JOURNAL OF MODERN MANUFACTURING SYSTEMS AND TECHNOLOGY (JMMST)
e-ISSN: 2636-9575
VOL. 7, ISSUE 2, 17 – 22
DOI: https://doi.org/10.15282/jmmst.v7i2.9935

ORIGINAL ARTICLE

Influence of Clad Layer Thickness of Aluminium Alloy by Friction Surface Cladding Process.

N.I Yusoff, L.H Sulaiman
Faculty of Manufacturing and Mechatronic Engineering Technology, Universiti Malaysia Pahang, 26600 Pahang, Malaysia.

ABSTRACT – Friction Surface Cladding (FSC) is a process that enables the deposition of clad material on a substrate through a hollow rotating tool to create thin clad layers at sufficiently high temperature. Heat is produced during cladding process by friction at the tool-clad layer and the substrate. This study focus on the influence of clad layer thickness of aluminium alloy AA2024 at the control process temperature around 300°C to 350°C. The material used is AA2024-T4 for clad layer and AA2024-T351 for substrate. A thermal model is built using COMSOL Multiphysics 6.0 and Heat Transfer in Solid (ht) with time dependent study is used to study the heat transformation as well as optimizing rotational speed at different clad layer thickness. The major finding in this study indicates that the heat genareted proportional to the clad layer thicknes. The highest heat transformation can be seen at the cladding region between the cladding rod and the substrate and the temperature reaches a maximum of 333.95°C.

ARTICLE HISTORY
Received: 6th Sept 2023
Revised: 31th Oct 2023
Accepted: 9th Nov 2023

KEYWORDS
Friction Surface Cladding
Aluminium Alloy
COMSOL Multiphysics

INTRODUCTION

A new solid-state cladding process called friction surface cladding (FSC) is the subject of this exploratory study. FSC is highly versatile and can be used for a wide range of materials, including metals, alloys, and composites. It offers several advantages over traditional cladding techniques, such as the absence of melting and solidification, resulting in reduced thermal distortion and minimal dilution between the clad and substrate materials. It makes use of a specially created tool that can be fitted with a cylindrical channel that holds the consumable rod of clad material [7]. During the cladding process, both the tool and the rod rotate while being pushed outward by a hydraulic pumping unit. Through friction between the rotating of the tool's interface with the clad layer and substrate, heat is produced during the cladding process. A good lateral distribution and bonding of the clad material to the substrate depend on the tool's presence, process parameters, and temperature distribution.

The FSC process consists of a preheating phase and a cladding phase. By referring to figure 1, starting from a specific height above the substrate, the rotating tool rotates. When the clad material leaves the tool at a predetermined supply rate and makes contact with the substrate, frictional heating begins. After some time, the pressure and rising temperature cause plastic deformation in the clad rod. The preheating phase is completed by lateral spreading of the softened clad material through the small opening between the substrate and tool bottom. As soon as the temperatures are high enough, the cladding phase starts. The tool continuously deposits clad material while moving along a predetermined trajectory at a specific speed. The width of the clad layer deposited is determined by the volume of the clad material supplied per unit of time, the tool translation speed, and the distance between the tool and the substrate.

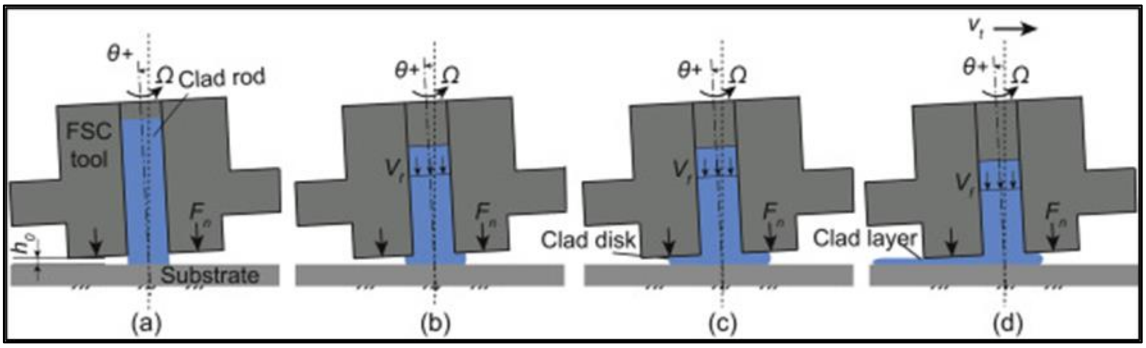


Figure 1: Schematic diagram of Friction Surface Cladding. (Liu et al., 2015)

