# EFFECTS OF PRESSURE IN CONTINUOUS DRIVE FRICTION WELDING ON AISI 304 AND A36

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Friction welding is a connection by frictional heating due to the rotation of one metal against another metal under the influence of axial compression. This study aims to determine and analyse the effect of pressure on the shape of the welded connection, microstructure, tensile strength and hardness in Continuous Drive Friction Welding (CFDW). The materials used were AISI 304 and A 36 carbon structural steel with a diameter of 10 mm. The Forging pressure was given 3 MPa, 4 MPa, and 5 MPa, at a constant rotating speed of 2000 rpm. The results of friction welding at a pressure of 5 MPa formed a perfect, straight and neat welded connection and the particle structure solidified and shrunk resulting in the highest tensile strength value of 510.26 MPa and an average hardness of 83.67 HRB. Frictional welding at 3 MPa pressure showed a tensile strength value of 476.20 MPa and a compacted and elongated particle structure resulting in a straight but wavy welded connection with a hardness value of 81.00 HRB. Meanwhile, frictional welding at 4 MPa pressure showed a low tensile strength value of 459.32 MPa, the solid particle structure following the direction of rotation produced a broken connection forming two welding lines with a hardness value of 81.67 HRB.

**KEYWORDS**

Friction welding, forging pressure, friction characteristics, strength of friction welding joint

## INTRODUCTION

Welding technology has been applied broadly in the field of engineering. In the petrochemical and power generation industries, especially on the motor shaft and generator, a connection between stainless steel and carbon structural steel is needed. Various welding methods have been developed to meet construction needs. One of which that can be applied to two different types of material with a cylindrical solid shaft-shaped rod is friction welding. It is a welding of solid state due to frictional heating and pressure. Former is produced from the relative motion of material by rotating or alternating motion [Meshram et al. 2007][Li et al. 2016], while latter has technical advantages and high efficiency and better process stability compared to fusion welding. In the weld area diffusion occurs between the metal which is joined [James and Sudhish 2016]. The amount of frictional heating determines the formation of intermetallic compounds which further affects the mechanical properties of the connection [Mehta 2019]. Friction welding is a forging technique since there is no melting and welding done by applying pressure [Akhil and Charles 2017]. The presence of pressure and friction causes an increase in temperature at the welding interface to form an intermetallic layer on copper and AISI 430 ferritic stainless-steel material [Shanjeevi et al. 2017].

At the connection of 1045 and 316L, the addition of welding pressure results in increased interface hardness, while the tensile strength and connection fail in the thermo-mechanical affected zone on the 316L stainless steel austenite side [Khidhir and Baban 2019]. In stainless steel duplex friction welding, the welding area has a higher hardness and tensile strength than base metal. This is due to grain repairs which cause failure away from the connection during tensile testing [Ajith et al. 2015]. The highest hardness in friction welding occurs at the interface area due to forging by friction pressure [Muralimohan et al. 2014].

Frictional pressure is one of the factors that influences welding results. Axial pressure is an important welding parameter [Handa and Chawla 2014]. Friction pressure affects the microstructure in the interface area and tensile strength. The connections on AISI 304 ZE and AISI 1060 are perfect and the tensile strength increases with the addition of frictional pressure [Ates and Kaya 2014], as well as on AISI 304 with AISI 1021, but the impact toughness decreases [Handa and Chawla 2014]. In addition, frictional pressure affects the hardness of the welding area. The higher the pressure, the harder the welding area [Handa and Chawla 2014]. Hardness of the welding occurs because of the oxidation process during friction welding [Ates et al. 2007]. Pressure, rotational speed and friction time affect the interface overflow interface [Kirik and Özdemir 2015], occurs because the material in the friction area becomes semi-solid. Friction time affects the quality of the welding joint. Long friction time causes a decrease in strength in the formation of eutectoid and insoluble systems and increased strength in soluble systems [Meshram et al. 2007]. The greater the pressure, the greater the tensile strength of the weld joint [Muralimohan et al. 2014].

There have been many studies on friction welding in similar and dissimilar materials. Study of the influence of rotational speed, friction pressure, friction time, forging pressure has been widely reviewed. Large friction and forging pressures are required to obtain a good weld joint, and the average pressure applied is above 25 MPa. However, in this study, by using a simple welding equipment design and welding was performed with relatively small forging pressures of 3 MPa, 4 MPa and 5 MPa, respectively. This study aims to determine and analyze the effect of pressure on the friction welding process on welding results, microstructure, hardness and tensile strength on stainless steel AISI 304 with ASTM A36 carbon structural steel.

