Propriétés microstructurales et mécaniques d'un nouveau composite métallique à base d'Aluminium

Microstructural and mechanical properties of new designed Al-based metallic composite

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RÉSUMÉ. Cette étude porte sur la mise en évidence de l'effet du renforcement à base de feuilles de cuivre poinçonnées sur les propriétés microstructurales et mécaniques du composite métallique à base d'Al avec des feuilles de 1100 Al agissant comme une matrice. Par conséquent, des joints homogènes et hétérogènes ont été préparés sur la base de la liaison par diffusion et ont été analysés par microscope optique (OM) et microscope électronique à balayage, pour les propriétés mécaniques des composites préparés sans traitement thermique et après vieillissement à 180 ° C ont été mesurées par un testeur de microdureté et machine d'essai de traction, les résultats expérimentaux ont démontré une bonne adhérence de l'Al et du Cu ainsi que des propriétés mécaniques élevées dans le cas de la feuille de Cu poinçonnée.

ABSTRACT. This study deals with highlighting the effect of punched copper sheet-based reinforcement on the microstructural and mechanical properties of Al-based metallic composite with 1100 Al sheets acting as a matrix. Consequently, homogeneous and heterogeneous joints were prepared based on diffusion bonding and were analyzed by optical microscope (OM) and scanning electronic microscope, for the mechanical properties of the prepared composites without heat treatment and after aging at 180°C were measured by microhardness tester and tensile test machine, the experimental results demonstrated good adherence of Al and Cu as well as high mechanical properties in the case of punched Cu sheet.

MOTS-CLÉS. composite métallique, diffusion, interface, microdureté Vickers, essai de traction.

KEYWORDS. metallic composite, diffusion, interface, Vickers microhardness, tensile test.

1. Introduction

Recently, metallic composites have gained more attention and are considered as promising materials to combine different characteristics such as stiffness, toughness, and lightweight needed in automotive and aeronautic domains. [1–5]. In this regards, there is a growing demand to develop new methods for metallic composite preparation through the application of severe plastic deformation, while the microstructure nature resulted from metallic composite dependent upon the processing route employed, as well as other factors such as the type, size, volume fraction, homogeneity of the reinforcement used. [6–10]

Among different processing routes used to produce a metallic composite, diffusion bonding is a process in which two matched surfaces of the same or different materials are stacked then bonded at an elevated temperature below melting temperature and under low pressure. [11], [12]. While in this solid-state diffusion process many studies [10], [13], [14] highlighted that the formation of intermetallic compounds (IMCs) and submicron-sized void called ‘‘Kirkendall void’’ at the interface between bonded metals reduces the bonding quality then causes engineering problems such as weakening the mechanical properties of the prepared samples.

Particularly, in the case of Al-Cu joints, due to the strong chemical affinity between Al and Cu, hard and brittle Al_xCu_y intermetallic compounds are easily formed at interface positions. Thus, J. Xiong et al [15] reported it is difficult to completely avoid the formation of the IMCs when Al and

Cu were directly joined, for this reason the introduction of severe plastic deformation (PSD) during joining step can lead to the partial suppression of interfacial IMCs.

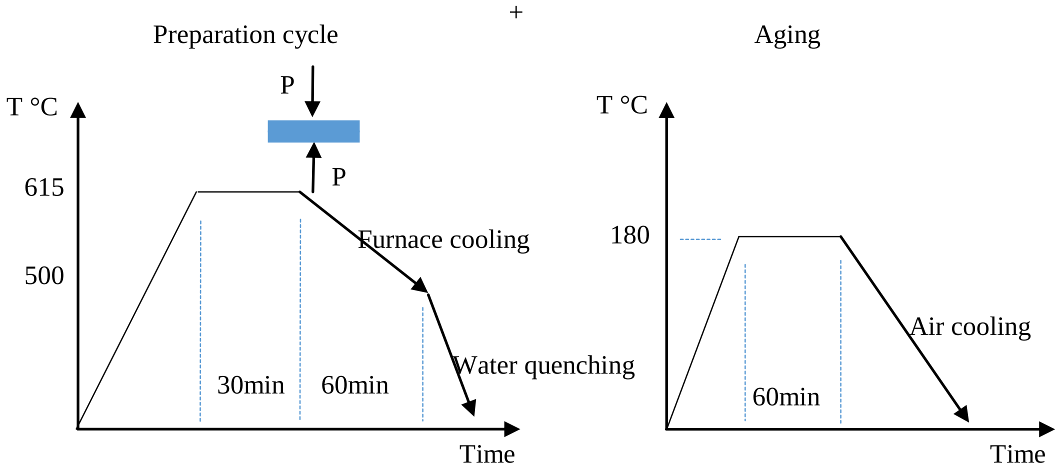
From mechanical point of view, it is well reported [10] that the brittle IMCs formed at the interface between Al and Cu reduce the overall ductility, while concerning the type of IMCs formed five equilibrium IMCs such as Al_2Cu (θ), Al_2Cu (η_2), Al3Cu4 (ζ_2),Al_2Cu_3 (δ) and Al4Cu9 (γ_2) phases could be generated by diffusion bonding between Al and Cu at temperature near 773K .