*CORRESPONDING AUTHOR | N.I Yusoff | imrah@umpsa.edu.my

The distance between the tool and the substrate can be used to control the layer thickness. The clad layer width can also be adjusted by varying the volume of clad material supplied per unit of time. Due to the presence of the tool, the FSC process is ideal for cladding soft metals on substrates.

The purpose of this study is to investigate the effect of clad layer thickness on the deposition quality of AA2024 at constant process temperatures. The material used is AA2024-T4 for the clad layer and AA2024-T351 for the substrate. Simulation on the thermal model of heat generation on the clad layer deposition is simulated using software COMSOL Multiphysics 6.0.

Based on the study by Liu et al., [1] The rotation rate used for the friction surface cladding experiments ranged from 250 rpm to 600 rpm in steps of 50 rpm. Except for rotations at a rate of 250 rpm, AA1050 clad material was continuously deposited on the AA2024 substrate in all cases. All the supplied clad material was applied to the substrate during the cladding process. The normal force and temperature rapidly rise as soon as the clad rod is forced out of the rotating FSC tool and comes into contact with the substrate during the initial stages of the FSC experiment when the tool is rotating at a fixed position above the substrate. The temperature rises due to frictional heating. The cladding phase begins as soon as the tool temperature reaches a sufficient level of roughly 250℃. The temperature gradually rises over time or levels off after a certain translational distance. In the cladding phase, observed tool temperatures range from around 300 ℃ for the lowest rotation rates to over 450℃ for the experiment carried out at 600 rpm.

Another related study is friction stir welding (FSW). In FSW, a tool plasticizes the material nearby and merges the joint edges while simultaneously rotating and translating along the joint line. Due to the multiple benefits of FSW, including its input of heat and low welding temperature, removal of melting material, avoidance of alloy element evaporation loss, and lack of solidification-related issues, it has been widely employed in industry. FSW is thus a perfect welding technique for lightweight structural materials like magnesium alloy and aluminum alloy. The Al-Li joints are nevertheless softened by the FSW welding temperature, which results in a significant loss of joint characteristics and a constrained welding process. The comparatively high welding temperature in traditional FSW makes the loss of the joint strength for Al-Li alloy seem inevitable, even under ideal welding circumstances Shi et al., [6].

RESEARCH METHODOLOGY

A thermal model is built which recreates the whole FSC process. The methodology of FSC involves several key steps, including material preparation of clad material, substrate, tool design, process parameters, and the experimental setup cladding process. The process parameters, such as rotational speed and cladding thickness play a critical role in determining the quality of the cladded layer. Additionally, post-processing steps such as heat treatment or surface finishing may also be employed to further enhance the properties of the cladding material but will not apply in this study.

Figure 2. shows the flow chart for the whole research study. The experiment setup is a step where all the device and part used in the study is set with the right dimension and specification. After that comes the software development which in this study use COMSOL Multiphysic 6.0. A thermal model is built and Heat Transfer in Solid (ht) with time-dependent study is applied at this stage. Then, the parameter is set in order to get the preliminary result and to run the simulation. If there is an error occurs, the parameter is readjusted until it is error-free. Once the simulation is running, the model is then validated by comparing the results obtained with previous experimental results. If the data comparison has a large gap, then this study needs to repeat from the experimental setup to eliminate error otherwise can proceed with the result and discussion.

Table 1 shows the simulation process parameter used in this simulation study.

