MICROSTRUCTURAL ANALYSIS AND HARDNESS ENHANCEMENT OF MILD STEEL PLATE COATED WITH STELLITE6 ALLOY BY FRICTION SURFACING METHOD

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Abstract-Friction surfacing is an effective surface coating technology to coat dissimilar metals. In comparison to conventional methods like laser cladding, thermal spraying etc., friction surfacing produces efficient coatings which are of minimal or no surface defects. In this study, the mild steel substrate material was coated with cobalt based stellite6 alloy which possesses excellent hardness, corrosion and wear resistance. The present investigation was carried out by employing three different rotational speeds (1200, 1400, 1600& 1800 RPM) keeping the load as constant. Scanning electron micrographs revealed a very fine martensitic microstructure. The microhardness tests showed an increase in surface hardness of up to 200% due to the uniform deposition of stellite6 material. A flawless coating can be observed when the friction surfacing mechanism was made to run at a rotational speed 1400 RPM. The present study demonstrates that an effective friction surfacing of stellite6 material is possible on low carbon steel.

***Key words*: Stellite6, Friction surfacing, Mild Steel, Coatings.**

1 Introduction

The Solid state coating is gaining popularity as one of the alternatives to conventional coating processes like laser cladding, thermal spraying etc.[1,2].Friction surfacing(FS) is one of the most promising surface engineering tools, where a wear and corrosion resistant material can be coated on the required substrate material by the principle of friction welding. A refined microstructure, zero dilution, absence of porosity and a narrow heat affected zone can be achieved by this process.

This method has been popular for a more than a decade now and much research has been done on steels, aluminum and other aluminum alloys[3-7]. Among the many newer materials developed for coating on steel, stellite6 alloy is gaining reputation as an effective coating material[8,9]. An attempt had been made in this investigation by effectively coating stellite6 alloy material on a mild steel plate. Three different rotational speeds were employed to determine the best possible speed of rotation that can be employed to obtain better hardness, reduced porosity and efficient bonding of the stellite6 alloy material with the mild steel substrate. Stellite is a cobalt based alloy consisting of complex carbides in an alloy matrix. They possess excellent wear, corrosion and thermal resistant properties [9, 10]. Carbide phase which is presentacross a Cobalt Chromium alloy matrix makes it highly wear resistant material. It also has a good resistance to impact and cavitation erosion. Stellite6 alloy is widely used in the manufacture of valve seats and gates, pump shafts and bearings, erosion shields and rolling couples [2, 4].

Stellite coatings are generally deposited by melting or hardfacing methods[6]. High dilution, non-uniform microstructure, inhomogeneous chemical composition, porosity and residual stress are the drawbacks related to melting process [6, 10, & 11]. With a refined microstructure, homogenous chemical composition, reduced porosity and residual stresses, the friction surfacing is one of the most promising methods to coat satellite6 on the base mild steel matrix. Although FS is a versatile process for coating on a given substrate, more research work is needed, to further improve its process parameters for coating stellite6 alloy. Thus the present investigation focuses on improving the coating speed by optimizing the rotating speed of the consumable rod under constant load conditions to get better coating characteristics.

2. Materials and Methods

In friction surfacing process a rotating rod called a mechatrode is pressed axially on the substrate material to generate heat as shown in fig 1. Due to the frictional force developed by the rotating mechatrode on the substrate material, plastic deformation takes place. When the tip of the rod attains a red hot condition it is made to move in a horizontal fashion with a suitable transverse speed. By this process the stellite6 alloy gets coated on the substrate material with a pocket at the end of the coated area.

In this study, the chosen stellite6 alloy mechatrode was made to rotate (at 1400, 1600 and 1800 RPM) against the mild steel plate (150× 150× 10 mm) under an axial load of 5 KN. The frictional heat generated between the mechatrode and substrate softens the rod, thereby depositing the stellite6 alloy on the substrate. Stellite6 consumable rod of 8 mm diameter and 100 mm length was used in this study. Consumable rod was cast by melting Stellite6 powder. To coat various samples, the friction stir welding machine at the central workshop from IIT Madras, Chennai was used. The stellite6 alloy material was coated at three different locations on the mild steel substrate by changing the mechatrode's rotational speed (1200, 1400, 1600 and 1800 RPM). In other words the first coating was done at a speed of 1200 RPM, second coating was done at 1400 RPM and so on.The coated samples were cleaned and etched as per ASTM E415 standards [3]. Optical microscope images were taken from OMEGA Labs, Guindy, Chennai. Scanning Electron Micrographs with EDAX for the samples and microhardness along the direction perpendicular to the coatings was also investigated.