## METHOD

The materials used were stainless steel AISI 304 and ASTM A36 carbon structural steel with a length of 100 mm each and a diameter of 10 mm. The chemical composition of the material by using a spectrometer is shown in Table 1. Continuous Drive Friction Welding (CFDW) used a friction welding tool with a rotation of 2000 rpm on stainless steel materials, while carbon structural steel provided pressure. Friction welding using equipment as shown in Fig. 1. The friction pressure of 1 MPa for 15 seconds, while the forging time was 5 seconds. The forging pressure was varied at 3 MPa, 4 MPa and 5 MPa. Micro observation used a metallurgical microscope, testing the average hardness used the Rockwell method and tensile testing used a universal testing machine with a draw speed of 10 mm/s. Hardness testing is carried out on the weld area (interface joining) and base metal. Tensile test specimens were made according to ASTM E8 standard.

| Material | Chemical compositions % wt |
|---|---|

| | S | Al | C | Ni | Nb | Si | Cr | V | Mn | Mo | W | P | Cu | N | B | Sb | Mg | Co | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AISI 304** | 0.024 | 0.004 | 0.027 | 8.457 | 0.017 | 0.413 | 18.574 | 0.075 | 1.153 | 0.321 | 0.018 | 0.036 | 0.542 | 0.078 | 0.001 | 0.011 | 0.002 | 0.148 | Bal. |
| **A36** | 0.024 | 0.001 | 0.057 | 0.008 | 0.000 | 0.147 | 0.336 | 0.002 | 0.309 | 0.000 | 0.000 | 0.019 | 0.012 | 0.003 | 0.000 | 0.001 | 0.002 | 0.002 | Bal. |

**Table 1.** Chemical composition of AISI 304 and ASTM A36 carbon structural steel

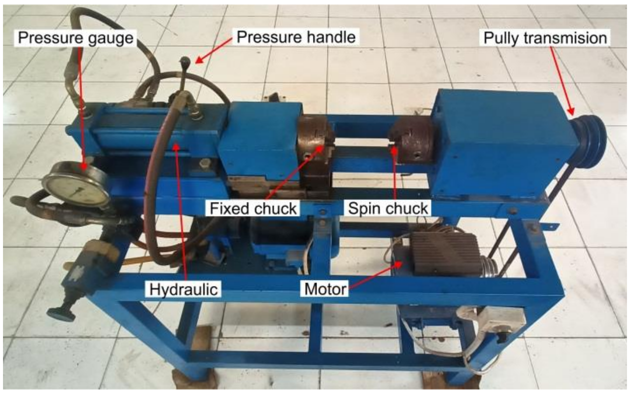



**Figure 1. Friction welding equipment**

## RESULTS AND DISCUSSION

The results of the welding joint using Continuous Drive Friction Welding (CFDW) are shown in Fig. 2. From each pressure variable, samples of carbon structural steel and stainless steel can be perfectly connected.

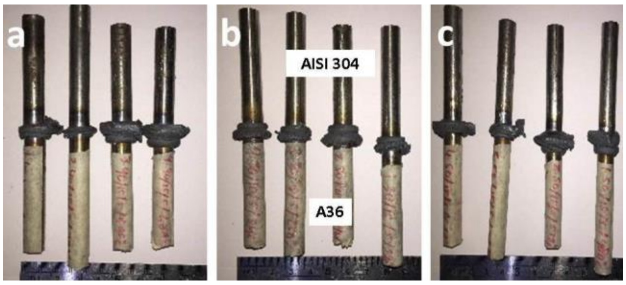



**Figure 2. Results of friction welding a). pressure of 3 MPa, b). pressure of 4 MPa, and c). pressure of 5 MPa.**

Macroscopically, all pressure variables can be connected properly. Stainless steel and carbon structural steel and generally have similar properties, especially the melting point. This causes the connection can be formed and overflow occurs on the side of stainless steel or carbon structural steel. At the connection, overflow was found because the tip of the sample experienced semi-solid and the influence of forging pressure. The presence of pressure and friction at the interface causes heat, and this heat can melt the interface into a semi-solid state. Macro photo and cross section of the weld joint are shown in Fig. 3.