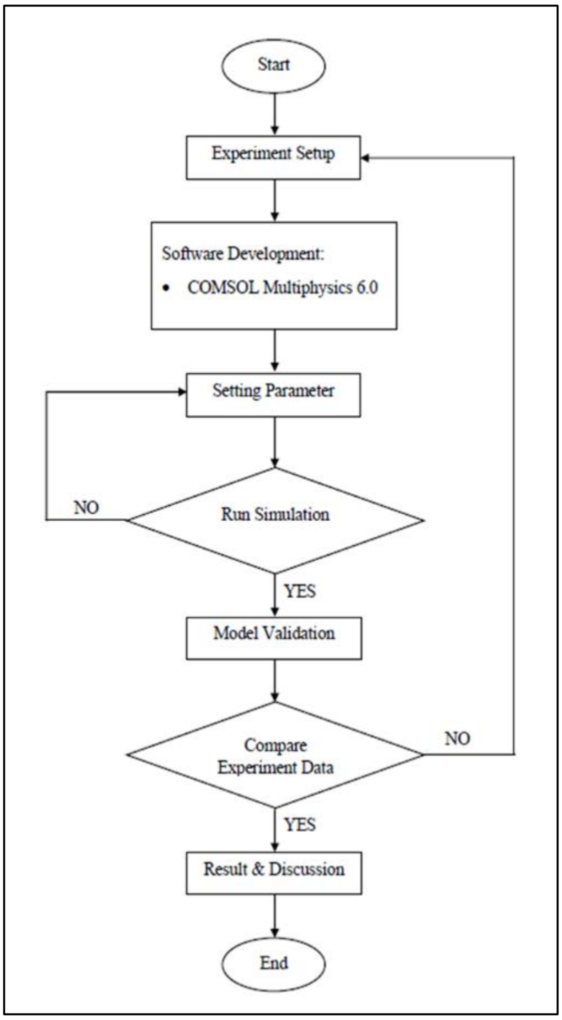


Figure 2. Flow Chart

Table 1. Simulation Process Parameter.

Clad Layer Thickness, h(mm)	Rotational Speed (rpm)	Translational Speed (mm/min)
0.2	250	60
	300	
	350	
0.4	300	60
	350	
	400	
0.6	350	60
	400	
	450	
0.8	450	60
	500	
	550	
1.0	450	60
	500	
	550	

$$\rho Cp \frac{\partial T}{\partial t} + \rho Cp \mathbf{u}.\nabla T + \nabla.\mathbf{q} = Q + Q\text{ted} \qquad (1)$$

$$\mathbf{q} = -\mathbf{k}\nabla\mathbf{T}$$

The physic selected is Heat Transfer in Solid (ht) with time-dependent. In the setting, there are a few data that need to be defined such as volume reference temperature, T_{ref}, Thermal Conductivity, k, Density, ρ, and heat capacity at constant pressure, Cp. Another method that can be used is to use the value defined by the software. One interesting function from COMSOL Multiphysics 6.0 is that it generates the governing equation based on the physic selected as shown in (1).

EXPERIMENTAL RESULTS

Figure 3. depicts the temperature distribution as a function of time for various experiments. As soon as the clad rod is forced out of the rotating FSC tool and comes into contact with the substrate during the initial stages of the experiment when the tool is rotating at a fixed position above the substrate, the normal force and temperature quickly rise. The temperature rises due to frictional heating. The cladding phase begins as soon as the tool temperature reaches a sufficient level, which is around 300℃. The temperature levels off to a roughly constant value after some translation distance or gradually rises over time. The experimental result was conducted at the clad layer thicknesses, h = 0.2, 0.4, 0.6, 0.8, and 1.0mm at constant Tool temperatures around 300℃ to 350℃ with various rotational speeds.

To simulate the temperature distribution during the FSC process, a number of thermal simulations were carried out. This method can also be used to calculate the effective temperature close to the tool-substrate interface, as shown in Figure 4. To study the heat transformation in the cladding region, a sample of the simulated temperature field in the FSC tool and the substrate for the 350 rpm sample on 0.2 mm clad layer thickness. At the tool-substrate interface, the temperature reaches a maximum of 333.950℃ and a minimum of 26.831 ℃ when it is far from the cladding zone. These temperature readings demonstrate the presence of significant thermal gradients close to the tool-substrate interface

