Finite element study on rotary friction welding process for mild steel

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Abstract. The purpose of study is to investigate friction welding of series of mild steel by using Finite element analysis by a 3D model made in order having a proper rotational speed and time friction. This Numerical analysis divided into two categories that is structural analysis, and thermal analysis. Structural analysis process parameters can also have divided 4 kinds that are frictional time, frictional pressure, deformation and rotational speed. The thermal analysis process parameters are dealing with and counted as heat flux, and temperature. Friction welding with three different rotational speeds (2000 RPM, 2500 RPM, and 3000 RPM) & three different friction time (150 s, 200 s, and 250 s) This study used SOLIDWORKS 2016 and ANSYS 17.2. SOLIDWORKS 2016 is the software used for designing work pieces’ geometry while ANSYS 17 is the software is used to analyzed finite element analysis on the work pieces. The second purpose of study is the numerical analysis would be compared with the experimental analysis. The experimental analysis is taken place at friction welding machine in the laboratory of technology production of the University of Riau. Based on the numerical analysis we can summarized that the faster the shaft rotates would resulting the higher the temperature generated, the higher the heat flux generated, & the higher the reduced of length. Also the influence of friction time shown that the longer the time of friction would result the lower the temperature generated, the lower the heat flux generated, the lower the reduced of length value. By compared the numerical and experimental analysis we can conclude that the difference reduced of length data between simulation and experimental happened because on simulation only input the friction pressure, while on experiment friction and forging pressure happened simultaneously.

By interpolating the result with the melting point of mild steel (1350 °C ) we can gather the minimum requirement for getting a uniform weld temperature for each friction time, that were; 2650 rpm for 150 s friction time, 2852 rpm for 200 s friction time, & 3034 rpm for 250 s friction time.

1. Introduction
Friction welding is a solid-state welding without applying filler metal which only using pressure method whereby two work pieces to be connected in contact and regulated relative motion in pressure, then on the surface contact will be heated (close to the melting point), while the metal connection performed after the rotation stopped.

The principle of this process a mechanical change energy becomes heat energy. One component is gripped and rotated around its axis while other components are welded for it is gripped and does not rotate but can be moved axially to make contact with rotating components. At the fusion point temperature is reached, then rotation is stopped and forged pressure applied. Then heat is generated due to friction and concentrated and localized to the interface, grain structure perfected by heat work [1].
Figure 1 illustrates the variation of welding speed, friction force and forging force with time during various stages of the friction welding process. The first paragraph after a heading is not indented (Bodytext style).

Some of the advantages of friction welding are material savings, requiring fast time for connecting the same or different materials. Friction welding can also connect caterpillar or non-spherical material. While the important process parameters are friction time, friction pressure, forging time, forging pressure and rotational speed.

The success of friction welding is influenced by five factors, which are related to material properties and working conditions. The five factors are:

- Relative speed between surfaces.
- Pressure applied.
- Temperature formed on the surface.
- Bulk properties of materials.
- Surface conditions and the presence of thin layers on the surface.

In this context, the work of this research aims finite element analysis of the friction welding process for Mild steel - Mild steel. Also as comparison in this simulation study, the author also did some experimental data used A friction welding machine in the laboratory of technology production of the University of Riau. This device showed at fig 2 below.
Explanation:
1) Rotating Friction Welding Machine Frame
2) Electro Motor
3) Flywheel
4) V-belt
5) Tier Pulley
6) Head stock
7) Tail Stock
8) Pneumatic systems and pressure gauges
9) Rail Tail Stock
10) Compressors
11) Control unit
12) Display Data Logger
13) Laptop

2. Literature Review
Akhil krishna A et al [4] 2014. Develop a Numerical Analysis for Finding the Parameters on Rotary Friction Welding of Al-6063 T6, their studied obtained temperature and mechanical characteristic such as equivalent stress, equivalent strain, and directional deformation. Hazman Seliet al [5] 2010. Mechanical evaluation and thermal modelling of friction welding of mild steel and aluminium. Ali. Moarrefzadeh [6] 2011. Numerical Modeling of Friction Welding Process. W. Li and F.Yohanes et al [7] 2018. Performance Analysis of Flywheel Addition on Drive System of Rotary Friction Welding Machine, their studied obtained addition of the fly wheel is intended so that there is no shock during the pressure shift in the intermediate rotation: friction pressure to forging pressure so that the round shock can be reduced. El-oualid Bouarroudj, Salah Chikh, Said Abdi, Djamal Miroud [8] 2017. Thermal Analysis during a Rotational Friction Welding.

2.1 Finite Element Modelling
In this study, ANSYS workbench (17.2) software was used in the coupled transient thermal and static structural analysis during friction welding of Mild steel - Mild steel. An 3D model Mild steel brass rods of 8 mm diameter and 90 mm length was made using Solidwork 2016 & export to ANSYS workbench as shown in fig 2. Hexahedron elements were used to mesh the Mild steel and Mild steel brass rods. The rotating part was modeled with 319 elements and 1724 nodes and the non-rotating part was meshed with 319 nodes and 1724 elements.

