A Composite Surface Formation during Friction Surfacing for Aluminum Pipe Internally Coated With Zinc

Vootla Ashok Kumar and Pulla Sammaiah

Abstract--- Coating involves the application of a thin film of functional material to a substrate, such as paper, fabric, film, foil or sheet stock. Coatings may be applied as liquids, gases or solids. Coatings can be measured and tested for proper opacity and film thickness by using a draw down card. At the lower speed and lower forward time, the hardness is approximately equal but a slightly difference in hardness. The hardness increases with an increase in reverse time at high speed of the pipe and higher forward time but there is a difference in hardness at lower forward time and higher forward time. The thin film is formed during machining between aluminum and zinc. The hardness of the internal surface of the pipe varies with the speed of the pipe at the constant forward time and reverse time. This happens due to lower speed and at higher forward and lower reverses time results higher friction leads to more deposition. The coating thickness is increases with an increase in forward time at low speed and low reverse time. The coating thickness is higher at higher forward time and lower reverse time due to more amount of zinc deposition due to more axial compressive forces. The coating thickness is increases with an increase in forward time at the condition of higher pipe speed and at lower reverse time due to higher plastic deformation which results coarse grain structure. The coating thickness of the internal surface of the pipe varies with the speed of the pipe at the constant forward time and reverse time. This happens due to lower speed and at higher forward and lower reverses time results higher friction leads to more deposition. The study reveals it is a technique to improve the properties at the interface between aluminum and zinc.

Keywords--- Friction Surfacing, Forward Time, Reverse Time, Properties of Intersurface

I. INTRODUCTION

COATING is a covering that is applied to the surface of an object, usually referred to as the substrate. In many cases coatings are applied to improve surface properties of the substrate, such as appearance, adhesion, wet ability, corrosion resistance, wear resistance, and scratch resistance. In other

cases, in particular in printing processes and semiconductor device fabrication (where the substrate is a wafer), the coating forms an essential part of the finished product. Low-pressure cold spraying was used to deposit aluminium particles (~25 μm diameter) on to low carbon steel, and the particle-particle interactions of the aluminium coating were analyzed. A simplified energy conservation model was developed to estimate the temperature at the interface of the deformed particle during deposition of the powder [1]. In this paper, post annealing of cold-sprayed (CDGS) coatings for intermetallic compounds (IMC) in the matrix at low temperature and dependences of types and dispersion characteristics of intermetallic compounds on spraying pressure condition were investigated [2]. In cold spraying, many factors, e.g., powder characteristics and compositions, spraying parameters, and post-treatments affect coating formation. Cold spraying is the optimal technique to produce highly dense coatings. Furthermore, denseness and impermeability are the criterions for the corrosion resistance of anodically protective coatings. Denseness of the coatings is evaluated by corrosion tests [3]. Surface temperature is expected to play an important role, since the deformation process leading to particle bonding and coating formation takes place both on the particle and the substrate side [4]. The effect of surface conditions focusing on active newly formed surface on aluminium particle deposition is studied and the mechanical properties of low-pressure cold-sprayed aluminium coatings are investigated by four-point bending tests. It is found that for efficient particle deposition it was necessary to obtain active newly formed surface of the substrate and particle surfaces by several impingements because the existence of inactive native oxide films has an adverse effect on the deposition [5]. The U.S. Army Research Laboratory (ARL) Centre for Cold Spray has developed a cold spray process to reclaim magnesium components that shows significant improvement over existing methods and is in the process of qualification for use on rotorcraft [6]. Micro structural developments and deposition behaviors from a deposited single particle to a thick coating layer were observed by high resolution electron microscopes. A single titanium particle sprayed onto the substrate was severely deformed and grain-refined mainly along the interfacial boundary of particle/substrate by the impact of the sprayed particle [7]. This study is devoted to thermal spraying and presents the state of our current knowledge, as well as the following research or development needs: spraying heat sources, i.e., flame, high-velocity oxifuel flame (HVOF), detonation gun (D-Gun), and plasma torches; particle heat and momentum transfer (measurements and modelling), process on-line