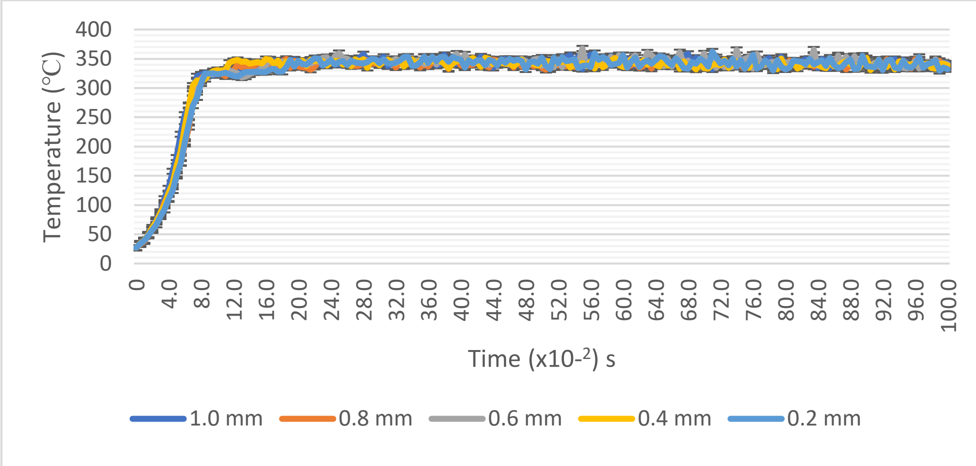
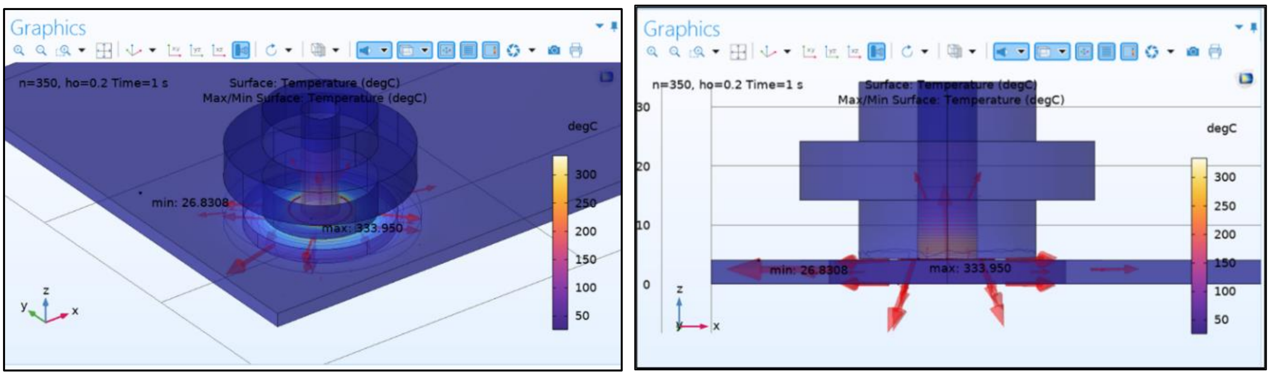


Figure 3. Heat Generation distribution with different clad layer thickness.



(a) (b)

Figure 4: (a) 3D view , (b) side view of clad layer thickness, h=0.2mm with 350 rpm.

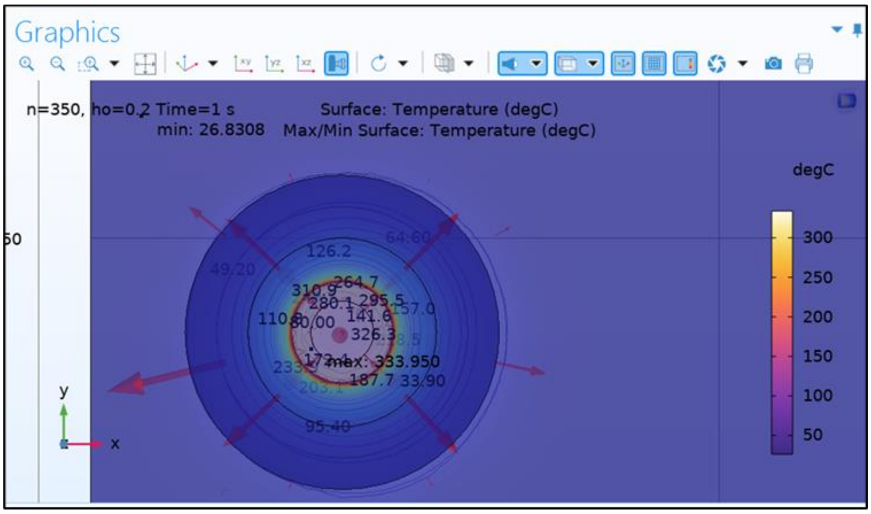


Figure 5: Heat flow from the center of clad region.

