

# Study of Normalizing Post – Treatment Effect on the Mechanical Characteristics and Microstructure of the Joint Rotary Friction Welded JIS S45C Medium Carbon Steel

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**Abstract** - Friction welding is one of the solid – state welding, and this welding technique does not involve any other material like filler when the process is executed. This experiment is aim to inspect about the normalizing post weld heat treatment (PWHT) on the rotary friction welded joint of JIS S45C steel, with particular attention to the modification of the joint interface microstructure and the correlation with mechanical characteristics. At 900°C for 74 minutes with room temperature cooling rate, the normalizing treatment were administred. Two mechanical testing like tension testing and Vickers microhardness were accomplished. The treatment specimens exhibited an ultimate tensile strength of 714.95 MPa, corresponding to the joint efficiency of 96.80% and undergo escalate in percentage of elongation as big as 5.73%. In opposition, the as – weld specimen have 101.28% efficiency joint compared to the base metal and all of variety of tensile specimen test failure at the base metal. Normalizing treatment make the distribution of hardness value decrease and make it more homogent in all area, while in the as – weld condition, the hardness values roses sharply in the contact area and it surroundings. Base on the microstructure characteristics, the normalizing treatment make the grains more coarser, and eliminate all of the differences in zone compared to the as – weld condition because of the softening phenomenon.

**Keywords:** Friction Welding, JIS S45C, Microstructure, Normalizing, Post – Weld Heat Treatment, Tensile Strength.

## I. INTRODUCTION

One of the most have wide application in the industrial word is carbon steel[1]. JIS S45C (equivalent to AISI 1045) carbon steel is a medium-carbon steel containing approximately 0.45% carbon, commonly used in machine components such as shafts or boiler due to its high strength and hardness[2], [3], [4], [5], [6]. Because of the higher carbon content, it is hard to joint it using traditional welding, and

higher carbon make pronounce to cracking during the process because of the brittle nature[7]. There is other option like friction – welding technique, that is more suitable for material that have higher carbon content[8], [9], [10].

Friction welding is a solid-state joining process that does not involve material melting and is particularly effective for cylindrical components[11], [12], [13]. It utilizes heat generated by friction and axial pressure between contacting surfaces[14]. Compared to conventional fusion welding, friction welding offers advantages such as the absence of filler materials and the formation of a narrower heat-affected zone (HAZ), thus minimizing thermal distortion and causing a hint of modification in the microstructure[15].

Even though it is only a little change in the microstructure in nearest spot of the contact joint, there is still residual stress formation[16], [17]. This change will make the structure more harder and brittle in carbon steel, and with assumptionthis microstructure will reduce the ductility and endurance joints to impact[18]. Hence, additional heat treatment needed in order to restore the mechanical properties of the material to its initial condition or even improve them[19].

Eka Susanto et al., doing research about the effect of stress relieving treatment on mechanical properties and microstructure of friction welded joint of medium carbon steel JIS S45C. Base on the results, there is a slightly decline in the tensile strength, and yield strength but instead it is increasing the ductility properties of the joints. The reason is because of the coarsening microstructure on the relieving treatment. Also, the treatment contributing decreasing the distribution of hardness value, especially in the weld center zone (WCZ) area, and heat affected zone (HAZ)[20]. In addition, this researcher doing some evaluation of the full annealing impact on the integrity of rotary friction welded joint AISI 1018. From the results, because of the welding parameter not good, there is significant decrease in the tensile test properties and hardness of the welded sample, and when the sample is subjected to full

annealing post weld heat treatment (PWHT), it will further reduce the value because on the microstructure, there are softening phenomenon on the grains[21]. Friction stir welding (FSW) DP780 steel is done by Chaudry et al., the sample were subjected to annealing PWHT at a temperature range of 450°C – 650°C for 1 hour. It was found all of the ruptured sample specimen tensile test at the HAZ, this is the indication the welding parameter is not perfect. There is significance depletion in the tensile and yield strength in all PWHT samples, except that the sample subjected at 500°C experiencing an increase in the percentage of elongation[22].

On the other hand, many experiment about dissimilar friction welded material also initiated. According to Dong et al., when TiAl alloy was friction welded to 40Cr steels, TiC will emerge, causing aggregation of C at the weld interface. The aggregation of C vanished and the joint strength is rose as result of PWHT. PWHT may therefore help to improve the mechanical characteristics of a joint by homogenizing the microstructure, particularly at the weld interface[23]. Navasinh et al., doing an experiment about microstructure evolution and corrosion resistance of friction welded dissimilar AISI 1010/D3 steels joint. For the as – weld sample the microstructure was formed ultrafine ferrite grains at the interface. After PWHT was performed it is changed the distribution of microstructure secondary carbides and dissolved primary carbides to assist homogenize the microstructure. PWHT also helped the corrosion behavior in joints between this material[24]. When Cu interlayer was applied during friction welding of Inconel 600 and stainless steel 316L interface, Mishra et al., found 10.8% improvement in strength

above the weld generated without interlayer, which is increased by 14.2% following PWHT. When compared to joints formed without interlayer, refined grains made with interlayer assumed to have stronger joint[25].

From the authors knowledge and according on the literature review, there is not many research using normalizing treatment on the friction welded joint of JIS S45C carbon steel. Many research using stress relieving or annealing type PWHT on the friction welding joints. To narrower the gap, this experiment will be focused on the friction welded joint fabricated using modified lathe machine with normalizing treatment after welding was done and performing mechanical testing for more better understanding.

