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DIFFUSION BONDING OF AL ALLOY USING DIFFERENT IINTERLAYERS

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ABSTRACT
The present study includes characterization of diffusion bonding of aluminum alloy 2024-O without and with applying different interlayers as pure powder such as copper, silver and titanium. Bonding was performed in vacuum up to (1×10^{-5} mbar) using vacuum system bonding. Aluminum alloy 2024-O specimens was used as cylinder shape as diameter (15mm) and (35mm) length and interlayer thickness was equal 100 μm, under bonding conditions of (330-480°C) and (1-4 Mpa) and duration of (60 min). Interlayer was classified according to diffusion coefficient of each element in the base alloy. Bonding joint under optimum conditions were examined for microstructure properties using light microscope, scanning electron microscope (SEM) with energy dispersive spectroscopy (EDS) for determining microstructure and depth diffusion and micro hardness was also used at bonding zone. XRD was used to determine the phase's formation at bonding zone. XRD results show that the dominant intermetallic compound phase form was Al_2Cu when enhancing the mechanical properties of the bond zone. The maximum depth of diffusion obtained was 19.2 μm.

INTRODUCTION
Solid phase welding of materials becomes important in this time for many applications such as properties of compounds like thermal expansion, thermal conductivity and corrosion resistance [1]. Solid phase welding considers modern technique for assembly materials when the low temperatures and at all importance [2]. Welding by using fusion methods joining are needed high temperatures and control the melting on the both side of materials so become more difficult using this technique [3]. In addition, many defects result with using fusion welding method such as crack, segregation and porosity and these defects can be eliminated by using solid state methods [4]. Solid state bonding is the placing of two extremely clean metal surfaces in such intimate contact that a cohesive force between the atoms of the two surfaces holds and welds them together at the temperature blow the melting point of base metal and the pressure could or could not be applied without addition of filler metals. It is more industrial important process and widely used for similar and dissimilar materials [5]. Diffusion bonding is one kind of solid state welding technique used for similar and dissimilar materials using interlayers or without using interlayers [6]. The bonding with using interlayers is used to improve the bonding joint. The interlayer can be used as foil, powder, and sheet or by deposit coating process. There are many advantages of using suitable interlayer such as increasing the strength of the bonding joint, decreasing the formation of weak intermetallic at bonding zone [7]. Aluminum and alloy's welding by traditional methods causes many defects such as cracks, air holes and deformation, so there was a special welding technique necessary to reduce or prevent these defects. Diffusion bonding technique is one of the joining processes method for similar materials with the interlayers between the two materials that be welding by which both sufficient strength and thermal conductivity might be resulted in aluminum alloy. In addition, diffusion bonding limits the oxidation process which is considered the main problem occurring during welding the aluminum and alloy's. Diffusion bonding of similar aluminum alloy 2024-O without using interlayers and with using pure powder of copper, silver and titanium as interlayers has been studied by using diffusion bonding system under vacuum (1×10^{-5} mbar) to obtain sound joints. Minitab 17 program is used in this research to know number of the specimens of aluminum alloy 2024-O that will be joined and to reduce number of experiments tensile test and to evaluate the effect of the factors on the joint strength so to know the optimum bonding conditions for joining aluminum alloy 2024-O.

EXPERIMENTAL WORK

Materials and Methods

Aluminum alloy 2024-O is used as the base metal and powders of copper, silver and titanium are used as the interlayers. For joining aluminum alloy 2024-O with different interlayers of powders (copper, silver and titanium) by diffusion bonding process to obtain sound bonding joint, a diffusion bonding vacuum system is required. The purpose of joining under the vacuum is to reduce the impurity contained, even for the case of the high reactive metals and prevent oxidation from degassing materials. The diffusion bonding system consists of vacuum tube furnace, diffusion vacuum pump, rotary vacuum pump, heating system, cooling system, loading unit, control unit. The whole system is shown in figure (1).

