Applied Research and Smart Technology (ARSTech)

Research Article

The effects of heat input and electrode type on the mechanical properties of welded A309 stainless steel using a shielded metal arc welding

Kingsley Onyekachi Anyanwu[1,*], Harrison Ogochukwu Nzei[2], Chukwudike Onuoha[1], Victor Ikechukwu Ehirim[3]

[1]Department of Materials and Metallurgical Engineering, School of Engineering and Engineering Technology, Federal University of Technology Owerri, 460114 Owerri, Imo State Nigeria.

[2]Department of Civil Engineering, School of Engineering and Engineering Technology, Federal University of Technology Owerri, 460114 Owerri, Imo State Nigeria.

[3]Department of Mechanical Engineering, Imo State Polytechnic Omuma,1472 Owerri, Imo State Nigeria.

*Corresponding author: kings.onyekaa2016@gmail.com

ARTICLE INFO

ABSTRACT

This study deals with an experimental study to evaluate the influence of heat and electrode type on the mechanical properties of welded A309 stainless steel using shielded metal arc welding (SMAW). Samples were prepared with a welding angle of 45 deg. Seventy-eight samples made of A309 stainless steel were used in the experiments, in which half of the pieces were welded using A309 electrodes and half with E7018 electrodes. The samples were subjected to a tensile test and Charpy test accordingly. Several parameters, such as welding current (I), heat input (H), the final length of the tensile specimen (Lf), elongation percentage (%E), yield strength (σy), and impact energy, were observed. The results show that the increase in current from 100 to 225 A causes the growth of heat input from 0.56 to 1.26 kJ/mm, impacting the decrease of the percentage elongation and yield strength, including the energy impact reduction. On the other hand, all mechanical properties tested have relatively low heat input at 0.56 kJ/mm and relatively high heat input at 0.7 kJ/mm.

1. INTRODUCTION

Welding technology has evolved over decades, and its application broadens with technological advancement [1-2]. It is used in various engineering aspects, including automotive, aerospace, construction, and military [3]. Due to the vast welding application, there is a rising need for high-quality welding. In all welding jobs, high-quality welding, safety, economy, and proper time management are often placed as a priority [4-5]. However, welding quality is always a critical factor as it becomes a reason behind many failures and accidents.

The consequences of weld failure have been emphatically explained by Thomas [6]. A railway accident that took 22 lives and got 150 injured was reported by Akleker [7]. According to the investigation report, a 50105 Diva-Sawantwadi passenger train derailed due to a weld fracture on the rail. A picture taken at the accident scene is given in Figure 1. Furthermore, a weld failure accident was also reported, in which a barge broke away from its mooring and severely damaged a pier [8]. The weld on the shackle that connected the barge to the mooring chain failed, allowing it to drift. Additionally, Carey [9] reported the catastrophic failure of the San Bruno pipe. Based on the investigation report, the exploded pipe was most likely a result of weld failure. Yet another case is the failure of the North Sea Platform reported by France [10]. In this case, the investigation report points to a defective weld bead as the cause of the accident. Looking at the drawbacks associated with weld failure, the need for proficiency in welding is quite obvious. Characteristics of high weld quality include good mechanical properties, good corrosion performance, structural stability, and good surface finishing. In order to make a high-quality weld, the possible causes of defects should be appropriately identified and controlled.

There are many types of welding processes. One of them is called Shielded Metal Arc Welding (SMAW) [1]. In the SMAW process, heat from an electric arc is maintained between the tip of a consumable electrode and the surface of the base material in the joint being welded, resulting in the coalescence of metals [6]. SMAW is typically used to weld stainless steel, carbon steel, alloy steel, and cast steel [11]. Compared to other welding processes, SMAW apparatus is inexpensive and uncomplicated, making it easier to use outside than other processes that require shielding gas and are ineffective in the wind. There is more mobility for the welder. More crucially, altering merely the electrode materials can weld a wide range of metals. Hence, SMAW became the most widely utilised arc welding technology. However, SMAW's arc time factor is rather low because it takes time to chip away slag after welding and changing the electrodes [6].

The common causes of failures in SMAW processes have been summarised in Table 1 [12]. These causes can be mitigated by properly selecting consumables (electrodes) and controlling weld parameters (heat input). The engineering performance of weldment greatly depends on its mechanical properties, thus; it is necessary to investigate factors that influence the mechanical properties of weldment, such as compatibility between base metal/s and the consumables, type of welding process, heat input to the workpiece, welder skills, and others.