The main objective of this present experiment is to evaluate the impact of normalizing treatment on the mechanical properties like tensile test properties, and microhardness Vickers distribution value of friction welded joints of JIS S45C carbon steel. For analyzing the data from mechanical properties, observation microstructure will be conducted and it will be connected together.

**II. MATERIALS AND METHODS**

The raw material that was used in this experiment is JIS S45C structural carbon steel, and it is in circular shape, also it was earned in hot – rolled condition with 14 mm diameter. Table 1 showing the chemical makeup of S45C carbon steels according to JIS G 4051[26]. The mechanical properties of JIS S45C carbon steels can be seen visible in Table 2.

**Table 1: Chemical makeup of JIS S45C carbon steels (wt.)[26]**

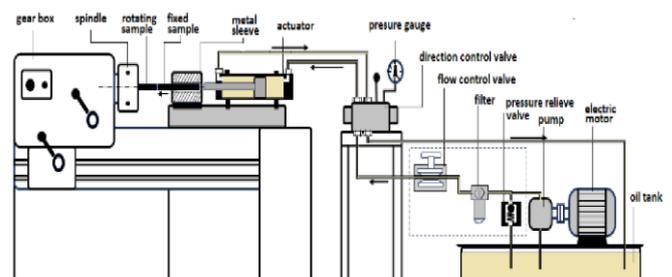
C	Mn	P	Si	Ni	Cu	S	Ni + Cr	Cr
0.42 – 0.48	0.60 – 0.90	0.03 max.	0.15 – 0.35	0.20 max.	0.30 max.	0.035 max.	0.35 max.	0.20 max.

**Table 2: Mechanical properties of JIS S45C carbon steels**

Yield Strength (MPa)	Tensile Strength (MPa)	Percentage of Elongation (%)	Reduction of Area (%)
405	665	22	40.5

Before the friction welding will be executed, the surfaces of two materials to be joined are faced on lathe and aligned. This experiment involved friction welding process on the modified lathe machine, like in Fig. 1. To make the ensure, it can control the parameters like pressure and time during jointing process control device were connected to the machine. In order for the stationary specimen to be pushed, the stationary chuck is connected to metal sleeve. This metal sleeve also connected to the hydraulic system which is the

main source of its propulsion for this machine[27]. In this experiment, friction load was set at 40 Bar for 5,5 seconds, and the forging load setted at 45 Bar for 5,5 seconds, the rotation speed of the spindle setfixed at 1330 rpm. The output of the friction welding joint shown in Fig. 2.



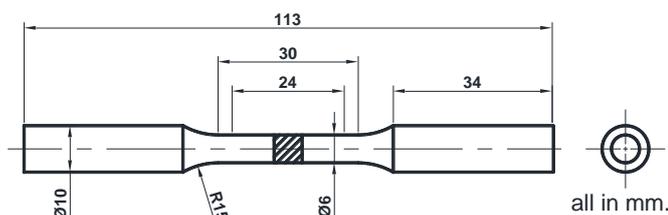
**Figure 1: The modified lathe machine for rotary friction welding [27]**



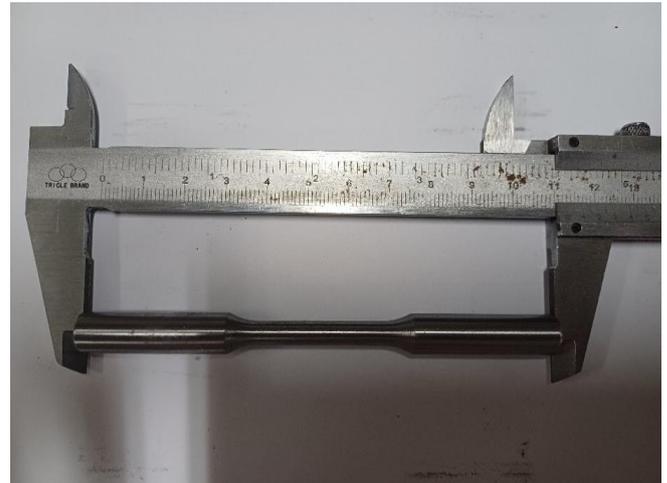
Figure 2: The outcome of the friction welded joint

Normalizing treatment managed after the process of joining was finished and it was executed inside furnace. The normalizing treatment performed at 900°C for 74 minutes, and it was cooled relative fast at room temperature[28]. To make sure temperature reached 900°C, a thermocouple was placed into the furnace and place it near the specimens. After that, the specimen is machined so that it can be shaped into a specimen that is ready for tensile testing, microstructural observation, and microhardness Vickers. It was machined with conventional lathe machine and low speed rotation revolution (900 rpm) are used during the turning process, moreover antifreeze fluids also used. This low rotation and antifreeze fluids are used to ensure that was no white layer arise during machining process[29]. The specimen is surface finished by using sandpaper and after that metal polish paste is used.

All of the tensile testing method conducted according to ASTM E-8 standard and in Fig. 3 shows the complete dimensions of tensile test specimen. 50 Ton universal testing machine (JTM – UTC 6604, Taiwan) is used to obtain the tensile mechanical properties of each type specimens. This machine crossheads speeds set at 2 mm/min, because there is no extensometer attached on the universal machine, the strain rates determined using the starting of gauge length, as the specimens was tested for longer period times, the strain rate may decrease. This test was carried at temperature room, approximately at 28°C – 36°C[30].