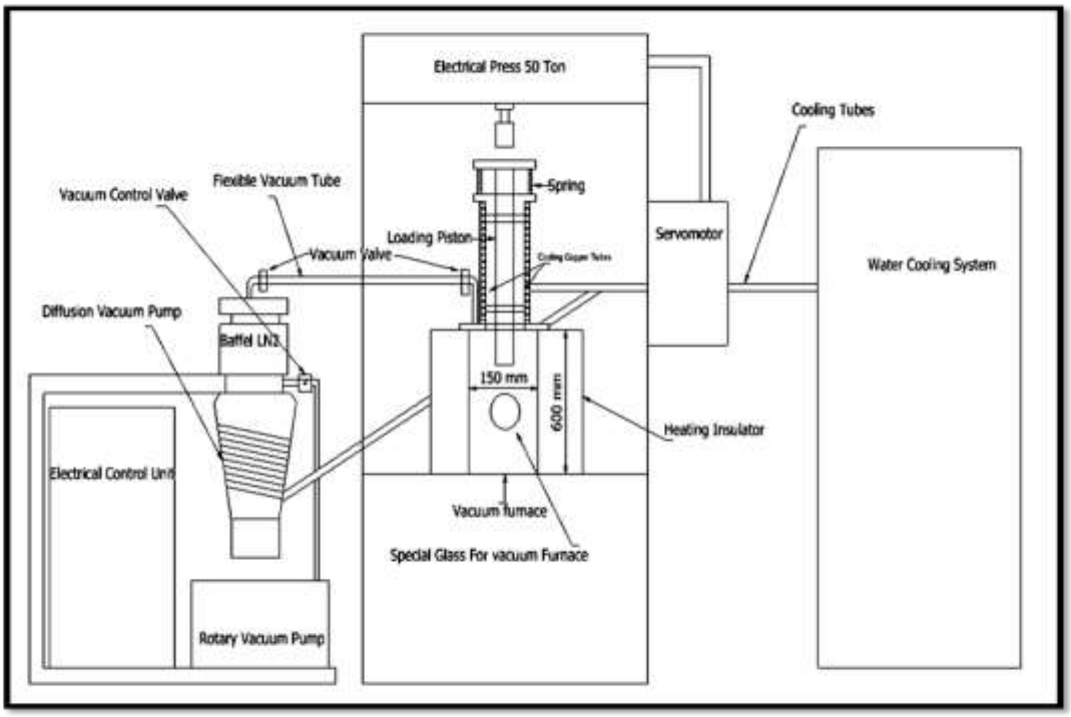

Figure (1) the schematic diagram of the diffusion bonding system.

The materials were examined by chemical composition analysis and show in tables.

Table (1) the chemical composition analysis of aluminum alloy 2024-O.

Elements	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**
Standard	0.5	0.5	3.8-4.9	0.3-0.9	1.2-1.8	0.1	0.25	0.15
Measured	0.191	0.178	4.9	0.813	1.22	0.0086	0.136	0.015

Table (2) the chemical composition analysis of the copper powder.

Cu	**Pb**	**In**
99.805	0.123	0.072

Table (3) the chemical composition analysis of the silver powder.

Ag	**Si**	**Cu**	**Fe**	**Mn**	**C**
99.657	0.171	0.073	0.063	0.027	0.01

Table (4) the chemical composition analysis of the titanium powder.

Ti	Fe	Ca	Cu	Mn	Zn
99.872	0.034	0.031	0.027	0.024	0.012

The aluminum alloy 2024-O was cut by wire cutting machine into cylinder shape specimens of 35mm length and 15mm diameter then grinding and polishing and cleaning surface to remove any contaminations adhering on the specimens. Similar diffusion bonding of aluminum alloy 2024-O without interlayers and with using different powders of Cu, Ag, Ti as interlayers under vacuum (1×10^{-5} mbar). As shown in figure (2)

Figure (2) diffusion bonding joint specimens.

RESULTS AND DISCUSSION

Tensile Test

Diffusion bonded specimen have been cut by wire cutting machine into tensile test specimens. The tensile strength has been examined to evaluate the strength of joints by knowing the ultimate tensile strength. Table (5) shows the results of tensile strength of diffusion bonding specimens.

Table (5) Results of tensile strength of diffusion bonding specimens.

EXP. Numbers	Interlayers	Bonding temperature °C	Bonding pressure (Mpa)	Fracture location	Ultimate strength (Mpa)
1	None	330	1	at interface	122.66
2	None	380	2	at base metal	113.53
3	None	430	3	at interface	139.37
4	None	480	4	at interface	146.13
5	Ag	330	2	at base metal	75.8
6	Ag	380	1	at base metal	65.89
7	Ag	430	4	at base metal	60.17
8	Ag	480	3	at base metal	50
9	Cu	330	3	at interface	173.71
10	Cu	380	4	at interface	187.53
11	Cu	430	1	at interface	191.73
12	Cu	480	2	at interface	178.11
13	Ti	330	4	at base metal	4.1
14	Ti	380	3	at base metal	6.78
15	Ti	430	2	at base metal	10.87
16	Ti	480	1	at base metal	11.23

From table (5), all tensile test specimens for copper interlayer, fracture occurred at base metal. This means that bonded area is higher strength at bonding zone due to good surface roughness of specimens and high vacuum atmosphere with good conditions which led to diffusion of copper powder towards base metal. The best results have been obtained when using copper powder as interlayer and the range of ultimate tensile strength was (173-191) Mpa. The bonding strength for joint bonded without interlayer gives good results and the range of ultimate tensile strength was (122-146) Mpa. Lowest ultimate tensile strength was obtained when bonding with silver and titanium interlayers, the range of ultimate tensile strength for silver is (50-75) Mpa and for titanium was (4-11) Mpa. The maximum ultimate tensile strength is 191.73 Mpa with copper powder interlayer at bonding temperature of 430°C and applied pressure of 1 Mpa.