Several researchers have investigated the influence of process parameters on the mechanical properties of weldment and have come up with significant results. Owolabi et al. [13] is a typical example. He evaluated the effect of welding current on the mechanical properties of weld joints between mild steel and low-carbon steel. The study results show a decrease in yield and impact strength concerning an increase in welding current. In addition, the ultimate tensile strength decreases with an increase in welding current but increases at a welding current of 200A for both mild and low-carbon steel. Wardoye et al. [14] investigated the mechanical properties of SMAW low-carbon steel, considering the butt joint effect and uncapping of the excess weldment. From the results obtained, all tested samples show similar tensile strength, indicating that butt joint type and uncapping of excess weld have no significant effect on the mechanical properties. The hardness of the weld metal was slightly higher than that of heat affected zone and base metal, which both showed close hardness values.

Figure 1. Picture taken at the accident scene of the Diva-Sawantwadi train [7].

Table 1. Failures in SMAW: Types, Causes, and Effects [12].

Quality Issue	Description of the issue	Causes	Effects
Weld Spatter	During welding, tiny molten metal droplets are released and may land on nearby surfaces.	1. Excessively high current; 2. Long arc length (causing farther distance of the molten metal droplets must travel before they can reach the weld pool); and 3. Arc blow (Magnetic forces cause the electric arc to be redirected away from the targeted weld pool, causing the arc to travel erratically and creating splatter)	Weld spatter doesn't directly impact the weld's structural integrity. / Has a considerable impact on the finished weld's appearance and general quality. / Increasing cleaning costs
Porosity	The welded metal may have tiny gas pockets or voids that endanger the integrity of its construction	1. Joint contamination (During welding, contaminants on the joint surfaces, such as dust, oil, rust, or moisture, may evaporate and cause porosity); 2. High welding speed (The molten metal may not have enough time to fully solidify when welding too fast, trapping gases inside the weld), 3. Long arc, 4. Arc blow	Voids cause stress concentration locations and decrease the weld's effective cross-sectional area, which can damage the weld joint. / Reduce the weld's mechanical qualities, such as its strength, ductility, and resistance to corrosion and fatigue
Poor Fusion	A weld connection with insufficient bonding between the base metal and filler metal	1. Improper welding parameters, such as heat input, electrode angle, and arc length; 2. Inadequate cleaning of joint surface before welding, 3. Poor fit-up Reduced load-bearing capacity makes the joint more susceptible to breaking under applied loads	Causing leaks, allowing dangerous substances to enter, or jeopardising the structural stability of the welded component
Shallow Penetration	The weld pool doesn't reach into the joint	1. Improper welding parameters, 2. Inadequate heat input, 3. Poor joint design	Decreased Mechanical Strength (A smaller fusion zone as a result of shallow penetration lowers the weld joint's mechanical strength, making the joint less capable of withstanding applied loads, which could lead to structural problems) / Reduced Fatigue Resistance (A weld is more prone to fatigue fracture development and propagation when there is insufficient penetration because this causes stress concentrations at the joint edges) / Lack of Fusion Defects: The filler metal does not fuse with the base metal or neighbouring weld passes / Increased Susceptibility to Corrosion: Shallow penetration can create cracks and holes in the weld joint, which makes it more vulnerable to corrosion
Cracking	Cracks formation in the weld	1. High residual stresses, 2. Improper cooling, 3. Inadequate electrode selection Weakened	Strength: Cracks serve as stress concentrators, which lowers the welded joint's ability to support loads. / Increased Vulnerability to Corrosion: Cracks create passageways through the weld that allow moisture, fumes, and corrosive materials to access the base metal, accelerating the corrosion process. / Structural Failure: Cracks can spread and eventually cause catastrophic structural failure if they are not found and fixed.

Also, Bodude and Momohjimoh [15] studied the effect of welding parameters on the mechanical properties of welded low-carbon steel, in which Oxy-Acetylene Welding (OAW) and Shielded Metal Arc Welding (SMAW) were used for 10mm thick low-carbon steel. From the result obtained, the tensile strength and hardness reduce as heat input increases. However, the weldment's impact energy increases with the heat input. Similar research was conducted by Ibrahim et al. [16], in which the effect of the Gas Metal Arc Welding (GMAW) technique on the mechanical properties of Duplex Stainless Steel was studied. The samples were subjected to post-welding treatment (quenching in engine and neem oil). The results show that welding and heat treatment influences the mechanical properties of the alloy. Moreover, Using the SMAW process, Asibeluo and Emifoniye [17] studied the effect of arc welding current on the mechanical properties of A36 carbon steel weld joints. From the results obtained, increasing the current could raise the temperature of the weld joint.

