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Influence of FSW and MIG on the mechanical properties of Al-Mg-Mn alloy with minor additions of 0.4% Sc and 0.1% Zr

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Abstract: The present work focuses on the influence of solid-state welding, namely, friction stir welding (FSW) and arc welding, namely, metal inert gas welding (MIG), on the mechanical characteristics of new lightweight 5 mm thick Al-Mg-Mn alloy plates with the addition of 0.4% Sc and 0.1% Zr. The alloys were fabricated using aluminium with 10% magnesium, aluminium with 2% scandium, and aluminium with 5% zirconium master alloys in combination with the Al-Mg-Mn alloy- with the help of a stir casting melting technique. The hardness, tensile strength, 3-point bend strength, impact strength and microstructure of the rolled Al-Mg-Mn alloy plates with the addition of 0.4% Sc and 0.1% Zr were examined. Both the mechanical properties of the FSW and MIG weld joints were compared with those of the non-welded plates. The strength of the non-welded Al-Mg-Mn-Sc-Zr alloy plates was greater, than that of the FSW and MIG weld joints. However, the friction stir welded joints exhibited the improved mechanical properties in comparison with those the MIG welded joints due to more refined precipitation. Compared with the non-welded Al-Mg-Mn-Sc-Zr alloy plates, the friction stir welded joint exhibited a 91.6% joint efficiency and a 63.8% metal inert gas welded joint.

KEYWORDS: Al-Mg-Mn, scandium, zirconium, solid state welding, gas-metal arc welding, mechanical behavior.

1 Introduction

The demand for lightweight metals has grown across various technological sectors. For our current study, we opted for the Al-Mg-Mn alloy, which is known for its lightweight properties, impressive corrosion resistance, high ductility, capacity for work-hardening and excellent weldability [1]. Consequently, these alloys have applications in the automotive, aerospace, and shipbuilding industries [2].

Typically, increasing the magnesium (Mg) concentration to 4.2% enhances the strength of Al-Mg-Mn alloys. Further strengthening is achieved by incorporating alloying elements, such as scandium and zirconium in small quantities. Scandium, which has a density similar to that of aluminum, is an ideal alloying element when combined with zirconium [3]. This combination promotes recrystallization and enhances strength, and surface morphology, due to intermetallics such as $Al_3Sc_xZr_x$, $Al_6(Fe, Mn)$, Mg_2Si, and Al_3Mg_2 [4, 5].

Therefore, the aim of this article is to examine the influence of friction stir welding and gas metal arc welding processes on the mechanical and microstructural characteristics of Al-Mg-Mn alloy plates with the addition of 0.4% Sc and 0.1% Zr.

2 Materials and Methods

2.1 Materials

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The research involved examining alloy plates made from a combination of aluminium with 10% magnesium, aluminium with 2% scandium, and aluminium with 5% zirconium master alloys through a stir casting process, resulting in Al-Mg-Mn alloy plates with the addition of 0.4% Sc and 0.1% Zr. The details of the melting and cold rolling processes are outlined in our previous publication [6]. Table 1 and Table 2, show the chemical element composition and mechanical properties of the fabricated alloy.

Table 1. Weight percentages of the main constituent elements of the fabricated alloy [6].

Element	Weight percentage
Magnesium	4.2
Manganese	0.6
Scandium	0.4
Zirconium	0.1
Aluminium	Bal

Table 2. Properties of the fabricated alloy [6].

Mechanical Property	Unit	
Hardness	VHN	139
Tensile strength	MPa	260.4
Yield stress	MPa	208
Elongation	%	7.4
Bend strength	MPa	3480
Impact strength	MPa	2.5

2.2 Experimental methods

Plates with dimension of 120 x 120 x 5 mm were machined with a water jet machine. Subsequently, these fabricated plates were further processed for friction stir welding, with an applied load of 10 kN, a tool rotational speed of 1200 rev/min, and a tool traverse speed of 25 mm/min. H13 tool steel was used for friction stir welding [7, 8].

Metal Inert Gas welding, which employs a continuous solid aluminum wire as the electrode. The process parameters included a current of 117 A, a voltage of 18 V, and the use of argon as the shielding gas [9, 10]. Figure 1 shows the non-welded plate and the plates that underwent welding.

