Effect of Welding Groove and Electrode Variation to the Tensile Strength and Macrostructure on 304 Stainless Steel and AISI 1045 Dissimilar Welding Joint Using SMAW Process

Suheni¹, A A Rosidah¹, D P Ramadhan¹, T Agustino¹, F F Wiranata¹
¹ Department of Mechanical Engineering, Institut Teknologi Adhi Tama Surabaya, Surabaya, Indonesia
afiraar@itats.ac.id

Abstract. AISI 1045 and 304 stainless steel are widely used in automotive and industrial fields. However, both of these steels have their own advantages and disadvantages. AISI 1045 is not resistant to corrosion but has good wear resistance and low price. Meanwhile, the 304 stainless steel provides good corrosion resistance and mechanical properties but is costly. Their combination is able to provide a good property and reduce the costs. Thus, in order to combine these two metals, shield metal arc welding is carried out using welding groove and electrode variation. The groove variations used were double bevel, V, and double V-groove, additionally, the electrode variations used were E6013 and E7016. Then, the welding results were characterized using the tensile strength and macrostructure analysis. The results revealed that the specimen using E7016 electrode for the double V-groove resulted in the highest tensile test results the value of 270.48 MPa yield strength, 411.49 MPa tensile strength, and 19.81% elongation. The macrostructure analysis showed that the specimens using E7016 electrode gave a narrow HAZ that led to higher mechanical properties.

1. Introduction
Some methods of joining materials have been developed through the years, most notably welding. Welding is described as a joining or fusion process of metals or nonmetals conducted by heating the materials to the required temperature. Shielded Metal Arc Welding (SMAW) is one of the most popular welding processes [1]. SMAW is a protected electric arc welding that requires a consumable electrode. In this welding process, the heat is produced from the electric arc between the electrode tip and the welded metal [1,2]. Many researchers have utilized SMAW due to its simplicity, portability, and low-cost equipment [3–5]. On its application, many factors affect the physical and mechanical properties of the results of the SMAW process, such as welding current, angle, groove, and electrode [5–7]. Pathak et al (2020) revealed that increasing the welding current and electrode angle value gives an improvement to the ultimate tensile strength on the welded area of low carbon steel [6]. Furthermore, the selection of groove types also affects the mechanical properties of the welded metal. The single-V groove showed the highest value in impact strength compared to the single-bevel and double-bevel groove when they was applied to the medium carbon steel [5]. In addition, Setyowati et al (2016) used different filler metals to observe the tensile strength and macrostructure of the welded 304 stainless steel. The results exhibited the higher ultimate tensile strength and the weld form filling the welding groove well using NSN-312 electrode due to its manganese contain [7].
Many researchers commonly used low and medium carbon steel as the selected material to be welded using SMAW process [4,6,8,9]. One of the most popular medium carbon steels is AISI 1045 that contains carbon around 0.4-0.45%. This kind of carbon steel is widely used for automotive components, such as gears, crankshafts, and bearings, additionally, it has good wear resistance [10]. On the other side, steels have relatively poor corrosion resistance. They form rust in air, acids, and high temperature. Nonetheless, there is an iron-chromium-nickel alloy or called stainless steel which is resistant to acids and high temperature up to 1100°C [11]. It has large usefulness with good combination of mechanical properties and manufacturing characteristics [12]. This causes the stainless steel is suitable to use in pipe fabrication systems, automotive exhaust systems, and some equipment related to the chemical and nuclear power industries [7]. Therefore, some studies also observed the behaviour of stainless steel after SMAW process, specifically using 304 stainless steel [11,13,14]. The 304 stainless steel contains maximum 0.08% of carbon, 18-20% of chromium, maximum 2% of manganese, and 8-12% of nickel [13].

AISI 1045 and 304 stainless steels have wide application in automotive and industrial fields. Nevertheless, AISI 1045 is not resistant to corrosion, but has good wear resistance and low price. The 304 stainless steel provides good corrosion resistance and mechanical properties, but it is costly. Thus, their combination is believed to provide a good property with reducing the costs. Additionally, as James et al (2016) stated that dissimilar metal joints are conducted in different applications requiring a certain special property combination and also to save costs against pricey and rare materials [15]. In order to combine these two metals, shield metal arc welding is carried out as the widely used welding process. For further experiment, this research focused on the tensile strength and visual appearance of 304 stainless steel and AISI 1045 dissimilar welding joint using SMAW process with the welding groove and electrode type as the parameters.

2. Experimental methods
Stainless steel 304 and AISI 1045 were used as material in a plate shape with a thickness of 12 mm. The materials were cut using a grinder cutting machine. The welding process was conducted using a 100 A electrical current and 220 V voltage. The parameters analysed in this study were groove variation and electrode type. The groove variation used was double bevel groove, V-groove, and double V-groove. Additionally, the groove angle used in the specimen was 60° and using 2 mm gap. The electrodes were E6013 (RB-26) and E7016 (LB-52) with 3.2 mm in diameter. The mechanical properties of RB-26 and LB-52 are given in Table 1.