Based on the previous works mentioned above, it can be concluded that heat and electrode properties can affect the mechanical properties of the welded material. Hence, this study investigates the effects of heat and electrode type on the mechanical properties of A309 stainless steel alloy subjected to the SMAW process. The material is subjected to a welding angle equal to 45°. Two types of electrodes, namely A309 electrodes and E7018 electrodes, are used in this study. The electricity current input is varied to study the effect of heat input. After welding, the welded specimens are tested using tensile and Charpy tests to analyse the mechanical properties of the welded materials.

2. MATERIAL AND METHOD

2.1. Materials

In this study, A390 stainless steel material is used. It is an austenitic chromium-nickel stainless steel alloy frequently utilised for higher-temperature applications. This alloy is highly corrosion resistant, has remarkable resistance to oxidation, and excellent heat resistance while offering good strength at both low and high temperatures,

thanks to its high chromium and nickel content [18]. It is used in aerospace, pipelines, boilers, medical equipment, domestic wares, etc. Samples were prepared with a welding angle of 45 deg. Seventy-eight samples made of A309 stainless steel were used in the experiments, in which half of the pieces were welded using A309 electrodes and half with E7018 electrodes.

2.2 Methods

Welding

The joint surface of each tested specimen was fluxed with borax. The sample was then welded using the Back-Hand Technique, maintaining position PA according to EN 26947 specification. The weld length of each sample was 100 mm, and an average travel speed of 4 mm/s was maintained. A constant arc voltage of 28V was maintained using A309 and E7018 electrodes without filler metals. There was neither pre-weld nor post-weld heat treatment.

Tensile test

In this test, each prepared sample was mounted on the machine. The machine was driven by electrical power, and the specimen continued to elongate as the applied tensile stress increased until the specimen fractured. The stress-strain curve of the tested specimen was displayed on the computer's monitor incorporated into the test machine. From the stress-strain curve, 0.20% proof stress was deduced. The length of each sample at fracture was measured using Mitutoyo 500-196-30 digital callipers and was recorded.

Charpy test

In this test, each sample was mounted correctly on the machine, and the sample was subjected to cyclic impact loading until the specimen broke. The impact energy was displayed on the monitor of a computer connected to the machine. Figures 2A-2C show the surface morphology of a prepared sample, a sample welded with an A309 electrode (after the test) and a sample welded with an E7018 electrode (after the test) tests, respectively. The shape and dimensions of the tested samples are given in Figure 3.
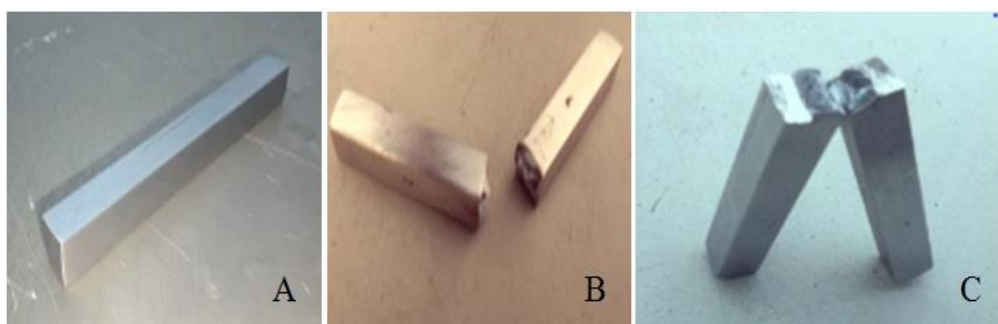

