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EFFECT OF MOLYBDENUM ADDITION ON ALUMINUM WELDING

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Abstract

Welding aluminum is very important in engineering, particularly in the aircraft and automobile industries. Its recommended properties such as thermal conductivity which is a high value, the coefficient of thermal expansion which also has a high value, hydrogen high solubility, oxide coating e.g., High strength-to-weight ratio, electrical conductivity, and all these properties have a high ratio for aluminum alloys. On the other side, aluminum has some properties that affect its mechanical behavior, for example, surface finish, tear resistance, mechanical strength, and thermal resistance. Therefore, adding rare materials with specific amounts in the casting process before the solidification is a powerful technique used to enhance these characteristics by adding these rare materials that are useful for affecting the welding properties and defects problems. Al-Ti is commercially available with Al-15% Ti. This paper investigates the effect of Molybdenum, Mo, in addition to pure aluminum which is commercially available and refined by Titanium and Boron on its weldability. The obtained results are presented and discussed.

Keywords*:* *welding; mechanical behavior; casting; rare materials; solidification; molybdenum*.

Introduction

Aluminum has a great impact in the industrial field which is one of the most widely used materials in the transportation sector such as in airplanes and automobile factories.

Aluminum's mechanical and physical characteristics, for example, low density, high strength, and good corrosion resistance provide it with strong points to be used in the industrial field [1].

One of the joining procedures for the metals is the welding which uses heat as a source for the adhesion [2]. The common welding processes that are considered the most optimum to weld Aluminum are the GMAW and GTAW(TIG) welding processes which are considered low-cost techniques, easily constructed and resulted well in the mechanical properties [3]. Recognizing and understanding aluminum welding characteristics and the parameters that affect aluminum mechanical and physical characteristics are so important to result in good welding. Minimum defects and fewer cracks are highly recommended for welding and can be improved by taking into consideration avoiding the porosity in aluminum alloys which is the reason for increasing the ability to create cracks in the welding [4].

Welding of aluminum has some critical challenges, for example, high aluminum shrinking during solidification in comparison to steel, and this is due to its thermal expansion which has high value resulting in some problems: high residual stresses in the HAZ zone plus high distortion, so is recommended to be aware that high solidification is responsible for the cracks [5].

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Aluminum in its melting case can solute high hydrogen which this hydrogen can be gained from multi-sources upon welding processes such as contaminants in the base material, water vapor, filler metal, welding equipment, shielding gases, hydrated oxides, and other sources, so all these sources can decrease the efficiency of the welding [6]. Aluminum and most of its alloys solidify with a coarse columnar structure, whereas fine and the equiaxed grain structure is obtained by adding small amounts of these rare materials such as Ti, Ti+B, Mo, and others into the aluminum molten before casting [7]. When Ti is added, its presence in the melt must exceed the peritectic composition of about 0.15% by weight, to obtain a satisfactory enhancement effect on its mechanical properties. However, in the presence of boron, even in ppm order, an important enhancement is obtained at Ti contents as low as 0.005 % [7].

Experience, based on experimental results, has shown that optimum mechanical characteristics properties are achieved using Al-Ti-B master alloys with Ti to B ratio of about 5. [8]. The ternary Al-Ti-B master alloy in common use contains 5% Ti and 1% B, wt. and has two crystalline intermetallic compounds, namely: small crystallites of titanium debride and larger crystals of $TiAl_3$. [7,8]. The ternary Al-0.05%Ti - 0.01%B master alloy is usually about five to six times more efficient than a binary Al-Ti master alloy [7,8].

In this investigation, adding 0.1% Mo to Al-0.05%Ti-0.01%B alloy mechanical properties of cast aluminum components are made between specimens before adding the rare materials (Ti, B, and Mo) and after adding these materials to the aluminum for studying the improvement & enhancement that can be noticed by adding Mo. Tests are conducted for the (Al, Al-0.05%Ti-0.01%B & Al-0.05%Ti-0.01%B-0.1%Mo) alloys casting including. Photographic examinations of the specimens are performed and investigated.

Materials and Methods

Pure aluminum with 99.8% purity was used. Table 1 indicates the chemical composition that was used for this experiment.

Table 1. Commercially pure aluminum chemical composition (Wt.%).

Element	Fe	Si	Cu	Mg	Ti	V	Zn	Mn	Na	Al
Wt.%	0.09	0.05	0.005	0.004	0.004	0.008	0.005	0.001	0.005	Rem

High purity molybdenum of 99.98% purity titanium and aluminum powders of 99 99% purity were used in manufacturing Al -0.15%Ti and Al-3%Mo master alloys which were later used for manufacturing the different micro alloys.