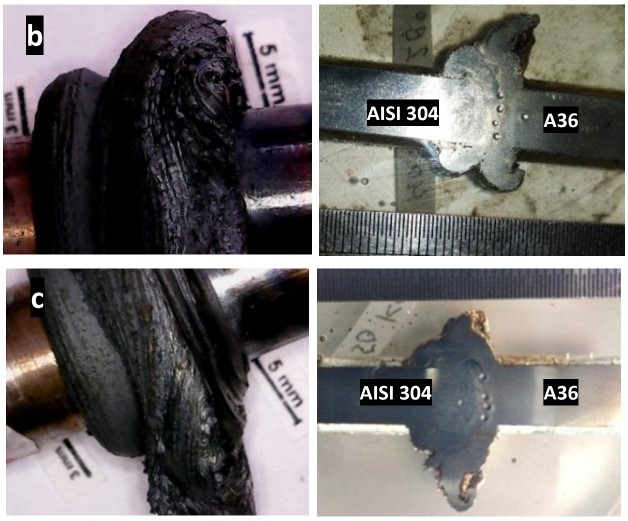




**Figure 3. Macrostructures of the result of friction welding and its cross section a). pressure of 3 MPa, b). pressure of 4 MPa, and c). pressure of 5 MPa.**

Fig. 3 shows the weld joint worked well since there was no visible porosity or failed to swell at each connection macroscopically. In each variable, the cross section showed the side of the carbon structural steel pressed by stainless steel. Overflow also appeared higher in carbon structural steel compared to stainless steel. This was due to the higher hardness of stainless steel compared to carbon structural steel. Therefore, the deformation of carbon structural steel was greater than stainless steel. The results of measurements of overflow height at each pressure variable are shown in Fig. 4.

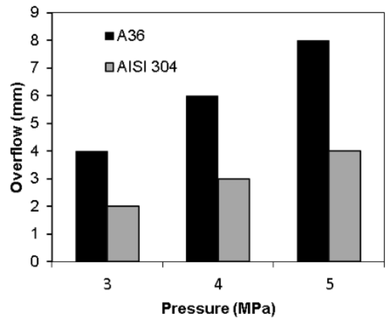



**Figure 4. Relationship of welding pressure with the formed overflow**

The greater the pressure, the greater the average overflow formed. This overflow was formed because the interface experienced friction into heat. The heat reached its melting point so that it became semisolid. Due to pressure, the semi-solid material formed an overflow. The higher the pressure, the greater the compressive force of the interface surface. Thus, the deformation that occurred was greater.

The microstructure at the interface or weld zone is shown in Fig. 5. The boundary between stainless steel and carbon structural steel is clearly visible. Microscopically it is visible gap in the interface.