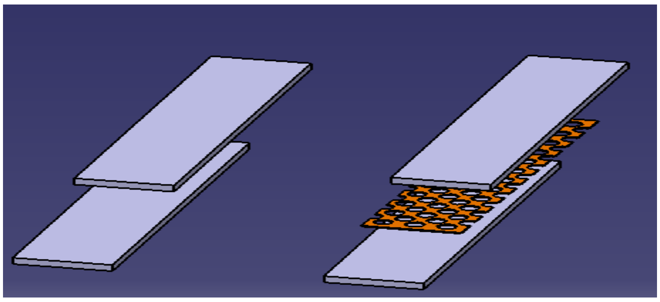
On the other hand, it is well known that depending on the process conditions especially temperature and time different IMCs phases are formed, in this optic Lee et al [10] found the presence of only two phases such as Al_2Cu and AlCu at the interface of friction welded Al-Cu joints for relatively short process time due to the low diffusion rate of copper into aluminum, While Chen and Hwang et al [16] have reported that at temperatures intervals between 573K and 773K, there were formation of saturated solid solution in Al-side at interface between Al and Cu especially Al_2Cu, Al_4Cu_9, Al_2Cu with Additional IMCs like AlCu and Al_3Cu_4 formed after generation of previous two phases such as Al_2Cu and Al_4Cu_9, this is due to the fast diffusion rate of Al into Cu compared to that of copper into Al.

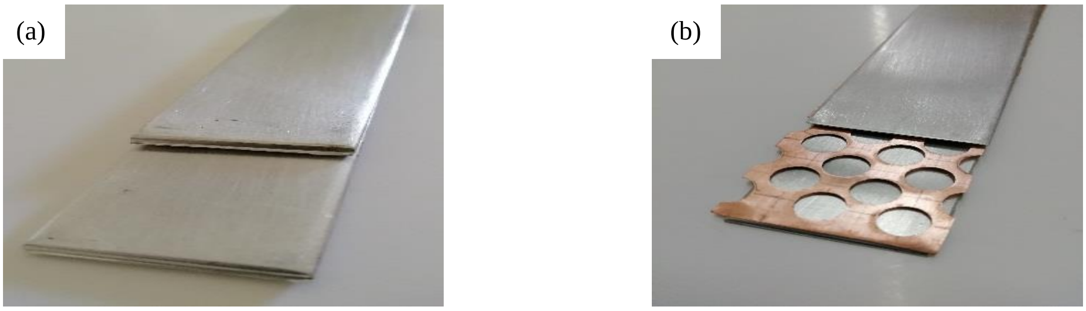
Consequently, the present paper deals with highlighting the effect of copper punched sheet used as reinforcement on the microstructural and mechanical properties of Al-based composites prepared using diffusion process.

2. Material & Experiments

In this paper a combination of static pressing and high temperature was adopted as simple way to produce Al-based metallic composites, the detail of this method is illustrated schematically in Fig. 1 that shows the thermal cycle used as well the type of reinforcement stacked between two Al sheets. The base metal used of the designed bimetallic composite was a commercially 1100Al, with the use of copper thin (0,5mm) punched sheet as reinforcement stacked between Al sheets under combination of static compression and high temperature for 1h at 620°C, then followed by first slow furnace cooling until 500°C, and finally water quenching. Aging post heat treatment at 180°C for 1h followed by air cooling is adopted.







The materials’ chemical composition determined using X-Ray fluorescence spectrometer are listed in Table.1. While their initial optical micrographs are presented in Fig.1. The SEM-JEOL IT 500 scanning electron microscope equipped with EDS analyzer was used to examine the interface positions, moreover to assess and compare the adherence of each composite’s compounds of the prepared samples. Moreover, tensile tests were conducted under a displacement rate of 3mm/min using Zwick 50KN machine in order to assess the mechanical properties of all samples, while vivkers microhardness measurements were performed along the cross section of the prepared samples, a set of three repeats in each condition were tested.