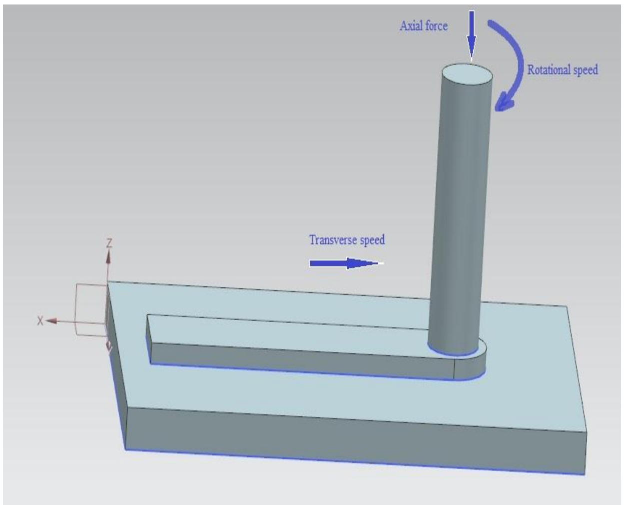

Fig 1-Friction surfacing process parameters

3 RESULTS AND DISCUSSIONS

3.1 Morphology – Optical and SEM

Samples were prepared by cutting the deposited material along with the substrate in the direction perpendicular to the deposition. Standard metallographic practices were adopted for polishing the cross sections. The samples were analyzed for microstructure, phase composition and Vickers microhardness.The sample and their respective process parameters are listed in table-1

Table – 1Process parameters selected for various samples

Samples (Mild steel coated with Stellite alloy – MSS6)	Rotational speed(RPM)	Transverse speed(mm/s)	Axial force(kN)
MSS6 - 1	1200, 1400, 1600, 1800	2	5
MSS6 – 2	1200, 1400, 1600, 1800	2	5
MSS6 – 2	1200, 1400, 1600, 1800	2	5

Optical microscopic images and SEM images of (mild steel substrate coated with stellite6 alloy) MSS6 - 1 are shown in the fig 2a and 2b. FS had efficiently led to the metallurgical flow of the stellite6 layer over MS substrate. The optical and SEM micrographs of the stellite6 alloy coating, heat affected zone and the substrate material (mild steel) exhibit, good penetration and effective bonding of the coating material i.e., stellite6 alloy. SEM observations indicate the microstructural changes that had occurred as a result of FS process.

