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Experimental analysis of the strength of silver–alumina junction elaborated at solid state bonding

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The mechanisms of ceramics–metal assemblies, particularly silver and alumina, can be better understood by studying the strength of their adhesion. These two materials are a priori non-reactive, their thermodynamic work of adhesion is low and the difference between their thermal coefficients of expansion in very considerable. In this study, the strength of silver–alumina junctions elaborated at solid state by thermo-compression is tested by an indirect tensile test and shearing one. The effects of several parameters such as: the pressure of bonding, the time of bonding, the temperature, and the oxygen dissolve in metal solid solution on the strength of the junction are analyzed. The obtained results show that the resistance of the junction is affected by all this parameters and it is essential to optimize these different parameters in order to increase the durability of the junction. It was also shown that the diffusion of the silver in alumina could be the cause of the damage of alumina near the interface.

1. Introduction

Mechanisms occurring during metal–ceramic bonding nowadays have begun to understand owing to recent adhesion studies. It has been proved that strong intra-molecular chemical bonds exist and lead to higher adhesion energy compared to the adhesion achieved by Van der Waals bonds [1,2]. Two kinds of bonding can be distinguished [1,3]:

- Non-reactive bonding where no phase is growing at the interface. In that case it is possible, after optimization, to obtain very strong joining particularly by solid state bonding [4,6].
- Reactive bonding, for which at least one new phase is formed at the interface between the two base materials. In this case, the bonding strength will be related to the interface properties but also to the properties of the new phases.

This study is carried out in this context and concerns alumina–silver joining. Alumina is still today a very commonly used ceramic, its physical and mechanical properties have been fully characterized. It is also well characterized from the fundamental point of view. Silver is a non-oxidized metal and it does not react with alumina. Moreover, diffusion properties in this system are well known (within bulk, along grain boundaries or dislocations) [7,8]. The thermal expansion coefficient of silver is about 2 times higher than that of alumina ($\alpha_{Ag} = 19.6 \times 10^{-6}\,K^{-1}$, $\alpha_{Al2O3} = 8.8 \times 10^{-6}\,K^{-1}$) and its Young modulus is much lower (E_{Al2O3} = 340 GPa, E_{Ag} = 79 GPa). The energy of adhesion of silver on alumina is low (W_{ad} = 590 mJ/m^2) [1,9] by comparison with other metals used in non-reactive condition (Cu, Ni, Fe, Al, ...). This is related to weak wettability of alumina in silver (contact angle $\theta = 130°$) [9].

In general, the effect of the metal diffusion in the ceramic during the junction on the properties of the assembly is not well known, its then essential to choose a perfectly known metal in this point of view: the diffusion coefficients of silver in sapphire and in polycrystalline alumina in the bulk and along dislocations are well-known.

Because of these characteristics, silver/alumina bonding seems to be particularly difficult to realize. Solid state bonding processes have been used to overcome these difficulties. In this method the metallic joint (here silver) is placed between two alumina bodies. The joint is plastically deformed under the simultaneous effects of pressure and temperature. The latter ranges from 0.57 T_f to 0.9 T_f (T_f is the melting temperature of metallic joint). The solid state bonding process allows us to obtain high strength and good air-tight bonds but sometimes requires very high temperature and pressures and even long bonding times. This results in a high cost for the ceramic–metallic components obtained by this technology. Works already published are essentially relevant to the optimization of solid state bonding parameters (pressure, temperature,

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