The optimum conditions of temperature and pressure can be found of each level for each factor by averaging the results of ultimate tensile strength at table (5) which contain that level and that factor. From the result, it can be seen that the best combination of factors is Copper interlayer, T3 and P4 these are factors which produce the largest results. The optimum bonding conditions is applied to calculate the tensile strength. The tensile strength value of optimum bonding conditions is 189.2 Mpa

Microhardness Test of Diffusion Bonding Joint

Microhardness test has been performed for the testing specimen diffusion bonding joint at optimum conditions. The hardness was measured at bonding zone and base metal on both sides of interdiffusion region. Test points are 0.2 mm spaced and beginning from left side of base metal passing through interlayer to right side of base metal. Figure (3) shows the microhardness at optimum conditions, the microhardness measured recorded (89 Hv) at base metal and increased gradually up to (109 Hv) near the interlayer. The microhardness measurement at interlayer is more than of base metal and recorded (127 Hv) because the interlayer is pure powder of copper and has higher hardness than the base metal. Then, the microhardness through the interlayer towards the base metal on the right of bonding zone began to decrease. The hardness measurement was (97 Hv) and decrease to (85 Hv) at base metal. The reason for this variation across the bonded region was due to the high hardness of the copper powder which was higher than other regions.

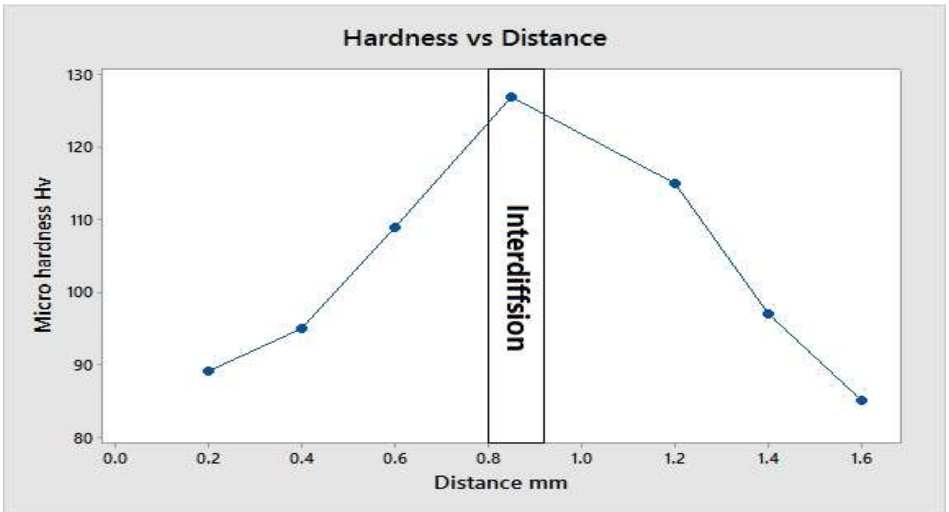

Figure (3) Hardness of the optimum bonding condition.

Microstructure Examination of Diffusion Bonding Joint Zones

Optical microscope and scanning electron microscope are used for evaluation of the microstructure of diffusion bonding joint performed at optimum conditions. The bonded joint specimen has been performed at the optimum conditions of temperature of 430 °C, and pressure of 4 Mpa through a duration time of 60 min using copper powder interlayer. The microstructure of the diffusion bonding joint of aluminum alloy 2024-O using microscope and scanning electron microscope are shown in figure (4) and figure (5).