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control, powder morphologies, and injection within the hot jet and reactions with environment; coating formation, i.e., particle flattening and solidification, splat layering, residual stresses, coating microstructure, and properties; and reliability and reproducibility of coatings [8]. Cold spray technology, originated from the Institute of Theoretical and Applied Mechanics Siberian branch of the Russian Academy of Sciences, is a rapidly emerging industrial coating technology. Cold sprayed particles with high-velocity impact onto a substrate so as to induce severe plastic deformation and then create a deposit [9]. In this study, the in vitro degradation behavior of a friction stir processed AZ31 magnesium alloy was investigated. Electrochemical experiments in simulated body fluid suggest that friction stir processing marginally enhances the degradation resistance of the alloy, which could be attributed to the dissolution of secondary phase particles [10]. Analysis of mass transport in a high gradient thermal field initiated in micro-areas of materials subjected to FSP and FSW processes are included as well. Regarding the practical aspect of this research the analysis focuses on a Fe-Ni and Fe-Cu diffusion systems in a structural materials [11]. Dry sliding wears behavior of die cast aluminum alloy composites reinforced with copper-coated short steel fibers were investigated using a pin-on-disk wear-testing machine [12]. Friction surfacing is a candidate process for depositing corrosion and wear resistant coatings [13]. Thermocouple measurements, tool torque, extent of material mixing, and macro structural observations all indicate that the temperature under the tool is more strongly dependent on the rotation than the traverse speed [14]. In the present investigation, a numerical three-dimensional (3-D) heat flow model for friction stir welding (FSW) has been developed, is provided with a separate module for calculation of the microstructure evolution and the resulting hardness distribution [15]. The present study is concentrated on deposition of zinc on aluminum by using High speed Lathe machine.

II. EXPERIMENTAL WORK

The proper tool is selected according to pipe material and fixed in continuous drive friction stir processing machine. The tool is fixed in a stationary member while pipe is fixed in a rotary member. A tool material is inserted into the pipe and rotated inside the pipe to get sufficient temperature due to friction. So that a thin layer is formed between tool and pipe. Then the tool is slowly removed from the pipe. This thin layer (intermetallics) is formed inside the pipe material. This intermetallics act as anti-corrosion material. The friction factor and viscosity of the fluid inside the pipe/tube depends on surface roughness.

A. Material Selection

The material is selected based on mechanical, thermal and physical properties of metals. The intension of this process is to select the tool as low melting point material compared to pipe material and the tool is low hardness material where as pipe material is high hard material. The deposited material on internal surface of the pipe material is selected as zinc (Pure Zinc) where as pipe material is selected as aluminium (Pure

Aluminium) as shown in table 1. The following are the composition of tool and pipe materials are:

Table 1: Composition of Tool Material and Pipe Material

Sl.No	Composition of parent metals	
	Tool material (Zinc)	Pipe material (Aluminum)
1	99.9% Zn, 0.06P, 0.04S	99.9% Al, 0.05P, 0.05S

B. Tool Design

The tool is made up with zinc material and designed according to dimensions required for fitting inside the pipe material to deposit the zinc as coating inside the aluminum pipe. The tool is prepared from zinc billet is converted into required tool shape as shown in Fig. 1.

Fig. 1: Zinc Tool Material

The zinc billet is fixed in vice and cut into rectangular blocks of size 200X50X40 mm. Then the rectangular block is fixed in lathe machine and turning it into cylindrical rods of size length 200mm and 36mm dia. and cut into tool dimensions and pipe is also cut into required dimensions of 200mm.

The Auto CAD model of pipe material dimensions, tool material dimensions and tool supported material are prepared prior to design the actual dimensions of the tool and pipe as shown in Fig. 2.

Fig. 2: Auto CAD Model of Tool and Pipe

C. Experimental Setup

The All Geared Lathe machine is selected to do the operation for coating by friction technique. The aluminum pipe is fixed in rotating member (i.e. chuck) while tool is fixed in stationary member (Tool is fixed in horizontal rectangular rod which is fixed in tool post). The tool is adjusted to the

center of the pipe with the adjusting of tool post and set the external curvature of tool matches with internal curvature of the pipe. The tool always contacts with the pipe and start the rotation with given speed to the pipe. The tool is feeding slowly according to the selected parameters in forward direction after some time then the tool is slowly in reverse direction. The following parameters are selected and list of parameters are shown in Table 2.