1100Al	**Al**	**Si**	**Co**	**Fe**	
	99.52	0.05	0.02	0.38	
Copper sheet	**Cu**	**Sn**	**Mn**	**Fe**	**Cr**
Be-Cu, C110	99.44	0.17	0.01	0.16	0.04

Table.1. *Chemical composition of the used materials (wt. %)*

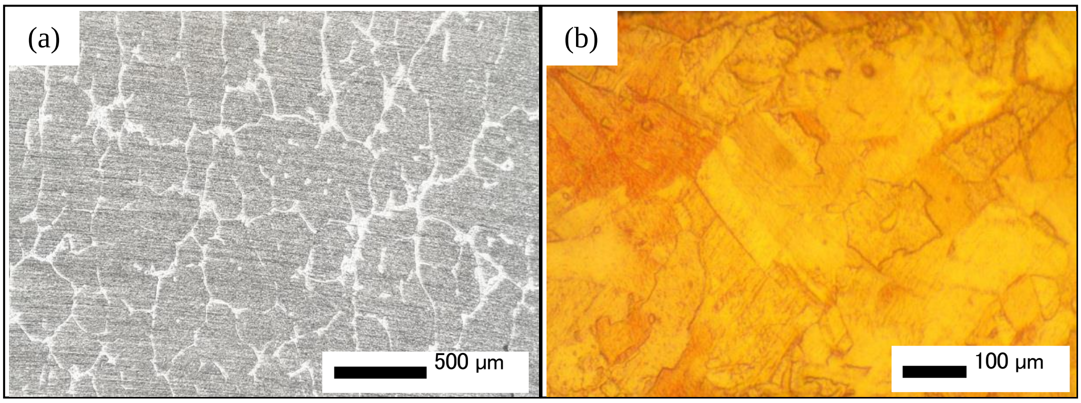


Figure 1. *Optical micrographs of (a): Al base metal, (b): Copper punched sheet*