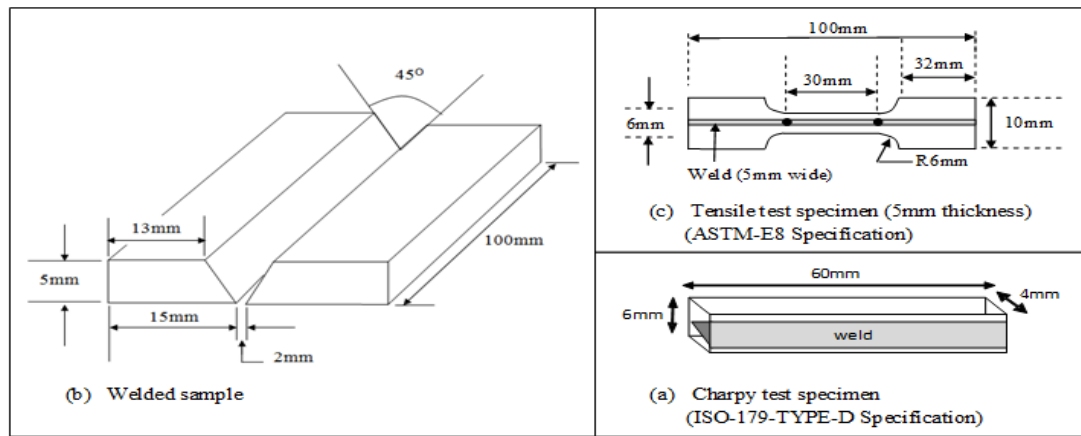Figure 2. Surface morphology of some Charpy test samples.

Figure 3. Schematic diagram shapes and dimensions of tested samples.

2.3 Calculations

In this study, the material's mechanical properties were characterised by tensile strength, yield strength, hardness, ductility, and toughness.

Tensile stress

Tensile stress is the ability of a material to withstand a tensile load. Tensile strength may be subdivided into ultimate tensile and yield strength, as often considered in engineering. According to Faridmehr et al. [19]. Nominal and true tensile stresses are given by Equations (1) and (2).

$$\sigma_E = \frac{P}{A_O} \tag{1}$$

$$\sigma_T = \frac{P}{A} \tag{2}$$

where σ_E and σ_T are engineering stress and true stress, respectively. A_O is the original cross-sectional area of material, A is the instantaneous cross-sectional area, P is the applied tensile force.

Ultimate Tensile strength

It is the maximum stress a material can withstand under the influence of applied tensile load before failure [20-21]. The engineering performance of a material depends on its ultimate tensile strength. However, ultimate tensile strength is not often considered in engineering design; instead, yield strength is considered more often. It is so because plastic deformation starts at the yield point, and at this point, the material loses its integrity in engineering service.

Yield Stress

This limits applied tensile stress beyond which a material starts deforming plastically [20]. Looking at stress-strain curves, most metals like steel do not have specific points as yield strength. Thus, 0.20% proof stress is usually taken as yield strength. Details of the

determination of 0.2% proof strength have been given by Faridmehr et al. [19].

Ductility

This measures the total tensile strain a material can undergo under applied strain's influence before fracture. Ductility is usually expressed as percentage elongation or percentage reduction, as given by Equations (3)-(6) [19].

$$\%E = \frac{\Delta l}{l_o} \times 100\% \tag{3}$$

$$\%E = ln\frac{l}{l_0} \times 100\% \tag{4}$$

$$\%R = \frac{\Delta A}{A_0} \times 100\% \tag{5}$$

$$\%R = ln\frac{A_0}{A} \times 100\% \tag{6}$$

where $\%E$ is percentage elongation, Δl is the change in length, l_0 original length (or gauge length), l is final length, $\%R$ is percentage reduction, ΔA is the change in cross-sectional area, A_0 is the original cross-sectional area, A is the instantaneous area, and ln denotes the natural logarithm.

Toughness

This is the measure of impact energy per unit volume a material can absorb before it fractures. It is also defined as the ability of a material to absorb energy and deform plastically without fracturing [22-23]. Toughness is defined as the total area under the stress-strain curve of a material, given by Equation (7) [24]. The area under the linear portion of the stress-strain curve is referred to as the modulus of resilience, provided by Equation (8), according to Campbell [25]. Toughness can be determined by subjecting a material to the Charpy or Izod tests [26- 27].

$$\frac{energy}{volume} = \int_0^{\varepsilon_f} \sigma d\varepsilon \tag{7}$$

$$U_r = \frac{\sigma_y^2}{2E} = \frac{\sigma_y \varepsilon_y}{2} \tag{8}$$

where U_r Modulus of resilience is, ε is tensile strain, ε_y is the strain at the yield point, ε_f is the strain at fracture, σ is tensile stress, σ_y is yield strength, and E Young's modulus.

Travel speed

The travel speed equation given by Baghdadi et al. [28] was used in this paper and calculated as shown in Equation (9).

$$S = \frac{L_w}{t} \qquad (9)$$

where S is travel speed (mm/s), L_w is weld length (mm), t is the time to take weld (s).

