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Diffusion bonding of alumina using interlayer of mixed hydride nano powders

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Abstract

In this study, mixed hydride/alanate nano powders in the Al–Mg system were used as the interlayer for low temperature diffusion bonding of dense alumina parts. Decomposition of hydride nanopowders at bonding temperatures in-situ formed metals and alloys nano particles with oxide free surfaces and high sinter-ability in the interlayer. Nano powders sintering behavior in the interlayer and formation of compounds in the reaction layer during diffusion bonding were studied. Mixture of 50–50 M ratio of AlH_3 and $Mg(AlH_4)_2$, as the interlayer improved bond strength of the joints. Diffusion bonding products were formed in the MgO–Al_2O_3 spinel system with different stoichiometries. Bond strength improved up to 202 MPa by induction hot pressing alumina parts at low bonding temperature of 400 °C under pressure of 20 MPa during 30 min bonding period.

Keywords: D. Al_2O_3; Diffusion bonding; Hydride; Alanate; Nanopowder

Introduction

Oxide based ceramic bodies, with exceptional physical and mechanical properties at corrosive and high temperature mediums and high wear resistance with low friction coefficients, have been used in many different industries as semiconductors, insulators, and armors [1,2]. Despite the unique properties of the engineering oxide ceramics in optical, electronic, refractory, and tribological fields, many applications require special shapes in each dimension which can be achieved by using different parts with reliable joints. These bonding processes required the developments in techniques to join ceramics to ceramics/metals [2]. Ceramic parts can be bonded via various methods: (i) transient liquid interlayer bonding, (ii) refractory braze alloys, (iii) refractory glass bonding, (iv) bonding using polymer precursors, and (v) diffusion bonding. Among these techniques, brazing and diffusion bonding are more suitable methods and had been the subject of many researches [3–5]. Diffusion bonding is mostly carried out by holding two nominally flat surfaces together at elevated temperatures. Bonding happens in three steps: (i) elimination of interfacial voids by material transition or compaction, (ii) adhesion by atom flow relaxation or grain formation, and (iii) chemical reaction and phase formation along interfaces [6]. Direct diffusion bonding of oxide ceramic parts requires high pressures and temperatures, up to 250 MPa and 1500 °C, resulting exaggerated grain growth in parts [7]. Mutual bonds form via diffusion along interfaces, diffusion in outer layers of bulk (for ceramics and metals) or plastic flow after yield and creep (for metals). As seen, based on presence of metal interlayers (as foils or powders) combination of controlling mechanisms can be activated which can moderate pressure and temperature of the process [8]. Hybrid diffusion bonding processes like transient liquid phase bonding (TLPB) and partially transient liquid phase (PTLPB) are based on melting or partially melting metal interlayers during heating, liquid flow and filling voids, and resolidification [7,9]. Residual metallic interlayer materials affect joint strength and operating temperature range of bonded parts [9]. Most diffusion bonded parts (like laminate composites) with dense bulk or foil interlayers showed defects like un-joined areas, cracked ceramic surfaces, inclusions

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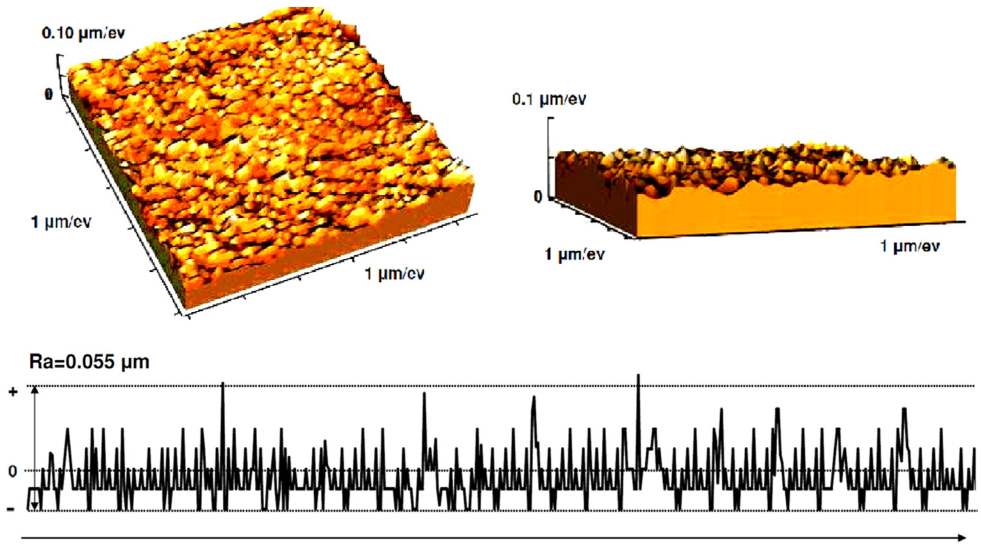

