Influence of tool speed on the friction stir welding joint of aluminium and steel with single weld line

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Abstract. The objective on this research is to investigate the influence of tool rotation to the welding strength of Aluminium and Steel. AA1100 and ST37 were material selected for the specimens. The welding process was conducted by using Friction Stir Welding (FSW) method. The tensile strength and hardness of the specimens will be indicators of welding strength. FSW was carried out by using conventional milling machine with tool rotation of 800 rpm and 1250 rpm. Feed rate 10 mm/minute for all process. The tool tilt angle was 1° and 1.8 mm of depth plunge. By using 800 rpm, the average of Tensile Stress was delivered of 82.22 MPa and Strain of 1.09%. While for the use of 1250 rpm, Tensile Stress given 96.23 MPa and Strain 1.14%. The hardness of HVN on the weld zone was 42.2 and 56.2 HVN for rotation of 800 and 1250 rpm respectively. Based on the Tensile Stress and the Hardness of the weld zone, the FSW process was influenced by tool rotation. The higher rotation given higher Tensile strength.

1. Introduction
In the manufacturing industry is often found the manufacture of products and components that required joining two or more of metals. Most of that can be found in the fields of automotive, shipping industries, aircraft, and construction. Welding is one of the most commonly used connecting methods for joining metal materials. Currently, the manufacturing industry develops welding methods to improve product quality and to decrease the production costs [1].

The metal welding process is classified into two groups, i.e. Liquid State Welding (LSW), and Solid State Welding (SSW). LSW is a metal welding process that is conducted by melting the material part to be connected. While SSW is a welding process performed on the solid phase of the material to be connected. One of the SSW methods is Friction Stir Welding (FSW). FSW is a process of connecting metal by using heat energy generated due to friction between tool and workpiece. This connection occurs due to stirring two-sided pieces of metal that begin to soften due to friction, but still in the solid state. This method was developed by Wayne Thomas in 1991 at TWI (The Welding Institute) the United States [2].

Many researchers have studied the effect of machine parameters on the mechanical properties of AC4CH material by using the friction stir welding method [3]–[5]. Variations of parameters used were round tool, tool shape, and slope tool [6]. The results show that the friction stir welding method can produce a good joining. Tensile strength could decrease by employing the constant feeding and increase tool rotation. The cylindrical pin was given lower tensile strength than the tapered and bullnose tool. The use of tool tilt angle more than one degree can decrease the tensile strength as well [7].
The FSW method can be applied to dissimilar material between nonferro and ferro. For example, joining between Aluminium alloy and Steel. The most important problem during FSW is the softening material in the weld nugget. Therefore, it causes a decrease in the tensile strength of the specimen due to the recrystallization process in the nugget zone during the welding process.

2. Research Method
The materials used in this research are Aluminium alloy of AA1100 and ST37 Steel. The materials were a plate in 2 mm thickness. An FSW tool is used Bohler K100 steel with the diameter of shoulder 18 mm, pin diameter 4 mm, and 1.7 mm of pin high as shown in Figure 1. The tool rotates counterclockwise direction and the tilt angle of a tool is 1°.

ST37 steel was installed in the advancing side during the welding process. The FSW process was performed by using a conventional milling machine with an adjustable head tool. The brand was Richon, X8140A type, and 3-380v 50Hz power. Table 1 shows the FSW conditions of each specimen.

![Figure 1. Dimensions of tool in FSW process.](image)

| Materials | Tool speed (rpm) | Welding speed (mm/mnt) | Tilt angle (deg) | Depth plunge (mm) |
|-----------|------------------|------------------------|-----------------|------------------|
| AA1100 x ST37 | 800              | 10                     | 1               | 1.8              |
| ST37      | 1250             | 10                     | 1               | 1.8              |

3. Results and Discussion
Figure 2 shows the appearance of the weld surface result of AA1100 and ST37. Figure 2(a) was the result of FSW by employing 800rpm of tool rotation. While the figure 2(b) is for the 1250 rpm. All specimens are then analyzed based on the welding surface visualization. The analysis was conducted to observe the weld surface contour, exit hole, and a defect that may occur during the welding process.

In the specimen, as shown in figure 2(a) and 2(b), it has shown a rough weld surface. Weld flash appeared as well in the weld line. It could be caused by reconstructed soft material (AA1100) out the surface around the tool shoulder [7]. The value of tool tilt angle more than one degree could influence the appeared of weld flash [5], [8].

The exit hole always appears in the friction stir welding as shown in figure 2(b) and 2(c). The hole was created by the pin tool that used in the FSW. That is one of the disadvantages of FSW. The hole can be eliminated by exiting tool after the outside of the material. In the exit hole zone, there is a line between material AA1100 and ST37. That indicates that the stirring was not conducted totally. The welding contour of all specimens was almost same between 800 rpm and 1250 rpm. The gap in the weld nugget was seen closed although the weld surface was not smooth.
The FSW result is then cut for tensile and hardness test specimen. Figure 3(a) shows the specimen for the tensile test based on JIS Z 2201 standard. The broken zone was occurred in the weld nugget for all specimens both 800 and 1250 rpm, as seen in figure 3(b) and 3(c). The broken weld nugget indicates that the welding has lower strength then the base AA1100. It also can be seen in the Table 2 to Table 5 about the results of tensile strength experiment. The experiments of tensile were conducted twice for every specimen. Then, the final value is the mean of two tensile stress. The values of tensile stress were below the tensile stress of base metal AA1100. It can be seen in the Figure 4. The maximum tensile stresses were 82.22 and 96.23 MPa for the use of tool rotation 800 and 1250 rpm respectively. The higher tool rotation can increase the tensile strength of FSW process. In this case, it can increase around 17% of tensile strength.
Table 4 and 5 shows the result of tensile strain for each specimen. All tensile strains of the specimens were below the base material, AA110 and ST37. According to that results, it can be said than the specimens of FSW were brittle if compared with the base AA110. The use of tool speed 800 and 1250 rpm is not an influence on the tensile strain significantly.

![Figure 4. Tensile stress and strain FSW of AA1100-ST37.](image)
Figure 5 shows the result of HVN hardness for the specimen of 800 and 1250 rpm. The use of higher tool rotation speed can increase the hardness of weld zone. The hardness of weld nugget was 42.2 HVN for the FSW with 800 rpm tool rotation. While the 1250 rpm can deliver 167.1 HVN in the weld line zone. The hardness can increase around 300%. It could be caused by the debris of ST37 distributed equally in stirring zone. But, it should be investigated by using scanning electron microscopy (SEM).

4. Conclusion
Welding of Aluminium alloy AA1100 and steel ST37 by using friction stir method was conducted successfully. Joining performance of FSW was influenced by tool rotation. The results were obtained as follows. From the tensile test, the higher tool rotation gives higher tensile stress and strain compared with the lower tool rotation. The hardness of stir zone or weld nugget was shown harder for the use of high rotation tool. Overall properties, the use of 1250 rpm tool rotation was delivered better performance than the 800 rpm during FSW between AA100 and ST37.

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