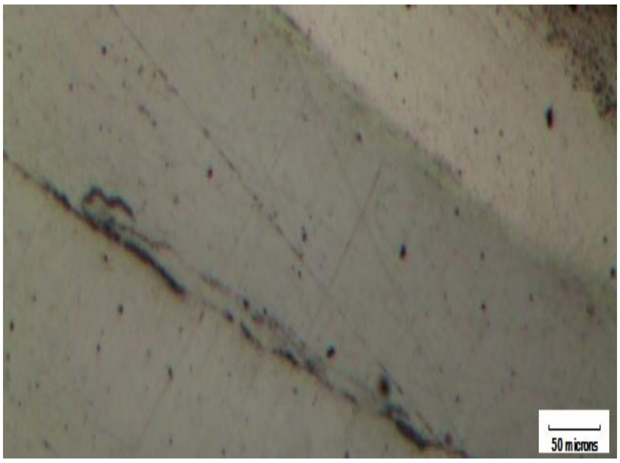

Fig 2 a) Optical micrograph of MSS6-1

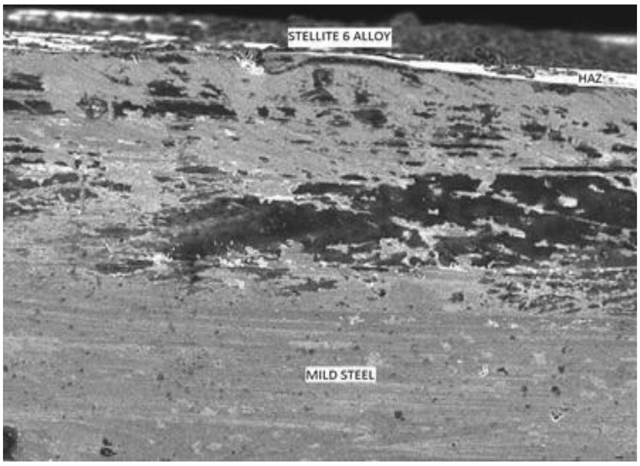

Fig 2 b) SEM micrograph of MSS6-1

Optical microscopic images and SEM images of MSS6 - 2 are shown in the fig. 2 (c) and (d).A superior mixing of coating material with the substrate can be seen from the SEM images. Though the mixing is not uniform throughout the length, a good interdentritic structure is visible in the heat affected zone and the coated area.

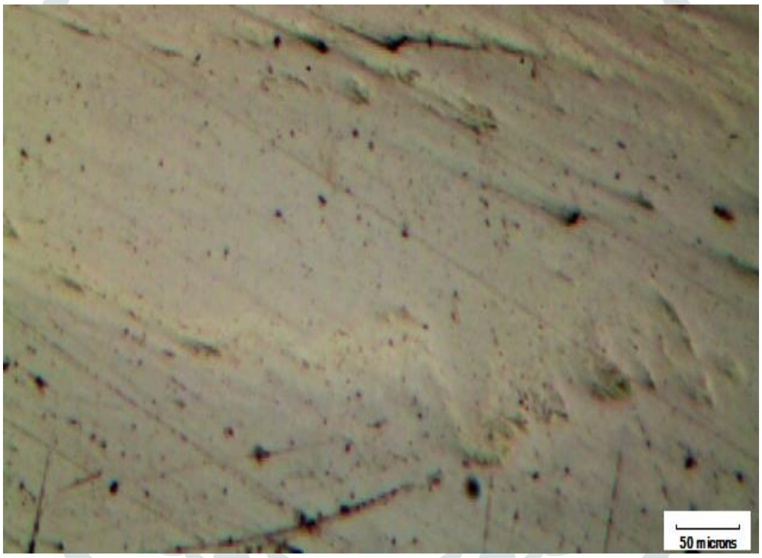

Fig. 2 (c) Optical micrograph of MSS6-2

Fig. 2 (d) SEM micrograph of MSS6-2

Optical microscopy images and SEM images of MSS6 - 3 are shown in the fig 2 (e) and (f).As seen earlier, the mixing of stellite6 and FS are clearly visible similar to the other samples. The coating was seen uniform throughout the length, unlike other samples. The uniformity is maintained even in the heat affected zone. Due to the phenomenon of recrystallization during friction surfacing process, a very refined microstructure can be observed. [2, 4, and 12]. This led to the formation of hard second phase particles at the interface[4,5]. A combination of frictional heat and stirring action led to the formation of hard second phase particles throughout the length of the coating[5,8,10].