Percentage elongation

Faridmehr et al. [19] gave the formula for percentage elongation (Equation (10)) used in this study.

$$\%E = ln\left(\frac{L_f}{L_g}\right) \times 100\% \qquad (10)$$

where $\%E$ is percentage elongation, L_f is the length of the test specimen upon fracture (mm), L_g is the gauge length (mm).

Arc energy

According to Arya and Sing [29], arc energy may be calculated using Equation (11).

$$Q = \frac{IV}{s} \qquad (11)$$

where Q is arc energy (kJ/mm), I is welding current (A), and V is the arc voltage (V).

Heat input

The Welding Institute [30] gave an equation as shown in Equation (12), used in the study, for calculating heat input from arc energy.

$$H = kQ \qquad (12)$$

where H is the heat input (kJ/mm), and k is the process efficiency factor. For the SMAW process, $k = 0.8$ [30]. Thus, this study used the stated value of k for calculating heat input.

3. RESULTS AND DISCUSSION

The experimental results in Tables 2 and 3 show the welding current, heat input, final length of tensile test specimens, percentage elongation, yield strength, and impact energy. Each table gives the mechanical properties of the tested samples. The tables also show the variation of

the mechanical properties with heat input. The base metal has a final length of 46.56 mm, a percentage elongation of 44%, a yield strength of 308 MPa, and an impact energy of 400 J.

Table 2. Mechanical Properties of samples welded with A309 electrode (as welded)

Mechanical properties of welded samples (A309 electrode)					
I (A)	H (kJ/mm)	L_f (mm)	$\%E$	σ_y (MPa)	IE (J)
100	0.56	40.08	29	231	277
125	0.70	43.86	38	286	365
150	0.84	41.70	33	273	345
175	0.98	40.50	30	250	253
200	1.12	39.69	28	205	200
225	1.26	38.52	25	185	180

Table 3. Mechanical Properties of samples welded with E7018 electrode (as welded)

| Mechanical properties of welded samples (E7018 electrode)					
I (A)	H (kJ/mm)	L_f (mm)	$\%E$	σ_y (MPa)	IE (J)
100	0.56	37.74	23	187	192
125	0.70	39.30	27	245	243
150	0.84	38.16	24	233	211
175	0.98	37.74	23	183	190
200	1.12	37.38	22	164	158
225	1.26	36.66	20	155	155

Figures 4 to 6 compare the percentage elongation, yield strength, and impact of energy between base metal, welded metal with A309 electrode, and welded metal with E7018 electrode, respectively. As shown in these figures, the yield strength values, percentage elongation, and impact energy of both the welded samples are relatively lower than the base metal at all heat inputs, showing that the SMAW process in this study reduces the quality of the materials overall. This may have resulted from an incomplete weld bead and weak penetration due to insufficient energy to melt the workpiece and electrode.
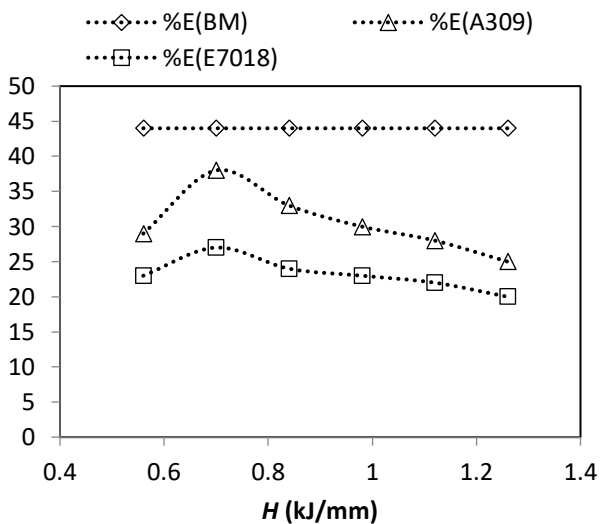
Keterangan

%*E*(BM)   Percentage elongation of base metal
%*E*(A309)   Percentage elongation of samples
                welded with A309 electrode
%*E*(E7018)   Percentage elongation of specimens
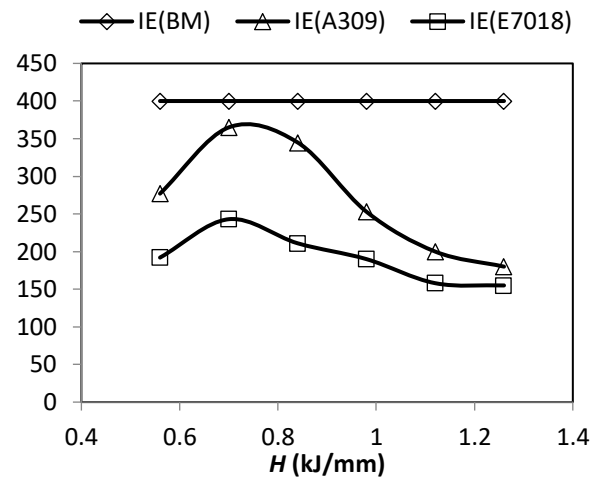   welded with E7018 electrode