An Electric furnace was used to melt the Aluminum and its alloys, the furnace can reach 1400 C as a maximum Temperature, with a high furnace chamber with five-sided heating for very good temperature uniform -LH Model. Hollow rectangular brass mold was used to prepare the specimens with 5mm inside diameter and 55 mm external diameter, graphite crucible and graphite rods were used for stirring, and for the tensile tests were used universal testing devise-2000 (KN) Universal Testing Machine type EM. LaboPol 30 Grinding/Polishing Machine (50-500 rpm). Digital Microscope, AmScope type, PN ME300TZ-3M 40X-1000X, Welding Machine with argon as inert shielded gas was used for welding the specimens, TIG SBG 220 and the HWBM-3 at 100 gm force were used.

The commercially pure bundles of the Al wires, supplied & tested by the University Politehnica of Bucharest, were immersed in HNO_3 to eliminate the oxide layer and any other contaminant, then it was used in a graphite crucible inside an electric furnace at 800˚C for aluminum melting and then were left to solidify in hollow rectangular brass of 10 mm inside width and 55 mm external width and 3 mm thickness.

Al-3%Mo and Al-0.15%Ti master alloys were produced by adding the specified amount of Mo to the calculated amount of aluminum in the graphite crucible at 850˚C for Al-3%Mo binary master alloy, mixed by the graphite rod for around a minute, and back it to the furnace for 15-20 minutes for two times then were poured to solidify in the thick brass rods. Finally, the specimens prepared were of 3 mm thickness,10 mm width, and 240 mm length. The two prepared master alloys were used for preparing the Al-0.05%Ti-0.01%B and Al-0.05%Ti-0.01%B-0.1%Mo micro alloys.

The tungsten inert gas welding, GTAW, the process of the experimental was used for preparing the single lap joint, The Vickers's microhardness survey was done by taking the average of ten values along the HAZ and away from it (base zones) along the base metal regions, using the digital micro-hardness tester model HWBM-3 at 100 gm force.

Results

Regarding thermal conductivity, aluminum loses heat rapidly, which makes welding harder. It was noticed that it required a small while after establishing the arc for the puddle to add the filler and that because of the heating dissipation at a high rate, the heat transferred away from the welded area very quickly. The time that the part is heated and raised in temperature is the time that we can get that puddle started, after that filler can be added. Also, the Al*Al specimen shows clear signs of lack of fusion even though with supplying hot start conditions on welding equipment, this issue always is available with aluminum welds, which are presented in the type of the weld line, Fig. 1, that the weld line is strictly straight which gives proof that the two welded Al specimens still have lack of fusion.

The specimens are investigated in the HAZ region (Heat Affected Zone) and the base metal zone. The components that are added result in 15 specimens referenced and shown in Table 2.

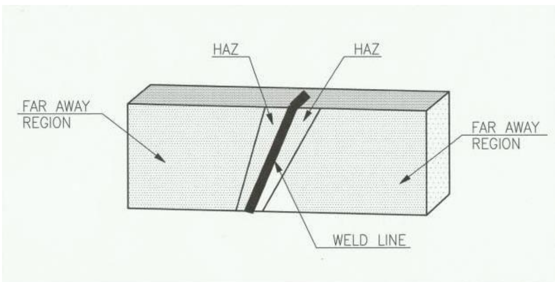


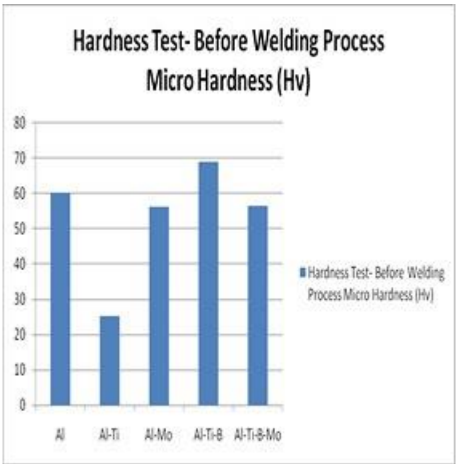
Fig. 1. Specimen observed regions HAZ and the base metal [7].