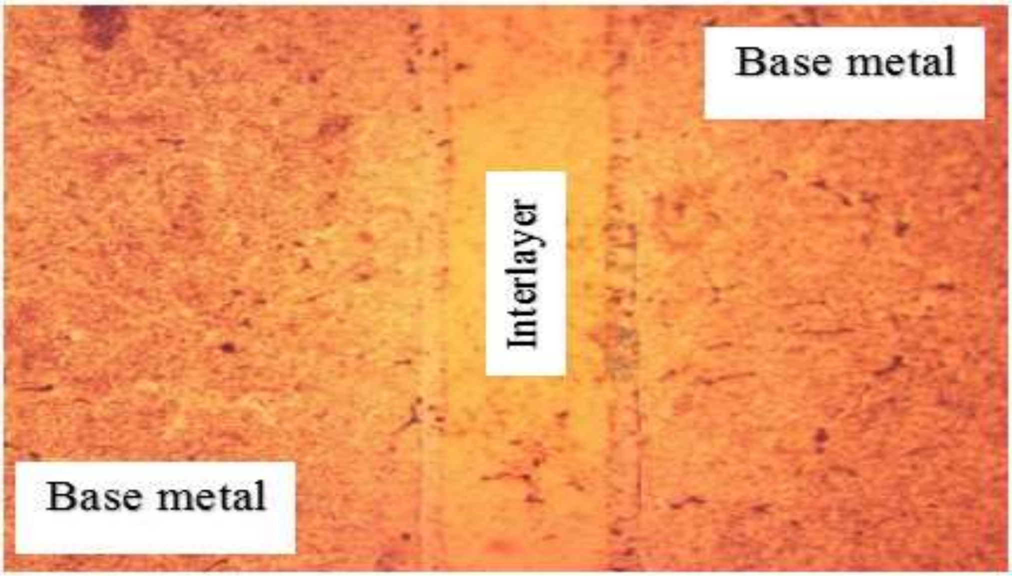

Figure (4) Optical microscope of bonding joint.

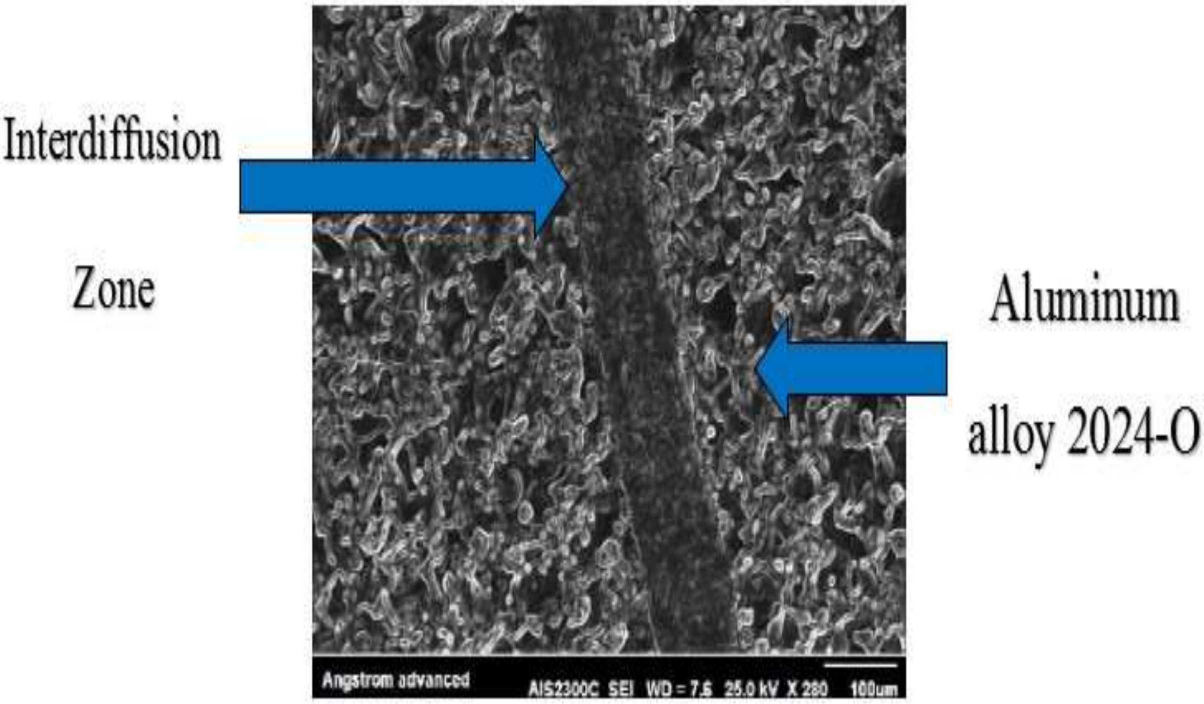

Figure (5) Scanning electron microscope of bonding joint.

The important factors for diffusion atoms in the diffusion joining processes were enough time, temperature and pressure applied. The diffusion process requires adequate time to occur and when the atoms are large extra time is needed to obtain a homogenous structure [8]. Scanning electron microscope examination determined the structure, diffusion depth and phase distribution. Figure (6) shows the microstructure of optimum bonding joint zones with powder copper interlayer.