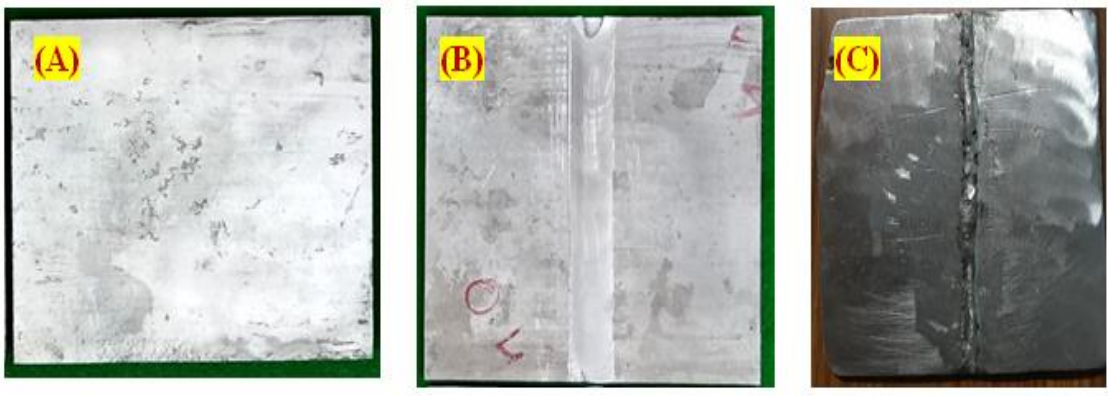


Fig. 1 (A) Al-Mg-Mn alloy plates with the addition of 0.4% Sc and 0.1% Zr, (B) FS welded Al-Mg-Mn alloy plates with the addition of 0.4% Sc and 0.1% Zr, (C) metal inert gas welded Al-Mg-Mn alloy plates with the addition of 0.4% Sc and 0.1% Zr

The alloy specimens were machined from both friction stir welded plates and metal inert gas welded plates. The Vickers hardness (VHN) of the alloy was measured before and after MIG and FSW, using a microhardness tester. The specimen was subjected to a 200gf load-for a 15 second dwell time on the cross-section of the specimen. The tensile strength (UTS) was determined as per ASTM-E8 for specimens with a 50 mm gauge length; using a TUE-C-600 model testing machine. Additionally, a bend test was conducted on the same machine with a 4 t mandrel size, where "t" represents the specimen's thickness, and specimen size (100 long x 10 width x 5 mm^3 thick). Impact tests were conducted on specimens 10 x 5 x 55 mm^3 in size, with notch dimensions of 450 V-notch and 2 mm deep and a root radius of 0.25 mm, using a Krystal Elmec with a range of 168 J. The sample specimens are presented in Figures 2 and 3 respectively [11].

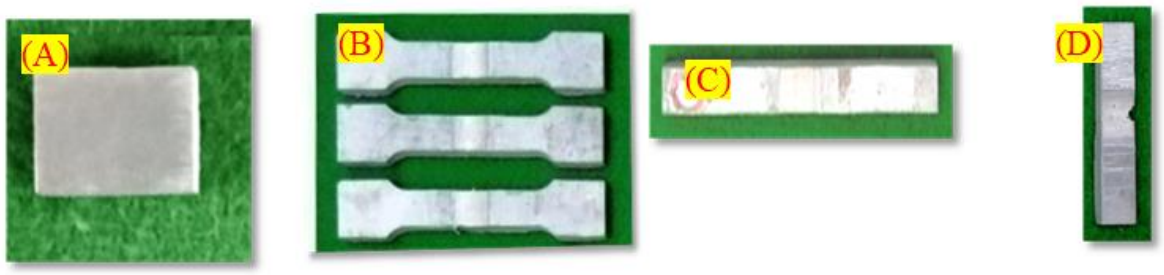


Fig. 2 FS-welded specimens (A) hardness, (B) tensile strength,
(C) bending and (D) impact tests

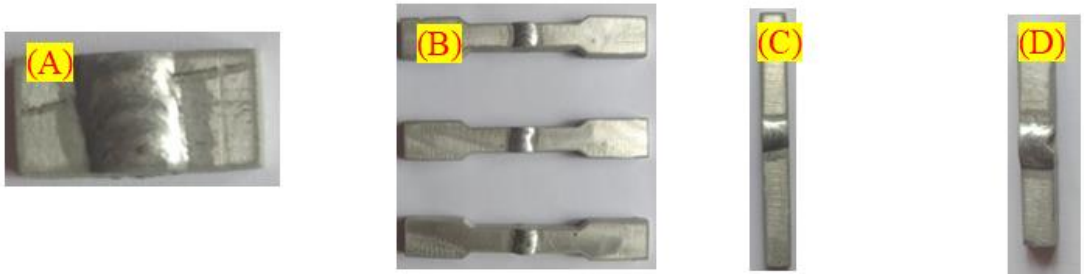


Fig. 3 MIG welded specimens (A) hardness, (B) tensile strength,
(C) bending and (D) impact tests