Table 2. Welded specimen's reference

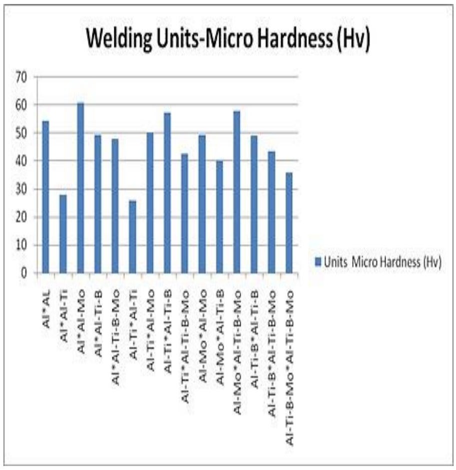
Ref	Welded specimen	Material 1 of the specimen base metal	Material 2 of the specimen base metal
1	Al X Al	Al	Al
2	Al X Al-Ti	Al	Al-Ti
3	Al X Al-Mo	Al	Al-Mo
4	Al X Al-Ti-B	Al	Al-Ti-B
5	Al X Al-Ti-B-Mo	Al	Al-Ti-B-Mo
6	Al-Ti X Al-Ti	Al-Ti	Al-Ti
7	Al-Ti X Al-Mo	Al-Ti	Al-Mo
8	Al-Ti X Al-Ti-B	Al-Ti	Al-Ti-B
9	Al-Ti X Al-Ti-B-Mo	Al-Ti	Al-Ti-B-Mo
10	Al-Mo X Al-Mo	Al-Mo	Al-Mo
11	Al-Mo X Al-Ti-B	Al-Mo	Al-Ti-B
12	Al-Mo X Al-Ti-B-Mo	Al-Mo	Al-Ti-B-Mo
13	Al-Ti-B X Al-Ti-B	Al-Ti-B	Al-Ti-B
14	Al-Ti-B X Al-Ti-B-Mo	Al-Ti-B	Al-Ti-B-Mo
15	Al-Ti-B-Mo X Al-Ti-B-Mo	Al-Ti-B-Mo	Al-Ti-B-Mo

Examination of the hardness

The Vickers's micro hardness test was achieved by an average of ten readings along the HAZ and away from its (base zones) regions, using a digital microhardness, model HWBM-3 at 100 gm force, and was conducted for each part of the welded specimens in the HAZ zone and in the two base metals for the welded specimens which are shown in Fig. 2.



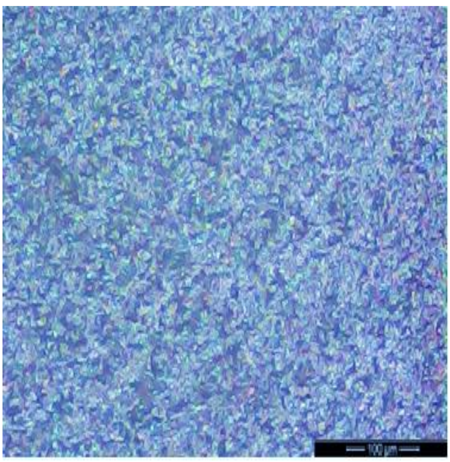
a)



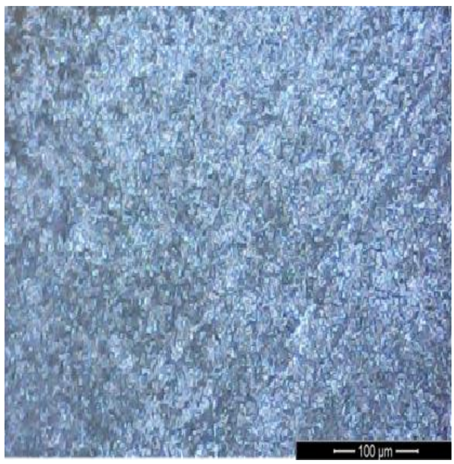
b)

Fig. 2. (a) Effect of Ti, Ti+B, and Ti+B+Mo addition on the Vicker's microhardness before welding; (b) Effect of adding Ti, Ti+B, and Ti+B+Mo to Al on the Vicker's microhardness at the HAZ region.