Figure 4. Comparison of the percentage elongation between base metal, welded metal with A309 electrode, and welded metal with E7018 electrode.
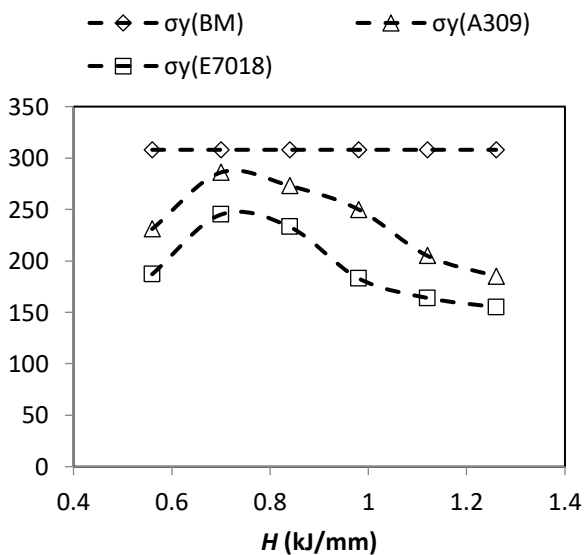
Keterangan

σ*γ*(BM)   Yield strength of base metal
σ*γ*(A309)   Yield strength of samples welded with
                A309 electrode
σ*γ*(E7018)   Yield strength of samples welded with
                E7018 electrode

Figure 5. Comparison of the yield strength between base metal, welded metal with A309 electrode, and welded metal with E7018 electrode.

Keterangan

IE(BM)   Impact of energy of base metal
IE(A309)   Impact of energy of samples welded
                with A309 electrode
IE(E7018)   Impact of energy of samples welded
                with E7018 electrode

Figure 6. Comparison of the impact of energy between base metal, welded metal with A309 electrode, and welded metal with E7018 electrode.

It also can be seen that a dramatic rise in all three tested parameters was shown at a heat input of 0.7 kJ/mm, almost reaching these parameter values of the base metal. This result suggests that a heat input equal to 0.7 kJ/mm is the optimum heat input required for SMAW welding of A309 stainless steel. However, all the parameters tested for continued falling at heat input above 0.7 kJ/mm. This shows that the increased heat input (above 0.7 kJ/mm) decreased yield strength, percentage elongation and impact strength of welded A309 stainless steel. This result is similar to that given by Wardoye et al. [13], Bodude and Momohjimoh [14] and Ibrahim et al. [15]. The slight differences in the results might have come from differences in compositions of tested metal, test procedure and facilities used for the tests. Noting that, as the material properties of the welded materials are relatively lower than base metals, a future investigation between heat input 0.7 kJ/mm and 0.84 kJ/mm is needed to see if there is still increment of the tested parameters, which can be equal or higher than the base metal value.

Figures 4-6 also indicate that the percentage elongation, yield strength, and impact of energy of the welded metal using the A309 electrode is higher than those of welded metal using the E7018 electrode. These results show that the A309 electrode is more suitable for stainless steel joining than the E7018 electrode. This is probably due to the carbon in the E7018 electrode that can reduce the material strength of the welded material.

4. CONCLUSION

Mechanical properties of welded A309 stainless steel have been successfully analysed to identify the impact of heat and electrode type during shielded metal arc welding. It can be concluded that the welding reduces the yield strength, ductility, and impact strength of welded A309 stainless steel. Furthermore, welded A309 stainless steel has relatively low yield strength, weak impact strength, and poor ductility when welded heat input is less than 0.56 kJ/mm. The optimum heat input required for SMAW welding of A309 stainless is most likely 0.7 kJ/mm. The results also show that an increase in the welding heat input (above 0.7 kJ/mm) causes a continuous decrease in yield strength, toughness, and ductility. Lastly, A309 electrode is more suitable for SMAW welding of A309 stainless steel.