(A)



(B)

Figure 3: Tensile testing specimens; (A) Dimensions; (B) The specimen

Before the microstructure observation and microhardness Vickers test were performed, preparation for the specimen is carried out according to standard ASTM E-3[31]. The specimen is grinded using metallography cutting machine at the cross sections area, and then, the specimens mounted with black powder resin in the mounting machine. Sand paper and polishing metal paste used to make sure there is no excrement on the surface and making it smoother. To reveal the microstructure, chemical etchant like 1 - 5 mL HNO<sub>3</sub> + 100 mL C<sub>2</sub>H<sub>5</sub>OH is used to soak the specimen surface for 50 seconds[32]. Then, the specimen surface washed with ethanol. After etching, the specimen was inspected under optical microscope (Metallurgy Union model, Japan). This inspection helping to understand the shape and makeup of the microstructure. Following that, to obtain the idea of hardness distribution value each zone, Vickers microhardness were performed out on the Vickers hardness machine (Mitutoyo HM - 102, Japan). In agrees with ASTM E-384, 0.987 N test force used on the surface for 15 seconds, and 0.1 mm spacing between indentation was used and it was measured at centerline axis[33].

### III. RESULT AND DISCUSSION

#### Tensile Properties Results

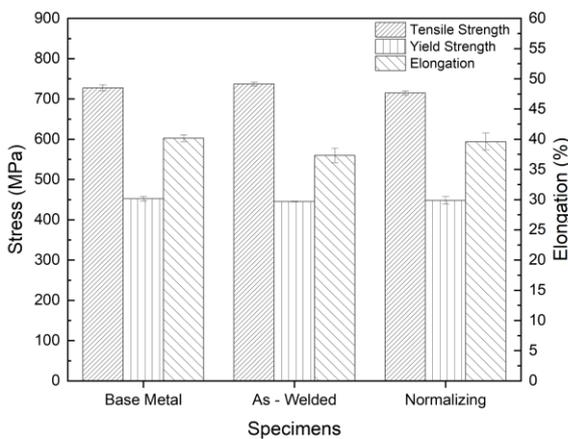
Engineering stress and strain, also the tensile properties of all type specimens are given in the Fig. 4. Base on the Figure, there is no discernible difference exist in the mechanical properties between base metal specimen and as - welded specimen, only slightly improvement on the tensile strength, and slightly reduction with the elongation. Overall, the as - welded condition provides the highest tensile strength with

737.16 MPa, compared with base metal there is improvement about 2.5%, but dropping 5.5% in the elongation. On the other hand, there is also slightly reducing in tensile strength of normalizing treatment (714.95 MPa) in amount of 4%, and increasing in ductility with 6% compared to as – welded condition. The increasing in elongation value reflecting improvement in ductility, and the yield strength of the 3 types specimens does not change dramatically. Whereas the normalizing condition offers more balanced combinations of strength and ductility, making it more suitable for the applications that requiring enhanced toughness and formability [34]. The similar trend on the improvement of the tensile strength on the as – weld condition also reported by Firmanto et al. [35].

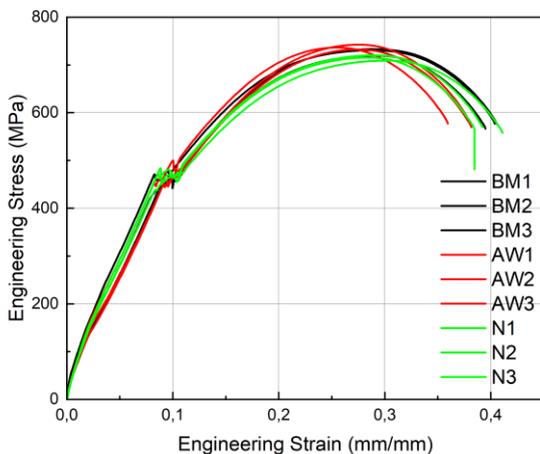
To determine the joint integrity, joint efficiency calculation was performed, by dividing tensile strength of the as – welded joint or the treatment conditions with tensile strength of base metal or as – welded specimen [36], it was shown in Eq. (1):

$$\text{Joint Efficiency} = \frac{\text{tensile strength of the as – welded joint or the treatment conditions}}{\text{tensile strength of base metal or as – welded specimen}} \times 100\% \quad (1)$$

From the calculation, the joint efficiency of as – welded metal achieved on 102.42%, this improvement somehow related to grain refining in the joints without forming martensite [37], and when the specimen subjected into normalizing treatment it was decreased to 96.98%. There is a slightly reduction in this efficiency calculation. Again, the value remains above 75%, it is still considered as a good joint[38]. Due to the grain at base metal (BM) more coarser (displayed in Fig. 7), all of the tensile specimens ruptured at the base metal, and it can be seen in Fig. 5. In addition to prove there is coarsening on the BM area, the hardness value on the BM was the lowest among other areas [39], like in Fig. 6. Also, as stated by Ates et al., to make the friction welded joint ruptured far from contact zone/interface, an optimal welding parameter like friction time is needed to create mechanical bonding and diffusion[40]. All of ruptured specimen indicated with necking case, it implies the specimen have ductility properties, either in as – welded condition or with addition normalizing treatment [41].