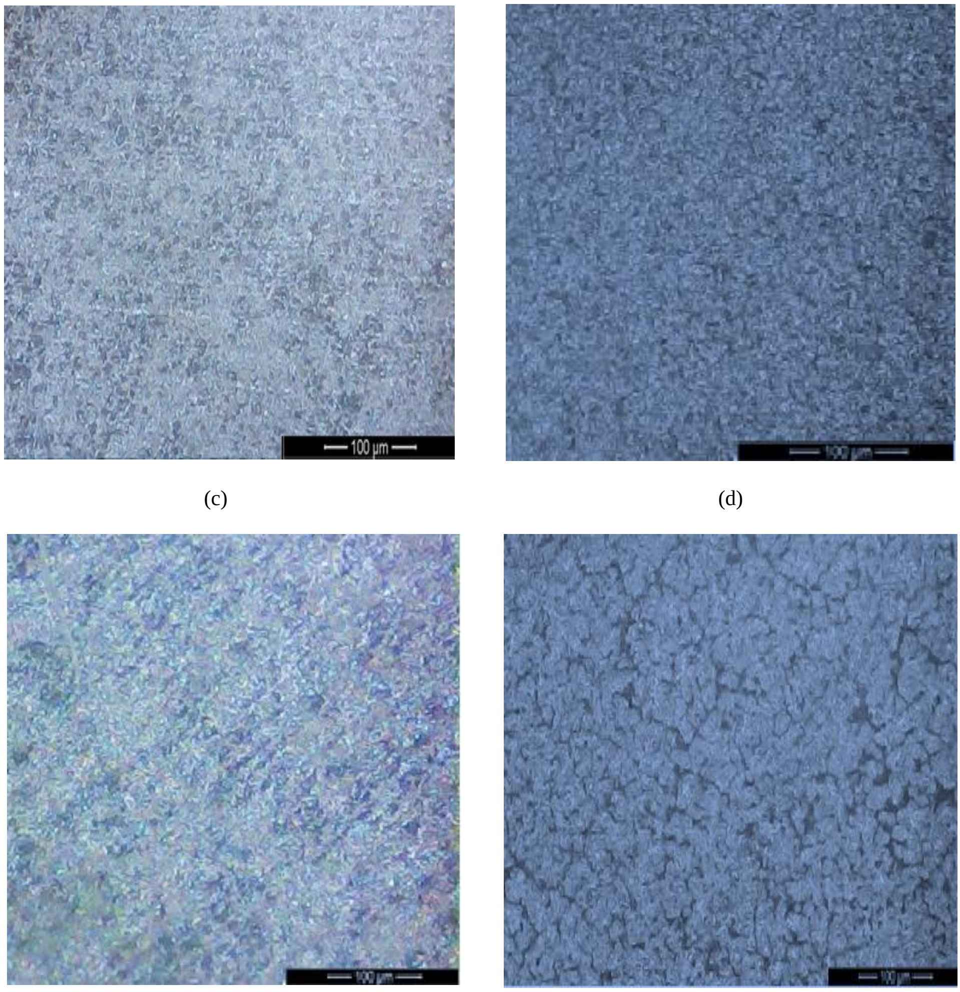
It can be noticed that the hardness values are affected by adding the Ti, B, and Mo which are indicated in Fig. 2, and Fig. 3 presents the microstructure of these alloys.



(a)



(b)



(c) (d)

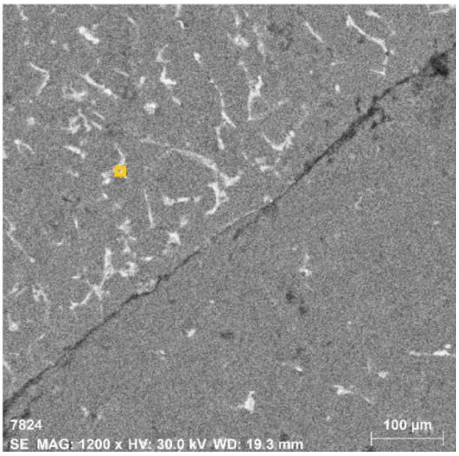
(e) (f)

Fig. 3. (a) Photograph Al-Ti-B-Mo in the base metal Region; (b) Photograph Al-Ti-B in the HAZ region; (c) Photograph Al-Mo in the HAZ region; (d) Photograph Al-Ti-B-Mo in the HAZ Region; (e) Photograph Al-Mo in the base metal Region; (f) Photograph Al in the HAZ Region

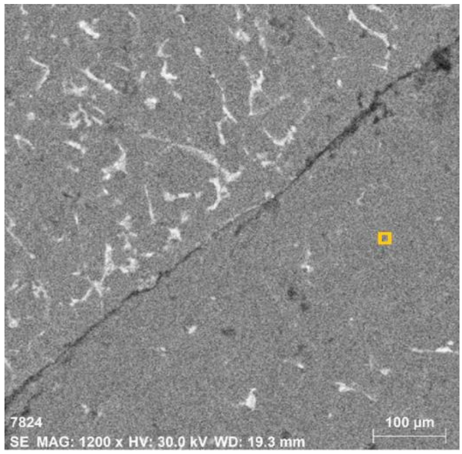
Examination of the welding

In this section, we can test the affection of the enhancement that was gained by adding Molybdenum alone or with some other rare materials such as Ti &B.

