Finite Element Analysis and Mechanical Testing of Friction Stir Processed Low carbon Steel Plate

Gaurav S. Patil[#1], N. V. Satpute[#2],
[#1]M.Tech Student, Mechanical Engineering Department, Vishwakarma Institute of Technology- Pune, India
[#2]Assistant Professor, Mechanical Engineering Department, Vishwakarma Institute of Technology- Pune, India

Abstract

Friction stir process is a solid state technology with increasing applications in the context of localized surface engineering. FSP 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. Main applications include surface properties improvement and coating. A wide range of material combinations have been deposited by FSP, mainly alloy and stainless steels. Aluminium, magnesium and titanium alloys have also been investigated, including the production of metal matrix composites. In this report coating of AISI 304 stainless steel powders was used as coating material and it is applied on low carbon steel. For above coating purpose we use non-consumable W C tool. The main process parameters are Tool RPM, Normal force, travel speed. In this report thermal model is made by using moving co-ordinate system in order to get temperature distribution across plate. This temperature data from FEA is used as input to the further analytical calculations. Free- Free vibration analysis is done on the steel plate and Zinc coated plate and natural frequencies are extracted. Stress analysis of steel plate and Zinc coated plate is done using experimentally and FEA. Bend test and Wear test is performed on Steel plate and Zinc coated plate.

Keywords — *FSP, Low Carbon Steel, AISI 304 Stainless steel, Bend Test, Wear Test, Modal Analysis.*

I. INTRODUCTION

Friction stir processing (FSP) is an emerging surface engineering technology, developed on the basic principles of friction stir welding (FSW), which can provide localized microstructure modification in near surface layers of processed materials. A rotating tool consisting of a shoulder and a pin is plunged into a work piece and then travels in an expected direction. The tool serves two primary functions, heating and deformation of a material. The material in FSP zone undergoes extreme levels of plastic deformation and thermal exposure, which normally results in significant microstructural refinement and homogeneity of the processed zone, thereby improving strength, wear property, corrosion resistance and so on. The technology of FSP essentially provides a high integrity smooth repair of shallow surface defects. Compared with conventional weld repair methods, this technology can offer advantages for online application particularly in terms of its lower risk of through wall penetration? Friction stir processing is a solid state coating process based on the plastic deformation of a metallic consumable rod. As depicted in Fig. 1, a rotating rod is pressed against the substrate under an applied axial load. Frictional heat generates a visco-plastic 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 visco-plastic shearing interface is formed between the rotating consumable rod and the deposited layer. With the on-going heat conduction, this visco-plastic shearing interface moves away from the substrate surface, increasing the thickness of the layer. By applying a travelling movement, the visco-plastic material is deposited onto the substrate surface in a continuous process. Note that FSP relies solely on inter-facial 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.

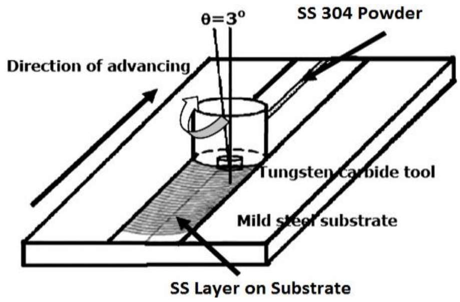

Fig.1. Schematic Of FSP For Fabrication Of Stainless Steel Layer On Mild Steel Substrate

II. MATERIALS AND METHODS

A low carbon steel plate with nominal chemical composition was used as the substrate material. The workpiece was prepared with thickness, width, length of 10, 120 and 250 mm, respectively. A groove was made in a straight line along the middle length of the workpiece with its width and depth of 2 and 2 mm, respectively. The grove of the workpiece was filled with AISI 304 stainless steel powder (with average particle size of 45 µm) before FSP experiment. The tungsten carbide tool was fabricated with a shoulder and pin diameter of 25 and 6 mm, respectively. The pin length used was 2.7 mm. Friction stir processing on the substrate was carried out using a tool rotation, traverse speed and normal force of 1000 rpm, 63 mm/min and 10 kN, respectively. Process parameters such as tool rotation, traverse speed, normal force and groove dimensions were selected according to detailed literature review. Fig. 2 shows the actual FSP experimental setup developed on the milling machine.

