Journal of Al-Nahrain University Science Vol.16 (3), September, 2013, pp.92-97

The Reliability of Bonding between Alumina-Pure Metals Through Diffusion Mechanism

Thamir A. Jabbar[*1], Zareh A. Sarkis[**] and Arwa G. Nagie[*]
[*]Department of Physics, College of Science, University of Al-Nahrain.
[**]Department of Material Research, Ministry of Sciences and Technology.
[1]E-mail: Mialdrthamir05@yahoo.com.

Abstract

Bonding between dissimilar materials such as alumina to metals by diffusion mechanism was investigated in this work. Foils of high purity metals (Silver, Copper, Zinc, Aluminum, Lead and Tin) have been prepared with 1mm thickness and area of 1cm x 1cm. The foils have then be placed between two alumina blocks of similar area and 0.5cm thickness as a sandwich panel.

Bonding has been achieved by using a suitable fixing under pressure of 0.3 MPa and then heated to about 90% of the melting point temperature of each investigated metals for 2 hours as a socking time in an atmospheric condition.

For evaluation the bonding strength of fabricated joints, tensile test technique was used for this purpose. Three categories of bonding strength were obtained but the upper value of joint strength obtained is $86.5x10^4$Pa of the joint involved silver and tin metals. Obviously three types of fracture surfaces were obtained; fracture in alumina part, fracture in the interface region and fracture in metal part. Fracture surfaces were attempted by NDT (non destructive test) using optical microscope and x-ray techniques.

Due to reduction of surface and bulk diffusivity an oxidation layers which covered the contact surfaces was found effected parameters caused to reduce the diffusivity and followed bonding strength of the fabricated joints.

Keywords: Bonding, Solid State diffusion, Fracture Surfaces, Dissimilar materials.

Introduction

Joining of dissimilar materials like ceramic to metals presents a challenge, significantly different than similar materials joining. Generally, the joint strength is a result of mechanical, chemical and physical interactions between the flat faced of alumina-metal prepared for joining [1].

One of direct bonding techniques is solid state diffusion bonding, which is defined as a process by which two normal flat interfaces can be joined at an elevated temperatures (about 50%-90% of its melting point of parent materials) using an applied pressure for suitable time [1]. The aim of diffusion bonding is to bring the surfaces of the two pieces being joined sufficiently close that inter diffusion can result in bond formation. However, there are two major obstacles that need to be overcome in order to achieve satisfactory diffusion bonds. Firstly, even highly polished surfaces come into contact only at their asperities and hence the ratio of contacting area to facing area is very low. Secondly in certain materials, the presence of oxide layers at the faying surfaces will affect the ease of diffusion bonding. Diffusion bonding of most metals is conducted in vacuum or in an inert atmosphere (normally dry nitrogen, argon or helium) in order to reduce detrimental oxidation of the faying surfaces. Bonding of a few metals which have oxide films that are thermodynamically unstable at the bonding temperature (e.g. silver) may be achieved in air [2,3].

Solid state diffusion can be mathematically describe by two differential equations which are called Fick's first and second laws [4,5]. Many factors are found effected in diffusion mechanism such as particle size at interfaces of both joint components, oxidation and thermal gradient across the potential barrier (joint surfaces)[5].

The advantages of solid-state diffusion bonding can be summarized in some points; the process has the ability to produce high quality joints, joining of dissimilar materials with different thermo-physical characteristics, high precision components with complicated shapes or cross sections can be manufactured without subsequent machining and the consumable costs of diffusion bonding are relatively low [6] .

The purpose of this study was to evaluate the reliability of bonding which is achieved between alumina and metals through diffusion mechanism.

Experimental Part

High purity metals of Sn, Pb, Zn, Al, Ag, and Cu of 99wt.% manufactured by Fluka company, Swiss product, as a thin foils of thicknesses about 1mm were prepared in this study as well as the other partner is polycrystalline alumina of 99.8wt.% purity, manufactured by ALM-41 Sumito. U.K., with dimension 1cm x 1cm x0.5 cm. To achieve sufficiently smooth surfaces at microscopic scale, wet grinding and polishing has been accomplished for all samples [6]. A suitable stainless steel fixture was fabricated to hold the partners contact together as shown in Fig.(1), where the metal foil was placed in between alumina blocks then under an applied pressure of $3x10^5$ Pa by using torque- spanner.