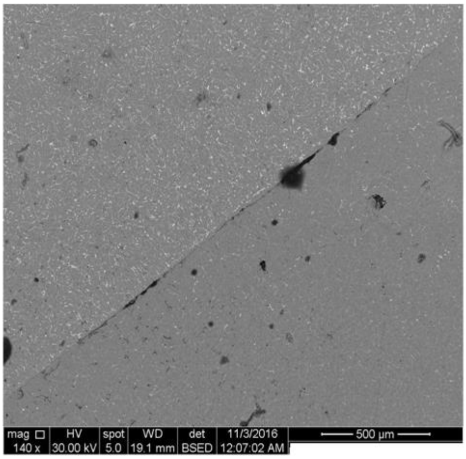
Figure 4 and Fig. 5 are indicating the spectrum analysis for the materials around the welding line which has stream effecting which this affection can be noticed in the welding process.


7824
100 µm
SE MAG: 1200 x HV: 30.0 kV WD: 19.3 mm

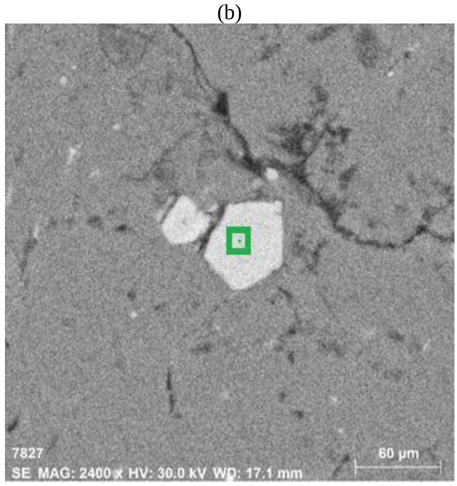
(a)


7824
100 µm
SE MAG: 1200 x HV: 30.0 kV WD: 19.3 mm

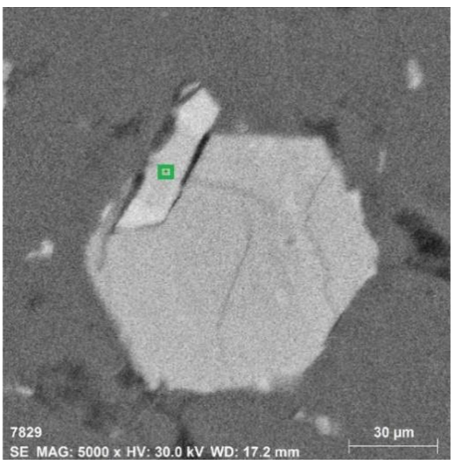
(b)


mag □ 140 x
HV 30.00 kV
spot 5.0
WD 19.1 mm
det BSED
11/3/2016 12:07:02 AM
500 µm

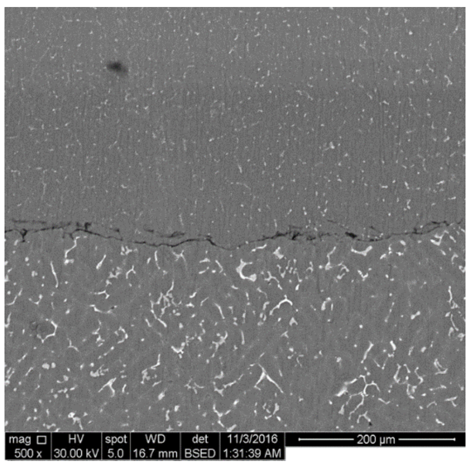
(c)


7827
60 µm
SE MAG: 2400 x HV: 30.0 kV WD: 17.1 mm

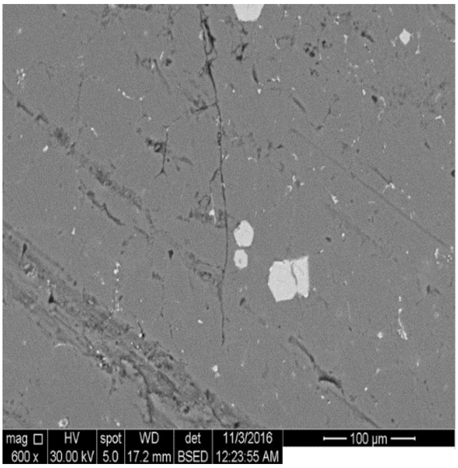
(d)