(A)



(B)

Figure 4: Outcome of tensile test; (A) mechanical properties of all specimens; (B) engineering stress – strain graphic

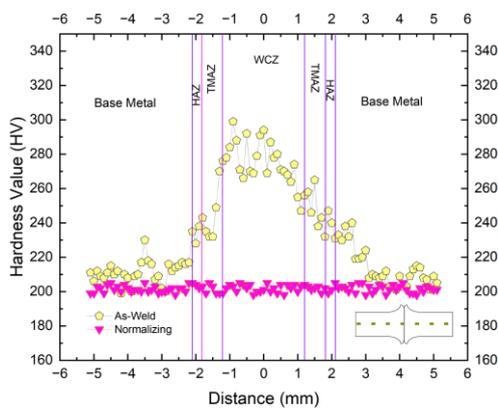


Figure 5: Ruptured tensile test specimens appearances; (A) as – welded specimens; (B) normalizing treatment specimens

### The Distribution of Microhardness Vickers Value Results

The hardness distribution over the welded joint is shown in Fig. 6, which contrast the as – welded and normalizing treatment conditions. The cross – section between one side of the base metal, the weld center zone (WCZ), and the opposing base metal represented by the distance (mm) on the x – axis. Vickers hardness (HV) values are displayed on the y – axis. Compared to base metal hardness of about 200 HV, the as – welded condition shows a substantial rise in hardness values within the welded center zone (WCZ), peaking about 299 HV. Grain refining because of dynamic recrystallization in the contact zone are the examples of localized microstructural changes brought on by welding that are indicated by this dramatic rise, the grains on TMAZ also got refined[42]. The hardness values changes between the base metal and the weld center occur gradually in the surrounding areas, such as the

heat – affected zone (HAZ) area and thermo – mechanically affected zone (TMAZ) area. On the TMAZ and HAZ area, the hardness on HAZ reduced to 228 – 256 HV, and on the TMAZ side 246 – 265 HV, due to the grains become more coarser rather than in the WCZ area[43]. In the BM area, the hardness continue decrease even more to 205 – 208 HV, because in this area does not undergo microstructural change. Microstructural change during welding process was reflected in this hardness value, with each areas shows distinctive features resulting from collaborative influence of welding heat and mechanical forces. Several experimental studies also displaying this behavior from friction welded joint[44], [45], [46].



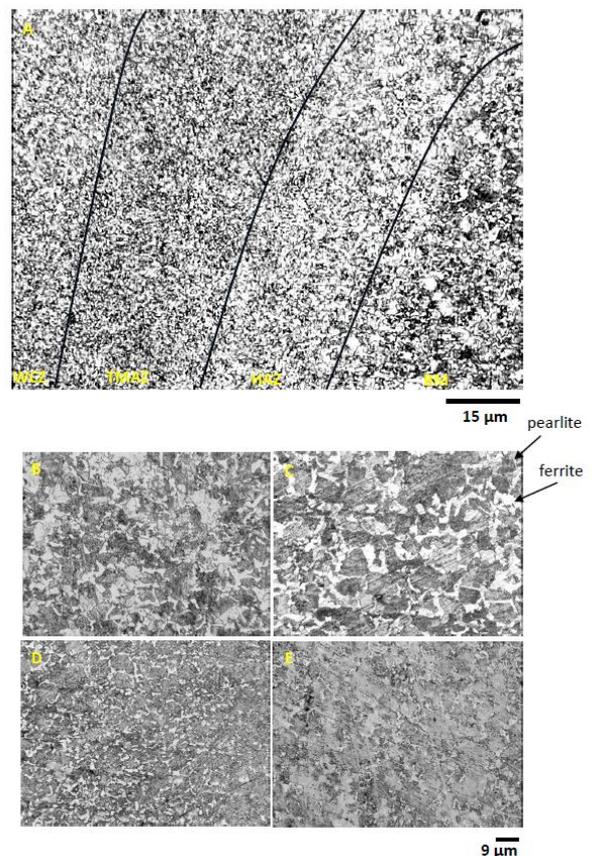
**Figure 6: The distribution values of all specimens**

Normalizing treatment, on the opposite of the welded conditions, stabilizes the specimen at around 200 HV, which almost same to the base metal, and shows a considerably more uniform hardness distribution over the whole cross – section. This finding implies that normalizing treatment successfully removes the hardness gradient caused by welding, reduces the residual stress, and make the microstructure more uniform[47]. As a result of this uniformity, the hardness peak in WCZ and it in surroundings vanishes. This uniformity also proved in Fig. 8 on the microstructure photograph, where the ferrite and pearlite looking more uniform. This demonstrates how normalizing, as a PWHT operations, may effectively restore the uniformity and ductility while minimizing hardness differences on the base metal[48]. This phenomenon has also documented by Tan et al.[34].

**Characteristic of Microstructure Observation Results**

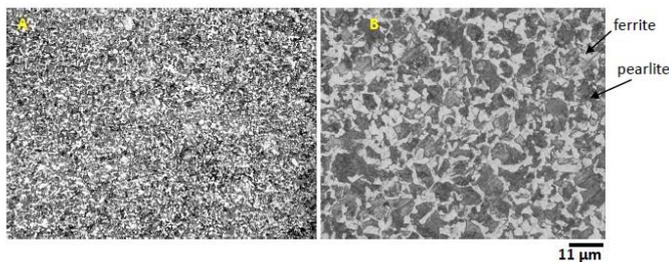
In Fig. 7, the as – welded specimen joint displays clear microstructural transitions across different zone: base metal (BM), heat affected zone (HAZ), thermo – mechanically affected zone (TMAZ), and the weld center zone (WCZ). These difference draw attention to the intricate of the mechanical and heat effects that occurs during welding and the