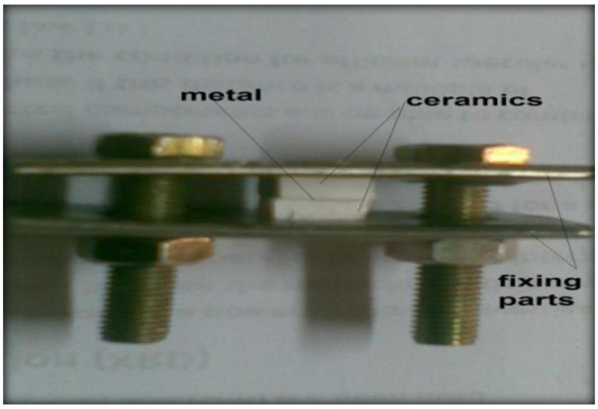


Fig.(1) Joining Fixture Set up.

The density and porosity of alumina which is used in this investigation were calculated and found 3.82 g/cm^3 and 4.03% respectively [7,8]. The surface roughness of alumina is shown in Fig.(2) with the help of an optical microscope under magnification of 100x.

Fig.(2) Optical Microscope image for face2 for Zinc. (Magnification 100x).

To reduce the metal oxidation, the assembly was embedded in alumina powder. The assembly was placed in a furnace at 0.9 T_m (T_m is the melting point of each metals) for two hours (socking time) under an atmospheric condition. The joining assembly was allowed to cool down gradually in the same way of heating in order to avoid the mismatch of thermal expansion between the partners.

Results and Discussion

Tensile tests were carried out on all actually joined bond as illustrated in Fig.(3), where the results state in Table (1).

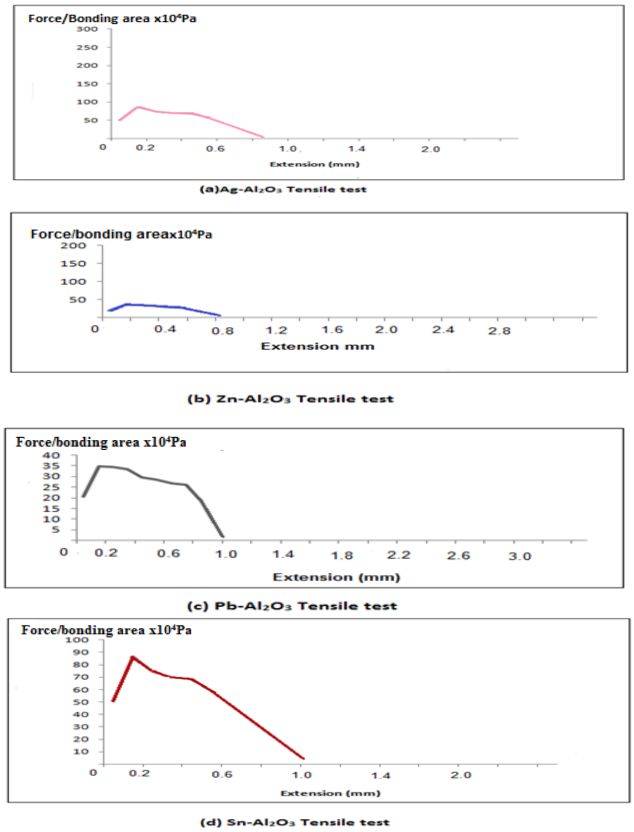
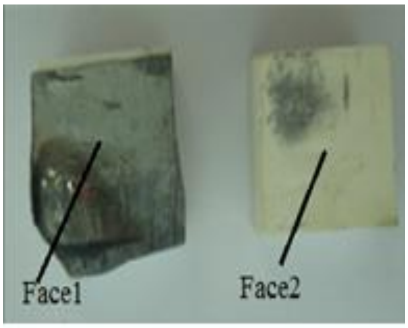


Fig.(3) Typical Tensile tests for (a) Ag-Al_2O_3. (b) Zn-Al_2O_3. (c) Pb-Al_2O_3.(d) Sn-Al_2O_3.