- Speed(N) in rpm
- Forward time(F_T) in min
- Reverse time(R_T) in min

Table 2: Parameters are used in this Process

Sl. No.	Speed, N (rpm)	Forward time, F_T (min)	Reverse time, R_T (min)
1	1000	20	5
2	1000	20	10
3	1000	30	5
4	1000	30	10
5	1200	20	5
6	1200	20	10
7	1200	30	5
8	1200	30	10

In forward direction, the tool touches with the internal surface of the pipe and the friction generated between tool and pipe. This friction is enough to soften the tool surface and wear of the tool. The deposition is taking place on internal surface of the pipe. In reverse direction, the tool moves with less time improves the surface finish of the pipe.

D. Corrosion Test

The corrosion test is conducted on internal surface of coated aluminum pipe for corrosion under NaCl solution for certain period. The sample is according to corrosion test dimensions as shown in Fig. 3.

Fig. 3: Sample Prepared for Corrosion Test

E. Micro Hardness Test

The measurement of micro hardness was carried out using a Leitz-Wetzlar (Miniload 2) micro hardness tester, which can be conveniently equipped with a Vickers diamond square indenter or a Knoop indenter. Figures 4 show the photograph and schematic representation of the instrument used in the present studies. The main parts of this tester are the circular stage (a facility for pre-selection of the indentation site), indenter, load and a micrometer eye-piece for measurement of the indentation impression. The equipment is supplied with different weights of 10, 15, 25, 50, 100 and 200 g. The dead

weight of the machine or the basic force of the indenting unit is $5 \text{ g} \pm 50 \text{ mg}$. For these microhardness measurements, loads ranging from 10 to 100 g were used and for any applied load the indentation time was 15 sec. To ensure the correct timing a signaling device is provided in the hardness tester. The minimum dimension of the samples should be about $3 \times 3 \times 1 \text{ mm}^3$ and also they should be flat. At least three trials were made at each load and the average diagonal length of the indentation impressions was used to calculate hardness values. Further, indentations were made on the sample surface at different sites such that the distance between any two consecutive indentations was more than five times the diagonal length so as to avoid the surface effects.

Fig. 4: Photograph of Leitz-Wetzlar (miniload 2) Micro Hardness Tester

F. Metallography

The specimen were prepared in mounting press and polished on various emery papers the followed by etching. The microstructure is observed under microscope having AVER Cap software.

III. RESULTS AND DISCUSSIONS

A. Hardness

The parameters are plays a greater role to improve the hardness of coating, which is deposited inside the aluminum pipe. The parameters used in the experimentation are pipe speed, forward time for tool and reverse time for tool as shown in table 3. Pipe speed (N) in rpm – 1000 and 1200, Forward time for tool (F_T) in min – 20 and 30, Reverse time for tool (R_T) in min – 5 and 10 and Base metal:Aluminum pipe - 46.812 Hv, Zinc - 57.937 Hv

Table 3: Hardness varies with the Parameters

Sample No.	Parameters			Hardness, Hv
	Speed in rpm	forward time in min	Reverse time in min	
1	1000	20	5	56.515
2	1000	20	10	52.551
3	1000	30	5	106.521
4	1000	30	10	42.872
5	1200	20	5	118.239
6	1200	20	10	302.693
7	1200	30	5	50.135
8	1200	30	10	99.650

At the lower speed and lower forward time, the hardness is approximately equal but a slightly difference in hardness with an decreasing order due to low time is not enough to create coating. This leads to lower hardness which is equal to base

metals. The lower speed and higher forward time, the hardness is higher (Double value) than the base metal with the lower value of reverse time due to higher amount of zinc is deposited inside the internal surface of the aluminum pipe. In reverse time, the deposited zinc redistributed equal into the internal surface due to less time, which leads to more axial compressive forces acting onto the internal surface of the pipe. The hardness is increases with an increase in forward time at low speed and low reverse time. Lower reverse time allowed more axial compressive forces acting inside the surface of pipe. The hardness is higher at higher forward time and lower reverse time due to more amount of zinc deposition due to more axial compressive forces.

The hardness is decreases with an increase in forward time at the condition of higher pipe speed and at lower reverse time. The hardness is higher due to lower forward time results higher friction generated between tool and pipe then the more deposition of the zinc sticks with internal surface of the pipe.

