KSME

Springer

Journal of Mechanical Science and Technology 38 (12) 2024

Original Article
DOI 10.1007/s12206-024-1132-7

Keywords:
· Arc welding
· A588K high strength low alloy steel
· E308L filler wire
· Microstructural
· And fracture morphology

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Citation:
K., S., M., K. (2024). A comparative study on the microstructures and mechanical properties of arc welded of HSLA steel. Journal of Mechanical Science and Technology 38 (12) (2024) 6791~6798.
http://doi.org/10.1007/s12206-024-1132-7

Received August 21st, 2023
Revised July 1st, 2024
Accepted August 5th, 2024

† Recommended by Editor
Hae-Jin Choi

A comparative study on the microstructures and mechanical properties of arc welded of HSLA steel

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Abstract This study focuses on the tensile strength properties and microstructural development of A588 Grade K high strength low alloy (HSLA) steel. The research involves welding of 4 mm thick HSLA using E308L filler wire in the MIG welding process. The correlation between microstructure and tensile strength is explored with a welding current ranging from 120-150 A and a welding speed between 2-6 mm/s, rest of the parameters are consider as a constant. Results indicate that, the combination of 130 A and 2 mm/s reveals the better mechanical properties, exhibiting enhanced tensile strength with fewer defects compared to other parameters. Notably, the improved tensile strength at 130 A is 1.07 times higher and at 120 A is 1.05 times higher than that of the friction stir welding (FSW) process. However, there is a noteworthy improvement compared to laser welding, with 1.034 times at 130 A and 1.06 % at 120 A. The microstructure evolution in various zones are studied, no major defects are found, and confirming a transformation of ferrite morphology in the heat affected zone (HAZ), particularly with an increased amount of acicular ferrite in the fusion zone under the 130 A input current. The paper further details the tensile behavior and fracture morphology analysis under the specified experimental conditions.

1. Introduction

High strength low alloy (HSLA) steels was industrialized in response to ongoing research and industrial demand to improve the mechanical properties of low carbon steel [1]. To develop, a specific alloying elements in meager quantity (a process known as microalloying) are mixed with steel [2]. Due to their low carbon and alloy content, these HSLA steels have better tensile strength than low carbon steel without adding any additional weight to the structures [3]. A588 grade K HSLA, in particular, has excellent properties such as high strength, weldability, and ductility, as well as superior low temperature impact strength when compared to high yield strength steels [4]. Many researchers performed with friction stir welding (FSW) process, as a results of green welding, higher productivities with lower emission of harmful gases [5]. But, due to the frictional stirring effect on the base metal, the originality of the microstructure may have altered [6] and also fast cooling rate causes a significant factor which extensively affects the microstructure evolution. There are two major challenges during FSW process, viz., tool wear and plastic deformation [7]. Tool wear: due to chemical affinities or mechanical damage, as well as variations in stress, strain rate, and the tool experiences high temperature deformation and chance to undergo fracture before welding few distance [8] and plastic deformation are two of the most difficult issues encountered during FSW of high melting point alloys [9]. Due to the reason, the MIG welding is proposed in this paper to welding of A588 Grade K high-strength low-alloy steel. The MIG is a promising fusion welding process, widely accepted to joining of similar and dissimilar metals and alloys is already recognized and realized in the many industry applications [10].

In addition, A588 grade K HSLA steel is more durable than carbon steel with the same carbon composition when compared to low carbon steel [11]. It is widely used to manufacturing of pressure vessels, pipe, agricultural machine parts [12]. Due to the disputes in FSW process, E308L filler is used in MIG welding to study the mechanical and fracture behaviors of the A588 grade K.

Due to the advantages over the solid state processes in joining HSLA steel, various fusion processes, such as arc welding, laser welding, and electron beam welding, can be used to join HSLA steel [13]. Since the heat source converts electrical energy into heat energy and uniformly melts the work piece, it is possible to deeply penetrate into the substrate materials, resulting in constrained bead geometry. However, because it is conveniently focused on a smaller working spot than FSW, neither wider bead width nor deeper penetration is possible [14]. The formation of intermetallic compounds (which can reduce strength) and distortion of weldments are negligible during arc welding processes because the welding torch does not physically contact the substrate material, allowing for more flexible welding and easier automation [15].