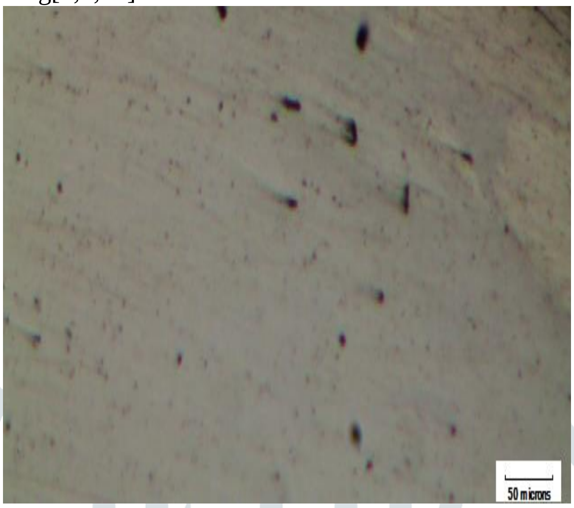

Fig. 2 (e) Optical micrograph of MSS6-3

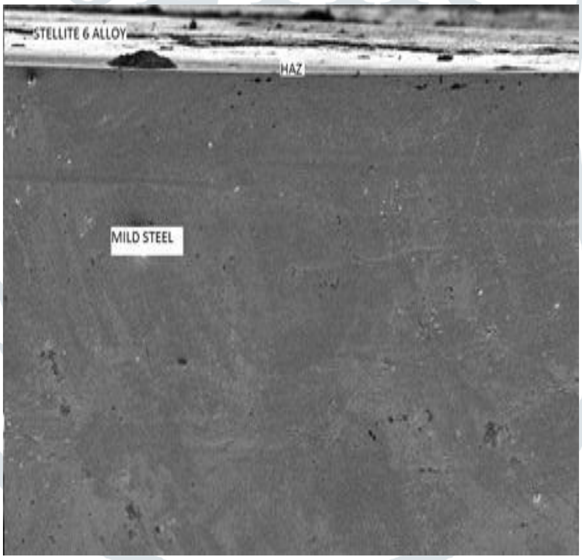

Fig. 2 (f) SEM micrograph of MSS6-3

3.2 ENERGY-DISPERSIVE X-RAY SPECTROSCOPY (EDS)

EDS analysis of the MSS6-1 & 2 samplesreveal the following observations,

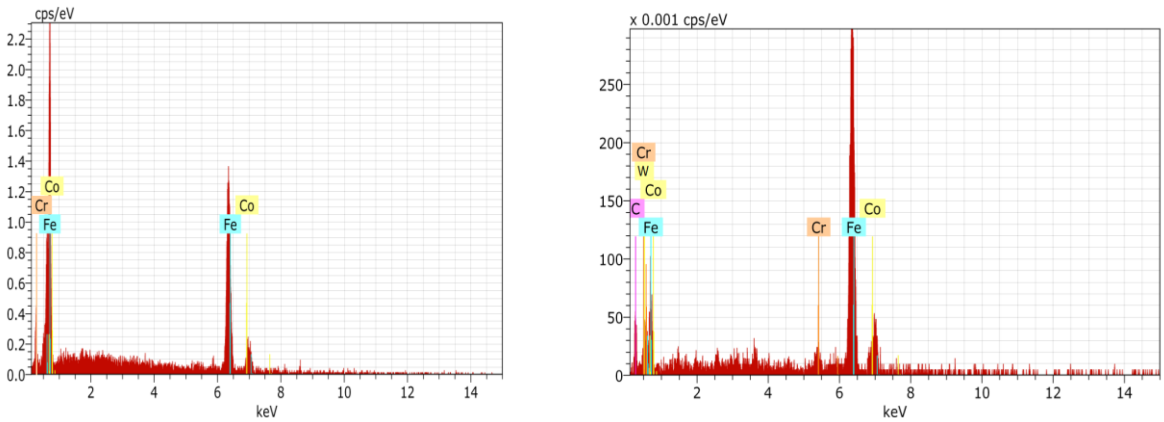

Fig.3(a) and (b) showingEDAX graphs of samples MSS6 -1 and 2

A good combination of Fe and Co along with Cr was observed in MSS6-1. The presence of Cr contributes to the higher wear resistance and better hardness of the stellite6 alloy coating. [12, 13, 14]. Carbon contributes to the increase in hardness property. Tungsten (W) contributes to the high thermal resistance property of the coated mild steel plate sample. MSS6-2[12, 16, 17].

3.3 VICKER'S MICROHARDNESS

The microhardness values of the mild steel plate coated with stellite6 alloy are shown in table 2. and in figs. 3(c) to (e).

Table-2VickersMicro hardness profile on the Cross Section Measurement

Layer	Distance, mm	MSS6-1	MSS6-2	MSS6-3
Coating	0.2	630.2	625	621.6
	0.4	622.5	628.3	628.6
	0.6	628.7	630.1	625
HAZ	0.8	153.8	154.8	152.7
	1	151.8	151.5	146.8
	1.2	155.1	152.3	150.8
Base	1.4	127.9	125.3	122.4
	1.6	130.1	128.7	124.1
	1.8	128.5	123.8	123.5

The micro hardness results show a tremendous increase in hardness as a result of coating with stellite6 alloy. As the hardness measurement was performed from the base metal towards the coating area, a drastic increase in hardness can be observed. The rotational speed was optimized to 1400 RPM after a number of trial runs. Hardness increased near the interfacial areas compared to the original hardness of the substrate, i.e., before the coating process. This increase in hardness can be related directly to the microstructure formed at the interface as a result of frictional heat and plastic deformation [3, 4, 5].