The hardness is decreases with an increase in forward time at the condition of higher pipe speed and at higher reverse time. The hardness is higher due to lower forward time results higher friction generated between tool and pipe due to more deposition of the zinc stick with internal surface of the pipe. The hardness of the internal surface of the pipe varies with the speed of the pipe at the constant forward time and reverse time. This happens due to higher speed and at lower forward and reverse time results higher friction leads to more deposition. The hardness of the internal surface of the pipe varies with the speed of the pipe at the constant forward time and reverse time. This happens due to higher speed and at lower forward and higher reverse time results to high friction leads to higher deposition. The hardness of the internal surface of the pipe varies with the speed of the pipe at the constant forward time and reverse time. These happen due to lower speed and at higher forward and lower reverse time results higher friction leads to more deposition. The hardness of the internal surface of the pipe varies with the speed of the pipe at the constant forward time and reverse time. This happens due to higher speed and at higher forward and reverse time results higher friction leads to more deposition. This trend is different from at lower reverse time.

B. Coating Thickness

The coating is developed due to friction technique during rotation of the tool inside the aluminum pipe. The thickness of the coating is varied with different parameters used in the process as shown in table 4.

Table 4: Coating Thickness varies with the Parameters

Sample No.	Parameters			Coating thickness, mm
	Speed in rpm	forward time in min	Reverse time in min	
1	1000	20	5	0.0292
2	1000	20	10	0.0940
3	1000	30	5	0.0430
4	1000	30	10	0.0412
5	1200	20	5	0.0702
6	1200	20	10	0.1054
7	1200	30	5	0.1995
8	1200	30	10	0.0640

At the lower speed and lower forward time, the coating thickness is increases with an increasing reverse time due to more deposition of zinc in reverse time as shown in Fig. 5 and Fig. 6.

Figure 5: Sample 1

Figure 6: Sample 2

The lower speed and higher forward time, the coating thickness is approximately equal but a slightly difference with respect to reverse time. The higher forward time and lower reverse time results higher coating thickness due to higher amount of zinc is deposited inside the internal surface of the aluminum pipe. The coating thickness is increases with an increase in forward time at low speed and low reverse time. The coating thickness is higher at higher forward time and lower reverse time due to more amount of zinc deposition due to more axial compressive forces. The coating thickness is decreases with an increase in forward time at higher reverse time and low speed due to higher reverse time results lower deposition of the zinc. The coating thickness increases with an increase in reverse time at high speed and lower forward time. The maximum thickness is observed at higher speed due to more plastic deformation between tool and pipe. More plastic deformation happens due to higher speed.

The coating thickness decreases with an increase in reverse time at high speed of the pipe and higher forward time but there is a difference in hardness at lower forward time and higher forward time. The coating thickness is increases with an increase in forward time at the condition of higher pipe speed and at lower reverse time due to higher plastic deformation which results coarse grain structure. The coating thickness of the internal surface of the pipe varies with the speed of the pipe at the constant forward time and reverse time. This happens due to higher speed and at lower forward and reverse time results higher friction leads to more deposition. The coating thickness of the internal surface of the pipe varies with the speed of the pipe at the constant forward time and reverse time. This happens due to higher speed and at lower forward and higher reverse time results to high friction leads to higher deposition.

The coating thickness of the internal surface of the pipe varies with the speed of the pipe at the constant forward time and reverse time. This happens due to lower speed and at higher forward and lower reverse time results higher friction leads to more deposition. The coating thickness of the internal surface of the pipe varies with the speed of the pipe at the constant forward time and reverse time. This happens due to higher speed and at higher forward and reverse time results higher friction leads to more deposition. The similar trend is observed even at lower reverse time also.

C. Corrosion

White Rust Observed inside the Tube at 12Hours and further intensifies at 24Hours. No damage is observed to the Base Material. The sample 1 and 2 are shown in Fig. 7 and Fig.8 that the intensity of corrosion increases if the sample kept in chemical for 24 hours.

Fig. 7: Coated sample after corrosion test during 24 Hrs

Fig. 8: Base metal after corrosion test during 24 Hrs

IV. CONCLUSION

The following points are concluded based on experimental results:

- At the lower speed and lower forward time, the hardness is approximately equal but a slightly difference in hardness.
- The hardness increases with an increase in reverse time at high speed of the pipe and higher forward time but there is a difference in hardness at lower forward time and higher forward time.
- The hardness of the internal surface of the pipe varies with the speed of the pipe at the constant forward time and reverse time. This happens due to lower speed and at higher forward and lower reverse time results higher friction leads to more deposition.
- The coating thickness is increases with an increase in forward time at low speed and low reverse time. The coating thickness is higher at higher forward time and

lower reverse time due to more amount of zinc deposition due to more axial compressive forces.