output in significant variations in the grain is distribution and structure throughout joint[49], [50]. The BM alone, maintain it original microstructure with fairly uniform grain size, whereas the HAZ (compared to the BM) gotten finer because of the heat exposure from the friction process during welding, however it has a higher amount ferrite. On the besides of HAZ region, there is TMAZ and WCZ that have combinations between plastic deformation + recrystallization, and in this area the microstructure become more finer[51], [52]. In the TMAZ area there is more ferrite rather than WCZ area, but the WCZ area have the highest volume fraction of pearlite (darker) with very little ferrite grain compared to other areas. The findings indicate that the area near contact surface underwent transformation into austenite [7], [53]. The grain refining phenomenon on these 3 areas, make the values of hardness distribution dived up rather than in BM area, this similar trend behavior was also proposed by a few researcher [39], [50], [54], [55]. In addition, this also makes the tensile test joint on the as – welded specimen has more higher tensile strength rather than the base metal specimen with the sacrifice of the elongation properties and the grain refining also makes this condition specimen ruptured at the base metal[56], [57], [58].



**Figure 7: Microstructure of as - welded specimen; (A) Gradation of all zone 50X; (B) BM area, 200X; (C) HAZ area, 200X; (D) TMAZ area, 200X; (E) WCZ area, 200X**

The normalizing treatment specimens, in stark contrast, exhibits a uniformity in the throughout microstructure. A consistent ferrite (light) with pearlite colonies (dark) can be seen in the Fig. 8. There is a complete recrystallization and grain growth (heated above upper critical temperature) followed by relatively slowly cooled in normalizing treatment. Which leads coarsening in the grains rather than the as – welded condition and promotes uniformity[59]. This slowly cooled method gives no times to the carbon atoms to diffuse out and make the pearlite become more finer rather than full annealing treatment [48]. Because of this, there is softening phenomenon on this treatment, in addition, this case also promotes relaxation on the residual stresses + the work hardening from the welding, eliminating all the differences between zones, and the production history (hot – working or casting)[21], [60]. This softening also makes the tensile strength, and the distribution hardness values decreased also make it more homogen compared to the as – welded conditions. Furthermore, it is also improving ductility properties with the proof rise of percentage elongation values [34]. From photographic of this 2 types specimen, there is no void, crack, or inclusion were formed during welding.



**Figure 8: Microstructure of normalizing treatment specimen; (A) 50X; (B) 200X**

#### IV. CONCLUSIONS

Similar joint of JIS S45C carbon steels were fabricated through friction welding in this experiment. The impact of normalizing treatment after joining process was done was systematically studied, and the major conclusions can be drawn as follows:

1. By applying friction welding followed by normalizing treatment, the joint still considered reliable and it ruptured at the base metal after tensile testing was done. The treatment led to improvements in the percentage of elongation. However, compared to the as – welded condition, the treatments make a slightly deterioration on the tensile strength with increasing the elongation percentage values.
2. The treatment also makes the distribution hardness values drop almost like the base metal and make it more

uniform. It is also eliminating all of the differences in all areas.

3. From the microstructure of normalizing treatment, the grain becoming more coarser and uniform, and from this microstructure type it can be concluded it is slightly affecting the mechanical properties.

#### REFERENCES

- [1] M. A. Marir, E. L. Sheng, I. O. Bachi, and M. R. Isa, “Tensile efficiency and fatigue life of similar and dissimilar carbon steel joints subjected to rotary friction welding,” *Journal of Advanced Joining Processes*, vol. 8, p. 100168, Nov. 2023, doi: 10.1016/J.JAJP.2023.100168.
- [2] G. D. Haryadi, A. Fredy Utomo, I. Made, and W. Ekaputra, “Pengaruh Variasi Temperatur Quenching dan Media Pendingin terhadap Tingkat Kekerasan Baja AISI 1045,” 2021. [Online]. Available: <https://jurnal.polines.ac.id/index.php/rekayasa>
- [3] M. Dat Nguyen *et al.*, “Anti-Fouling Ceramic Coating for Improving the Energy Efficiency of Steel Boiler Systems”, doi: 10.3390/coatings8100353.
- [4] I. Ekaputra, Y. Akas Wibisono, G. Dwi Haryadi, and J. Teknik Mesin, “Carbon Size and Temperature Effects to JIS S45C Carburized Steels,” pp. 297–303, 2024, doi: 10.21776/jrm.v15i3.1499.
- [5] T. Shinoda and S. Kawata, “Friction Welding of A 6061 Aluminum Alloy and S45C Carbon Steel,” *Materials Science Forum*, vol. 449–452, pp. 437–440, Mar. 2004, doi: 10.4028/www.scientific.net/MSF.449-452.437.
- [6] M. Imam, R. Ueji, and H. Fujii, “Microstructural control and mechanical properties in friction stir welding of medium carbon low alloy S45C steel,” *Materials Science and Engineering: A*, vol. 636, pp. 24–34, Jun. 2015, doi: 10.1016/j.msea.2015.03.089.
- [7] Y. Morisada, T. Shirasawa, and H. Fujii, “Medium and high carbon steel joints formed by friction welding below A1 temperature,” *Science and Technology of Welding and Joining*, vol. 25, no. 5, pp. 438–445, Jul. 2020, doi: 10.1080/13621718.2020.1738663.
- [8] M. R. Kelly, S. R. Schmid, D. C. Adams, J. Fletcher, and R. Heard, “Experimental investigation of linear friction welding of AISI 1020 steel with pre-heating,” *J Manuf Process*, vol. 39, pp. 26–39, Mar. 2019, doi: 10.1016/J.JMAPRO.2019.01.038.
- [9] T. Dhamotharakannan *et al.*, “Joining different grades of low carbon steel to develop unsymmetrical rod to plate joints using rotary friction welding for automotive applications,” *Forces in Mechanics*, vol. 10, p. 100153, Feb. 2023, doi: 10.1016/J.FINMEC.2022.100153.