Fig. 1. Surface roughness of the alumina parts before diffusion bonding with 150 µm linear profile.

along interlayers, and pores near joint surfaces [8,10]. Using mixtures of powders as the interlayer materials improved bond qualities along mutual surfaces by activation of rapid sintering of powders during joining processes [11]. High activity and sinter-ability of nano-sized powders in interlayers improved bonding qualities [12]. Sintering process in interlayers can coincide with reactions between interlayer materials and oxide ceramic surfaces, like formation of mixed ceramics (RR'_2O_3) in oxide systems [10,13]. In-situ formed nano powders with minimum surface contaminations like surface oxides can improve diffusion bonding processes by reducing bonding pressure and temperature during sinter–welding process [14–16].

In this study, mixed metallic hydride and alanate nanopowders were used as the interlayer materials for diffusion bonding of alumina parts using the induction hot pressing system. Effects of interlayer on bond formation at lower temperature and pressures, inter layer powders sinter-ability (axial shrinkage), and bond properties like shear strength were studied.

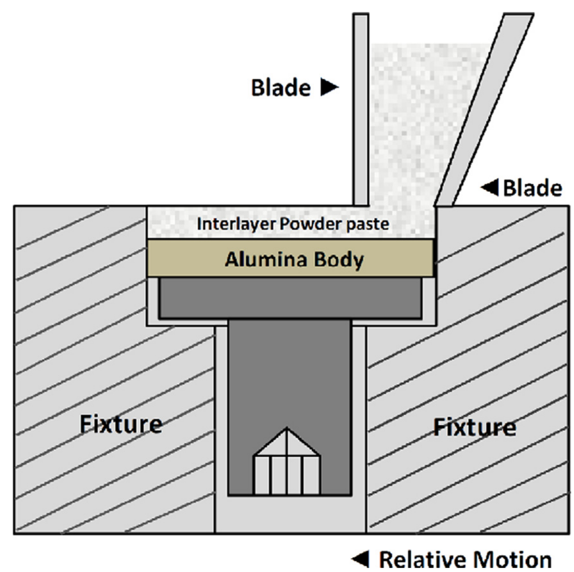

Fig. 2. Schematic view of custom designed tape casting die and blade.

1. Materials and methods

Solid state diffusion bonding of ceramic bodies was carried out by applying sufficient pressure on ceramic bodies with appropriate interlayer in temperatures lower than the melting point of the parts, especially interlayer nanopowders. Powders of polycrystalline alumina ((Al_2O_3, $>95\%$ pure (<1 wt% CaO, <0.5 wt% MgO, <1 wt% Fe_2O_3, <1 wt% Cr_2O_3, <1 wt% TiO_2)), Grauf Klaus Gmb, Germany) were used to manufacture disks with ϕ17 mm and 5 mm height. Pressureless sintering regime of uni-axial pressing at 100 MPa with 1650 °C sintering temperature for 24 h dwelling time and 36 h cooling under air atmosphere was applied for manufacturing ceramic bodies. The surfaces of Al_2O_3 bodies to be joined were ground using 400, 600, 1000, and 1200 grid silicon carbide papers, followed by polishing with diamond paste and Al_2O_3 suspension to achieve average surface roughness of Ra: ~55 nm, measured by non-contact mode atomic force microscopy (AFM, solver P47H instrument). Roughness profile was analyzed along surfaces. A schematic micrograph of polished surface roughness and roughness profile are shown in Fig. 1. Alumina bodies were cleansed before bonding using a three stage washing process, consisting of 30 min in de-ionized water medium with supersonic wave to remove residual debris, 30 min in methanol medium for degreasing, and 30 min in acetone medium for final wash and dehumidifying. The interlayers, AlH_3 and $Mg(AlH_4)_2$ nanopowders, were synthesized via mechano–chemical activation process (MCAP). The interlayer was applied using custom designed Cr-steel die and blade tape casting instrument. The thickness of the interlayer could be controlled with 10 µm precision by turning treaded spindle. A schematic image of the mechanism is shown in Fig. 2. Nitromethane (CH_3NO_2), a non-reactive liquid with hydride/alanate, was used to make starting 90 wt% nano powder mixtures (pastes) for tape casting. 50 µm thickness interlayers