- The coating thickness is increases with an increase in forward time at the condition of higher pipe speed and at lower reverse time due to higher plastic deformation which results coarse grain structure.
- The coating thickness of the internal surface of the pipe varies with the speed of the pipe at the constant forward time and reverse time. This happens due to lower speed and at higher forward and lower reverse time results higher friction leads to more deposition.

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REFERENCES

- [1] M. P. Dewar, A. G. McDonald and A. P. Gerlich, 2012, Interfacial heating during low-pressure cold-gas dynamic spraying of aluminum coatings Journal of Materials Science, Volume 47, Number 1, Pages 184-198.
- [2] Lee, H. Shin and K. Ko Journal of Thermal Spray Technology, 2010, Effects of Gas Pressure of Cold Spray on the Formation of Al-Based Intermetallic Compound Volume 19, Numbers 1-2, Pages 102-109.
- [3] Heli Koivuluoto and Petri Vuoristo, 2010, Structural Analysis of Cold-Sprayed Nickel-Based Metallic and Metallic-Ceramic Coatings Journal of Thermal Spray Technology, Volume 19, Number 5, Pages 975-989.
- [4] J. G. Legoux, E. Irissou and C. Moreau, 2007, Effect of Substrate Temperature on the Formation Mechanism of Cold-Sprayed Aluminum, Zinc and Tin Coatings Journal of Thermal Spray Technology, Volume 16, Numbers 5-6, Pages 619-626.
- [5] K. Ogawa, K. Ito, K. Ichimura, Y. Ichikawa and S. Ohno, et al. 2008, Characterization of Low-Pressure Cold-Sprayed Aluminum Coatings Journal of Thermal Spray Technology, Volume 17, Numbers 5-6, Pages 728-735
- [6] The Repair of Magnesium Rotorcraft Components by Cold Spray JOURNAL OF THERMAL SPRAY TECHNOLOGY Volume 16, Number 2, 306-317, DOI: 10.1007/s11666-007-9039-2.
- [7] KeeHyun Kim, Seiji Kuroda and Makoto Watanabe, 2010, Microstructural Development and Deposition Behavior of Titanium Powder Particles in Warm Spraying Process: From Single Splat to Coating Journal of Thermal Spray Technology, Volume 19, Number 6, Pages 1244-1254
- [8] P. Fauchais, A. Vardelle and B. Dussoubs, 2001, Quo vadis thermal spraying Journal of Thermal Spray Technology, Volume 10, Number 1, Pages 44-66.
- [9] XiangKun Wu, JiShan Zhang, XiangLin Zhou, Hua Cui and JingChun Liu, December 2011 Advanced cold spray technology SCIENCE CHINA Technological Sciences, Online First™, 17
- [10] M. Bobby Kannan, W. Dietzel and R. Zettler, 2011, In vitro degradation behaviour of a friction stir processed magnesium alloy Journal of Materials Science: Materials in Medicine, Volume 22, Number 11, Pages 2397-2401.
- [11] Kocańda, A. Górka and D. Zasada 2011, Formation of a Metal Coating by Means of Friction Stir Processing, ICAF Structural Integrity: Influence of Efficiency and Green Imperatives, Part 3, Pages 167-178.
- [12] Durbadal Mandal, B. K. Dutta and S. C. Panigrahi, 2007, Dry sliding wear behavior of stir cast aluminium base short steel fiber reinforced composites Journal of Materials Science, Volume 42, Number 7, Pages 2417-2425.
- [13] C Ramesh Puli, E. Nandha Kumar and G. D. Janaki Ram, 2011, characterization of friction surfaced martensitic stainless steel (AISI 410) coatings
- [14] Transactions of the Indian Institute of Metals, Volume 64, Numbers 1-2, Pages 41-45 Show SummaryHide SummaryDownload PDF (375.1 KB).

- [15] M. J. Peel, A. Steuwer, P. J. Withers, T. Dickerson and Q. Shi, et al, 2006, Dissimilar friction stir welds in AA5083-AA6082..Metallurgical and Materials Transactions A, Volume 37, Number 7, Pages 2183-2193.
- [16] A Frigaard, Grong and O. T. Midling , 2001, process model for friction stir welding of age hardening aluminum alloys Metallurgical and Materials Transactions A, Volume 32, Number 5, Pages 1189-1200.