In the thermal model shown in Figure 5, the heat transformation can be observed. The heat flow from the center of the clad region which has the highest temperature which then conducted outward where the temperature is then lowered. The area outside of the clad region has a lower temperature compared to the inside clad region indicating the transformation of heat in the FSC process.

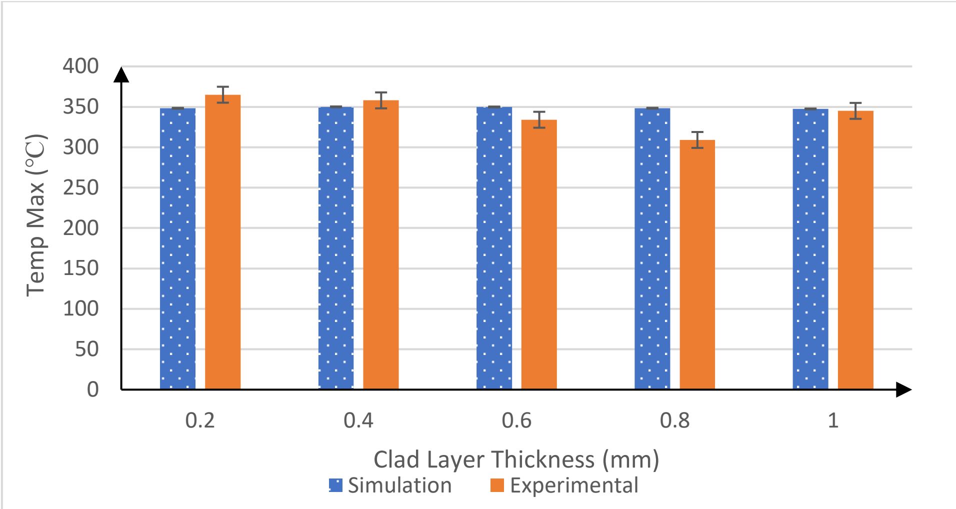
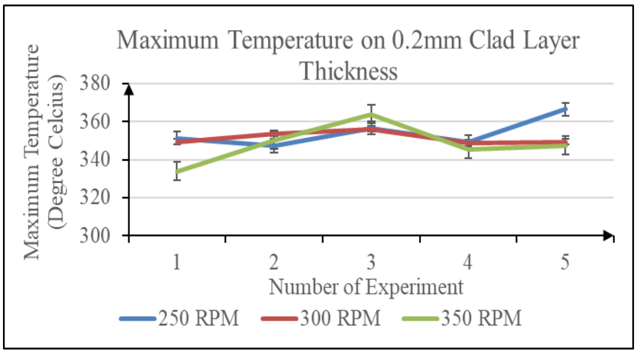
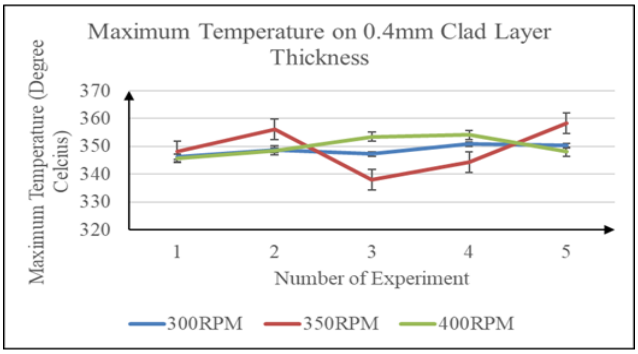


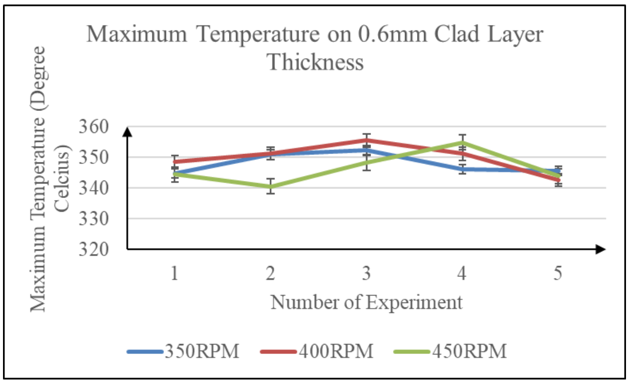
Figure 6: The maximum temperature for the experimental and simulation results.



