Sustainability of Welding Process through Bobbin Friction Stir Welding

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Abstract. Welding process is in high demand, which required a competitive technology to be adopted. This is important for sustaining the needs of the joining industries without ignoring the impact of the process to the environment. Friction stir welding (FSW) is stated to be benefitting the environment through low energy consumption, which cannot be achieved through traditional arc welding. However, this is not well documented, especially for bobbin friction stir welding (BFSW). Therefore, an investigation is conducted by measuring current consumption of the machine during the BFSW process. From the measurement, different phases of BFSW welding process and its electrical demand are presented. It is found that in general total energy in BFSW is about 130kW inclusive of all identified process phases. The phase that utilise for joint formation is in weld phase that used the highest total energy of 120kWs. The recorded total energy is still far below the traditional welding technology and the conventional friction stir welding (CFSW) energy demand. This indicates that BFSW technology with its vast benefit able to sustain the joining technology in near future.

1. Introduction
In general, welding process and jobs can be indicated as ready for growth. This is founded based on the forecast of the increase in the manufacturing and construction employment that happening around the world [1-3]. Based on Malaysia manufacturing index expansion, 5.9% increment is shown in 2015 compared to 2014 in the same period [4]. For energy consumption the industrial sector in Malaysia used about 46.6% of the total electrical used [5]. With the excitement for progressiveness that provides stable economy, this in some way causes environmental degradation if no attention taken towards sustainability of the environment. For example, according to International Energy Agency (IEA) the CO\textsubscript{2} emission increase to 2.2% in 2013 compared to 2012 [6] which largely contributed from the industrial sector. For that reason, manufacturing sectors are now focusing on green manufacturing approaches to conserve energy and to reduce greenhouse gas emission [7, 8].

In welding, FSW technology has been introduced by The Welding Institute (TWI), UK in 1991. It is a solid state welding process that creates the joint behind the tool as is travel forward. It used a non-consumable tool that produce frictional heat and pressure for the solid bonding formation. In general FSW process is stated to provide metallurgical, environmental and energy benefits. It has been stated that this process only consume 2.5% of the energy needed for laser weld [9]. There is no harmful gases...
produces and no post processing cleaning involves. The beneficial of this process is huge thus it can be suggested to provide a sustainable process in the welding fielding. This is founded on a comparison study conducted by Shrivastava, Krones and Pfefkerkorn [10] whereby they found that FSW only use total energy of 174 kWs compared to gas metal arc welding (GMAW) that used 303 kWs of total energy. At high energy consumed in the GMAW process, the weld strength is still lower than FSW. Referring to Buffa, Campanella, Di Lorenzo, Fratini and Ingarao [11] the carbon footprint is not well documented. Only limited studies have been recorded its energy demands. Mostly in machining and sheet metal work. Therefore, there is a need to start publishing the finding of energy demand for realistically supporting green manufacturing. Accurate strategies can be laid by the planners based on the actual measurement.

The FSW technology can be divided into two types that are conventional friction stir welding (CFSW) and BFSW. These processes are differentiated based on the tool design as illustrated in Figure 1. Although the process is similar, however the way of the join formed is effected by the different approach [12]. The reason is because of the additional shoulder in BFSW. This cause no plunge force and tilting angle required. Additionally, the challenges on fixturing and clamping in BFSW provide more mechanical compliances that potentially alter the material flow [13, 14]. The differences are so significant; hence dedicated studies need to be conducted for the BFSW process. The finding is useful for process selection and advancement that support the reduction of greenhouse effect.

![Figure 1. Types of FSW. (a) CFSW (b) BFSW](image)

Based on the authors’ findings, there are limited publication focusing on BFSW process and its characteristics especially for energy consumption. Study conducted by Buffa, Campanella, Di Lorenzo, Fratini and Ingarao [11] found that travel speed influence small changes on energy demand. The welding speed cause faster completion, hence short period of power is required. For the work conducted in [15], the investigation is about the impact of different backing plate materials on average weld energy consumption. They found that Titanium backing plate required less weld energy compared to steel and copper. The reason is of low thermal diffusivity of the material. Focusing on energy demands in FSW as a general, works that are stated above are focusing on CFSW. Therefore, in this study, electrical energy demand of BFSW and its characteristics when welding Aluminium alloy is presented.

2. Methodology

The approach of the welding is carried out by welding AA3000 series with dimension of 140 mm (length) x 140 mm (width) x 6 mm (thickness) in a butt joint configuration. Fixed gap bobbin is used having features of cylindrical shoulder and pin. The shoulder and pin have a diameter of 25 mm and
8.5 mm respectively. Tool material is H13 that has been heat treated for hardening which follow ASTM A681.