- [10] V. T. Gaikwad, M. K. Mishra, V. D. Hiwarkar, and R. K. P. Singh, "Microstructure and mechanical properties of friction welded carbon steel (EN24) and nickel-based superalloy (IN718)," *International Journal of Minerals, Metallurgy and Materials*, vol. 28, no. 1, pp. 111–119, 2021, doi: 10.1007/s12613-020-2008-1.
- [11] H. Ghari, A. Taherizadeh, B. Sadeghian, B. Sadeghi, and P. Cavaliere, "Metallurgical characteristics of aluminum-steel joints manufactured by rotary friction welding: A review and statistical analysis," *Journal of Materials Research and Technology*, vol. 30, pp. 2520–2550, May 2024, doi: 10.1016/j.jmrt.2024.03.089.
- [12] M. Dellepiane, L. Da Silva, and A. Toumpis, "Design and Development of a Bespoke Rotary Friction Welding Machine in Exploration of Joining Dissimilar Materials for Nuclear Applications," *Journal of Manufacturing and Materials Processing*, vol. 9, no. 1, Jan. 2025, doi: 10.3390/jmmp9010027.
- [13] F. Khalfallah, Z. Boumerzoug, S. Rajakumar, and E. Raouache, "Optimization by RSM on rotary friction welding of AA1100 aluminum alloy and mild steel," *International Review of Applied Sciences and Engineering*, vol. 11, no. 1, pp. 34–42, Apr. 2020, doi: 10.1556/1848.2020.00005.
- [14] F. Ahmad Mir, N. Zaman Khan, A. Noor Siddiquee, and S. Parvez, "Friction based solid state welding – A review," *Mater Today Proc*, vol. 62, pp. 55–62, Jan. 2022, doi: 10.1016/J.MATPR.2022.01.457.
- [15] S. Senthil Murugan, P. Sathiya, and A. Noorul Haq, "Rotary Friction Welding and Dissimilar Metal Joining of Aluminium and Stainless Steel Alloys," *Annals of "Dunarea de Jos" University of Galati, Fascicle XII, Welding Equipment and Technology*, vol. 32, pp. 85–92, Dec. 2021, doi: 10.35219/awet.2021.11.
- [16] R. Winiczenko, A. Sibicki, P. Skoczylas, and J. Trajer, "Multi-objective optimization of the process parameters for friction welding of dissimilar metals," 2019, doi: 10.1051/e3sconf/2019.
- [17] A. Haşcalik, E. Ünal, and N. Özdemir, "Fatigue behaviour of AISI 304 steel to AISI 4340 steel welded by friction welding," *J Mater Sci*, vol. 41, no. 11, pp. 3233–3239, Jun. 2006, doi: 10.1007/s10853-005-5478-7.
- [18] T. C. Nguyen and D. C. Weckman, "A Thermal and Microstructure Evolution Model of Direct-Drive Friction Welding of Plain Carbon Steel," 2005.
- [19] H. Ma, G. Qin, P. Geng, F. Li, X. Meng, and B. Fu, "Effect of post-weld heat treatment on friction welded joint of carbon steel to stainless steel," *J Mater Process Technol*, vol. 227, pp. 24–33, Jan. 2016, doi: 10.1016/j.jmatprotec.2015.08.004.
- [20] A. Eka Susanto, G. Dwi Haryadi, I. Haryanto, S. Nugroho, and I. Made WicaksanaEkaputra, "Evaluation of stress-relieving heat treatment on mechanical properties and microstructure of friction-welded JIS S45C steel," *Disseminating Information on the Research of Mechanical Engineering-JurnalPolimesin*, vol. 23, no. 3, 2025, [Online]. Available: <http://e-jurnal.pnl.ac.id/polimesin>
- [21] I. A. Soomro *et al.*, "Postweld heat treatment of rotary friction welded AISI 1018 steel: microstructure, mechanical properties and corrosion resistance evaluation," *Welding International*, 2024, doi: 10.1080/09507116.2024.2435481.
- [22] U. M. Chaudry, S. C. Han, and T. S. Jun, "Effect of welding speed on the microstructure and texture development in the individual weld zone of friction stir welded DP780 steel," *Journal of Materials Research and Technology*, vol. 23, pp. 4976–4989, Mar. 2023, doi: 10.1016/j.jmrt.2023.02.122.
- [23] H. G. Dong, L. Z. Yu, H. M. Gao, D. W. Deng, W. L. Zhou, and C. Dong, "Microstructure and mechanical properties of friction welds between TiAl alloy and 40Cr steel rods," *Transactions of Nonferrous Metals Society of China*, vol. 24, no. 10, pp. 3126–3133, Oct. 2014, doi: 10.1016/S1003-6326(14)63451-8.
- [24] R. Jesudoss *et al.*, "Improved Microstructure Evolution and Corrosion Resistance in Friction-Welded Dissimilar AISI 1010/D3 Steel Joints Through Post-Weld Heat Treatment," *J. Manuf. Mater. Process*, vol. 2025, p. 124, 2025, doi: 10.3390/jmmp9040124.
- [25] N. K. Mishra and A. Shrivastava, "Improvement in strength and ductility of rotary friction welded Inconel 600 and stainless steel 316L with Cu interlayer," *CIRP J Manuf Sci Technol*, vol. 41, pp. 19–29, Apr. 2023, doi: 10.1016/J.CIRPJ.2022.12.006.
- [26] JIS G4051, "Carbon steels for machine structural use," 2017.
- [27] H. Firmanto, S. Candra, and M. A. Hadiyat, "Rotary friction welding of 304 stainless steel: parametric study, mechanical properties, and microstructure of the joint," *Disseminating Information on the Research of Mechanical Engineering-JurnalPolimesin*, vol. 22, no. 2, 2024, [Online]. Available: <http://e-jurnal.pnl.ac.id/polimesin>
- [28] G. E. Totten, "Steel Heat Treatment Metallurgy and Technologies," Sep. 2006.
- [29] S. Han, S. N. Melkote, M. S. Haluska, and T. R. Watkins, "White layer formation due to phase transformation in orthogonal machining of AISI 1045 annealed steel," *Materials Science and Engineering: A*, vol. 488, no. 1–2, pp. 195–204, Aug. 2008, doi: 10.1016/J.MSEA.2007.11.081.