3. Results and Discussion

3.1. *Microstructural properties*

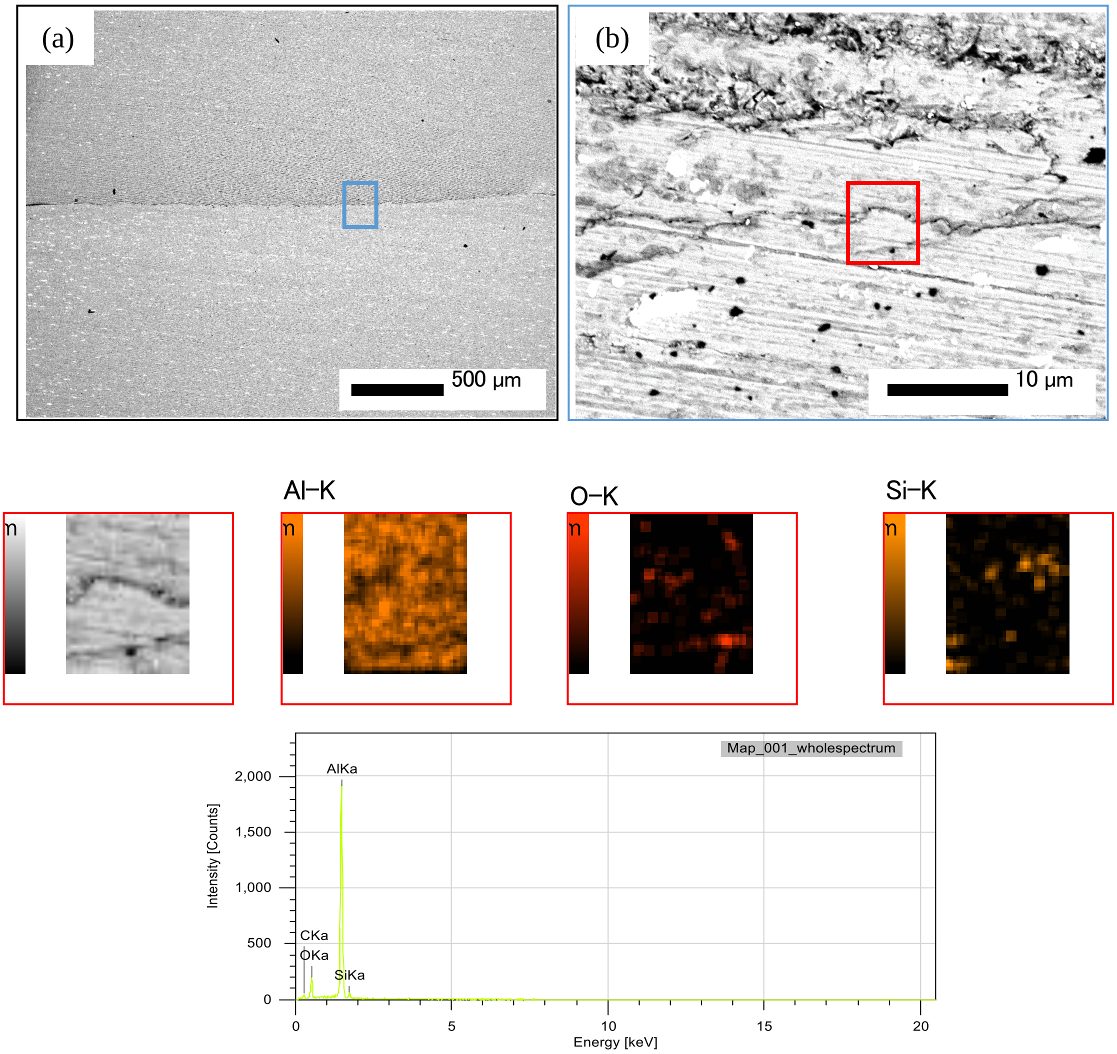


Figure 2. *SEM micrographs and EDS maps of the Al /Al metallic composite as prepared without heat treatment*

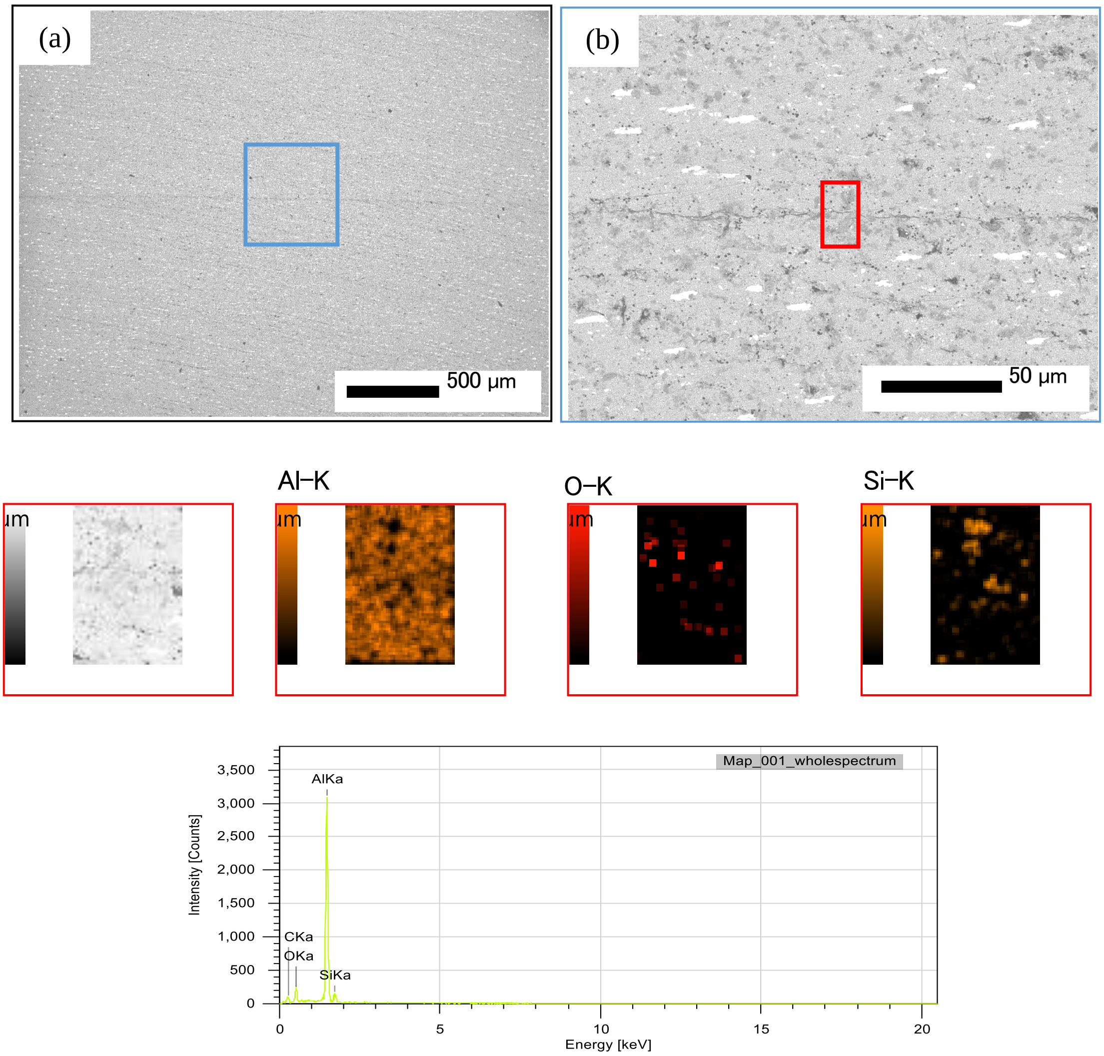
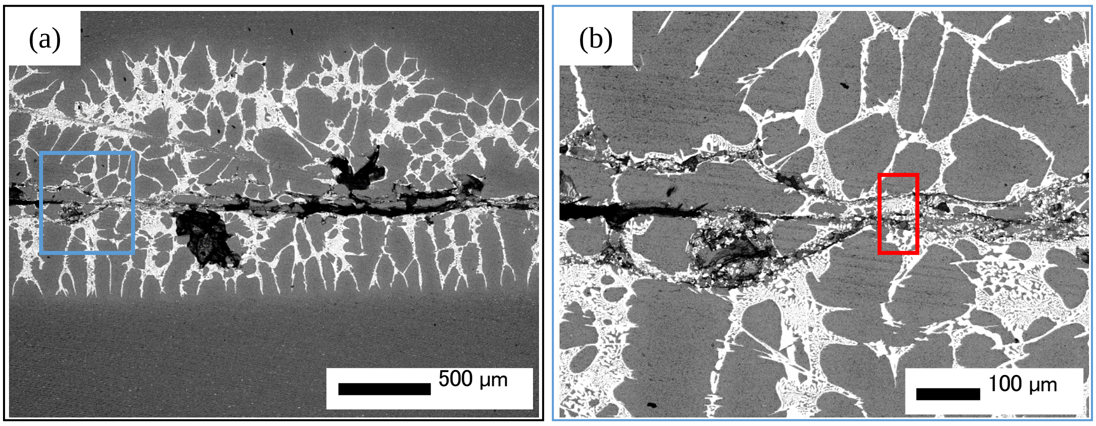