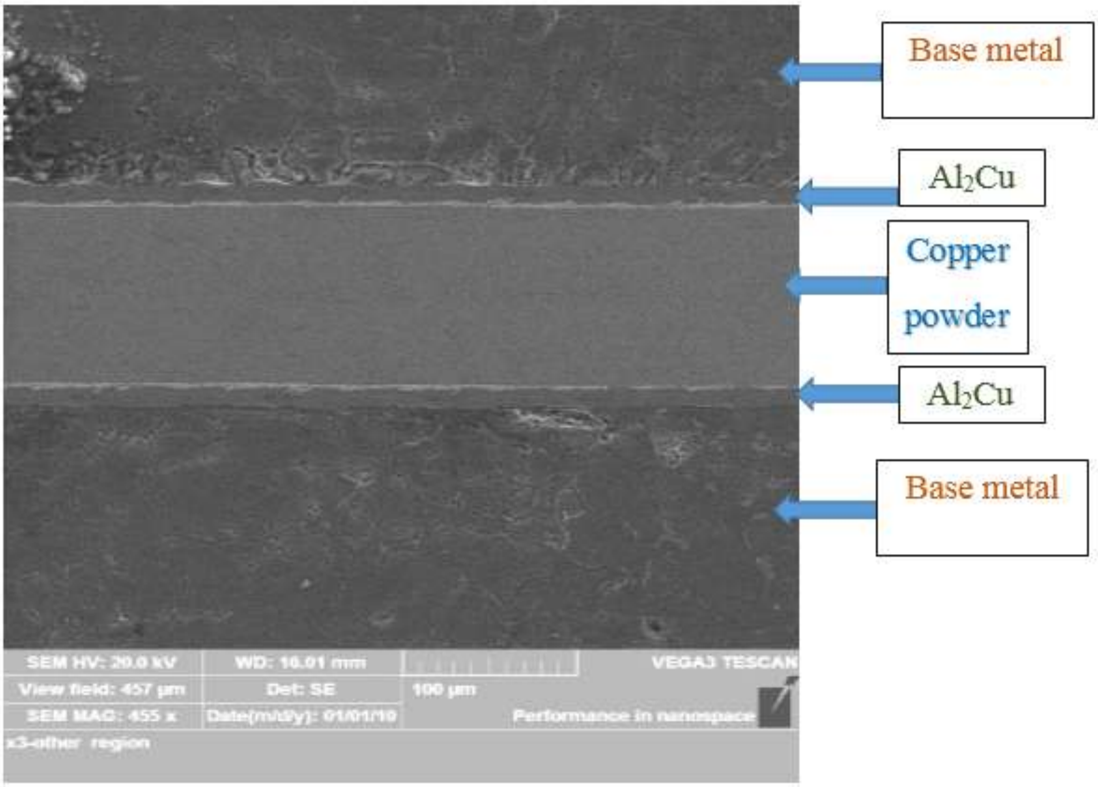

Figure (6) Scanning electron microscope of optimum bonding conditions specimen.

The micrograph of bonding joint indicated that the homogenous structure was due to good intimate contact between matting surfaces and no crack formation. Figure (7) represents the back scatter electron microstructure of optimum bonding joint. The back scatter showed the interdiffusion zone consisting of two recrystallizing area. First area indicated to copper powder and small second area indicated the bonding between copper powder and base metal and formation of intermetallic compound of Al_2Cu phase. The back scatter of zones also showed the diffusion of copper atoms through base metal.

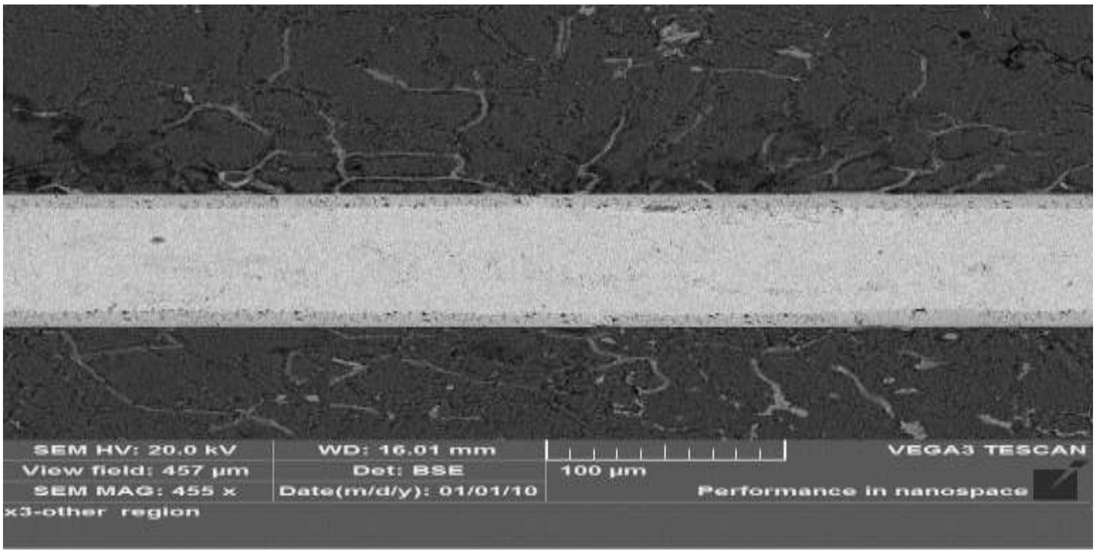

Figure (7) back scatter electron of optimum bonding conditions specimen.