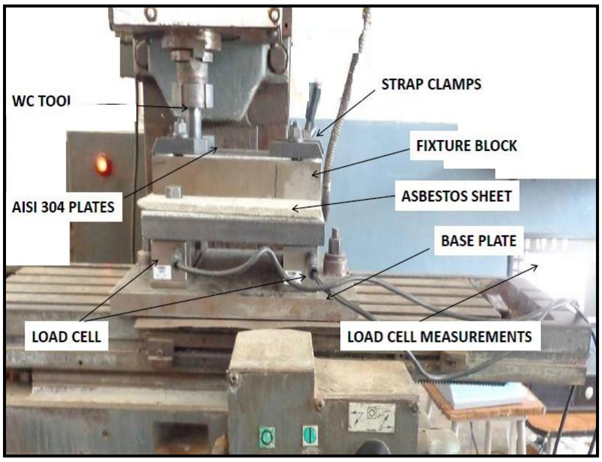

Fig.2. Experimental setup for FSP

Bend test was performed on the specimens which were cut out from the processed substrate to calculate the flexural strength and flexural modulus of the coated substrate. The three point bend test performed and specimen size were according to the ASTM E290 standard. To check the compressive and tensile flexural strength, internal as well as external three point bend test was performed. Also Finite element analysis of the plate was carried out. The specifications of the test and specimen were, distance between lower supports(c) = 65 mm, roller diameter(r) = 10 mm, specimen thickness (t) = 4.5 mm, width (w) = 9 mm and length (l) = 90 mm. Fig. 3 shows the three point bend test experiment.

Fig.3. Experimental Three Point Bend Test

Wear test was conducted using a pin on disk tribometer. Most requirements of ASTM standard G99-04 were followed. Cylindrical pin specimens wih diameter of 10 mm were made from as received low carbon steel and fabricated surface layer. The counter part disks were made of 100Cr6 (AISI 52100) steel with hardness value of about 60 HRC. Sliding track dimensions on the disk surface was 40 mm. before wear test, each pin specimen was ground down to 1000 grit abrasive paper. Wear test were performed under dey silding condtitons using sliding velocity of 2 m/s. A constant load of 40 N was applied. Both pin specimens were cleaned in acetone & weighed to an accuracy of 0.1 mg prior to testing and at different sliding distances during the test.

Wear test was performed to compare the wear rate and wear resistance of coated and uncoated side of the substrate. Fig. 4 shows the experimental wear test.

Fig.4. Expermental Wear Test on Pin-on-Disk Tribometer

Modal analysis of the coated plated was done to find out the natural frequencies and compare the same with the uncoated plate. To calculate the natural frequencies of the friction stir processed plate.

Modal analysis is used to get natural frequency of the model. And mode shapes derived from modal analysis will give rough idea about how model behave in certain conditions. Abaqus was used as a FEA tool to calculate the natural frequencies of the plate. It is the study of the dynamic properties of structures under vibration excitation. Under free-free vibration condition fundamental frequencies of vibrations are calculated.

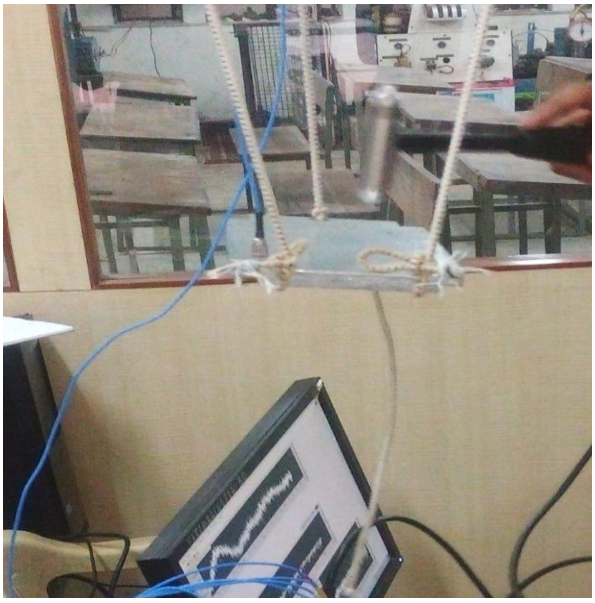

Fig.5. Experimental Modal Analysis (Free-Free)