Figure 3. *SEM micrographs and EDS maps of the Al /Al metallic composite after Aging at 180°C for 2h followed by air cooling*



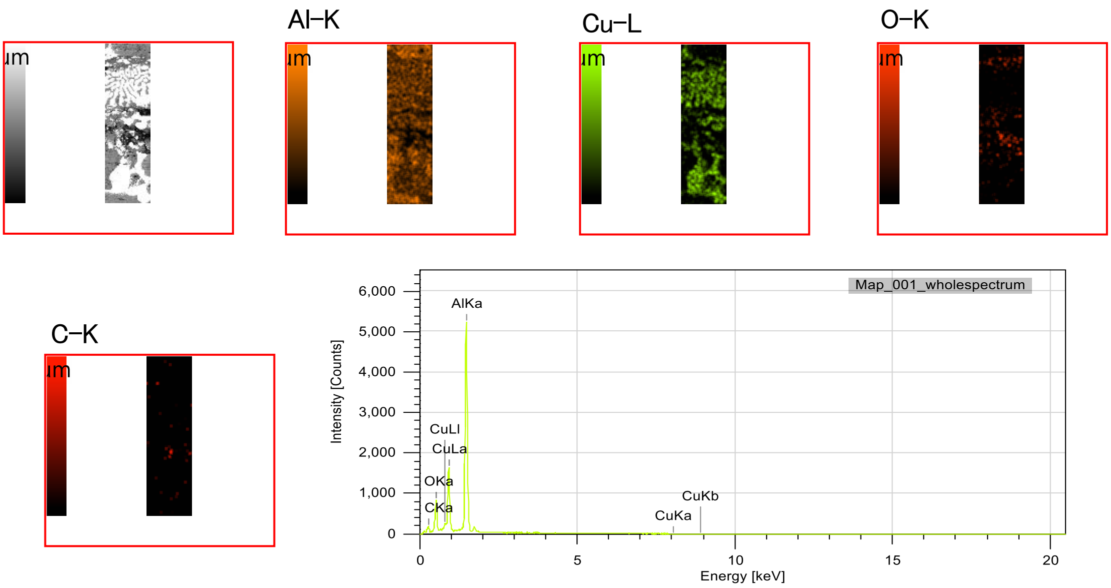


Figure 4. *SEM micrographs and EDS maps of the Al/Punched Cu sheet/Al metallic composite As prepared without heat treatment*