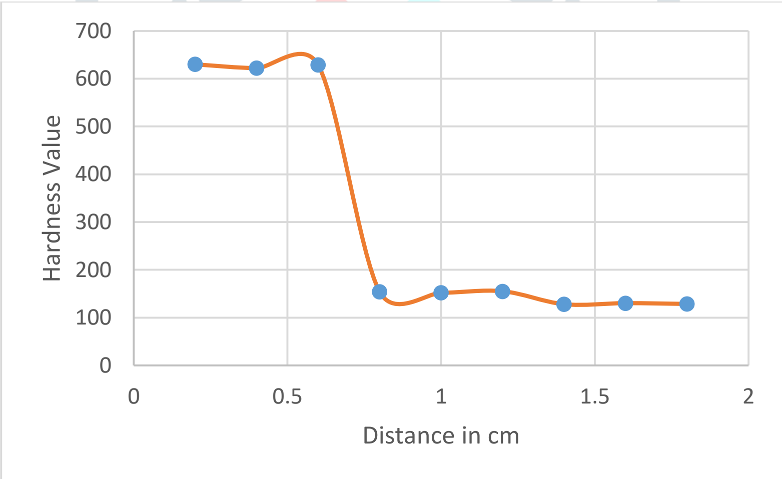

Fig 3 (c) -Hardness values of MSS6-1

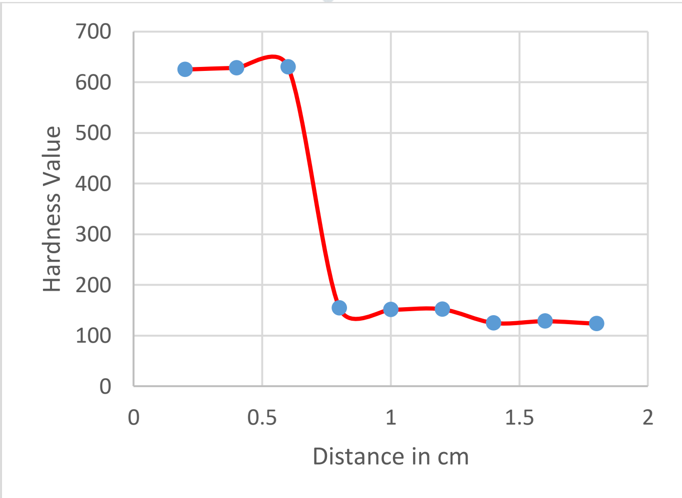

Fig. 3(d)-Hardness values of MSS6-2

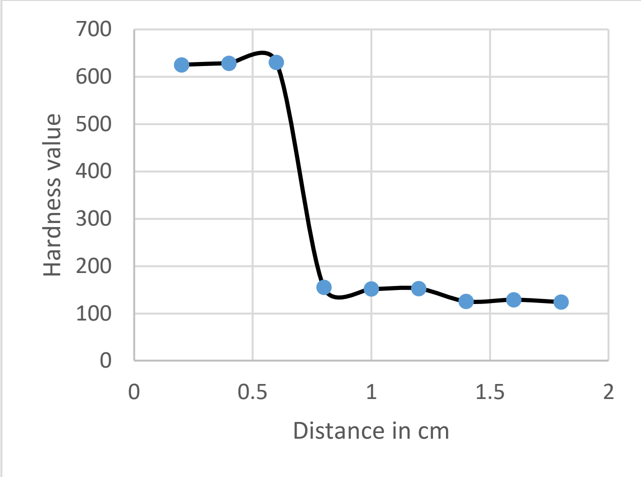

Fig. 3(e) -Hardness values of MSS6-3

The combined effect of heat and plastic deformation also caused a decrease in the grain size, thereby improving the hardness near the interfacial area [7,8]. At lower rotational speeds, longer heating times propagated more heat to the substrate, resulting in wider heat affected zone (HAZ) [8, 9, 12]. The substrate regions which exhibited higher hardness indicate the extent of HAZ. Coatings in as deposited condition showed anincreased hardness (630 HV) compared to the substrate material in mild steel (130 HV).

Conclusion

The present study demonstrated thatan efficient coating of Stellite6 alloy on mild steel substrate is possible.The process parameters,especially the rotational speed was optimized to 1400 RPM after a number of trial runs.During higher rotational speeds (e.g. at 1600 RPM and 1800 RPM) the coated area was characterized by poor microstructure and surface finish.A Finer microstructure was obtained when the rotational speed was maintained at 1400 RPM. Microhardness tests of the samples revealed a tremendous increase in hardness in the coated area as compared to the base metal or the HAZ portions. The microhardness of the samples recorded a drastic increase in hardness from 130 to 630 HV as a result of coating with stellite6 alloy.