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EDS line Examination

The energy dispersive spectroscopy line for optimum conditions joint zones has been examined as shown in Figures (8) and (9). The diffusion of copper atoms towards base metal on both side of interdiffsion zone are shown clearly. The diffusion of copper atoms is high from interlayer and decreases gradually towards base metal. The good intimate contact and no segregation of elements at diffusion zones resulted in good bonding. The maximum depth of diffusion of copper atoms towards base metal on both sides of diffusion zone is approximately 19.2 μm. The diffusion depth is high since the powder body is unstable and has high free energy and associated with presence of very large internal interface between solid body atoms of powder and cavity which caused increase in the diffusion of the powder followed by the temperature decrease at shrinkage [9].

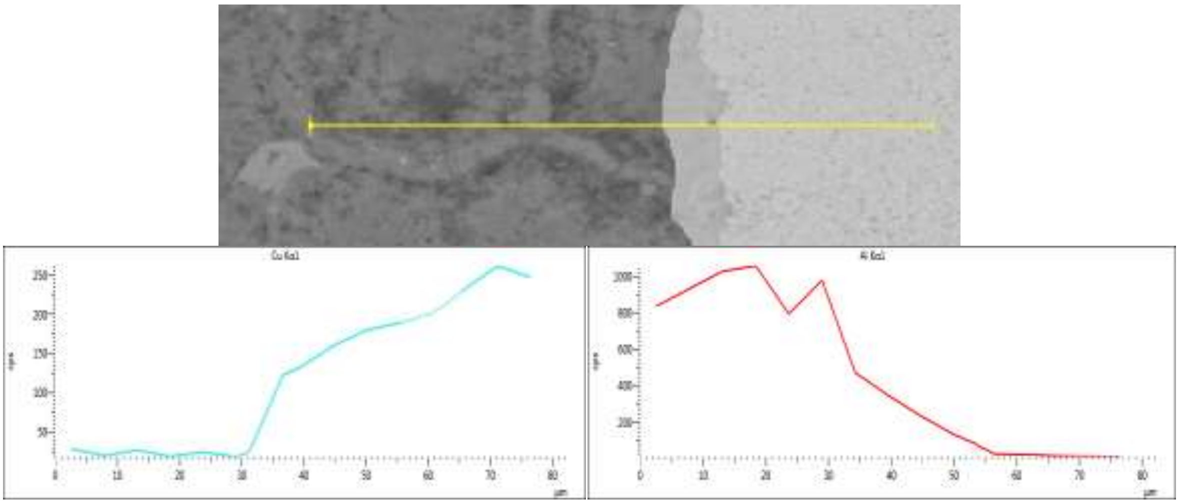

Figure (8) EDS line of optimum condition on left side interdiffusion.

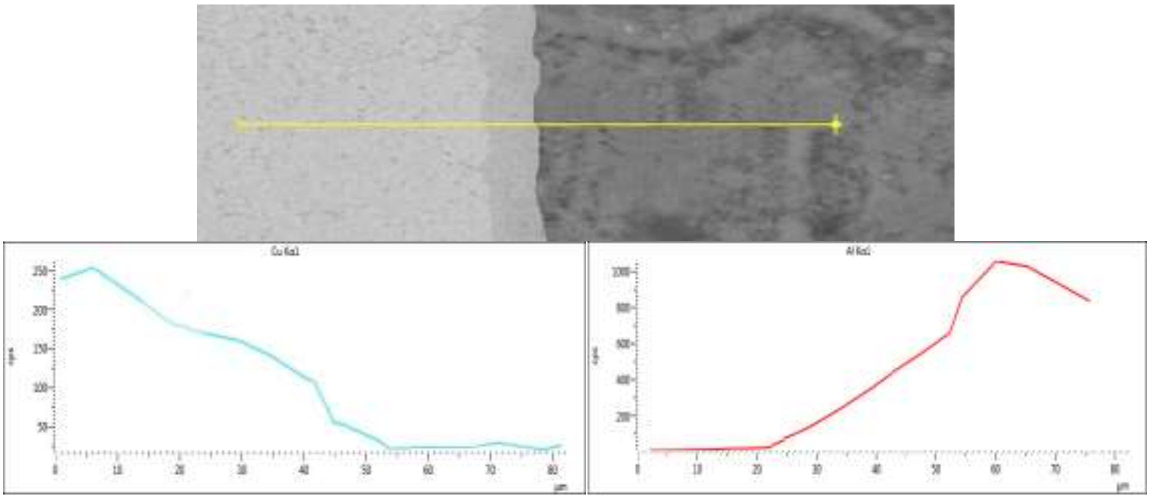

Figure (9) EDS line of optimum condition on right side interdiffusion.

EDS Point Examination

The bonded joint performed at optimum bonding conditions are examined using EDS at different points is shown in figure (10). EDS points showed the chemical composition of elements at the certain points. Point 16 represented the composition of the copper powder and other points (17,18,19 and 20) referred to diffusion of copper into aluminum alloy 2024-O. Table (6) represents the chemical composition of elements resulted at each point.