Table 1. Mechanical properties of E6013 and E7016 electrode [16].

|       | Yield Strength (MPa) | Tensile Strength (MPa) | Elongation (%) |
|-------|----------------------|------------------------|----------------|
| E6013 | 450                  | 510                    | 25             |
| E7016 | 500                  | 570                    | 32             |

Furthermore, the characterization was carried out to observe before and after the welding process of the specimens. The characterization performed was the tensile and macrostructure observation. The specimen dimension for tensile testing used ASME section IX as shown in Figure 1. In addition, macrostructure observation was carried out to determine the differences in three areas of the welded specimen, namely the base metal area, the Heat Affected Zone (HAZ), and the weld metal area. The macrostructure pictures were taken after grinding process using sandpaper from grade 100 to 1500, then followed by etching.
3. Results and discussion

3.1 Tensile test results

The ability of a material to endure a load is expressed as the strength of a material. The strength of a material can be obtained from tensile testing. The tensile test results showed the yield strength, tensile strength, and elongation in the electrode and welding groove variation. The results revealed that using a double V-groove had a significant increase in tensile strength (see Figure 2). This increase was in line with the previous studies [17,18]. The earlier researches said that the increase in tensile strength using double V-groove was due to the presence of ferrite and a little pearlite phase [17,19]. Moreover, the E7016 electrode also gave a higher tensile strength result compared to the E6013 electrode. These results were comparable to the past studies that the E7016 electrode generally resulted in a higher tensile strength than other types [20,21]. The reason could be due to the basic mechanical properties of the electrodes themselves as compared in Table 1 and the resulted welding area that will be further discussed in the following subsection.

The results from the tensile testing exhibited that the double V-groove using E7016 electrode had the highest tensile strength, followed by double bevel and V-groove with the value of 411.49 MPa, 250.85 MPa, and 193.05 MPa, respectively. The specimen using double V-groove and E7016 electrode presented the highest value in yield strength and elongation as well with the value of 270.48 MPa and 19.81%, respectively. It can be said that the increase in the yield strength and elongation for all specimens was consistent with the tensile strength enhancement as seen in Table 2.
Table 2. Tensile test of 304 stainless steel and AISI 1045 dissimilar welding with electrode and welding groove variation

| Electrode | Welding Groove | Yield Strength (MPa) | Ultimate Tensile Strength (MPa) | Elongation (%) |
|-----------|----------------|----------------------|---------------------------------|----------------|
| E6013     | Double bevel   | 89.20                | 187.64                          | 5.47           |
|           | V              | 159.63               | 173.89                          | 5.19           |
|           | Double V       | 218.42               | 362.32                          | 17.20          |
| E7016     | Double bevel   | 234.68               | 250.85                          | 7.52           |
|           | V              | 165.51               | 193.05                          | 7.89           |
|           | Double V       | 270.48               | 411.49                          | 19.81          |

3.2 Macrostructure results

Macrostructure analysis was carried out to distinguish differences and changes in the area that occurred after the welding process. Figures 3 to 5 display the macrostructure of the welded specimens in various groove types using E6013 electrode, additionally, Figures 6 to 8 show the macrostructure using E7016 electrode with the same variation. The welded metal of the specimen using double bevel-groove and E6013 electrode seems not well distributed to fill the groove compared to the specimen using E7016 electrode (see Figure 3 and 6). The specimens using E7016 electrode clearly seen to have a wider weld pool compared to the specimens using E6013 electrode. Furthermore, in terms of the area of the welded specimen, the HAZ area of the specimen using E7016 electrode is narrower than the specimen using E6013 electrode. This causes the welded specimens using E7016 electrode to have higher mechanical properties, as stated in the previous research [22]. Nevertheless, a wider HAZ area implies better penetration into the base metal, additionally, it leads to a decrease in the probability of porosity occurred.

![Figure 3. Macrostructure of weld metal using double bevel-groove and E6013 electrode](image)

![Figure 4. Macrostructure of weld metal using V-groove and E6013 electrode](image)

![Figure 5. Macrostructure of weld metal using double V-groove and E6013 electrode](image)
Figure 6. Macrostructure of weld metal using double bevel-groove and E7016 electrode

Figure 7. Macrostructure of weld metal using V-groove and E7016 electrode

Figure 8. Macrostructure of weld metal using double V-groove and E7016 electrode

4. Conclusion
The tensile test result proved that using a double V-groove provided substantial escalation in the mechanical properties. Then, comparing to the electrode variation, the specimen using E7016 electrode for the double V-groove resulted in the highest tensile test results that including yield strength, ultimate tensile strength, and elongation with the value of 270.48 MPa, 411.49 MPa, and 19.81%, respectively. These higher values were clarified with a narrow HAZ appeared in all specimens using E7016 electrode. Furthermore, the weld pool area of the welded specimens was also clearly differed between the two electrodes variation. The specimens using E7016 electrode had a wider weld pool compared to the E6013 electrode.