- [30] ASTM, "ASTM E8/E8M – 13a Standard Test Methods for Tension Testing of Metallic Materials," 2016, doi: 10.1520/E0008\_E0008M-13A.
- [31] ASTM, "Guide for Preparation of Metallographic Specimens," May 01, 2011, *ASTM International, West Conshohocken, PA*. doi: 10.1520/E0003-11.
- [32] ASTM, "Practice for Microetching Metals and Alloys," Jun. 01, 2015, *ASTM International, West Conshohocken, PA*. doi: 10.1520/E0407-07R15E01.
- [33] ASTM, "Test Method for Microindentation Hardness of Materials," Jun. 01, 2017, *ASTM International, West Conshohocken, PA*. doi: 10.1520/E0384-17.
- [34] J. Tan, Z. Gao, S. Ren, Q. Xu, K. Wang, and Q. Zeng, "Improving the microstructures and mechanical properties of U71Mn rail steel liner friction welded joint by normalizing treatment," *Mater Today Commun*, vol. 38, Mar. 2024, doi: 10.1016/j.mtcomm.2023.107736.
- [35] H. Firmanto, S. Candra, M. A. Hadiyat, Y. P. Triastomo, and I. Wirawan, "Tensile Strength and Microstructure of Rotary Friction-Welded Carbon Steel and Stainless Steel Joints," *Journal of Manufacturing and Materials Processing*, vol. 7, no. 1, Feb. 2023, doi: 10.3390/jmmp7010007.
- [36] G. I. Khidhir and S. A. Baban, "Efficiency of dissimilar friction welded 1045 medium carbon steel and 316L austenitic stainless steel joints," *Journal of Materials Research and Technology*, vol. 8, no. 2, pp. 1926–1932, Apr. 2019, doi: 10.1016/j.jmrt.2019.01.010.
- [37] L. Cui, H. Fujii, N. Tsuji, and K. Nogi, "Friction stir welding of a high carbon steel," *Scr Mater*, vol. 56, no. 7, pp. 637–640, Apr. 2007, doi: 10.1016/j.scriptamat.2006.12.004.
- [38] W. A. Society, "Fundamentals of Welding," 1976.
- [39] D. K. Thirumalaikkannan, S. Paramasivam, S. Murugesan, and B. Visvalingam, "Effect of rotational speed on the microstructure and mechanical properties of rotary friction welded AISI 1018/AISI 1020 asymmetrical joints," vol. 64, no. 11, pp. 1561–1571, 2022, doi: 10.1515/mt-2022-0188.
- [40] H. Ates, M. Turker, and A. Kurt, "Effect of friction pressure on the properties of friction welded MA956 iron-based superalloy," *Mater Des*, vol. 28, no. 3, pp. 948–953, 2007, doi: 10.1016/j.matdes.2005.09.015.
- [41] H. Ates and N. Kaya, "Mechanical and microstructural properties of friction welded AISI 304 stainless steel to AISI 1060 steel," *Archives of Metallurgy and Materials*, vol. 59, no. 3, pp. 841–846, 2014, doi: 10.2478/amm-2014-0142.
- [42] J. S. Chatha, A. Handa, and T. S. Bedi, "Strength analysis of rotary friction welded joints of dissimilar steel grades," in *Materials Today: Proceedings*, Elsevier Ltd, 2020, pp. 242–247. doi: 10.1016/j.matpr.2020.07.090.
- [43] A. Dadashi, A. Asghaie, and M. Azadi, "Evaluation of high-cycle bending fatigue properties and fracture behaviors in AM60 magnesium alloy joints by friction welding," *Forces in Mechanics*, vol. 20, Aug. 2025, doi: 10.1016/j.finmec.2025.100327.
- [44] H. E. Lakache, A. May, R. Badji, S. E. Benhammouda, and S. Ramtani, "The Impact of the Rotary Friction Welding Pressure on the Mechanical and Microstructural Characteristics of Friction Welds Made of the Alloys TiAl6V4 and 2024 Aluminum," *Exp Tech*, vol. 48, no. 3, pp. 473–484, 2024, doi: 10.1007/s40799-023-00671-z.
- [45] Y. Deng *et al.*, "Effect of Friction Time on Temperature Distribution, Plastic Flow, Microstructure, and Properties in Friction Welding of 1045 Carbon Steel and AISI 430 Ferritic Stainless Steel," *J Mater Eng Perform*, vol. 34, no. 5, pp. 3843–3858, 2025, doi: 10.1007/s11665-024-09410-w.
- [46] Vijay T Gaikwad, M. K Mishra, Abhishek Tripathi, and R. K P Singh, "On the role of upset pressure during friction welding of IN713LC and AISI 4140," *Materials Science and Technology*, vol. 41, no. 12, pp. 867–876, Aug. 2024, doi: 10.1177/02670836241273483.
- [47] V. B. Trindade, J. C. Payão-Filho, A. S. Guimarães, and R. P. R. Paranhos, "Effect of normalizing heat treatment on the mechanical behaviour of low-alloy steel weld metals," *Materials and Structures/Materiaux et Constructions*, vol. 38, no. 277, pp. 353–357, Apr. 2005, doi: 10.1617/14177.
- [48] Ishtiaq Muhammad, A. Inam, S. Tiwari, and J. B. Seol, "Microstructural, mechanical, and electrochemical analysis of carbon doped AISI carbon steels | Enhanced Reader."
- [49] A. Atamashkin, E. Priymak, E. Tulibaev, Y. Syomka, and V. Trushov, "Influence of force parameters of rotary friction welding on the microstructure and mechanical properties of welded joints of high-strength drill pipes," *International Journal on Interactive Design and Manufacturing (IJIDeM)*, vol. 19, no. 4, pp. 2937–2950, 2025, doi: 10.1007/s12008-024-02011-w.
- [50] A. U. Rehman, N. Kishore Babu, M. Kumar Talari, Y. S. Usmani, and H. Al-Khalefah, "Microstructure and Mechanical Property Correlation Between Rotary Friction Welded Nitinol-Nitinol Joints", doi: 10.3389/fmats.2021.726383.
- [51] N. Switzner, Z. Yu, M. Eff, T. Lienert, and A. Fonseca, "Microstructure and mechanical property variations within inertia friction-welded joints of stainless steel to steel: Within-joint microstructure and mechanical property distributions must be considered when

