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# APPLICATION OF FRICTION WELDING FOR PUMP DESIGN AND MANUFACTURING: A COMPREHENSIVE REVIEW

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## Abstract

The discussion regarding the balance between economical and performance for the pump design and manufacturing has been increasing in recent years. Of many intelligent innovations, the use of less costly materials for pump shaft is an interesting solution for the pump design. This solution can also be achieved by selecting less costly materials made from metal. Then, the less costly metal connected to electrical motor is joined with a more costly metal connected to the pump. Since both metals can be difference ones, an advance welding process to join both metals is then required. The friction welding process is expected to fulfill this requirement. In the friction welding, heat is generated during friction between these two dissimilar metals. The generated heat should achieve particular temperatures so that the two dissimilar metals can be joined. There are three types of friction welding, e.g. the stir friction welding, the linear friction welding and the continuous drive friction welding, which can be selected to join these two dissimilar metals. This paper is based on the authors' experience and literature review to discuss the application of friction welding for the pump design and manufacturing.

***Keywords***: *Pump Design, Friction Welding, Dissimilar Metals, Less Costly Design*

## 1. INTRODUCTION

Recently, an issue regarding the balance between cost and performance of pump has been increasing due to skyrocketing metal price as important material for pump manufacturing, e.g. for pump shaft and piston. Of many solutions, use of less costly metals is offered. The author's experience in the pump design process shows that a challenge remains since this less costly metal is a different metal than the main metal used for the pump. The metals used as the main pump materials are relatively expensive to meet the design and operational criteria, e.g. abrasion resistance, corrosion resistance, sound mechanical properties to bear the mechanical loads. Moreover, a particular pump, e.g. for food and pharmacy industries, needs very expensive materials, e.g. high grade expensive stainless steel, to meet the cleanliness and hygiene criteria. Thus, decreasing the materials cost should be an interesting topic. To achieve this goal, the pump shaft connected to the pump motor is replaced with less costly metals. Thus, two dissimilar metals should be joined in this process. Of many joining methods, the friction welding is offered in this work.

Innovation in the manufacturing sector has been growing rapidly, e.g. the friction welding (FW) process which utilizes the heat generated from the physical friction between two metals [1]. The FW offers particular advantages than the fusion welding. The FW is relatively less costly than the fusion welding. Moreover, it offers good weldability on the same and different metals and no filler is required. The FW offers low shrinkage and deformation to achieve good mechanical properties in the heat affected zone (HAZ) area [2].


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The possibility for welding of two dissimilar metals has been another advantage of the FW. During the welding process, the FW applies heat generated during the friction of these two dissimilar metals which is influenced by the length and duration of friction, pressing force during friction, rotational speed and properties of the two metals [3][4][5]. Moreover, many researches have been continuously performed to improve the result of the FW, e.g. by using the Taguchi method [6].

## 2. FRICTION WELDING

The FW is a solid state welding where joining method of dissimilar metals is obtained from heat generated due to friction and pressure until the temperature in join area is close to the melting point [7]. Thus, the material adjacent to the friction surface, e.g. between copper and aluminum, becomes plastic [8]. In the FW, no electricity or other energy sources are used, except to move the metals, either translational or rotational movement [9]. Shrinkage and deformation are relatively low in the FW. Therefore, the FW can deliver sound mechanical properties in the joining area [10]. The FW methods can be classified ino the friction stir welding (FSW), the linear friction welding (LFW) and the continuous drive friction welding (CDFW) [11].

The FW offers many advantages. It does not require any flux, filler metal, and protecting gas during the welding process [11][12]. For this reason, slag inclusions and porosity in the FW can be minimized. In addition, the FW is more environmentally friendly since it does not produce any excess gas. Maintenance cost of the FW machine is limited. The FW has good welding tolerances and can connect two dissimilar metals.

The FW, however, also has disadvantages. Although the cost of welding process is low, the price of the FW machine is high. Although the FW has good tolerances, its process control is more complicated than the fusion welding since it depends on the friction duration, friction speed and compressive load. Although two dissimilar metals can be joined, welding of two metals with significant differences in properties, e.g. melting point and thermal conductivity, is difficult.

### 2.1 Welding of the dissimilar metals

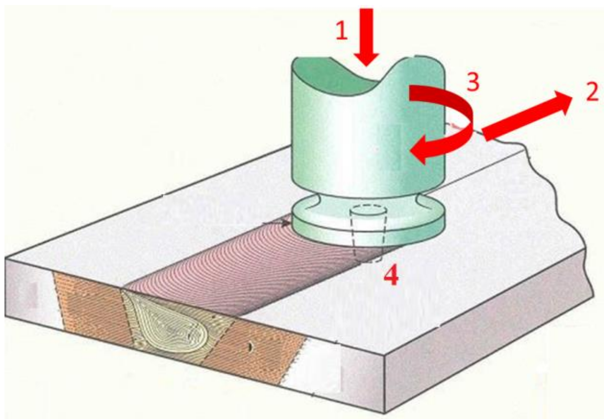
One of the main advantages of FW is welding of dissimilar metals [2]. However, joining two dissimilar metals is challenging due to differences in the thermal, metallurgical, mechanical and physical properties of the two metals [11]-[13]. Nevertheless, several works showed good joint for two dissimilar metals. The aluminium AA6061 can create sound joint with the carbon steel [14][15]. Romadhan *et al.* [16] also showed a good FW process between copper and steel in which the tensile strength of the joint increases as friction pressure increases up to 35 MPa.