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References

[1] Margam Chandrasekaran, Andrew William Batchelor and Sukumar Jana (1996), ‘Friction surfacing of metal coatings on steel and aluminium substrate’, Journal of Materials Processing Technology, Vol. 72, pp. 446-452.

[2] Vitanov V.I., Voutchkov I.I. and Bedford G.M. (2000), ‘Decision support system to optimise the Frictec (friction surfacing) process’, Journal of Materials Processing Technology, Vol. 107, pp. 236-242.

[3] Vitanov V.I. and Voutchkov I.I. (2005), ‘Process parameters selection for friction surfacing applications using intelligent decision support’, Journal of Materials Processing Technology, Vol. 159 pp. 27-32.

[4] Hidekazu Sakihama, Hiroshi Tokisue and Kazuyoshi Katoh (2003), ‘Mechanical Properties of Friction Surfaced 5052 Aluminum Alloy’ Materials Transactions, Vol. 44, No. 12 pp. 2688-2694.

[5] Xuemei Liu, Junshan Yao, Xinhong Wang, Zengda Zou and Shiyao Qu (2008), ‘Finite difference modelling on the temperature field of consumable-rod in friction surfacing’, Journal of materials processing technology, Vol. 209, pp. 1392-1399.

[6] Khalid Rafi H., Janaki Ram G.D., Phanikumar G. and Prasad Rao K. (2010), ‘Microstructural evolution during friction surfacing of tool steel H13’, Materials and Design, Vol. 32, pp. 82-87.

[7] Khalid Rafi H., Janaki Ram G.D., Phanikumar G. and Prasad Rao K. (2010), ‘Friction Surfacing of Austenitic Stainless Steel on Low Carbon Steel: Studies on the Effects of Traverse Speed’, Proceedings of the World Congress on Engineering 2010, Vol. II, London, U.K.

[8] Stefanie Hanke, Alfons Fischer, Matthias Beyer and Jorge dos Santos (2011), ‘Cavitation erosion of NiAl-bronze layers generated by friction surfacing’, Wear, Vol. 273, pp. 32-37.

[9] Prasad Rao K., Veera Sreenu A., Khalid Rafi H., Libin M.N. and Krishnan Balasubramaniam (2012), ‘Tool steel and copper coatings by friction surfacing – A thermography study’, Journal of Materials Processing Technology, Vol. 212, pp. 402-407.

[10] Gandra J., Miranda R.M. and Vilaca P. (2012), ‘Performance analysis of friction surfacing’, Journal of Materials Processing Technology, Vol. 212, pp. 1676-1686.

[11] Hanke S., Beyer M., Aulis Silvonen, dos Santos J.F. and Fischer A. (2013), ‘Cavitation erosion of Cr60Ni40 coatings generated by friction surfacing’, Wear, Vo. 301, pp.415-423.

[12] Gandra J., Krohn H., Miranda R.M., Vilac P., Quintino L. and dos Santos J.F. (2013), 'Friction surfacing-A review', Journal of Materials Processing Technology, Vol. 214, pp. 1062-1093.

[13] Gandra J., Vigarinho P., Pereira D., Miranda R.M., Velhinho A.and Vilaca P. (2013), 'Wear characterization of functionally graded Al-SiC composite coatings produced by Friction Surfacing', Materials and Design, Vol. 52, pp. 373-383.

[14] Sekharbabu R., Khalid Rafi H. and Prasad Rao K. (2013), 'Characterization of D2 tool steel friction surfaced coatings over low carbon steel', Materials and Design, Vol. 50, pp. 543-550.

[15] Hanke S., Beyer M., dos Santos J.F. and Fischer A. (2013), 'Friction surfacing of a cold work tool steel-Microstructure and sliding wear behaviour', Wear, Vol. 308, pp. 180-185.

[16] Javed Akram, Ramesh Puli, Prasad Rao Kalvala and Mano Misra (2014), 'A novel weld transition joint by friction surfacing', Manufacturing Letters, Vol. 2, pp. 104–107.

[17] Stegmueller M.J.R, Schindele P. and Grant R.J. (2015), 'Inductive heating effects on friction surfacing of stainless steel onto an aluminium substrate', Journal of Materials Processing Technology, Vol. 216, pp. 430–439.