5. References
[1] Jeffus L 2016 Welding: Principles and Applications (Boston: Cengage Learning)
[2] Jasman, Irzal and Pobrian 2018 Effect of Strong Welding Flow on the Violence of Low Carbon Steel Results of SMAW Welding with Electrodes 7018 Teknometanik 1 24–31
[3] Messler Jr. R W 2004 Principles of Welding (Weinheim: Wiley-VCH Verlag GmbH & Co. KGaA)
[4] Arifin A and Hendrianto M 2018 Pengaruh Arus dan Jarak Kampuh Pengelasan Terhadap Distorsi Sambungan Pelat Baja Karbon Rendah dengan Menggunakan SMAW Flywheel J. Tek. Mesin Untirta 4 20–5
[5] Siddiq M, Nurdin, Amalia I and Fathier A 2021 Analisa Pengaruh Kampuh Pengelasan SMAW Pada Penyambungan Baja Karbon Rendah dan Karbon Sedang Terhadap Uji Ketangguhan J. Mesin Sains Terap. 5 31–7
[6] Pathak D, Singh R P, Gaur S and Balu V 2020 Experimental investigation of effects of welding current and electrode angle on tensile strength of shielded metal arc welded low carbon steel plates Materials Today: Proceedings vol 26 (Mathura: Elsevier Ltd.) pp 929–31

[7] Setyowati V A, Widodo E W R and Suheni 2016 Analisa Pengaruh Jenis Elektroda Pengelasan SMAW Terhadap Kekuatan Stainless Steel 304 Seminar Nasional Sains dan Teknologi Terapan IV (Surabaya: LPPM ITATS) pp 179–84

[8] Chiong R, Khandoker N, Islam S and Tchan E 2019 Effect of SMAW parameters on microstructure and mechanical properties of AISI 1018 low carbon steel joints: An experimental approach 11th Curtin University Technology, Science and Engineering (CUTSE) International Conference vol 495 (Serawak: IOP Conference Series) pp 1–9

[9] Wardani I P, Setyowati V A, Suheni S and Samudra I P 2020 the Effect of Welding Current on Aisi 1045 Strength and Corrosion Rate J. Appl. Sci. Manag. Eng. Technol. 1 40–5

[10] Pramono A 2011 Karakteristik Struktur Mikro Hasil Proses Hardening Baja AISI 1045 Media Quenching Untuk Aplikasi Sprochet Rantai Tek. J. Sains dan Teknol. 7 115–24

[11] Sharifitabar M, Halvaea A and Khorsahian S 2011 Microstructure and mechanical properties of resistance upset butt welded 304 austenitic stainless steel joints Mater. Des. 32 3854–64

[12] Gowthaman P S, Muthukumaran P, Gowthaman J and Arun C 2017 Review on Mechanical Characteristics of 304 Stainless Steel using SMAW Welding MASK Int. J. Sci. Technol. 2 33–7

[13] Widodo E, Iswanto I, Nugraha M A and Karyanik K 2018 Electric current effect on mechanical properties of SMAW-3G on the stainless steel AISI 304 The 3rd Annual Applied Science and Engineering Conference vol 197 (Bandung: MATEC Web of Conferences) pp 1–4

[14] Setyowati V A and Suheni S 2016 Variasi Arus Dan Sudut Pengelasan Pada Material Austenitic Stainless Steel 304 Terhadap Kekuatan Tarik Dan Strukturmakro J. IPTEK 29

[15] James J A and Sudhish R 2016 Study on Effect of Interlayer in Friction Welding for Dissimilar Steels: SS 304 and AISI 1040 1st Global Colloquium on Recent Advancements and Effectual Researches in Engineering, Science and Technology vol 25 (Palai: Procedia Technology) pp 1191–8

[16] Kobe Steel Ltd. 2017 Kobelco Welding Handbook (Kobe: KOBE STEEL, LTD., Welding Business Marketing Department)

[17] Singh B K, Jha A K and Singh P K 2015 Effects of Joint Geometries on Welding of Mild Steel By Shielded Metal Arc Welding (Smaw) Int. Res. J. Eng. Technol. 02 95–100

[18] Kuncoro A T 2017 PENGARUH VARIASI ARUS DAN JENIS KAMPUH PENGELASAN SMAW TERHADAP KEKUATAN TARIK SAMBUNGAN BAJA ST 41 Simki-Techsain 4 2–8

[19] Arham Y 2016 Pengaruh Jenis kampuh V dan X Terhadap Struktur Mikro dan Kekuatan Impak Pada Pengelasan Baja Karbon ENTHALPY - J. Ilm. Mhs. Tek. Mesin 2 8–12

[20] Wahyudi R, Nurdin N and Saifuddin S 2019 Analisa Pengaruh Jenis Elektroda Pada Pengelasan SMAW Penyambungan Baja Karbon Rendah Dengan Baja Karbon Sedang Terhadap TYensile Strenght J. Weld. Technol. 1 43–7

[21] Arifin J, Purwanto H and Syafa’at I 2017 Pengaruh Jenis Elektroda Terhadap Sifat Mekanik Hasil Pengelasan Momentum 13 27–31

[22] Pahlawan I A, Arifin A A, Marliana E and Irawan H 2021 Effect of welding electrode variation on dissimilar metal weld of 316l stainless steel and steel ST41 IOP Conference Series: Materials Science and Engineering vol 1010 pp 1–8