The metal types play a significant role in the FW. For example, Aluminum alloy has a specific gravity between 2650 and 2800 kg/m$^3$, good electrical and heat conductivity, corrosion resistant, melting point between 650 and 720 ºC depending on its alloy composition [17],[18][19]. On the other hand, copper has the melting point of app. 1083 ºC depending on concentration and type of other alloying elements. To join the copper and aluminium through the FW process, several key parameters, e.g. the pressing duration, pressing force and rotational speed should be carefully determined to achieve good mechanical properties and microstructure in the joint area [20][21][22]. For example, excessively high rotational speed can decrease the tensile strength in the joint area. Ikhsan, *et al.* [22] reported that the shape of the tool also influences the tensile strength of welding aluminum and copper.

# 3. FRICTION STIR WELDING

## 3.1 Method of friction stir welding

Friction stir welding (FSW) utilizes the friction from a rotating tool while both stationary metals do not move (Figure 1). Porosity and crack formation is very limited in the FSW method [11]. The resulted grain is small which then delivers sound mechanical properties of the joint. The FSW is safe and low cost since only one tool is rotating [23]. The FSW process is a relatively simple process and it can also be carried out by using a vertical milling machine to rotate the welding indenter. This welding indenter provides the friction to generate heat and serves also as a stirrer [24]. The welding indenter material should have a high melting point compared to the weld metal to prevent impurity coming from the indenter metal.




1. Downward pressing force
2. Welding direction
3. The rotating indenter
4. The Pin

**Figure 1:** Illustration of friction stir welding

The shape of pin, located at the bottom tip of the indenter, on the FSW influences the welding quality. Helmi, *et al.* [25] reported that various pin shapes deliver different mechanical properties and microstructure. In addition, the welding quality of FSW is also influenced by the rotational speed of the pin. Higher rotation of the FSW results in higher tensile strength [26]. Sugito *et al.* [27] showed that the depth of pin influences the tensile strength. The lowest tensile stress is obtained at the shallowest immersion depth.

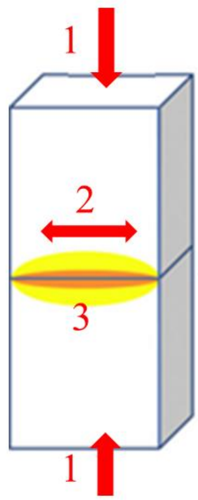
## 3.2 Defect and Microstructure in Friction Stir Welding

Several defects can occur in the FSW method, i.e. porosity, tunnel defect, lack of penetration, weak joint, kissing bond, flash formation [28]. The porosity is due to air cavities trapped in the weld joint. Depending on the size and amount, the porosity can significantly decrease the mechanical strength. The tunnel defect is characterized by the formation of a tunnel or cavity in the welding joint due to imperfect material flow. Meanwhile, lack of penetration is due to a lack of penetration of the FSW tool into the material. This results in in a weak welding joint. The kissing bond is characterized by the lack of metals adhesion between two welded surfaces. At many cases, this defect is undetectable by the visual inspection. The flash formation is due to the formation of excess material near the weld joint due to excessive material flow.

# 4. LINEAR FRICTION WELDING

## 4.1 Method of linear Friction welding

In the linear friction welding (LFW), surfaces of two metals are scratched linearly at high speed to create high friction generating heat below the melting point (**Figure 2**). The LFW offers several advantages compared than other FW methods, i.e. higher welding speed, increased welding accuracy, and the ability to join longer and thicker components [29][30]. The LFW is a very consistent and fast process which can be worked out in short time. Thus, higher productivity can be achieved.




1. Pressing fore
2. Translational repeated move
3. Generated heat due to friction

**Figure 2:** Illustration of linear friction welding

## 4.2 Defect and Microstructure in Linear Friction Welding

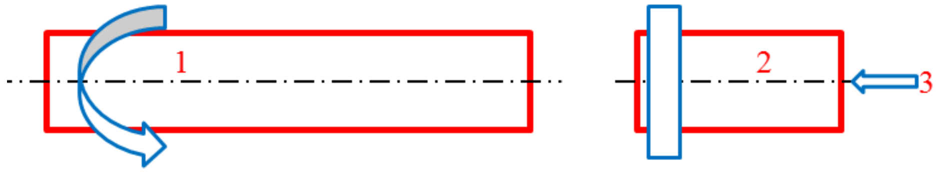
The quality of LFW is influenced by the surface's condition, cleanness and porosity [31]. The LFW method is characterized by a small HAZ since the LFW method is based on deformation at high temperature of two metal surfaces to be welded [32]. Thus, defects existing in the fusion welding, e.g. porosity, hot cracking, solidification crack and segregation, is minimized in this LFW method [33][34]. Astarita *et al.* [35] reported microporosity and kissing bond defect when Titanium is subjected to the LFW method.