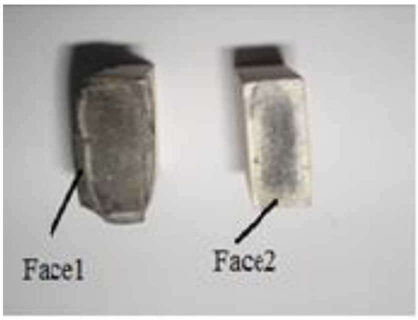
Table (1)
Fracture strength for ceramic-metals joined samples under bonding pressure of 0.3 MPa and 2hr socking time.

Metal	*Bonding Temperature ($\approx 0.9\ T_m{}^0C$) ∓10*	*Bonding Strength $x10^4 Pa(N/m^2)$*	*Bonding Category*
Ag	**864**	**86.5**	**strong**
Sn	**208**	**86.5**	**Strong**
Zn	**378**	**35**	**medium**
Pb	**295**	**35**	**medium**
Al	**594**	**Nill**	**weak**
Cu	**900**	**Nill**	**weak**

According to the results listed in Table (1), one can notice that the separation needs a different forces for separate each metals adhered with alumina although the whole joint samples were carried out at the same condition. The tensile tests revealed three types of fracture joint; fracture in the interface regions cleared in the joint involved metals of Zn and Pb samples, fracture in the alumina part as clear in Ag-Al_2O_3 joint and the fracture in the metal part as clear in joint involve Cu sample. The joints involved Ag-Al_2O_3 and Sn-Al_2O_3 considered as a highest values of bonding strength(these values was took a reference for comparison) and the joints involved Pb-Al_2O_3 and Zn-Al_2O_3, classified a medium values of bonding strength while the joints involved Cu-Al_2O_3 and Al-Al_2O_3 classified a weak values of bonding strength. These phenomena is shown in Figs. (4) and (5).



(a) Pb Sample



(b) Zn Sample

Fig.(4) Fracture in the joint interface for Pb and Zn samples.

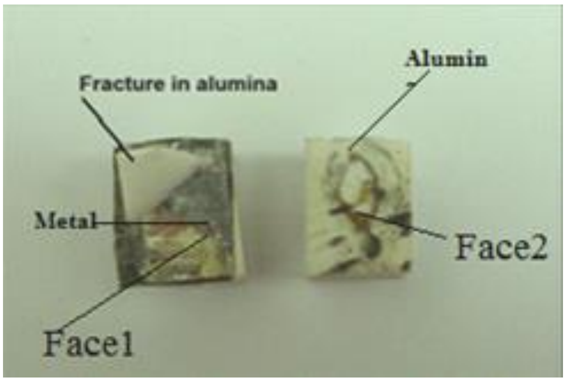


Fig.(5) The fracture in alumina part for Ag sample.

Due to diffusion mechanism between the alumina and pure metals, three categories of the joints strength are obtained as a result of fracture strength tests.

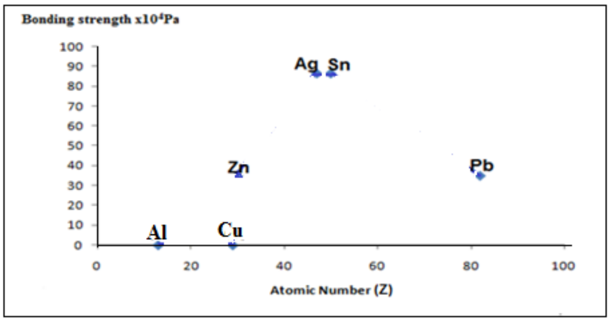


Fig.(6) Relationship of bonding strength against atomic number.

The good one include the metals Ag and Sn where these metals show a very thin oxidation layers covered the contact surfaces, the second category has a lower bond strength than the first and these joints include Zn and Pb, where these metals surfaces have also a very thin oxidation layers. While, the third category of joints which include Al and Cu have very lower bond strength where these metals have a thick oxidation layers covered its surfaces, due to the positive affinity of these metals against oxidation process. The oxides layers is a brittle property thus if the metals process shows a growth of metal oxide in the interface region thus the brittle layer will break the joint easily as expected. This behavior was studied by Shirzadi et.al[9]. Another expected reasons in which effects on the joint strength results are compatibilities of thermal expansion between the joint partners.

