INTRODUCTION

The friction surface cladding (FSC) method is comparable to the friction surface cladding (FS) and friction stir welding (FSW). The FSC system consists of an in-house created tool mounted on a modified planer machine with a hydraulic pumping unit that supplies the FSC tool with regulated amounts of hydraulic fluid [1]. Heat is generated by friction between the tool, clad material and the substrate. The FSC approach combines elements of both techniques to enhance the surface properties of the substrate. The interaction between the rotating consumable rod and the substrate generates heat during the cladding procedure, figure 1. Furthermore, the presence of the tool is required to provide adequate clad material distribution and attachment to the substrate. The gap between both the tool's bottom and the substrate, for example, determines the thickness of the clad layer. To optimise heat generation and allow mixing of the substrate and clad materials, the tool axis can also be changed in relation to the substrate normal.

**Figure 1**: Schematic of friction surface cladding
In this research project, the case of heat generation simulation was set up to predict the multilayer behavior of AA2024. The FSC method involves applying a clad material to a substrate with a rotating hollow tool, which allows for the formation of a thin clad layer at elevated temperature. The tool rotation rate $\Omega$, clad material supply speed $V_f$, layer thickness $h$, translation speed, $V_t$ are process parameter in the FSC process.

**METHODOLOGY**

**Experimental setup**

The material applied in this research AA2024 as a clad material and substrate. Table 1 indicated the chemical properties of AA2024. The substrate dimension with thermocouple inside 300mm x 141mm x 4mm and clad material with 10mm diameter. Figure 2 show the tool of H13 hardened steel with a diameter of 10mm for the centre opening. Table 2 show the process parameter that used in this experiment with different layer thickness and the rotation rate tool around 600rpm based on control temperature substrate approximately 350°C.

| Material     | Composition% | Material  | Composition% |
|--------------|--------------|----------|--------------|
| Aluminium    | 90.7-94.7    | Magnesium| 1.2-1.8      |
| Chromium     | 0.1          | Manganese| 0.3-0.9      |
| Copper       | 3.8-4.9      | Silicon  | 0.5          |
| Iron         | 0.5          | Titanium | 0.15         |

**Table 2. Process parameter for the experiment.**

| Layer | $h$ (mm) | $\Omega$ (rpm) | $V_t$ (mm/min) |
|-------|----------|----------------|----------------|
| First | 0.4      | 600            | 30             |
| 2nd   | 0.8      | 600            | 30             |
| 3rd   | 1.2      | 600            | 30             |
| 4th   | 1.6      | 600            | 30             |

**Comsol implementation**

The process for implementing COMSOL is similar to that of a standard nonlinear finite element analysis. Pre-processing, processing, and post-processing are the three steps in this technique. The Model Builder is broken into several parts to showcase the different distinct tasks that are completed under each job. The following significant points are taken from the Model Builder sections. Figure 3, show the Pre-processing, processing and post-processing task in the comsol. Comsol simulation require a lot of parameters that need to be solve. For a specific simulation setting, the FSC process is influenced by a number of process parameter. Table 3 depicts the parameter that been used in comsol multiphysics.

The parameter in Table 3 including translation speed, $V_t$, Tool rotation rate $\Omega$, clad material supply speed $V_f$, layer thickness $h$, radius clad rod, height clad according to conducted experiment.
Table 3: List of parameter inserted in Comsol Multiphysics.

| No. | Name     | Expression | Description                      |
|-----|----------|------------|----------------------------------|
| 1   | $F_n$    | 50[kN]     | Normal force                     |
| 2   | $v_t$    | 30[mm/min] | Translation Speed                |
| 3   | $R_s$    | 600[1/min] | Rotation speed (RPM)             |
| 4   | $F_c$    | 0.4[1]     | Friction coefficient             |
| 5   | htc1     | 10[W/m^2/K]| Heat transfer coefficient 1      |
| 6   | htc2     | 200[W/m^2/K]| Heat transfer coefficient 2     |
| 7   | $T_{melt}$| 919.15[K]  | Melting temperature              |
| 8   | omega    | 2*pi*[rad]*$R_s$ | Angular velocity        |
| 9   | $x_0$    | 100[mm]    | x=0 Tool                         |
| 10  | $y_0$    | 127.5[mm]  | y=0 Tool                         |
| 11  | $z_0$    | 83[mm]+$h_0$| z=0 Tool                         |
| 12  | $t$      | 4[mm]      | Material thickness               |
| 13  | $R_{rod}$| 5[mm]      | Radius Rod                       |
| 14  | $H_{rod}$| 10[mm]     | Height Rod                       |
| 15  | $D_{rod}$| 20[mm]     | Diameter Rod                     |
| 16  | $h_0$    | 0.4[mm]    | Clad layer thickness             |
| 17  | $R_{disk}$| 10[mm]    | Radius Disk                      |
| 18  | $D_{disk}$| 20[mm]    | Diameter Disk                    |
| 19  | $W$      | 20[mm]     | Clad Layer Width                 |
RESULTS AND DISCUSSION

Heat Input and temperature distribution

Figure 4: Simulation data

Figure 5: Temperature distribution of Tc and Tt for each layer.
Figure 4 shows the simulation data was chosen between 0 and 200 seconds. The temperature substrate (Tc) and temperature at tool (Tt) while adjusting the translation speed around 30(mm/min) and tool rotation speed 600 rpm. According to Figure 5, the value of Tc Max obtained from the maximum value at the substrate at each thermocouple point for the experiments with different layer thickness.

**Comparison with experimental result**

![Graph](image)

**Figure 6:** Comparison of Temperature distribution in simulation and experiment.

Graph from Figure 6 show the results of the temperature distribution measured form the experiment and simulation. The temperature result for the experimental result is significantly different from the simulation result. All the simulation temperature shows higher than experimental temperature. Tc has a temperature difference of 62.9% between experimental and simulation results, whereas Tt has a temperature difference of 66.9%. In this case, there was an error during parameter setting for simulation or experimental setup.

![Image](image)

**Figure 7:** Heat generation
Figure 7 shows the temperature distribution of the FSC tool, the substrate and the backing table for the simulation of thickness of layer h₀= 0.4mm, translational speed 30mm/min and rotation speed 600rpm when the tool is located exactly above the location of the middle substrate. The Maximum temperature approximately 258°C near the input region that is the cladding/ processing zone.

CONCLUSION

The study of the friction surface cladding (FSC) process depositing multilayer AA2024 in the solid state has been presented. Apart from that, the heat generated is shown to be strongly related to the thickness of the clad layer. From the simulation software Comsol Multiphysics, it shows that the highest temperature recorded for clad layer is 258°C with the thickness 0.4mm, translation speed 30mm/min and rotation tool is 600rpm. The simulation provides a way to determine the rate of heat generation from temperature data recorded during the experiments. The rate of heat generation is inversely proportional to the thickness of the clad layer. The thicker the clad layer, the lower the rate of heat generation.

RECOMMENDATION

i. Use variety value of the rotation tool speed to compare for friction surface cladding process.
ii. There are some parameter could be consider to add in this experiment such translation speed, normal force to increase the accuracy of the result.
iii. To investigate different material such as steel, iron and copper.

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