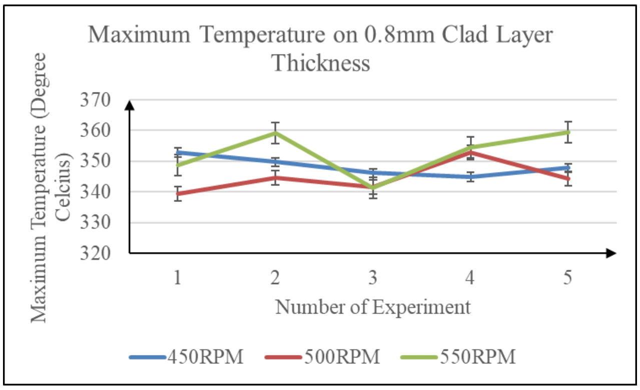
(a) *ho* = 0.2 mm



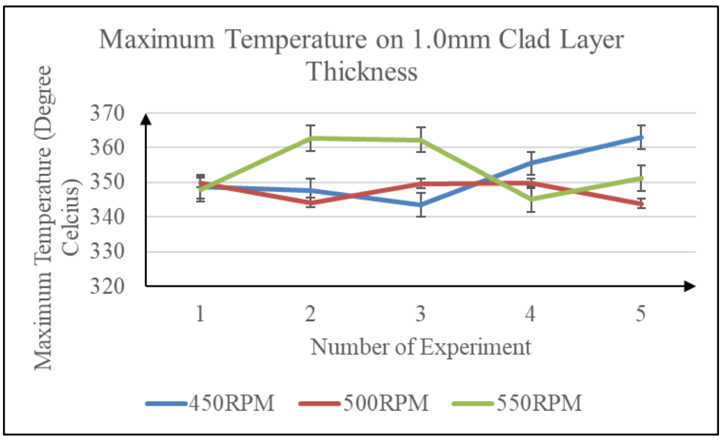
(b) *ho* = 0.4 mm



(c) *ho* = 0.6 mm



(d) *ho* = 0.8 mm



(e) *ho* = 1.0 mm

Figure 7: Maximum temperature For different clad layer thickness.

Figure 6. shows the comparison of maximum temperature against clad layer thickness for experimental and simulation results. All the data has a maximum temperature of higher than 300 ℃. This indicated that collected data are in the cladding phase. There is an insignificant difference between both results except for clad layer thickness, h=0.8 mm. Although the difference is quite significant, since both data are in the cladding phase, it is still acceptable. It can be concluded that the current data recorded is valid.

From the data collected through the simulation of the thermal model of different thicknesses on COMSOL Multiphysics 6.0, the rotational speed was been optimized in order to reach an average maximum temperature of 300 ℃ to 350 ℃ as shown in Figure 7. A clad layer thickness of 0.2 mm requires a rotational speed of 350 rpm in order to get a smooth clad surface. Both 0.4 mm and 0.6 mm clad layer thickness require 400 rpm rotational speed while 0.8 mm need a faster rotational speed of 450 rpm. As for the 1.0 mm clad layer thickness, since it is thicker, it requires 500 rpm rotational speed in order to generate enough heat to reach the required maximum temperature.

CONCLUSION

As a conclusion, the clad layer quality is highly dependent on the frictional and plastic deformation heat generated during the deposition process. The heat generated is shown to be strongly related to the tool rotation rate, the clad layer thickness, and the translational speed. Influence of clad layer thickness of AA2024-T4 on AA2024-T351 substrate by friction surface cladding process shows that for higher clad layer thickness, the generated heat required is larger, as also revealed by the temperature in the cladding region and rotational speed set up. The highest heat transformation can be seen at the cladding region between the cladding rod and the substrate. The flow of heat can be observed moving outward toward the tool shoulder and substrate.