7829
30 µm
SE MAG: 5000 x HV: 30.0 kV WD: 17.2 mm

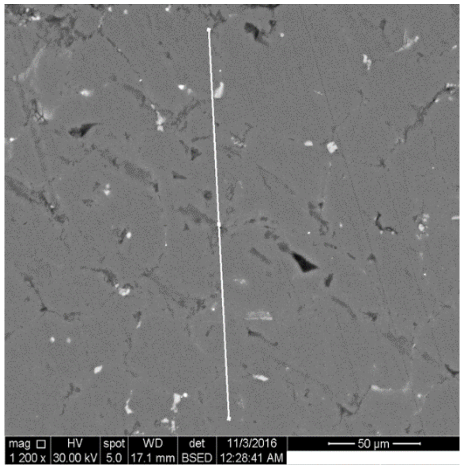
(e)


mag □ 500 x
HV 30.00 kV
spot 5.0
WD 16.7 mm
det BSED
11/3/2016 1:31:39 AM
200 µm

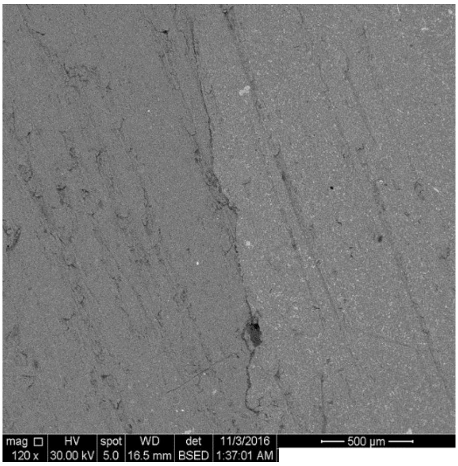
(f)



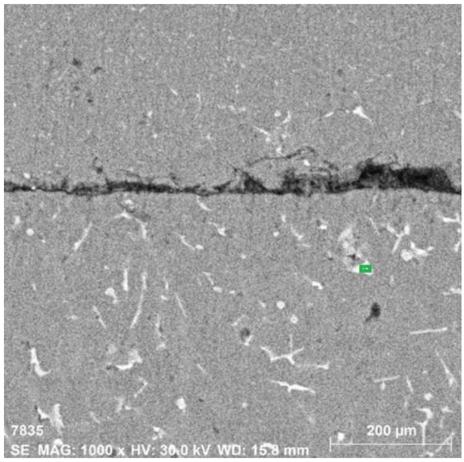
(g)



(h)



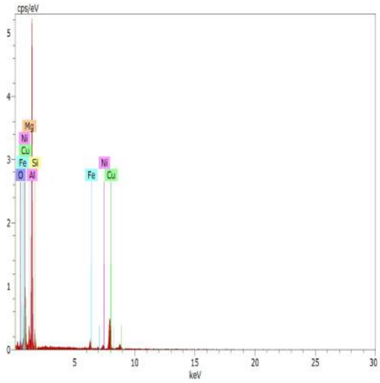
(i)



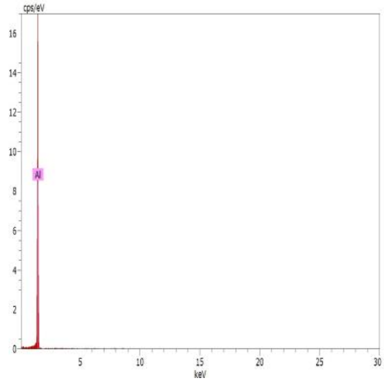
(j)

Fig.4. (a) Scanning picture for the aluminum face 1 at HAZ region 1200X; (b) Scanning picture for the aluminum face 2 at HAZ region 1200X; (c) Scanning picture for the aluminum welding line at HAZ region 140X; (d) Scanning picture for the Al-3%Mo crystal center contents; (e) Scanning picture for the Al-3%Mo crystal contents 5000X; (f) Scanning picture for Al-3%Mo welding line 500X; (g) Scanning picture for Al-3%Mo welding line for tracking the welding line 600X; (h) Scanning picture for Al-3%Mo welding line for tracking the welding line which the welding line disappeared and the white line represents the extension of the route if its continue appearing 1200X; (i) Scanning picture for the Al-Ti-B-Mo welding line at HAZ region 120X; (j) Scanning picture for the aluminum welding line cracks at HAZ region 1000X.