Metallurgical examinations of both the manufactured plate and the welded plates were performed using an optical microscope. The polished specimens were first cleansed with acetone and then subjected to etching in Keller's reagent solution.

3 Results and discussion

OM images of Al-Mg-Mn alloy plates with 0.4% Sc and 0.1% Zr were obtained at 100X, revealing the occurrence of fragmented intermetallic compounds. This can be attributed to the inclusion of scandium and zirconium in the fabricated alloy, resulting in the creation of spherical particles as illustrated in Figure 4(a). These observations were indicative of a measured hardness of 139 hardness number (VHN) [12].

Figure 4(b) illustrates the Al-Mg-Mn alloy plates with the addition of 0.4% Sc and 0.1% Zr, after undergoing FS welding. Specifically, the new fine grains less than two microns in size were uniformly distributed, starting from the center of the nugget zone. During friction stir welding, the alloy exhibited a hardness of approximately 111 VHN, which accounts for 79.8 % of the hardness of the non-welded alloy. This reduction in hardness is likely attributed

to the presence of small black particles, [13] which constitute the eutectic components of Al_3(Sc, Zr) within the primary aluminum solid solution.

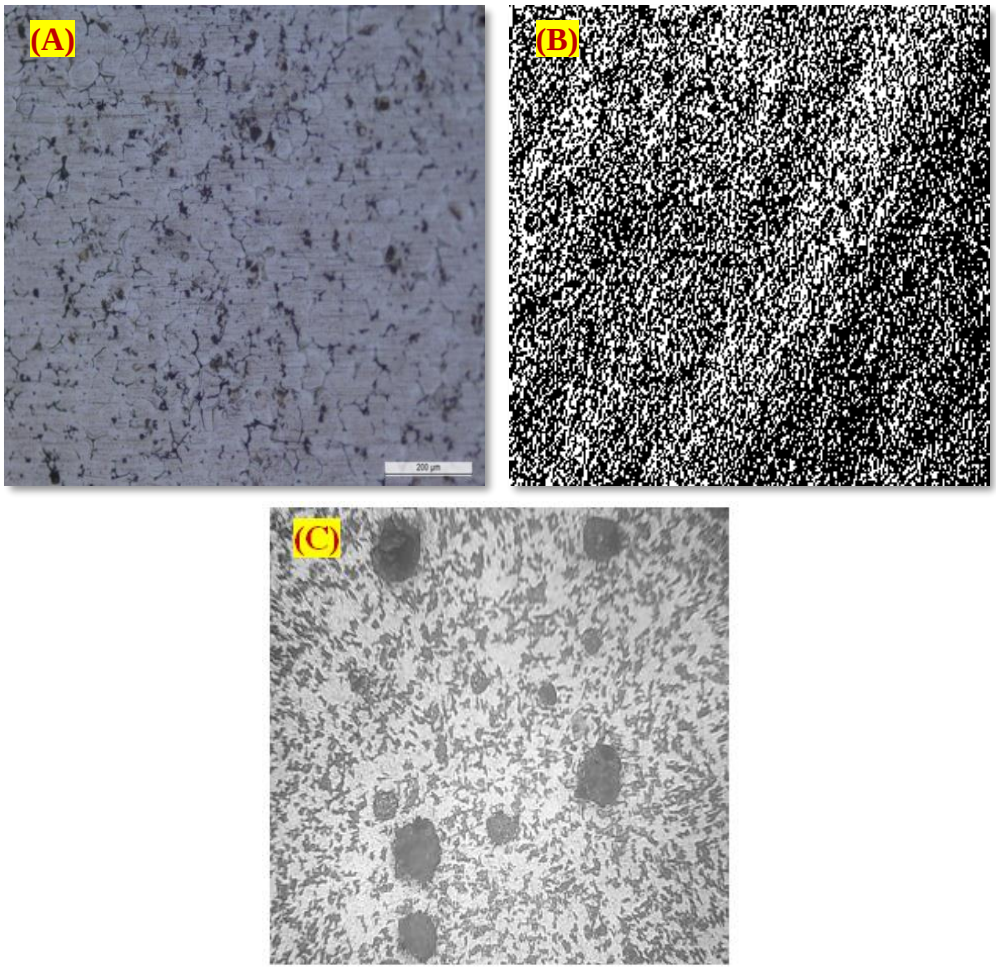


Fig. 4 Optical micrographs of (A) non-welded Al-Mg-Mn alloy plates with the addition of 0.4% Sc and 0.1% Zr, (B) FS welded Al-Mg-Mn alloy plates with the addition of 0.4% Sc and 0.1%Zr, (C) metal inert gas welded Al-Mg-Mn alloy plates with the addition of 0.4% Sc and 0.1% Zr

The microstructure in Figure 4(c) revealed a hardness rating of 87 VHN, representing 62.5% of the hardness revealed by the alloy in its non-welded state. This structure comprises a granular interdendritic network, with intermetallics of Al, Mg, and Mn dispersed within a dendrite composed of an aluminum solid solution [14]

Table 3 presents the properties of the fabricated alloy. Subsequently, the properties of the MIG and FS welded alloy respectively. Following the FSW procedure, the joint exhibited a strength of 238.34 MPa, equivalent to 91.6% of the strength of the unwelded alloy. Conversely, the MIG-welded joint demonstrates a strength of 166.20 MPa, corresponding to 63.82% of the strength of the unwelded alloy, indicating that it is less effective than the FSW process [15, 16, 17].