- designing novel applications for dissimilar friction welding,” *International Journal of Advanced Manufacturing Technology*, vol. 95, no. 9–12, pp. 4327–4340, Apr. 2018, doi: 10.1007/s00170-017-1568-3.
- [52] Q. Nie *et al.*, “Effect of post-weld heat treatment on the joint of friction-welded 1MnCrMoNi steel,” *Science and Technology of Welding and Joining*, vol. 26, no. 3, pp. 220–226, 2021, doi: 10.1080/13621718.2021.1882654.
- [53] S. Celik and I. Ersozlu, “Investigation of the mechanical properties and microstructure of friction welded joints between AISI 4140 and AISI 1050 steels,” *Mater Des*, vol. 30, no. 4, pp. 970–976, Apr. 2009, doi: 10.1016/j.matdes.2008.06.070.
- [54] V. Gaikwad, V. Hiwarkar, V. Pawar, and R. Singh, “Microstructure characterization and evaluation of mechanical properties for friction welded En-24 alloy steel,” in *Materials Science and Technology 2018, MS and T 2018*, Association for Iron and Steel Technology, AISTECH, 2019, pp. 822–829. doi: 10.7449/2018/MST\_2018\_822\_829.
- [55] Y. Belkahlaet *al.*, “Rotary friction welded C45 to 16NiCr6 steel rods: statistical optimization coupled to mechanical and microstructure approaches,” *The International Journal of Advanced Manufacturing Technology*, vol. 116, no. 7, pp. 2285–2298, 2021, doi: 10.1007/s00170-021-07597-z.
- [56] D. Gustianiet *al.*, “Effect of friction time on mechanical properties and microstructure of welded connections friction welding method 403 stainless steel solid cylinder material,” *PROCEEDINGS OF THE 8TH INTERNATIONAL CONFERENCE ON ENGINEERING, TECHNOLOGY, AND INDUSTRIAL APPLICATIONS 2021 (8th ICETIA 2021): Engineering, Environment, and Health: Exploring the Opportunities for the Future*, no. 1, Feb. 2024, Accessed: Aug. 17, 2025. [Online]. Available: <https://doi.org/10.1063/5.0180063>
- [57] M. Ostromecka, “Microstructure and Mechanical Properties of Dissimilar Friction Welded B500B-1.4021 Steel Joint,” in *Materials Research Proceedings*, Association of American Publishers, 2022, pp. 240–246. doi: 10.21741/9781644902059-35.
- [58] N. Özdemir, F. Sarsilmaz, and A. Hasçalik, “Effect of rotational speed on the interface properties of friction-welded AISI 304L to 4340 steel,” *Mater Des*, vol. 28, no. 1, pp. 301–307, Jan. 2007, doi: 10.1016/J.MATDES.2005.06.011.
- [59] D. W. Callister, “Materials Science and Engineering An Introduction,” 1998.
- [60] H. E. Emre and R. Kaçar, “Effect of post weld heat treatment process on microstructure and mechanical properties of friction welded dissimilar drill pipe,” *Materials Research*, vol. 18, no. 3, pp. 503–508, May 2015, doi: 10.1590/1516-1439.308114.

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