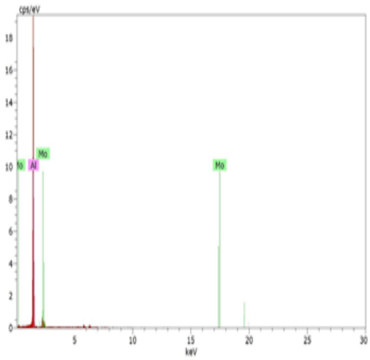
The following scan pictures in Fig. 4 represent the scanning welding area and it can be noticed that the welding line has different properties according to the materials that were added.



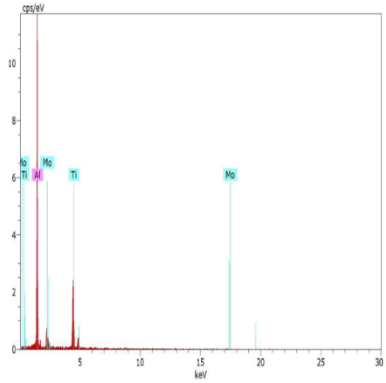
(a)



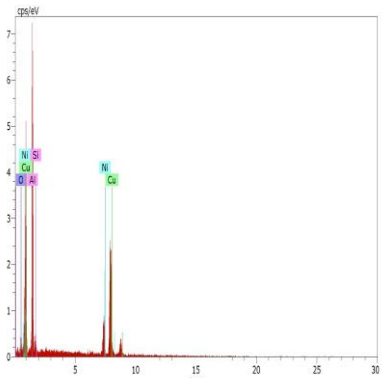
(b)



(c)



(d)



(**e**)

Fig .5. (a) Spectrum analysis for the welding area contaminations at HAZ region for the Al which is connected with Fig. 4a green point; (b) Spectrum analysis for the welding area contaminations at HAZ region for the Al which is connected with Fig. 4b green point; (c) Spectrum analysis for the welding area crystal center at HAZ region for the Al-3%Mo which is connected with Fig. 4d green point; (d) Spectrum analysis for the welding area contaminations around Mo crystal at HAZ region for the Al-3%Mo which is connected with Fig. 4e green point; (e) Spectrum analysis for the welding area contaminations at HAZ region for the Al-Ti-B-Mo which is connected to Fig. 4j green point

Discussion

Aluminum pure vs aluminum pure specimens in the HAZ region

Figure 4a and Fig. 4b show the distribution of the material around the HAZ zone, in addition, it gives spotting light on the type of the welding line, referring to these pictures we can notice that Fig. 5a represents the Aluminum as pure without any rare materials addition, hence, we note that the contaminations distribute as randomly over all the surface, and these contaminations can be expressed by the white particulars, in the other side Figure, 5b can show that the other type of the materials inside this surface is the Aluminum.

It can be noted that these contaminations affect the heat dissipation also can affect the diffusion quality, the mixing in the melting zone, also these contaminations affected the cooling rate for that zone resulting in cracks and different grains shapes and sizes, creating residual stresses, all of these parameters and more resulted in to show that the two specimens are welded, however, the welding line is still appearing and can be indicates as a sharp straight line which is not recommended Fig. 4c.

Aluminum -3%Mo vs aluminum -3%Mo specimens in the HAZ region

Figure 4d and Fig. 4e show the distribution of the material around the HAZ zone, by referring to these pictures it can be noticed that the contaminations distribute more organized than Aluminum pure case, and more than that the contaminations start to be like crystals, Fig. 4d, and the random distribution of the other elements become not available.

An additional 3% Mo resulted in eliminating the effect of the unwanted material by pulling these materials to create shapes that look like crystals, Fig. 4e, which gives more chance for the material to be more convenient or more homogenous.

Figures 5d and 5e can explain the process that Mo is concentrated in the center of the crystal and the other materials can be observed around Mo or between the Mo crystals.

This affection is reflected in the welding itself, we can still observe the welding line, but it converted to be like a zigzag, and in some areas, we could not recognize the welding area where the welding line disappeared, Fig. 4f and 4g.

As the reason for this enhancement in the welding characteristics, adding Mo resulted in enhancing the heat dissipation to be more adequate, also can be said that it affects the diffusion quality to be more efficient, the mixing in the melting zone becomes more convenient, in addition to its affection to the cooling rate for that zone. Resulting in reducing the cracks, and residual stresses and giving the ability to weld the specimens with full fusion. Fig. 4g indicates that the welding line disappears and the white line is indicating the extension of the weld line if it can be observed.

Aluminum -0.05%Ti-0.01%B-0. 1%Mo vs aluminum -0.05%Ti-0.01%B-0. 1%Mo

Figure 4i and Fig. 4j show the distribution of the material around the HAZ zone, by referring to these pictures it can be noticed that the contaminations distribute more organized than Aluminum pure case but less than the Al-3%Mo, which rises the enhancement to be better than the Aluminum itself. We can see the contaminations are spreading on the welded surface and at the same time, we can notice also crystals still available.