**Figure 3.** Meshing of model
Numerical simulation of welding process by ANSYS software for gaining the temperature field of mild steel and find out percentage shrinkage with different rpm and time fraction. Simulation condition parameters are listed in Table 1.

**Table 1. Condition parameters**

| Condition | n (Rpm) | t Friction (S) | n (Rad/S) |
|-----------|---------|---------------|-----------|
| 1         | 2000    | 150           | 209.44    |
| 2         | 2500    | 150           | 261.80    |
| 3         | 3000    | 150           | 314.16    |
| 4         | 2000    | 200           | 209.44    |
| 5         | 2500    | 200           | 261.80    |
| 6         | 3000    | 200           | 314.16    |
| 7         | 2000    | 250           | 209.44    |
| 8         | 2500    | 250           | 261.80    |
| 9         | 3000    | 250           | 314.16    |

The properties of mild steel from www.matweb.com are listed in Table 2.

**Table 2. Mild Steel Properties**

| Properties                      | Mild Steel |
|---------------------------------|------------|
| Density (kg/m3)                 | 7800       |
| Thermal Conductivity (W/m K)    | 43         |
| Specific Heat Capacity (J/kg K) | 470        |
| Melting Point                   | 1530       |

2.2 Heat Power

The amount of heat power can be calculated from the amount of kinetic energy carried by the workpiece.

\[ KE = \frac{1}{2} m v^2 \]

If we assume all of that kinetic energy is transferred to thermal energy during braking that certain time (\(\Delta t\)), we can calculate the heat power.

Heat power = KE/\(\Delta t\)

2.3 Boundary Condition

The boundary condition of this simulation were divide into two process, transient thermal and static structural analysis.

2.3.1 Transient thermal analysis

**Figure 4. Boundary condition for transient thermal analysis**
A heat flux (position “A” marked on fig 4) was given at the contact nodes since heat generation takes place during welding process based on heat power generated using equation above and the ends of two rods are given temperature of 22°C (position “B” marked on fig 4) assuming to be the atmospheric temperature.

2.3.2 Static structural analysis

Figure 5. Boundary condition for static structural

A pressure of 0.4 MPa is applied at the constrained end of the stationary specimen (i.e. at position “A” marked on fig 5). A 2000, 2500 and 3000 rpm is being applied to the part connected with the head stock (i.e. at position “B” marked on fig 5). The movement of Y and Z direction were kept on the contact surface of two parts (i.e. at position “C” marked on fig 5). The movement of X direction were hold on the end node of rotating specimen (i.e. at position “D” marked on fig 5).

3. Result and Discussion

3.1 Temperature

Figure 6. Temperature at welded joint

The maximum temperature happened on area between contact surface of two parts. maximum temperature on condition 1 was 673.82°C shown on fig 6. This value gradually drops until the end part at 22°C. maximum temperature for other condition were shown on fig 7.
The influence of rotation shown that the faster the shaft rotates, the higher the temperature generated due to friction between the two materials. The influence of friction time shown that the longer the time of friction, the lower the temperature generated. By interpolating the result with the melting point of mild steel (1350 °C) we can gather the minimum requirement for getting a uniform weld temperature for each friction time, that were; 2650 rpm for 150 s friction time, 2852 rpm for 200 s friction time, & 3034 rpm for 250 s friction time.

### 3.2 Total Heat Flux

The maximum heat flux happened on area between contact surface of two parts. maximum temperature on condition 1 was 8,6288e+005 W/m² shown on fig 8. This value gradually drops until the end part at 1,5128e+005 W/m². Total Heat Flux for other condition were shown on fig 9.
Figure 9. n vs Maximum heat flux graph

The influence of rotation shown that the faster the shaft rotates, the higher the heat flux generated due to friction between the two materials. The influence of friction time shows that the longer the time of friction, the lower the heat flux generated.

3.3 Directional Deformation

Figure 10. Directional deformation at welded joint

The maximum reduced of length happened on area near part connected with the head stock. maximum reduced of length 1 was -2,6321e-004 m shown on fig 10. Reduced of length for other condition were shown on fig 11.
The influence of rotation shown that the faster the shaft rotates, the higher the reduced of length value due to friction between the two materials. The influence of friction time shown that the longer the time of friction, the lower the reduced of length value. As comparison by experimental that had been done shown on figure 11.

It is noticeable that there are differences between simulation and experiment when the reduced of length data compared. The simulation result is much smaller than experimental. This happened because on simulation only input the friction pressure, while on experiment has friction and forging pressure happened simultaneously.

4. Conclusion
The result shows that from the numerical analysis we can conclude that the faster the shaft rotates would resulting the higher the temperature generated, the higher the heat flux generated, & the higher the reduced of length. Also the influence of friction time shown that the longer the time of friction would result the lower the temperature generated, the lower the heat flux generated, the lower the reduced of length value. The difference reduced of length data between simulation and experimental happened because on simulation only input the friction pressure, while on experiment friction and forging pressure happened simultaneously. By interpolating the result with the melting point of mild steel (1350 °C) we can gather the minimum requirement for getting a uniform weld temperature for each friction time, that were; 2650 rpm for 150 s friction time, 2852 rpm for 200 s friction time, & 3034 rpm for 250 s friction time.

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