The findings above indicate that the mechanical properties of weldments strongly depend on the type of electrode used and heat inputs. Nevertheless, the authors recommend more extensive research in which the mechanical properties will be tested on samples welded on both transverse section and longitudinal sections. A further study is also recommended to consider several other electrodes and different welding methods. It will also be interesting to conduct a similar study in which several other properties will be considered.

CONFLICTS OF INTEREST

The authors declare the original work reported in this paper with no financial or personal interest conflict.

ACKNOWLEDGMENT

REFERENCES

[1] A. Weber, "How welding has changed over the years", https://www.assemblymag.com/articles/85013-how-welding-has-changed-over-50-years [Accessed: 12 September 2022].

[2] Y.M. Ahmed, K.S.M. Sahari, M. Ishak, and B.A. Karim, "History of elements and welding processes", *Australian Journal of Basic and Applied Sciences*, vol. 8, no. 13, pp.296–315, 2014. http://www.ajbasweb.com/old/ajbas/2014/August/296-315.pdf

[3] R. Seitz (2022). "Welding Industry Outlook in 2022", https://climbcredit.com/resources/maintenance-repair/welding-industry-outlook-2022/ [Accessed: 13 September 2022]

[4] North American Trade School, "The importance of weld quality assurance after welding college", 2019. https://nats.ca/Home/NewsArticle/the-importance-of-weld-quality-assurance-after-welding-college/#:~:text=If%20you%E2%80%99re%20considering%20a%20welding%20career%2C%20you%E2%80%99ll%20need,turn%2C%20can%20help%20you%20advance%20in%20your%20career. [Accessed: 13 September 2022].

[5] Wilhelmsen Ships Service, "Maritime welding handbook: Welding and related processes for repair and maintenance onboard", Fourteen edition, *Marine Product.* https://www.wilhelmsen.com/globalassets/ships-service/welding/documents/wilhelmsen-ships-service---unitor-welding-handbook.pdf.

[6] D.J. Thomas (2018). "Analysing the failure of welded steel components in construction system", *Journal of Failure and Prevention*, vol. 18, pp.304–314, 2018. https://doi.org/10.1007/s11668-018-0392-x.

[7] R.B. Aklekar, "Welding failure behind spike in rail accident", 2014. https://mumbaimirror.indiatimes.com/mumbai/other/welding-failure-behind-spike-in-rail-accidents/articleshow/34794173.cms [Accessed: 13 September 2022].

[8] Waterways Journal, "NTSB: Weld failure led to berge striking finishing pier", 2020. https://www.waterwaysjournal.net/2020/11/22/ntsb-weld-failure-led-to-barge-striking-fishing-pier/. [Accessed: 9 September 2022]

[9] P. Carey, "Investigators say 'Catastrophic' san bruno pipe failure may have started with bad weld or corrosion", *The Mercury News.* 2010. https://www.mercurynews.com/2010/09/30/investigators-say-catastrophic-san-bruno-pipe-failure-may-have-started-with-bad-welds-or-corrosion/. [Accessed: 9 September 2022]

[10] E.J. France, "The Alexander L. Kielland disaster revisited: A review by an experienced welding engineer of the catastrophic North Sea platform collapse", *Journal of Failure Analysis and Prevention*, vol. 19, pp.875–881, 2019. https://doi.org/10.101007/s11668-00689-4.

[11] H. Liu and Y. Hu, "Welding", in F.G. Caballero, *Encyclopedia of materials: Metals and alloys*, pp. 39–65, 2020. https://doi.org/10.1016/B978-0-12-819726-4.00143-5.

[12] Welding and Welder. "MMA Welding Quality: Understanding common problems", *The Welding Institute*. https://www.weldingandwelder.com/mma-welding-quality-understanding-common-problems/#minimizing-arc-blow-and-its-impact-on-weld-spatter. [Accessed: 9 September 2022].

[13] O. Owolabi, S. Aduloju, C. Metu, C. Chukwunyelu, and E. Okwuego, "Evaluation of the effects of welding current on mechanical properties of welded joints between mild steel and low carbon steel", *American Journal of Metallurgical and Materials Engineering*, vol. 1, no. 1, pp.1–4, 2016. http://www.opensciencenline.com/journal/archive2?journalId=730&paperId=3542

[14] T. Wardoyo, S. Izman, S. Sharif, H. Ardhyananta and, D. Kumiawan, "Mechanical properties of shielded metal arc welded low carbon steel: effect of butt joint type and uncapping of excess weldment", *Advanced Materials Research*, 1125, pp.195–199, 2015. https://doi.org/10.4028/www.scientific.net/AMR.1125.195.