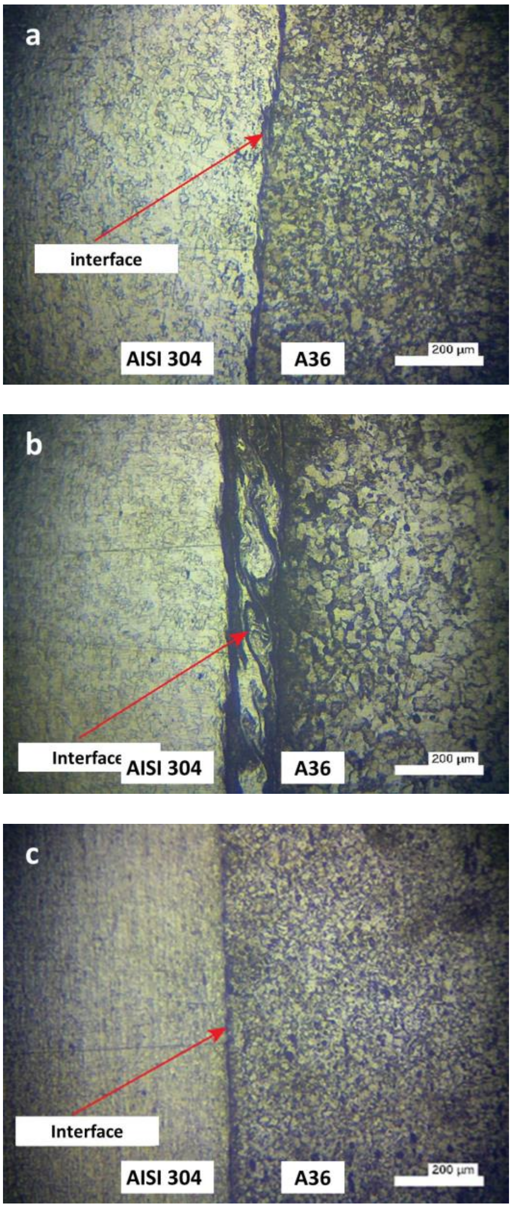



**Figure 5. Welding area (interface) SS 304 and A 36 carbon structural steel, a). pressure of 3 MPa, b). pressure of 4 MPa, and c). pressure of 5 MPa.**

Microscopically, the process of Continuous Drive Friction Welding material AISI 304 and A 36 carbon structural steel did not include stirring or mixing dissimilar material. Welding ties merely occurred at the interface. In this welding, unbounded religion, especially at the pressure of 4 MPa, was found (Fig.5b). Unlike the friction stir welding process, there was a stirring process for welded parts called nugget zones or weld nuggets [Mehta 2019] [Setiawan et al. 2018]. In the weld area, there were interface defects in the pressure of 3 MPa (fig. 5a) and 4 MPa (fig. 5b). There were also cavities at the interface between stainless steel and carbon structural steel. It was possible that the given friction pressure was still lacking. However, connection with pressure of 5 MPa (Fig. 5c) formed a perfect welding connection, straight and neat, and compact particle structure with minimal interface to the connection defects. With a pressure of 5 MPa, it looks microscopically enough to provide a good connection

Rockwell hardness test results in the base metal and the weld zone (interface) is shown in Fig. 6.

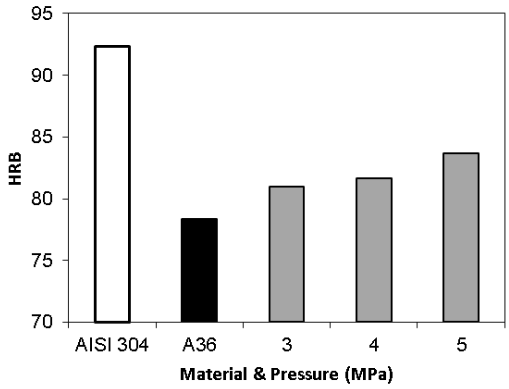
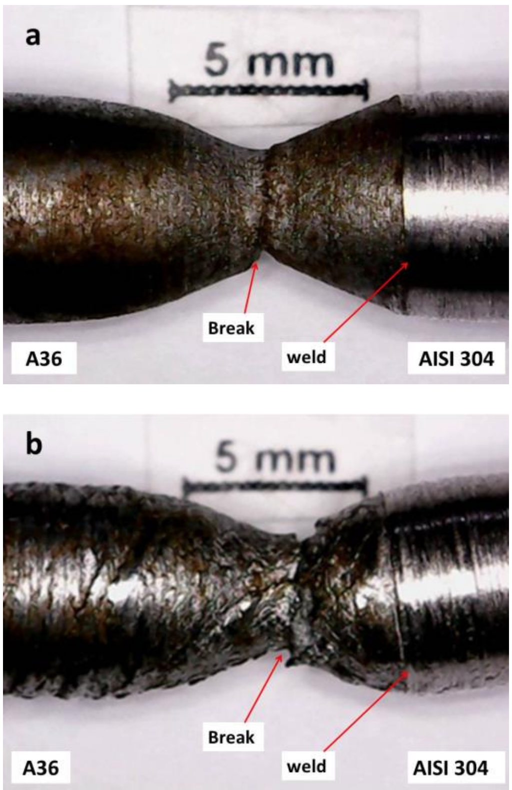



**Figure 6. Rockwell Hardness AISI 304, A 36 carbon structural steel dan hardness in the weld zone in each pressure variables**

The average hardness base metal of AISI 304 is 92.33 HRB and base metal A 36 carbon structural steel hardness was 78.33 HRB. The average weld zones in the variable of weld 3, 4 and 5 MPa were 81.00, 81.67 and 83.67 HRB, respectively. The average hardness of AISI 304 was higher than that of A 36 carbon structural steel; this made A 36 carbon structural steel more easily deformed compared to AISI 304 as shown in Fig. 3 and Fig. 4 (formed overflow). The average hardness in the weld zone was higher than A 36 carbon structural steel and lower than AISI 304. This proves that in the weld zone area there is a mixed phase between AISI 304 and A 36 carbon structural steel. The higher the friction pressure that was given during the friction welding process, the average hardness in the weld zone area was also greater. This also proves that pressure affects the forging of a semi-solid area due to heat friction.