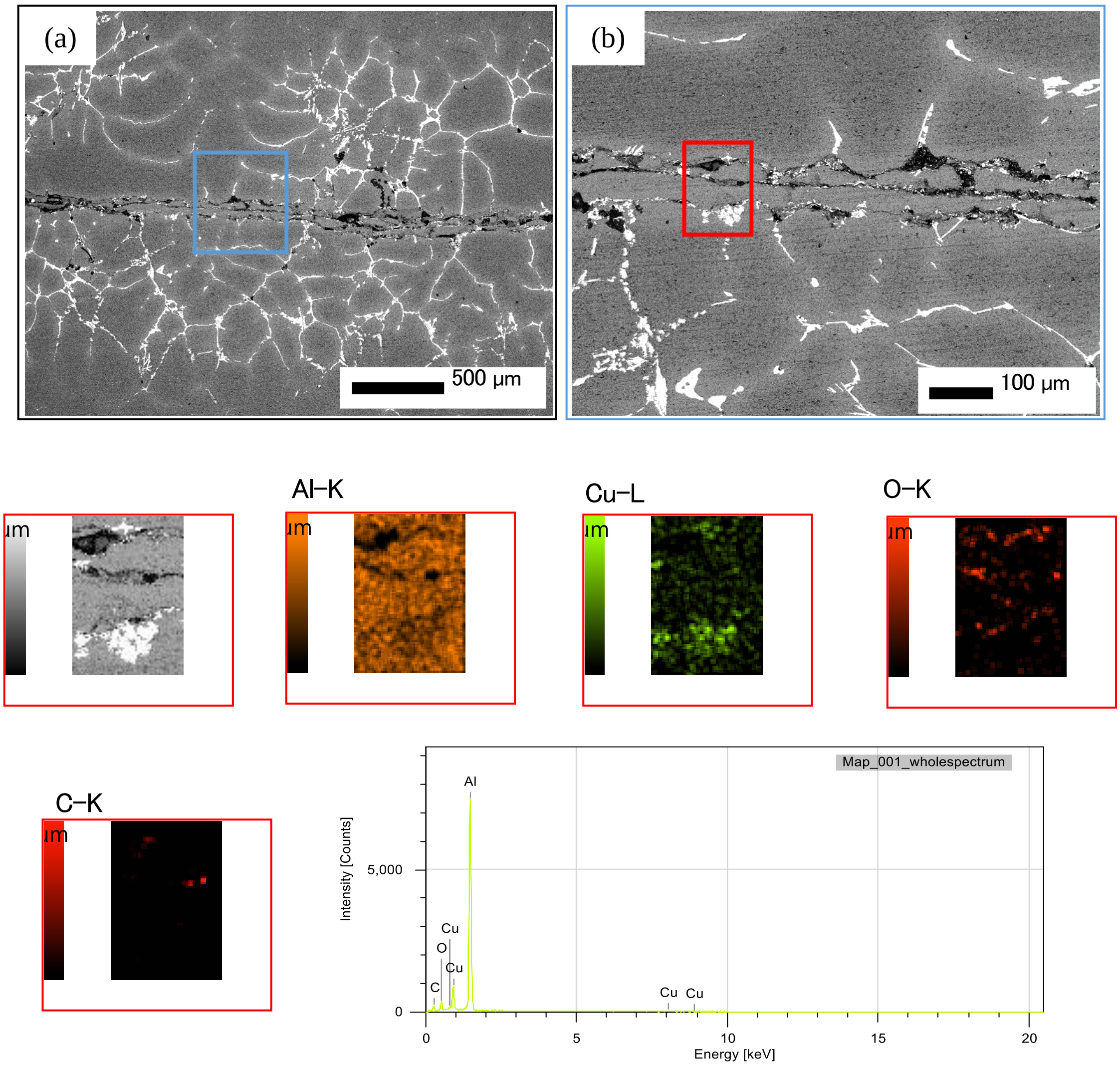


Figure 5. *SEM micrographs and EDS maps of the Al/Punched Cu sheet/Al metallic composite after Aging at 180°C for 2h followed by air cooling*

It can be seen from Fig.4. and Fig.5 that there is a copper diffusion within the aluminum sheet with a distance depassing the 500um from the interface, in addition to the formation of Kirkendall voids apart from intermetallic compound with a distance of roughly 100um from the interface in the case of both as bonded and after thermal aging treatment. The voids growth is less significant and are finer in the case of homogeneous bonds of Al/Al, compared to heterogeneous Al/Cu/Al bonds.in addition, the typical microstructure and mapping of element distribution for the bonded Al/Al and Al/Cu/Al joints without and after aging heat treatment shown respectively in Fig.3 revealed that the IMCs layer thickness of the Al/Al is very thin comparing to that Al/Cu/Al. Moreover, due to the lower (0,5mm) thickness of the punched Cu sheet used to produce the Al/Cu/Al, it was seen that there is disappearance of Cu sheet in both cases in as prepared without heat treatment and after aging.

3.2. *Mechanical properties*

The mechanical properties especially tensile behavior and micro-hardness profiles along the cross section of samples as produced without post heat treatment and after aging are presented in this section.