[15] M. Bodude and I. Momohjimoh, "Effect of welding parameters on the mechanical properties of welded low carbon steel", *Journal of Minerals and Materials Characterisation and Engineering*, vol. 3, no. 3, pp.142–153, 2015. https://doi.org/10.4236/jmmce.2015.33017.

[16] T. Ibrahim, D. Yawas, and S. Aku (2013). "Effect of gas metal arc welding on the mechanical properties of duplex stainless steel", *Journal of Minerals and Materials Characterisation and Engineering*, vol. 1, no. 5, pp.222–230. https://doi.org/10.4236/jmmce.2013.15035.

[17] I. Asibeluo and E. Emifoniye, "Effect of arc welding current on the mechanical properties of A36 carbon steel weld joint", *International Journal of Mechanical Engineering*, vol. 2, no. 9, pp.32–40, 2015. https://doi.org/10.14445/23488360/IJME-V2I9P113

[18] A. Oladoye and L. Osoba, "Corrosion behavior of wire arc additive manufactured and wrought 309 stainless steel in acidic solution", *Corrosion Communications*, vol. 8, pp.81–90, 2022. https://doi.org/10.1016/j.corcom.2022.08.001.

[19] I. Faridmehr, M. Osman, A. Adnan, A. Nejad, R. Hodjati, and M. Azimi, "Correlation between engineering stress-strain and true stress-strain curve", *American Journal of Civil Engineering and Architecture*, vol. 2, no. 21, pp.53–59, 2014. https://doi.org/10.12691/ajcea-2-1-6.

[20] P. Chou, J. Tsai, and J. Chou, "Modeling and optimising tensile strength and yield point on a steel bar using an artificial neural network with Taguchi particle swarm optimiser", *IEEE ACCESS*. 4, pp.2169–3536, 2016. https://doi.org/10.1109/ACCESS.2016.2521162.

[21] The Welding Institute, "Mechanical Testing – Tensile Testing Part 1-069", 2022. https://www.twi-global.com/technical-knowledge/job-knowledge/mechanical-testing-tensile-testing-part-1-069. [Accessed: 3 July 2022].

[22] Iowa State University, "Nondestructive Evaluation Engineering", https://www.nde-ed.org/Physics/Materials/Mechanical/Toughness.xhtml. [Accessed: 30 August 2022].

[23] D.R. Askeland, "The Science and Engineering of Materials", First edition. Springer New York NY. 2013. https://doi.org/10.1007/978-1-4899-2895-5.

[24] P. Kosky, R. Balmer, W. Keat, and G. Wise, "Materials Engineering", in P. Kosky, R. Balmer, W. Keat, and G. Wise, *Exploring Engineering*, Third edition, 2013. https://doi.org/10.1016/B978-0-12-415891-7.00011-X.

[25] F.C. Campbell, "Elements of Metallurgy and Engineering Alloy", *ASM International*, 2008. https://doi.org/10.31399/asm.tb.emea.9781627082518

[26] N. Saba, M. Jawaid, and M. Sultan, "An overview of mechanical and physical testing of composite materials", in M. Jawaid, M. Thariq, N. Saba (Ed), *Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites*. Woodhead Publishing, 2019. https://doi.org/10.1016/B978-0-08-102292-4.00001-1.

[27] V. Tvergaard and A. Needleman, "An analysis of thickness effect in the Izod test", *International Journal of Solids and Structures*, vol. 45, no. 14-15, pp.3951–3966, 2008. https://doi.org/10.1016/j.ijsolstr.2008.02.024

[28] A. Baghdadi, N. Selamat, Z. Sajuri and A. Kokabi, "Effect of travel speed on quality and welding efficiency of friction stir welded AZ31B magnesium alloy", *International Journal of Engineering and Technology*, vol. 7, no 3.17, pp.94–99, 2018. http://dx.doi.org/10.14419/ijet.v7i3.17.16629

[29] H. Arya and K. Sing, "Effect of current, voltage, and travel speed on microhardness of saw welded mild steel plate", *National Conference on Advancement in Mechanical Engineering and Energy Environment (AMEEE-2012)*. 2012.

[30] The Welding Institute, "*What is the Difference Between Heat input and Arc energy?*", 2022, https://www.twi-global.com/technical-knowledge/faqs/faq-what-is-the-difference-between-heat-input-and-arc-energy [Accessed: 3 July 2022].