III. RESULTS AND DISCUSSIONS

A. Bend Test

The bend test was performed on the two specimens, on one internal bend test and on other external bend test was performed. Load vs. Deformation curve were obtained from the test and from which peak load and peak deformation were determined thus flexural strength and flexural modulus of the processed plate were calculated. Finite element analysis of the plate was also done in Abaqus and the results were compared. Fig. 6 and Fig. 7 show the load vs. deformation curve of external and internal bend test respectively. Also the Table 1 shows the comparison of experimental and FEA value of flexural strength. Table 2 shows the experimental value of flexural modulus of the plate during internal and external bend test. The peak load and Peak deformation for the external bend test are 1813 N and 9.7 mm respectively, and for internal bend test are 1990 N and 10.5 mm.

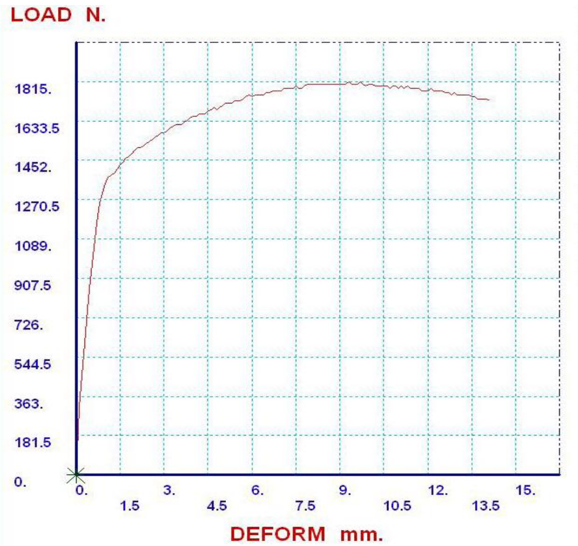

Fig.6. Load Vs. Deformtion Curve of External Bend Test

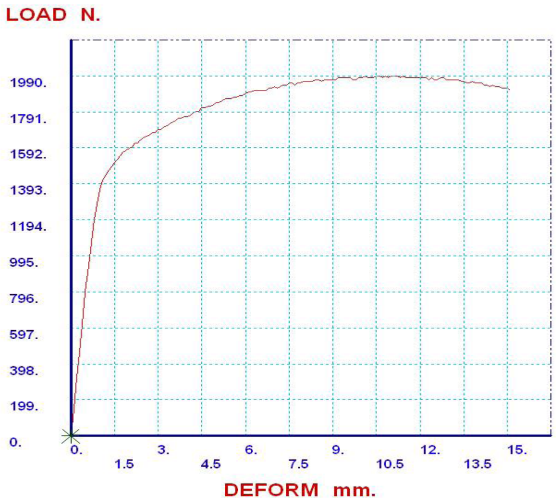

Fig. 7. Load Vs. Deformtion Curve of Internal Bend Test

Type of Bend Test	**Experimental value (Mpa)**	**FEA value (Mpa)**	**Error (%)**
External	969.90	850.13	12.37
Internal	1064.28	910.90	14.47

Table 1. Comparison of Experimental and FEA Value of Flexural Strength

Type of Bend Test	**Experimental Value (Gpa)**
External	175.80
Internal	217.65

Table 2. Experimental Value of Flexural Modulus

B. Wear Test

The weight loss data as a function of sliding distance against disks of 100Cr6 (AISI 52100) steel is shown in Fig. For the as-received low carbon steel and stainless steel coating pin specimen. In both cases, the wear volume loss value increased with sliding distance. Table 2 shows the wear volume loss and wear resistance values. It is clearly seen from the table that the volume loss of coated side is 3 to 5 times less than the volume loss of uncoated side as well as the wear resistance of the coated side is higher by the same factor. These results can be attributed to the hardening of the material due to intense localized deformation.