3.2.1. *Tensile behavior*

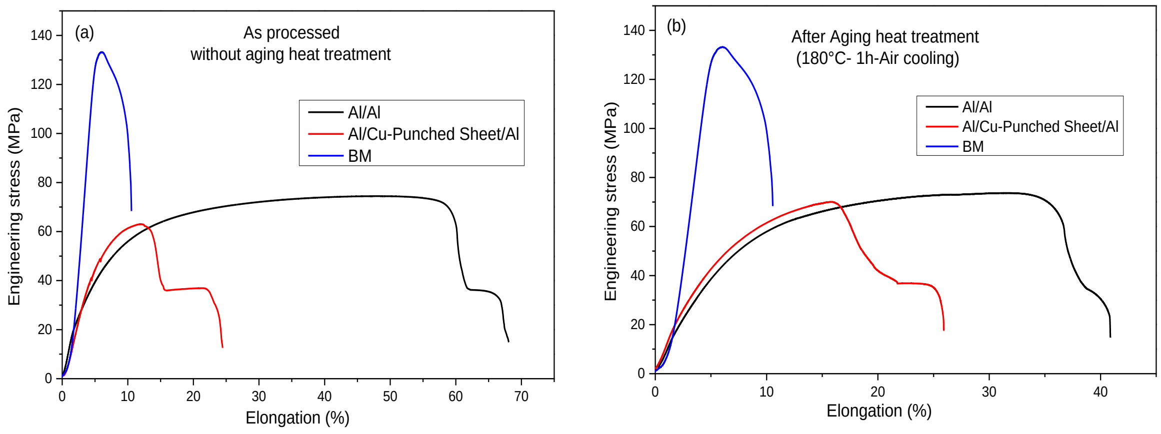


Figure 6. *Engineering Stress-strain curves of the prepared metallic composites: (a) without heat treatment, and (b) after aging at 180°C for 1h followed by air cooling.*

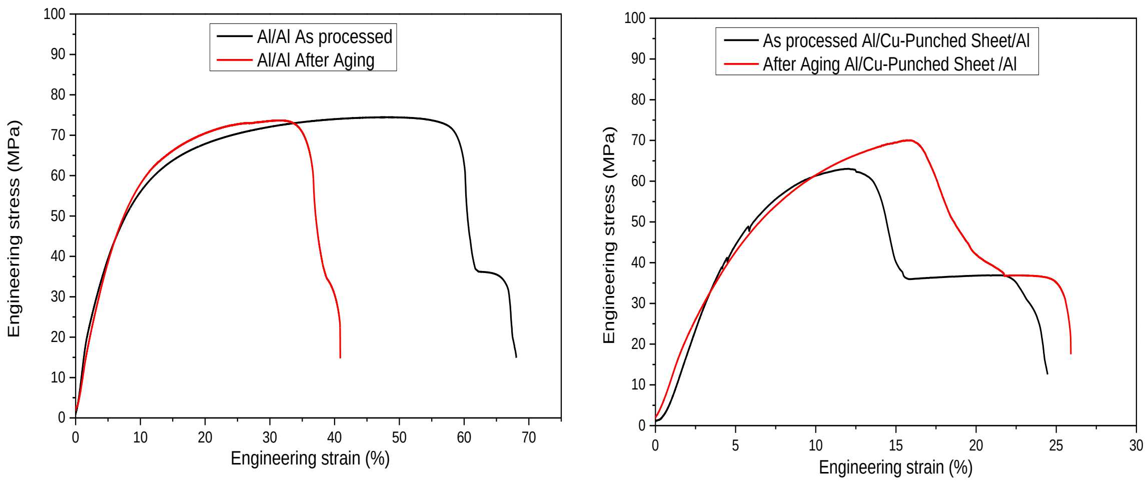


Figure 7. *Engineering stress-strain curves wihout and After aging of: (a) Al/Al sample and (b):Al/Cu punched sheet/Al sample*

From Fig. 7(a-b) that represents the engineering stress-strain curves of the prepared samples without post heat treatment and after aging, it is noticeable that in comparison with the Al base metal, the prepared bi-metallic composites exhibited drop of strength for both cases with and without aging. while a good elongation improvement was observed. Particularly in Al/Al samples based on homogeneous bonding and showed the higher total elongation roughly 70%, while an elongation of 43% is obtained in the case of sample prepared using the punched copper sheet. An improvement from 42% to 70 % is seen in the case of Al/Al with aging while an elongation drop is seen from 25% to 23% in the case of Al/Cu/Al samples such result is related to the presence of micro-voids when Cu is stacked between Al sheets as well as to the formation of IMCs at the interface.