A comparable pattern was noted in the case of bend strength (BS), indicating that as the overall strength increases, so does the ability to resist bending forces [18]. Notably, the impact strength (IS) of the FS-welded fabricated alloy surpasses that of both the non-welded alloy and the MIG-welded alloy. This superior performance is attributed to greater strengthening,

which is a result of the finer structure of the grains found in the nugget area compared to both the MIG-welded joint seam and the non-welded alloy

Table 3. Mechanical properties of the fabricated alloy

Mechanical Property	Unit	Fabricated alloy	fabricated alloy underwent FS welded	fabricated alloy underwent MIG welded
Hardness	VHN	139	118	87
Tensile strength	MPa	260.4	238.54	166.2
Bend strength	MPa	3480	3325	3264
Impact strength	MPa	2.5	11.25	3.8

CONCLUSIONS

- Metal inert gas welding and friction stir welding were performed successfully on Al-Mg-Mn alloy plates with the addition of 0.4% Sc and 0.1% Zr.
- The fabricated alloy exhibited notable mechanical characteristics, with a hardness of 139 Vicker's hardness number, tensile strength of 260.40 MPa, bend strength of 3480 MPa, impact strength of 2.8 KJ/m², and elongation of 7.4%.
- The mechanical properties of the fabricated alloy that underwent FSW, were a microhardness of 118 VHN, tensile strength of 238.54 MPa, bend strength- of 3325 MPa, impact strength- of 11.25 KJ/m² of and an elongation of 4.9%.
- In contrast, the friction stir weld joints showed improvements in hardness (79.85%), tensile strength (91.6%), impact strength (24.8%), bend strength (95.5%), and elongation (66.2%) compared to those of the nonwelded alloy.
- The hardness (87 Vicker's hardness), tensile strength (166.20 MPa), impact strength (3.8 KJ/m²), bend strength (3264 MPa), and elongation 4.8% of the MIG weld joint of the fabricated alloy were also measured. Compared with those of the nonwelded alloy, the hardness (62.5%), tensile strength (63.8%), bend strength (93.7%), impact strength (135.7%), and elongation (64.86%) of the MIG weld joint improved.
- The friction stir weld joint exhibited significant grain refinement and precipitate formation, suggesting positive microstructural changes compared to those of the MIG weld and the nonwelded alloy.

REFERENCES

[1] Lloyd, D.J "The deformation of commercial Aluminum-Magnesium Alloys", Metall. Mater. Trans. A 11, pp. 1287 – 1294, **1980**.

[2] Polmear, I. J. "Light Alloys: From Traditional Alloys to Nanocrystals" (4th ed.), Butterworth-Heinemann/Elsevier, UK, **2006**.

[3] Mandal, N. R. "Aluminum Welding" (2nd edition), Narosa Publishing Home Pvt. Ltd, Delhi, **2005**.