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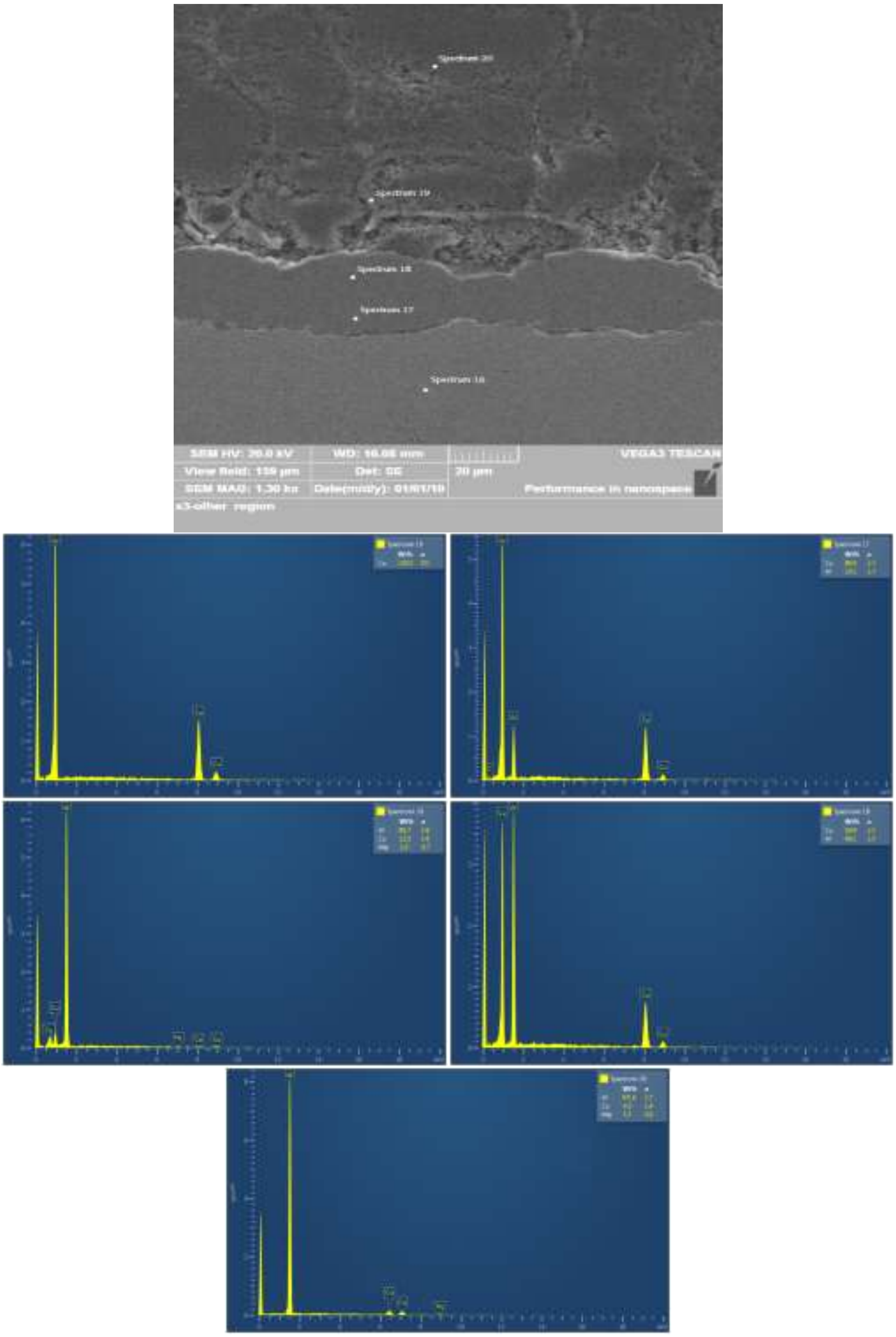

Figure (10) EDS analysis of points

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Table (6) The chemical composition analysis by EDS.

Points	Al	Cu	Mg
16	0	100	0
17	19.1	80.9	0
18	49.1	50.9	0
19	86.7	12.3	1.0
20	94.6	4.3	1.1

Fractographic Analysis

The fractured surface of diffusion bonding specimens have been examined by SEM after tensile test. Fracture of tensile test occurred on the both sides of diffusion bonding zone interface due to strong joining between the aluminum alloy and interlayer because the diffusion of copper atoms to aluminum alloy and formation a solid solution. Scanning electron microscope was used to know the nature and topography of fracture surface and fracture mode. The mode of fracture seems to be ductile where many big dimples which explains that the bonding resulted in high strength ductile between the aluminum alloys is redound to higher bond strength, micrograph of fractures surface is shown in figure (11).

