Chandrasekaran, A. W. Batchelor, S. Jana, *Friction surfacing of metal coatings on steel and aluminum substrate,* Journal of Materials Processing Technology, Vol. 72 (1997) 446–452
[5] V.I. Vitanov, I.I. Voutchkov, G.M. Bedford, *Decision support system to optimise the Frictec (friction surfacing) process*, Journal of Materials Processing Technology, Vol. 107 (2000) 236-242
[6] M. Chandrasekaran, A. W. Batchelor, S. Jana, *Study of the interfacial phenomena during friction surfacing of mild steel with tool steel and inconel*, Journal of Materials Science, Vol 33 (1998) 2709-2717.
[7] P. L. Threadgill, W M Thomas*, Manufacture of Metal Matrix Composites Clad Layers During Friction Surfacing: Preliminary Studies***,** Eurojoin 1: First European Conference on Joining Technology; Strasbourg; France; Vol 5-7 (1991). 433-440.
[8] G.M. Bedford, V.I Vitanov, I. I. Voutchkov, *On the thermo-mechanical events during friction surfacing of high speed steels,* Surface and Coating Technology, Vol.141(2001), 34-39
[9] G. Madhusudhan Reddy, T.Mohandas, *Friction Surfacing of Metallic Coatings on Steels,* Proceedings of the International Institute of Welding International Congress 2008, Chennai, India, January 2008, 1197 – 1213
[10] M. Chandrasekaran, A. W. Batchelor, S. Jana, *Study of the interfacial phenomena during friction surfacing of aluminium with steels,* Journal of Materials Science, Vol. 32 (1997) 6055-6062
[11] I. Voutchkov, B. Jaworski, V.I. Vitanov, G.M. Bedford, *An integrated approach to friction surfacing process optimization*, Surface and Coatings Technology, Vol. 141 (2001). 26_33
[12] V.I. Vitanov , I.I. Voutchkov , *Process parameters selection for friction surfacing applications using intelligent decision support*, Journal of Materials Processing Technology, Vol. 159 (2005) 27–32

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doi:10.4028/www.scientific.net/MSF.638-642

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References

[1] H. Klopstock and R. A. Neelands: An improved method of joining or welding metals, British Patent Specification 572789, 1941

[2] G.M. Bedford. Friction surfacing for wear applications, Met. Mater., Vol. 6 (1990) 702-705

[3] A.W. Batchelor, S. Jana, C.P. Koh, C.S. Tan, The effect of metal type and multi-layering on friction surfacing, Journal of Materials Processing Technology, Vol. 57 (1996) 172 -181.
doi:10.1016/0924-0136(95)02057-8

[4] M. Chandrasekaran, A. W. Batchelor, S. Jana, Friction surfacing of metal coatings on steel and aluminum substrate, Journal of Materials Processing Technology, Vol. 72 (1997) 446–452
doi:10.1016/S0924-0136(97)00209-4

[5] V.I. Vitanov, I.I. Voutchkov, G.M. Bedford, Decision support system to optimise the Frictec (friction surfacing) process, Journal of Materials Processing Technology, Vol. 107 (2000) 236-242
doi:10.1016/S0924-0136(00)00710-X

[6] M. Chandrasekaran, A. W. Batchelor, S. Jana, Study of the interfacial phenomena during friction surfacing of mild steel with tool steel and inconel, Journal of Materials Science, Vol 33 (1998) 2709-2717.
doi:10.1023/A:1004338210262

[7] P. L. Threadgill, W M Thomas, Manufacture of Metal Matrix Composites Clad Layers During Friction Surfacing: Preliminary Studies, Eurojoin 1: First European Conference on Joining Technology; Strasbourg; France; Vol 5-7 (1991). 433-440.

[8] G.M. Bedford, V.I Vitanov, I. I. Voutchkov, On the thermo-mechanical events during friction surfacing of high speed steels, Surface and Coating Technology, Vol.141(2001), 34-39
doi:10.1016/S0257-8972(01)01129-X

[9] G. Madhusudhan Reddy, T.Mohandas, Friction Surfacing of Metallic Coatings on Steels, Proceedings of the International Institute of Welding International Congress 2008, Chennai, India, January 2008, 1197 – 1213

[10] M. Chandrasekaran, A. W. Batchelor, S. Jana, Study of the interfacial phenomena during friction surfacing of aluminium with steels, Journal of Materials Science, Vol. 32 (1997) 6055-6062
doi:10.1023/A:1018635732454

[11] I. Voutchkov, B. Jaworski, V.I. Vitanov, G.M. Bedford, An integrated approach to friction surfacing process optimization, Surface and Coatings Technology, Vol. 141 (2001). 26_33

[12] V.I. Vitanov, I.I. Voutchkov, Process parameters selection for friction surfacing applications using intelligent decision support, Journal of Materials Processing Technology, Vol. 159 (2005) 27–32
doi:10.1016/j.jmatprotec.2003.11.006