3.2.2. *Hardness measurements*

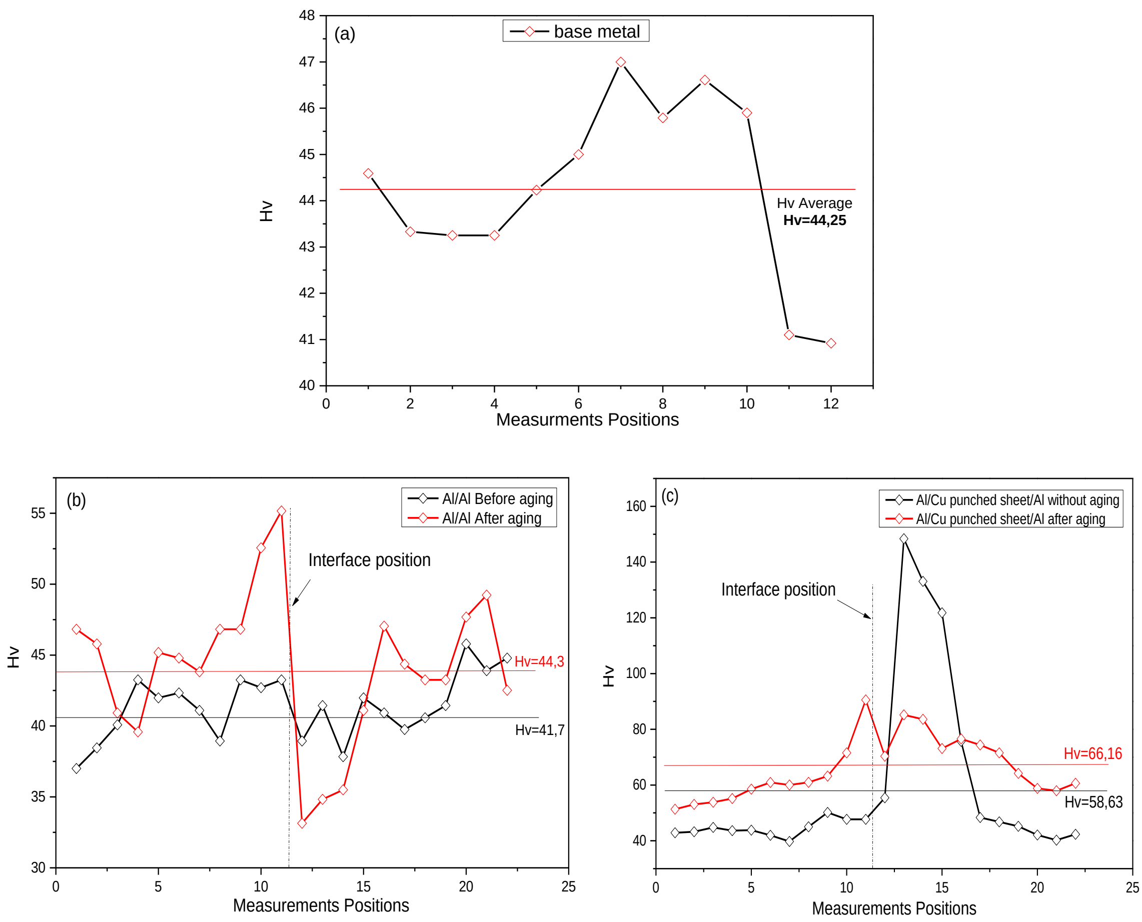


Figure 8. *Vickers microhardness profiles : (a) Base metal, (b) Al/Al, and (c): Al/Cu-punched sheet/Al samples*

On the other hand Fig. 4(b) shows the measured micro hardness profiles along the cross section direction of the prepared bimetallic composite, thus it can be seen that the higher values are obtained in the case of small grid size at Al and steel wire positions. The IMCs produced by the diffusion bonding are the thin layers, thus a localized evaluation method, the microhardness was used to quantitatively characterize the brittleness of the IMCs of the two kinds of joints. The Al-Al interface region in the homogeneous joint which has the lower hardness (Fig. 8(a)), because it keeps structure free of defect such micro-voids and IMCs Comparatively, the microhardness of Al-Cu of the heterogeneous bonding (Al-Cu-Al) with cracks at the interface exhibited high values especially at near to the interface positions (Fig. 8(b)) especially for sample without heat treatment.

Conclusion

Diffusion bonding process is a viable method to make reliable interconnections between Al and Cu. This paper investigates interface morphology and metallurgical behavior of the bond formed between Al/Al an Al/Cu for two different design and processing conditions with and without thermal aging period. Therefore, based on the comparative study the microstructures and mechanical properties of the diffusion bonding of Al/Al, Al/Cu/Al and the following conclusions can be drawn:

– The result showed an discontinuous bonded partion, despite the fact that the metals were physically bonded, this is due to the formation of Kirkendall voids in heterogeneous (Al/Cu) bonds comparing to homogeneous Al/Al bonds ;

– The distribution of intermetallic compounds and cavities at the interface position have a destructive impact on the bimetallic composite properties and affect the plasticity of the joint ;

– Mechanical improvement are obtained in the case of Al/Al after aging heat treatment while in the case of Al/Cu samples low properties are obtained.

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