The shape and location of the tensile test break are shown in Fig. 7, while the results of tensile testing are shown in the graph Fig. 8.



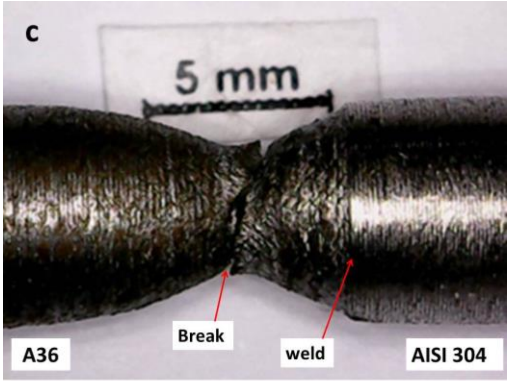



Figure 7. The shape and the tensile test break ]a). pressure of 3 MPa, b). pressure of 4 MPa, and c). pressure of 5 MPa.

All samples in the tensile test break use A 36 carbon structural steel material. This proves that the weld joint between AISI 304 and A 36 carbon structural steel by friction welding was successfully carried out. The connection strength was greater than the tensile strength of A 36 carbon structural steel.

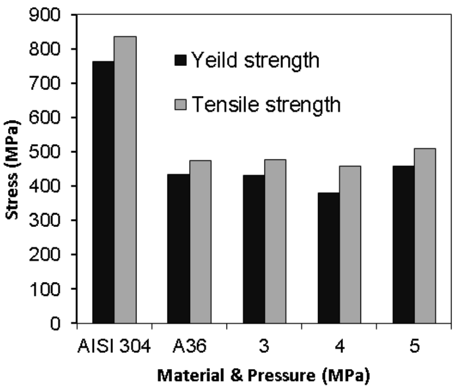



Figure 8. Yield stress and maximal stress AISI 304, A 36 carbon structural steel and pressure variable

The average results of yield strength and maximum tensile strength of AISI 304 were 763.39 MPa and 836.67 MPa, while A 36 carbon structural steel was 433.71 MPa and 474.19 MPa. In the tensile strength using friction welding with a pressure of 3 MPa, the average yield strength was 431.68 MPa and maximum tensile strength was 476.20 MPa. With pressure of 4 MPa, yield tensile strength was 381.38 MPa and the maximum tensile strength was 459.32 MPa. With pressure of 5 MPa, yield strength was 457.55 MPa and maximum tensile strength was 510.26 MPa. The pressure variables of friction welding did not seem to have a significant effect on tensile strength. This further proves the area of tensile test drop off occurs in the parent metal, i.e. A 36 carbon structural steel metal. This proves that the weld joint between AISI 304 and A36 using the Continuous Drive Friction Welding method has been successful with forging pressures of 3, 4 and 5 MPa. As has been reported by [Ajith et al. 2015] that the tensile strength of the welded joint is better than that of duplex stainless steel base metal. This is due to the improvement of grain in the area due to heat of friction, and confirmed by an increase in hardness compared to carbon structural steel.

## CONCLUSION

Based on observations and data obtained from experiments on friction welding dissimilar materials AISI 304 and A 36 carbon structural steel at low pressure, it can be concluded:

1. Stainless steel 304 could be connected using the Continuous Drive Friction Welding (CFDW) method at low pressure.
2. Microstructure in the weld zone did not appear to be stirring between stainless steel and carbon structural steel. It was apparent there was an interface area between stainless steel and carbon structural steel. At a pressure variable of 5 MPa a perfect, straight and neat welding connection was produced and the particle structure solidified and shrunk with minimal visible defect in the connection.
3. Frictional pressure affected the average hardness of the weld area or interface; the greater the pressure, the greater the hardness of the weld area.

The bonding of the welded connection was stronger than the strength of the parent metal, i.e. carbon structural steel. Thus, this method can be applied to construction.

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