The Fractographic analysis of optimum conditions compared with the standards and showed the same topography [10].

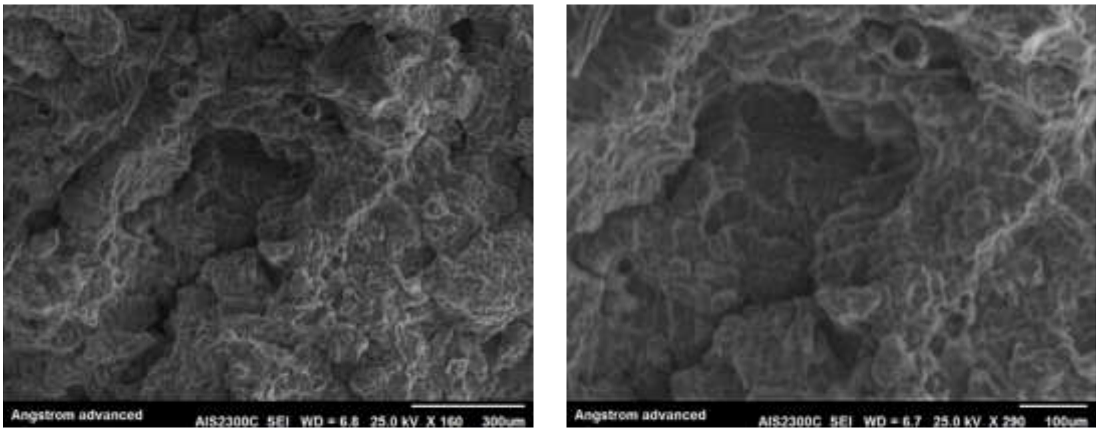

Figure (11) The Fractographic analysis of optimum bonding condition specimen.

XRD of Bonding Joint at Optimum Condition

The bonding joint at optimum conditions was examined by using XRD technique also. It was not possible to determine the phases by using EDS because the EDS is determining the distribution of elements. The XRD examination can be showing in figure (12). In figure (12) the XRD test of optimum conditions (temperature bonding of 430°C, pressure bonding 4Mpa and through holding time is 60min) with pure powder copper as the interlayer is presented. Three peaks of Al are determined and compared with standard data sheet. Al_2Cu phase is determined by three peaks and compared also with standard date sheet. Cu was determined by three peaks and also compared with standard date sheet.The migration of Cu atoms towards aluminum is easier than opposite since the diffusion coefficient of copper is higher than aluminum. The powder particles of copper diffused into aluminum alloy and resulted an increase in intimate contact and mechanical properties between the same alloy this was as a result of the increased formation of phases percentage of Al_2Cu [11].

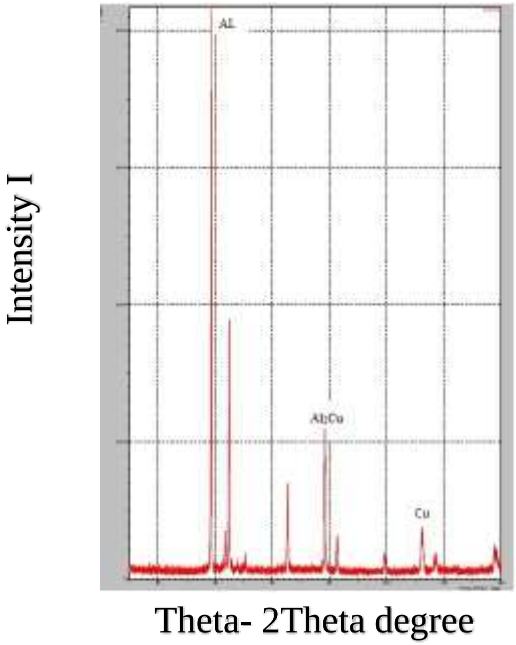

Figure (12) XRD examination of optimum bonding joint.

CONCLUSION

Similar bonding joint of aluminum alloy 2024-O has been used with powder interlayer of copper, silver, titanium and without interlayer. The copper interlayer was better than other. The optimum bonding conditions of diffusion bonding process are as temperature of 430°C, pressure of 4 Mpa and bonding duration 60 min. Optimum bonding condition resulted in tensile strength of 189.20 Mpa and bonding efficiency of 91.8 % compared to the aluminum alloy 2024-O (base metal). Fractographic analysis of fracture surface at optimum bonding tensile test showed ductile mode with dimple. The microhardness of the diffusion zone is more than of base metal since the hardness of copper is higher than of aluminum alloy 2024-O. Maximum depth of diffusion of copper powder into aluminum alloy 2024-O was about 19.2 μm. During diffusion powder of copper into the aluminum alloy matrix the increase of the percentage formation of Al_2Cu phase enhanced the tensile strength and hardness of aluminum alloy.

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