Sample No.	Coated Side		Uncoated Side	
	Volume Loss (mm^3)	Wear Resistance (m/mm^3)	Volume Loss (mm^3)	Wear Resistance (m/mm^3)
1	0.38033	1314.6478	1.9904	251.2058
2	0.76396	981.7396	2.2562	332.4173
3	0.89937	1111.4445	2.5183	397.0932

Table 3. Volume loss and Wear resistance of Coated and Uncoated Side

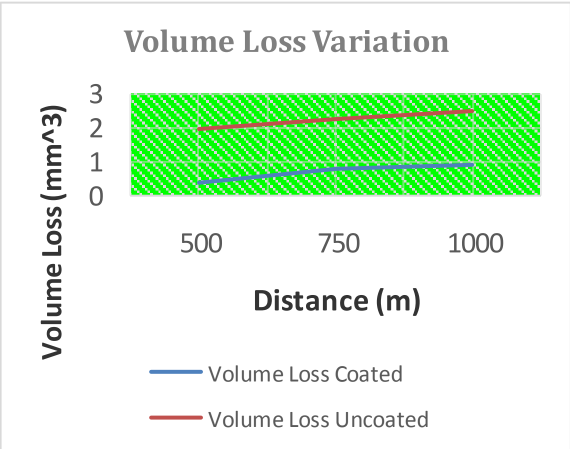

Fig.8. Graph of Volume Loss vs. Distance

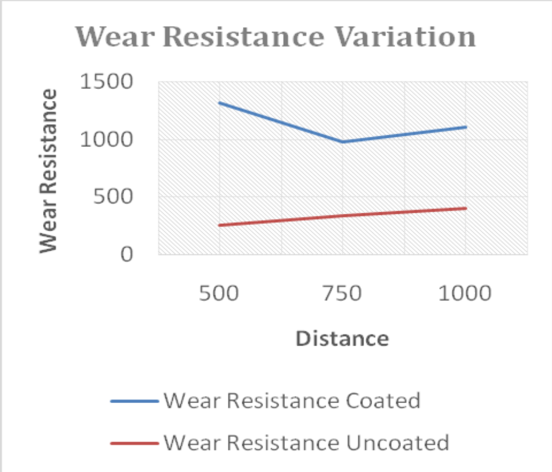

Fig.9. Graph of Wear Resistance vs. Distance

C. Modal Analysis

Free-free vibration analysis was performed to get the natural frequencies. Using the modal analysis natural frequencies of processed and unprocessed plate were found out. Table 4 shows the result of the first fundamental natural frequency for the processed and unprocessed plate. The increase in the value of the natural frequency of he processed plate can be attributed to the residual stresses introduced in the plate while processing.