High-quality clad layers were manufactured with a tool temperature ranging between 300 ℃ and 350 ℃ as in the literature. The developed thermal model provides a way to determine the heat generation rate which was shown to vary almost linearly with the previous recorded temperature. The extent of the heat-affected zone increases at higher tool temperatures. The rotational speed has been optimized for clad layer thickness 0.2mm, 0.4mm, 0.6mm, 0.8mm, and 1.0mm are 350 rpm, 400 rpm, 400 rpm, 450 rpm, and 500 rpm respectively. This parameter provides a better quality of AA2024-T4 clad layer on AA2024-T351 substrate.

ACKNOWLEDGMENT

The authors would like to thank the faculty for providing financial support and a computer lab.

REFERENCES

[1] Liu, S., Bor, T. C., Van Der Stelt, A. A., Geijselaers, H. J. M., Kwakernaak, C., Kooijman, A. M., Mol, J. M. C., Akkerman, R., & Van Den Boogaard, A. H. (2015). Friction surface cladding: An exploratory study of a new solid state cladding process. Journal of Materials Processing Technology, 229, 769–784. https://doi.org/10.1016/j.jmatprotec.2015.10.029

[2] Padhy, G. K., Wu, C. S., & Gao, S. (2018). Friction stir based welding and processing technologies - processes, parameters, microstructures and applications: A review. Journal of Materials Science and Technology, 34(1), 1–38. https://doi.org/10.1016/j.jmst.2017.11.029

[3] Rajendran, C., Kumar, M. V., Sonar, T., & Mallieswaran, K. (2022). Investigating the Effect of PWHT on microstructural features and fatigue crack growth behavior of friction stir welded AA2024-T6 aluminum alloy joints. Forces in Mechanics, 8. https://doi.org/10.1016/j.finmec.2022.100107

[4] Salhan, P., Singh, R., Jain, P., & Butola, R. (2022). Prediction of heat generation and microstructure of AA7075 friction stir welding using ANN: Effect of process parameters. Manufacturing Letters, 32, 5–9. https://doi.org/10.1016/j.mfglet.2022.01.004

[5] Salih, O. S., Ou, H., & Sun, W. (2023). Heat generation, plastic deformation and residual stresses in friction stir welding of aluminium alloy. International Journal of Mechanical Sciences, 238. https://doi.org/10.1016/j.ijmecsci.2022.107827

[6] Shi, L., Dai, X., Tian, C., & Wu, C. (2022). Effect of splat cooling on microstructures and mechanical properties of friction stir welded 2195 Al–Li alloy. Materials Science and Engineering A, 858. https://doi.org/10.1016/j.msea.2022.144169

[7] Stelt, A. A. van der. (n.d.). Friction surface cladding : development of a solid state cladding process.

[8] Stephen Leon, J., Alfred Franklin, V., Ravi, R., & Geetha, B. (2021). Numerical thermal modeling on tool and backing plate diffusivity in friction stir welding using non-circular tool pin. Materials Today: Proceedings, 51, 374–380. https://doi.org/10.1016/j.matpr.2021.05.469

[9] Sun, J., & Dilger, K. (2023). Reliability analysis of thermal cycle method on the prediction of residual stresses in arc-welded ultra-high strength steels. International Journal of Thermal Sciences, 185. https://doi.org/10.1016/j.ijthermalsci.2022.108085

[10] Vakkada Ramachandran, A., Zorzano, M. P., & Martín-Torres, J. (2022). Numerical heat transfer study of a space environmental testing facility using COMSOL Multiphysics. Thermal Science and Engineering Progress, 29. https://doi.org/10.1016/j.tsep.2022.101205

[11] Zhang, C., Cao, Y., Huang, G., Zeng, Q., Zhu, Y., Huang, X., Li, N., & Liu, Q. (2020). Influence of tool rotational speed on local microstructure, mechanical and corrosion behavior of dissimilar AA2024/7075 joints fabricated by friction stir welding. Journal of Manufacturing Processes, 49, 214–226. https://doi.org/10.1016/j.jmapro.2019.11.031

[12] Zhang, C., Huang, G., Cao, Y., Zhu, Y., & Liu, Q. (2019). On the microstructure and mechanical properties of similar and dissimilar AA7075 and AA2024 friction stir welding joints: Effect of rotational speed. Journal of Manufacturing Processes, 37, 470–487. https://doi.org/10.1016/j.jmapro.2018.12.014