The effect of atomic number is also studied and show more complicated, one can notice that the bonding strength seems to be reducing with atomic number, which means the difficulty of solid state diffusion process with higher atomic numbers. To explain what happened at the interface regions, non distractive test (NDT) where achieved. The elemental analysis by X-ray fluorescence technique over the fracture surfaces for each sample is illustrated in Fig.(7).

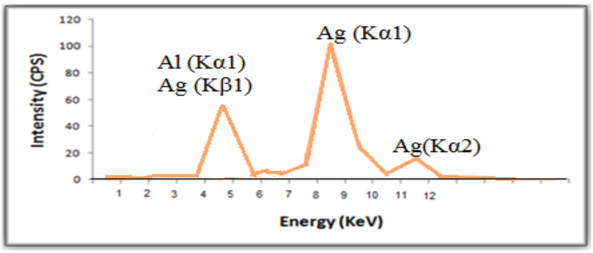


Fig.(7) X-ray fluorescence of silver- alumina sample (face-1).

In order to detect the chemical nature of interlocking bonding, an XRD technique was used to investigate the existence of chemical phases in the regions nearly from both surfaces of alumina and metals. One can think the un-existence of new chemical phases may be returned to the limitation of XRD technique, where these technique can be detect the phases of concentration more than 2wt. %. For these reason, the XRD patterns shows that no chemical reaction had been recorded in our study as shown in Fig.(8).

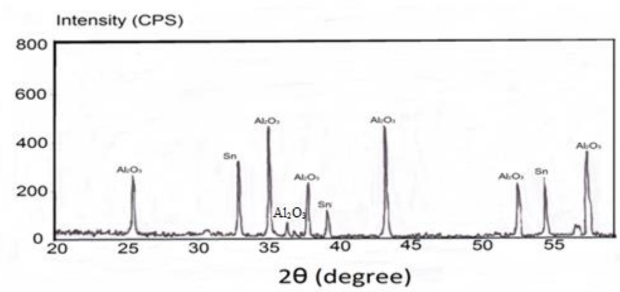


Fig.(8) X-ray diffraction of Sn sample face2.

From these experimental fact, one can conclude the nature of the bonds between the metals and alumina is not yet clear whether it is of chemical or physical nature [10]. In other hand the mechanical bonding by interlocking has been occurred between alumina of porous surface and the metals of smooth surfaces as shown in Fig.(9).

Optical microscope gives a good evident picture for all samples and express the cause of weakness of the bonding, such as the effect of oxidation, the characterization of the two fracture surfaces were illustrated in Figs. (9, 10) and (11).

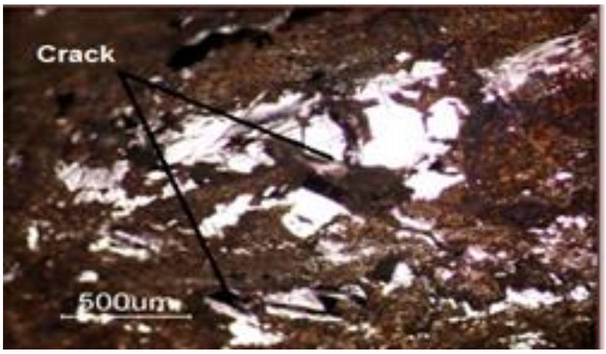


Fig.(9) Optical Microscope image for face2 for Zinc. (Magnification 50x).

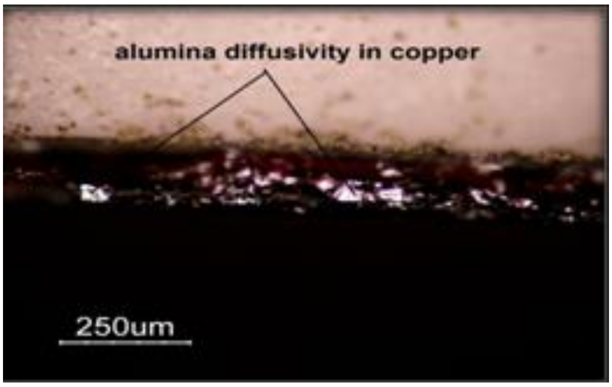


Fig.(10) Optical microscope image for Copper-alumina in tangential section. (Magnification 100x).