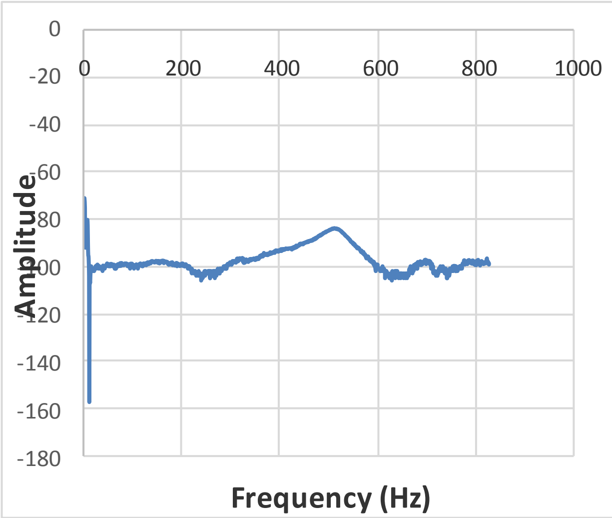

Fig.10. Frequency Response Curve for Stainless Steel Coated Plate

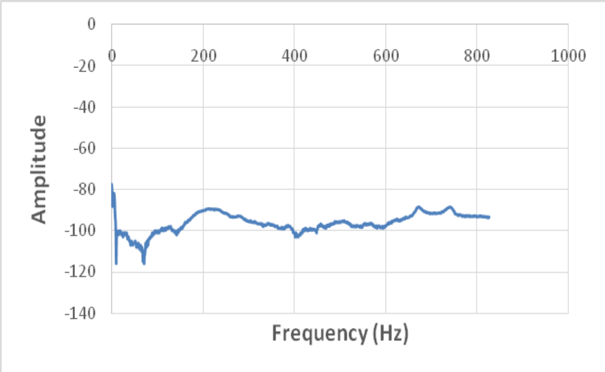

Fig.11. Frequency Response Curve for Steel Plate

	Stainless steel Coated	Steel
First fundamental frequency (FEA)	457	264
First fundamental frequency (Experimental)	515	210
Error (%)	11.2	20.45

Table 4. Comparison of Experimental and FEA values of first Fundamental Frequency

IV. CONCLUSIONS

In this investigation stainless surface layer was successfully fabricated by introduction of AISI 304 stainless steel powder into the stir zone using friction stir processing. Mechanical studies of the FSPed substrate with and without coating can be summarized as follows. Bend Test results show that compressive flexural strength of the plate is higher than tensile flexural strength. Also the flexural modulus of the coating side is less than uncoated side which shows that the coated layer is less ductile. Wear test results shows the improvement in the wear resistance of the coated side as compared to uncoated side and it is 3 to 5 times of that of uncoated side. Modal Analysis shows that the first fundamental Frequency of Stainless steel coated plate is higher than steel coated plate which implies that there are residual stresses in the plate, introduced while friction stir processing the plate.

ACKNOWLEDGMENT

The authors highly acknowledge the Mechanical Engineering Department for their continuous and valuable support.

REFERENCES

[1] JinwenQian, ‘In situ synthesizing Al3Ni for fabrication of intermetallic-reinforced aluminum alloy composites by FSP’, Materials Science & Engineering A, vol. 279 -285.

[2] Ahmad Ghasemi-Kahrizsangi, ‘Microstructure and mechanical properties of steel/TiC nano-composite surface layer produced by FSP’, Suraface and Coating Tchnlogy, vol. 462, 2007.

[3] R.S. Mishra, ‘Friction stir processing: a novel technique for fabrication of surface composite’, Materials Science and Engineering A341 (2003) 307/310

[4] D.Dhmadkhaniha, M. HeydarzadehSohi, A. Zarei-Hanzaki, S.M. Bayazid, M. Saba. “Taguchi optimization of process parameters in friction stir processing of pure Mg”, Journal of Magnesium and Alloys 3 (2015) 168-172.

[5] H Schmidt, J. Hattel and J Wert, An analytical model for the heat generation in friction stir welding, Modelling Simul. Mater. Sci. Eng. 12 (2004) 143–157.

[6] R. Nandan, G.G. Roy, T.J. Lienert, T. Debroy, Three-dimensional heat and material flow during friction stir welding of mild steel, ActaMaterialia 55 (2007) 883–895.

[7] A. Arora,R. Nandan,A.P. Reynolds and T. DebRoy, Torque, power requirement and stir zone geometry in friction stir welding through modelling and experiments, ScriptaMaterialia 60 (2009) 13–16.

[8] A. Arora, T. DebRoy, H.K.D.H. Bhadeshia, Back-of-the-envelope calculations in friction stir welding – Velocities, peak temperature, torque, and hardness, ActaMaterialia 59 (2011) 2020–2028.

[9] J.H. Hattel, H.N.B. Schmidt and C. Tutum, Thermo mechanical Modelling of Friction Stir Welding, Stan A. David, TarasankarDebRoy, John N. DuPont, Toshihiko Koseki, Herschel B. Smartt, editors, p 1-10.

[10] Y. Katayama, M. Takahashi, T. Shinoda, New friction surfacing application for stainless steel pipe, Welding in the World, Vol. 53, 11/12, 2009