An additional 0.01% Mo for this alloy increases the possibility to reach better characteristics, however, adding the Boron element has a poison effect on the grain size and also affects the casting process for the Aluminum alloys.

Referring to the same scanning Figures 4i and 5j can be noticed that the welding line has not a sharp shape and is close to being described as a zigzag, in another point of view can be observed that the cracks are obvious in some areas and the ant fusion areas are noticed.

The affection of adding Mo to the aluminum hardness

Figure 2a and Fig. 2b show that there is not a huge difference in the hardness value, therefore adding Mo resulted in a slight difference in the hardness which is shown in Fig. 3a.

It can be noticed that the maximum value for the hardness value before the welding process was for the alloy Al-Ti-B and the lowest value was for the Al-Ti, adding Molybdenum with a precise amount is not has that noticed affection, however, for the HAZ it can be noticed that adding Mo or Boron alone or together increase the enhancement of the hardness value.

These differences in the hardness value are connected directly by the grain size and the affection of these rare elements in the refining of the grains, which is highly recommended to be investigated in other studies Fig. 3a-4f.

Conclusions

Aluminum and its alloy are vastly used in the industrial field and because of that Aluminum welding takes a high potential value. GMAW and GTAW are generally the welding processes that are used in arc welding. In this investigation, GTAW is used in this study, so the welding area is subjected to less heat, especially in the HAZ region which increases the ability to apply heat more in focus on the welding zone. Adding Mo to Aluminum reflects well on the welding processes and provides many advantages. Among others, it can decrease the affection of the impurities by creating crystals and pulling the contaminations around these crystals giving the aluminum more chance to be homogenous in the welding region and avoiding the random distribution of the impurities over the surface of the welding, low heat dissipation and low cooling rate resulting in less porosity and fewer defects welding process. Adding Titanium or Boron improves the welding results but not as much as adding Molybdenum.

Adding Molybdenum to Aluminum does not improve the hardness in the HAZ region or the base metal region. The impact of additional Molybdenum on Aluminum casting before solidification can reduce the ability of the cracks, decrease the defects, and reduce the affection of the contamination.

Adding some rare materials like Molybdenum in the casting process for aluminum alloys can change their characteristics, and more research in this field should be conducted to eliminate the disadvantages of welding Aluminum alloy.

References

[1] Zhu, Chenxiao, Tang, X., He, Y., Lu, F., & Cui, H. *Study on arc characteristics and their influences on weld bead geometry in narrow gap GMAW of 5083 Al-alloy*. **The International Journal of Advanced Manufacturing Technology**, 90(9–12), 2513–2525, 2017.

[2] Ribeiro, R. A., Assunção, P. D. C., Dos Santos, E. B. F., Braga, E. M., & Gerlich, A. P. (2020). *An overview on the cold wire pulsed gas metal arc welding*. **Welding in the World**, 64(1), 123–140, 2020.

[3] Ramaswamy, A., Malarvizhi, S., & Balasubramanian, V. *Effect of variants of gas metal arc welding process on tensile properties of AA6061-T6 aluminum alloy joints*, 2020.

[4] Han, Y., Xue, S., Fu, R., & Zhang, P. *Effect of hydrogen content in ER5183 welding wire on the tensile strength and fracture morphology of Al-Mg MIG weld*. **Vacuum,** 166, 218–225, 2019.

[5] Gu, C., Lu, Y., & Luo, A. A. T*hree-dimensional visualization and quantification of microporosity in aluminum castings by X-ray microcomputed tomography*. **Journal of Materials Science and Technology**, 65, 99–107, 2021.

[6] Alawana, A.D.; Csaki, I.; Zaid, A.I.O.; Gembazu, L. *Comparison between the effect of Molybdenum additional to Aluminum grained refined by Titanium plus Boron on its hardness*. **Buletinul Institutului Polyethnic din Iasi**, 67(71), 2021.
[7] Zaid, A.I.O.; AL-Qawabah, S.M.A. *Effect of zirconium addition on the grain size and mechanical behavior of aluminum grain refined by titanium plus boron (Ti+B) in the cast and extruded conditions*. **International Symposium on Advanced Materials**, 2011.
[8] Zaid, A.I.O.; AL-Qawabah, S.M.A. *Different methods for grain refinement of materials*, **International Journal of Scientific and Engineering Research**,**7**, pp.2229-5518. 2016.

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