[4] Belov, I. A., Alabin, A. I. "Advanced Aluminum Alloys with Zirconium and Scandium", Tsvetn. Met. 2, pp. 99 – 106, **2007**.

[5] Norman, A. F., Hyde, K., Costello, F., Thompson, S., Birley, S., Prangnell, P. B. "Examination of the effect of Sc on 2000 and 7000 series aluminium alloy castings: for improvements in fusion welding", Materials Science and Engineering: A 354 (1–2), pp. 188 – 198, **2003**.

[6] Mallipudi, S., Nallu, R. “Optimization of Process Parameters for FSW of Al-Mg-Mn-Sc-Zr Alloy Using CCD And RSM”, Strojnícky časopis – Journal of Mechanical Engineering 68 (3), pp. 195 – 224, **2018**. DOI: 10.2478/scjme-2018-0035

[7] Cavaliere, P. “Friction stir welding of Al alloys: analysis of processing parameters affecting mechanical behavior”, Procedia CIRP 11, pp. 139 – 144, **2013**.

[8] Taraka, H., Pardeep, P., Pankaj, B., Anilkumar, D., Indira, B., Aadarsh, K.. "Friction Stir Welding Tool Life Assessment Through Fatigue Analysis" Strojnícky časopis - Journal of Mechanical Engineering 73 (2), pp. 163 – 180, **2023**. DOI: 10.2478/scjme-2023-0031

[9] Kim, G. G., Kim, D.Y., Hwang, I., Kim, D., Kim, Y.M., Park, J. “Mechanical Properties of Aluminum 5083 Alloy GMA Welds with Different Magnesium and Manganese Content of Filler Wires”, Applied Sciences 11(24), 11655, **2021**.

[10] Sejč, P., Bučány, M., Zifčák, P. "Properties of FSW and MIG Welded Joints of AlSiMg Aluminium Alloy", Strojnícky časopis – Journal of Mechanical Engineering 70 (2), pp. 141 – 152, **2020**. DOI: 10.2478/scjme-2020-0027

[11] Mallipudi, S., Nallu, R. “Effect of Scandium and Zirconium Additions on Mechanical Properties of Al–Mg–Mn Alloy”, Transactions of the Indian Institute of Metals 72, pp. 227 – 238, **2019**. DOI: 10.1007/s12666-018-1476-8

[12] Attallah, M. M., Davis, C. L. “Strangwood, M. Microstructure hardness relationships in friction stir welded AA5251”, Journal of Materials Science 42, pp. 7299 – 7306, **2007**.

[13] Sato, Y. S., Park, S. H. C., Kokawa, H. “Microstructural factors governing hardness in friction-stir welds of solid–solution–hardened Al Alloys”, Metallurgical and Materials Transactions A 32, pp. 3033 – 3042, **2001**.

[14] Ikeshita, S., Strodahs, A., Saghi, Z., Yamada, K., Burdet, P., Hata, S., Ikeda, K.-I., Midgley, P.A., Kaneko, K. “Hardness and microstructural variation of Al-Mg-Mn-Sc-Zr alloy”, Micron 82, pp. 1 – 8, **2016**.

[15] He, Z., Peng, Y., Yin, Z., & Lei, X. “Comparison of FSW and TIG welded joints in Al-Mg-Mn-Sc-Zr alloy plates”, Transactions of the Nonferrous Metals Society of China 21, pp. 1685 – 1691, **2011**.

[16] Mishra, R. S., Ma, Z. Y. “Friction stir welding and processing”, Materials Science and Engineering: R 50, pp. 1 – 78, **2005**.

[17] Liu, Z.W., LI, L.X., YI, J., LI, S.K., Wang, Z.H., Wang, G. “Influence of heat treatment conditions on bending characteristics of 6063 aluminum alloy sheets”, Transactions of Nonferrous Metals Society of China 27, pp. 1498 – 1506, **2017**.

[18] Mallipudi, S., Shankar, T., Srikar, P., Rao, U., Chandrasekhar, Y., Karthikeyan, K. “Effect of TIG and FSW Welding Processes on Mechanical Properties of Al-4.2Mg-0.6Mn-0.4Sc-0.1Zr Alloy”, Strojnícky časopis – Journal of Mechanical Engineering 71 (2), pp. 299 – 304, **2021**. DOI: 10.2478/scjme-2021-0036