On the research outcomes from the last few decades, many researchers have investigated the welding of HSLA through the processes of friction stir welding (FSW) and laser beam welding (LBW). In 2017 and 2020, Ramesh et al. [16] studied the microstructural and mechanical behaviours of HSLA by using the Nd: YAG laser beam and FSW welded thin high strength low alloy steel sheets. The observation from the FSW is macroscopic defects increased with an increase in welding speed and the result tells that decreasing trend of grain size with increased welding speed. They studied the tensile strength at different welding speeds, 540 MPa was at 57 mm/min and 407 MPa at 97 mm/min. The joint strength results are inferred that lower joint strength with further increase in welding speed. However, the laser weld indicated that the estimated value of tensile strength is 348 MPa at 70 mm/s and 475 MPa at 120 mm/s and all the joints failed in the base metal away from the fusion zone.

The microstructural impact on toughness of multi-pass submerged arc welded HSLA steel joints was investigated by Lan et al. [1]. The study's findings revealed that as heat input increased, joint strength decreased. The mode of fracture was also studied, and ductile fracture was observed at any heat input condition due to ferrite formation. Parkes et al. [17] also discuss the use of fiber laser welding to join DP980 and HSLA steels in order to understand the significance of fatigue behaviour. According to the results, the tensile strength of the two weld heat inputs was very close. Furthermore, the lower heat input has a shorter fatigue life than the higher heat input due to stress concentration caused by a slight misalignment of the welded joint.

Based on the above research findings from previous studies on HSLA steel jointing [18], it is clear that the effects of process parameters and welding process are significant in determining the HSLA joint and fracture behaviours. Researchers have investigated the HSLA steel through the friction stir welding and laser beam welding processes in recent decades due to the significant benefits. Another attempt has been made to join HSLA steel using the fusing welding process.

The novelty of the paper is to assess the effects of microstructural aspects on the tensile strength of single pass metal inert gas welded HSLA steel joints. The results compress the feasibility of MIG welding of A588 Grade K high-strength low-alloy (HSLA) steel using E308L filler wire and observes the microstructures, tensile properties, and fracture behaviour.

2. Experimental process

2.1 Material and parameters selection

In this study, HSLA (A588 Grade K) steel was chosen as the foundational material due to its widespread application in various industrial sectors, including automotive and agricultural machinery [19]. This particular steel type is known for its commendable attributes such as high ductility, superior strength, excellent weldability, and exceptional low-temperature impact toughness [14]. The samples were meticulously prepared in accordance with standard dimensions, specifically measuring $100 \times 50 \times 4$ mm for welding purposes [20].

The butt joint configuration was executed using the gas metal arc welding process, employing a 2 mm diameter conventional E308L filler wire [21]. To ensure compliance with ASTM specifications, the chemical composition of both the selected A588 Grade K steel and E308L filler wire is detailed in Table 1 and the Fig. 1 express the detailed flow of process.

The experimental trials were conducted: argon gas is used to produce the welding environment space by supplying at a constant flow rate of 15 liters per minute to avoid oxidation, direct current reverse polarity (DCRP) used for the process [22]. As per the literature survey, welding current, and welding speed, are selected as key independent process parameters, whereas wire feed rate (3.9 m/min) was eliminated in this study since it

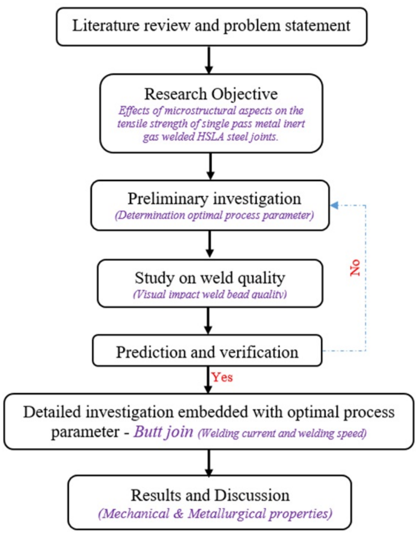

Fig. 1. Experimentation flowchart.