For medium carbon steel, Aoki *et al.* [36] reported a fine microstructure can be formed in the LFW method due to the recrystallization effect. The grain size was reported even smaller than that of the base metal. According to the Hall-Petch equation, this fine microstructure results in high strength of metal. For this reason, the LFW method is suitable to produce the ultrafine grain metals.

# 5. CONTINUOUS DRIVE FRICTION WELDING

## 5.1 Method of continuous drive friction welding

In the continuous drive friction welding (CDFW), the rubbing rotates a particular metal against another stationary metal [11]. The stationary metal is then subjected to an axial force (**Figure 3**). The friction generated by the continuous rotating metal against another can generate heat. Metals at high temperature can experience plastic deformation, large strains and large strain rates under a high axial pressure. Similar to the LFW, the CDFW also does not require any filler metal or flux. The welding quality of the CDFW method is influenced by rotation speed, i.e. the higher the rotational speed, the faster the heat generated. The pressure force also affects the welding quality. Optimum friction duration can result in an optimum tensile strength of the joint.




1. Rotating metal
2. Non-rotating metal
3. Axial pressing fore

**Figure 3:** Illustration of continuous drive friction welding

### 5.2 Defect and Microstructure in Continuous Drive Friction Welding

Excessively long friction duration decreases the tensile strength due to excessively high heat generation. This leads to excessively large HAZ area [34]. Moreover, high friction rotation results in high hardness [37]. Li *et al.* [38] showed that the highest tensile strength can be achieved at a specific friction pressure (**Figure 4**). Several defects often occur during the CDFW, i.e. cavity, void, excessive flash, microcrack and incomplete fusion lap [39]. The cavity and void are formed due to inappropriate welding conditions. Meanwhile, the excessive flash occurs due to excessively high pressure or temperature. The microcrack occurs due to inappropriate tool speed or precipitation. The incomplete fusion lap occurs due to dirt on the surface of the metal's surface or edges.

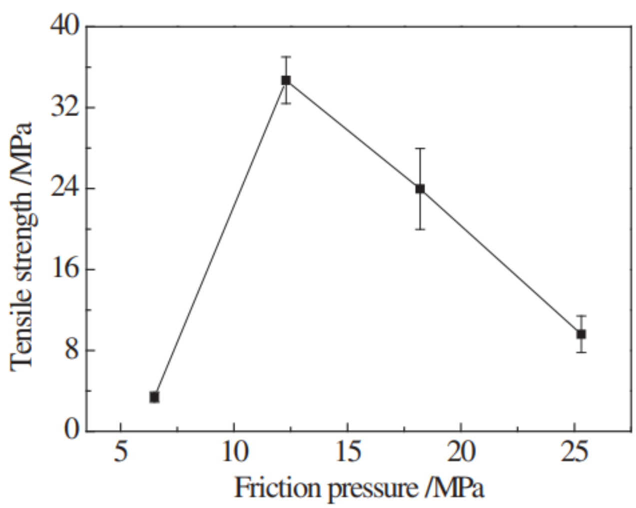



**Figure 4:** The influence of friction pressure on the tensile strength for the continuous drive friction welding [38]

## 6. FUTURE RESEARCH

The paper already outlines a promising application of friction welding in the pump design and manufacturing, particularly to adapt the use of low-price metals. Nevertheless, more research should be worked out in the future to adapt this welding technology in the pump design and manufacturing. When the friction welding is performed in pump shaft, the fatigue strength particularly at the joint must be well investigated. Moreover, further research is required to apply this method for wet-end shaft since corrosion possibility is higher for this shaft type than that of the dry-end shaft. At last, the authors suggest investigating the galvanic corrosion when two dissimilar metals are in contact. The difference in electrical potential between two dissimilar metals may induce the galvanic corrosion particularly if the potential difference is high. Many pumps are installed in corrosive environment.

## 7. CONCLUSION

Pump is exemplary turbo machinery used in our life, ranging from household until industrial use. For heavy duty and particular purpose, mechanical parts of pump should be well designed to fulfill its requirement. For many cases, materials used for the heavy duty and particular purpose pump are very costly. Thus, the pump manufacturer should combine the cost efficient and engineering purposes. The friction welding offers a promising solution to decrease the cost of pump manufacturing since the pump manufacturer can select the less costly metals. However, future works still remains to apply this welding method for pump manufacturing, e.g. corrosion resistance of the joint, mechanical property particularly fatigue strength.

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