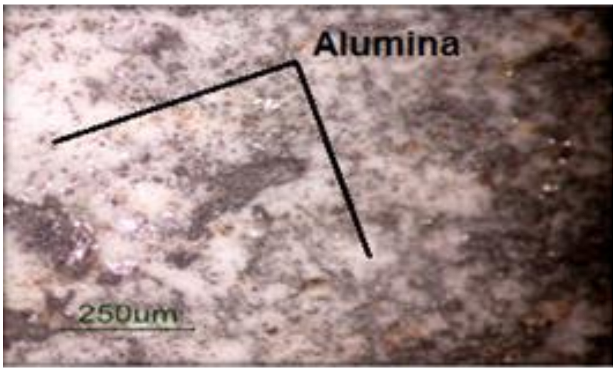


Fig.(11) Optical microscope image for face1 for lead.(Magnification100x).

Conclusions

1. Selected metals would diffuse to alumina ceramic if the components are maintained in close contact under predetermined pressure and heated to about 90% of their melting points. The pressure that necessitates good bonding was 0.3MPa (N/m^2) for all metals.
2. From XRD tests, no indications of possible new phases due to chemical reactions were observed at the contact regions.

References

[1] Amir. Sh., ***''Introduction to mechanical properties of materials"*** University of Cambridge, Surface and Interface Analysis, 2009.

[2] Donald, R. Askeland, Pradexpp P**.** ***"The science and engineering of materials"***, Thomson, 2009.

[3] Melvin M**.,** ***"Introduction to Mechanical Properties of materials"*** Eisenstadt collier Macmillan publishers, Ch. 10, London, 1971.

[4] Lawrence H. Vane Vlack, "***Elements of materials science and engineering***", sixth addition, Wesley publishing company, 1989.

[5] Wang, Juan, Liyajiang and Mahaijun " ***Effect of Cr and Ni on diffusion bonding of Fe3Al with steel"*** Indian Academy of Sciences, Bull. Mater. Sci., Vol. 28, No. 1, February 2005.

[6] William D. Callistr, **"Fundamentals of materials and science and engineering"**, John Wiley and Sons, 2007.

[7] Nicholas M. G., ***"Active Metal Brazing "*** British Ceramic Trans. J, 85 , PP.144-146, 1986.

[8] BORBIDGE W.E., ALLEN R. V. and WHELAN P. T., ***"Technique for Joining Ceramic to Metals"*** space cl-13 p.o box 160, 1986.

[9] Amir. A. Sh., Assadi H. and Wallach E.R. ***"Interface Evolution and Bond Strength when Diffusion Bonding Materials with Stable Oxide Films"*** Surface and Interface Analysis; 31:609-618, 2001.

[10] Mamora Nakamura and ststhis D. Peteve*s* ***"Solid State Bonding of Silicon Nitride Ceramic with Nickel Chromium Allot Interlayers"*** Vo.73, No.5, 1990.

الخلاصة

يهدف البحث الى دراسة متانة الربط الانتشاري بين المواد غير المتالفة مثل السيراميك (الالومينا) والمعادن. تم استخدام معادن عالية النقاوة (الفضة والنحاس والخارصين والامنيوم والرصاص والقصدير) وتم تهيئتها على شكل رقائق بسمك ١ ملم وبمساحة (١x١) سم^{٢} لغرض وضعها بين مكعبين من الالومينا وبابعاد (٠,١x١x١) سم^{٣} بعد ان اجريت عليها عمليات التنظيف والصقل. تم حصر المجموعة بقفيص فولاذي وضغطت بقوة ٠,٣ ميكاباسكال تمهيدا لوضعها داخل الفرن ليتم تسخين المجموعة بدرجة حرارة ٩٠% من درجة انصهار اي من معادن البحث ولمدة ساعتين. لوحظت ثلاث اصناف من متانة الربط ولكن تم تمييز اكبر قيمة وكانت ٨٦,٥x١٠^{٤} باسكال لمفصل الفضة. اجريت اختبارات للسطوح المتكسرة بواسطة التقنيات الغير اتلافية مثل الاشعة السينية والمجهر الضوئي. بسبب طبقات الاكسدة المتكونة على سطوح المعادن والتي ادت الى تقليل متانة الربط الانتشاري فقد تم تمييز ثلاثة انواع من السطوح المتكسرة وهي الكسر في منطقة الالومينا والكسر بين المنطقتين البينية بين الالومينا والمعدن والكسر الاخير في منطقة المعدن.