The empirical setup of the weld is demonstrated in Figure 2 and the welding parameters are shown in Table 1. Machine used is Haas 3 axis CNC milling machine as the FSW machine with 20hp capability. As the tool rotated and touch the material to be welded, current is measured using digital current clamp meter UNI-T UT232 with USB connection. The clamp is attached at the input current of the CNC machine and automatically measured and recorded the electrical demand for every second.

The tool rotation (spindle speed) is varied while the travel speed is constant. The tool entry is from the edge and 15 secs of dwell time is applied when half of the tool body is located inside the plate. The movement of the tool towards half body tool entry is at 30 mm/min. Then full travel speed is applied.

**Table 1.** Welding parameter

| Parameters                  | Setting    |
|-----------------------------|------------|
| Tool rotation (rpm)         | 700, 800, 900 |
| Travel speed (mm/min)       | 155        |
| Dwell time (sec)            | 15         |
| Location of tool entry      | Edge       |

The welded plate is inspected and then being cut at the middle of the plate using CNC wire cut following ASTM E8 for the tensile test specimen. The reason for mechanical testing is to for a quality reference to the identified energy demand. The measured current by the current clamp meter is then converted to power (Watt) and plotted against time. Characterization is conducted based on the pattern. Time study is conducted to reveal the energy demand at each stage that is identified.
3. Results and discussion

Figure 3 shows one of the welded plate using bobbin tool. The plates are free from external defects such as flash, open tunnel and holes, thus categories it as an acceptable weld. These defects may present if the process parameters and tool are not suitable. Comparing the weld formation of BFSW to the arc welding it is clearly shown that the weld is clean and there is no need of post processing. Common defect in arc welding such as spatter, slag inclusion, under filling and etc. are difficult to be control and required intensive monitoring.

![Welded plate](image)

Figure 3. Welded plate

Referring to Figure 4, the highest tensile strength is produced at tool rotational speed of 800 rpm that is 82.72 Mpa. It is a reduction of 27.28 Mpa from the parent material. The declination is believed because of excessive heat produced by the tool shoulder and material availability around the tool [16, 17].

![Tensile strength graph](image)

Figure 4. Maximum tensile strength for different tool rotation speed

The difference phases of energy consumption in BFSW welding are identified in Figure 5. These phases are milling power (machine ready for operation), tool entry, dwell time, weld and tool exit. In milling power phase, the tool is rotated and travel towards the material to be welded. In this phase average of 580 Watts of energy is consume. When the tool touches the solid metal, energy demand is suddenly increased to 2.4kWs with a total energy of 5.7kWs. The dwell time energy demand is as the milling power with slightly different energy demand. The reason is believed because of the work required to be performed by the tool to stir small amount of material around the tool. The utilization of energy is then increase again at the weld phase. The recorded peak energy in this phase is about
3.2kWs with a total energy of 120kWs. The tool is extensively stirring the weld and pairing the force created from shoulder compression and tool travel joint is formed behind the tool as the tool travel forward. When entering tool exit phase, energy demand is decreasing with a potential of sudden energy increase, due to releasing the tool away from the material before entering the milling phase again.

![Power consumption during the BFSW process for different tool speed rotation.](image)

**Figure 5.** Power consumption during the BFSW process for different tool speed rotation.

Figure 6 shows the time studies of each phase. It can be clearly identified that most of the time is consume for weld formation that can be categories as productive time. The most non-productive time is from the dwell time. It is believed that this period can be eliminate through proper tool design such as tool features and shoulder gap [18]. Then, a faster feed rate with lower spindle speed can be introduced [16]. Furthermore, BFSW technology such as adaptive tool and floating shoulder can be implemented.

![Time study of the BFSW process](image)

**Figure 6.** Time study of the BFSW process
Comparing the studies to CFSW and GMAW, the BFSW only consume about 130kWs of total energy compared to the one recorded for CFSW and GMAW. Although, the materials are slightly different in type and size, but they are welding a similar group of material that is Aluminium alloy with nearly the similar size. Additionally, in BFSW there is no plunge energy required, hence 8-13% of energy can be conserved.

4. Conclusion
In this investigation, the energy consumption of BFSW has been presented. In general, FSW has the capability of welding different joint configurations which comparative to traditional welding such as GMAW. With a better energy saving of BFSW and other advantages, the welding proces that commonly labelled as non-environmentally friendly and hazardous to human through traditional welding can be eliminated. The welding process now can be better sustained and more competitive. About 50% of energy is saved between CFSW and GWAW. An additional of 20-25% energy can be further reduced when applying the BFSW technology.

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