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Analysis of interfacial joint strength of microwave and conventionally brazed alumina ceramic joints using scratch test method

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Abstract

The present investigation demonstrated the comparative studies on interfacial joint strength of the alumina-alumina joints fabricated by conventional and microwave-assisted brazing techniques using scratch test method. Scratch tests were performed on cross-sectional surfaces of the alumina joints under steadily increasing normal loads up to 140 N. The scratches were made with a Rockwell C hardness tester stylus with 200 µm radius. The response of the joints was investigated by measuring the fluctuations in the tangential force during scratch test as well as by the examination of the scratch tracks. It was observed that microwave brazed joint had better interfacial joint strength in comparison to the conventionally brazed joint.

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Keywords: Ceramics; Alumina; Scratch test; Microstructure; Interfacial joint strength

1. Introduction

Surface engineering of materials plays a significant role in a variety of functional applications ranging from decorative appearance to protecting the substrates from wear, corrosion and other forms of attacks. An important

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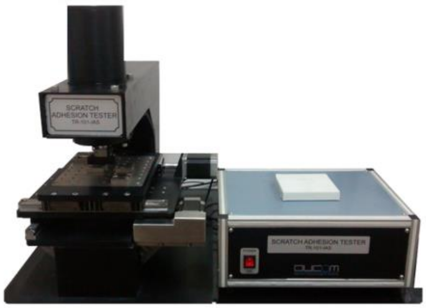
factor that determines the quality and service lifetime of the coatings is their cohesive and adhesive strength. Heaven [1] first developed the scratch test for adhesion evaluation in 1950. Benjamin and Weaver [2] proposed critical load (L_c) as a quantitative value to evaluate the coating adhesion. Later on, the use of scratch testing increased remarkably with the application to adhesion testing of thin hard coatings [3]. The scratch test has been established as one of the main techniques for adhesion testing of coatings [4–6]. The technique was made more useful by the introduction of acoustic emission [5], which can also be used in the assessment of damage to monolithic materials [6]. Scratch testing is a potential technique for providing more fundamental information on wear mechanisms. It can be utilized as a test that creates the interaction of a material with a single abrasion scratch occurrence [4]. Over the past two decades, this technique has been extensively used to assess the adhesion of PVD/CVD deposited super hard nanocomposite coatings that usually exhibit a high residual stress at the interface of coating and substrate [7–9]. Moreover, the scratch test is an essential tool for quality control of materials used in wear and abrasive environments and can detect premature adhesive and cohesive failure of the coatings during realistic applications. Siddiqui and Jones [10] measured adhesion strength of Nb thin film over polished alumina substrate using nanoscratch testing.

Researchers have not ever utilized the scratch tests for the characterization of interfacial joint strength of the ceramic joints. Therefore, the present investigation aims to assess the interfacial joint strength of the ceramic joints at microscopic length scales by using scratch test technique.

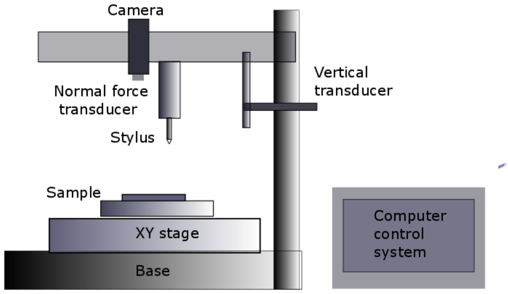
2. Experimental procedure

Pure alumina powder (Alcoa, USA; 99.99 % purity) was cold isostatically pressed (EPSI NV, SO, 10036 Belgium) to form cylindrical shaped compact, dried and subsequently calcined in an electrical furnace at 800 ˚C for 1 h (ELECTROHEAT, Model No. EN170QT, Naskar & Co., Howrah, India). The calcined powder compacts were cut and finally sintered at 1600 ˚C for 2 h. The joining faces of the sintered alumina samples (Dia.–10 mm, thickness–2 mm) were ground in a grinding machine (BAINLINE Belt linishing machine, Chennai Metco Limited, Chennai, India) and polished in a polishing machine (SS1000, LECO Corporation, MI, USA) with 6 µm, 3 µm and 0.25 µm diamond pastes (Buehler USA) resulting in average surface roughness (R_a) of ~0.05 µm. Samples were then cleaned ultrasonically with acetone for 15 min. TICUSIL paste (68.8Ag–26.7Cu–4.5Ti in wt. %, WESGO Inc., Hayward, CA 94544 USA) was used as filler metal, which was painted onto the prepared alumina surface using an artist's brush. Alumina samples were joined conventionally in a high vacuum furnace (Hindhivac Private Limited, Bangalore, India) at 950 ˚C for 20 min with a vacuum of 5×10^{-6} mbar. Heating and cooling rate was maintained according to our earlier paper [11]. The microwave-assisted joining was conducted in a multimode microwave furnace (Enerzi Microwave Systems Pvt. Limited, Bangalore, India). Principle of microwave hybrid heating (MHH) was employed using SiC powder as susceptor so as to initiate coupling of the microwaves with the alumina specimen. The alumina fiberboard was used as the insulator. The specimens were brazed by microwave heating at 950 ˚C for 20 min with a heating and cooling rate of 25 ˚C /min in argon atmosphere.

The low load scratch test system was designed to enable tests to be carried out accurately at low applied loads. The rationale that lies behind this test system is that the abrasion that occurs in many applications takes place through low load contacts. Key features of the test system (Fig. 1(a-b)) are the frictionless bearings (based on crossed leaf spring suspension) for the lever arm, full computer control and data acquisition, measurement of frictional load by a horizontal axis of a dynamometer, measurement of the applied load by a static load cell in addition to the vertical axis of the dynamometer, measurement of the horizontal position of the test-piece, and the vertical position of the indenter.



(a)



(b)

Fig. 1. (a) Scratch tester and (b) schematic diagram of scratch tester.

The sample was clamped onto the X–Y table, and the system was adjusted so that the lever arm was horizontal when the indenter just touched the sample. The position of the sample was adjusted using the X–Y table so that the full array of scratches could be carried out automatically under the control of the personal computer (PC). Arrays of six scratches separated by 1 mm were performed on the samples with 5, 50, 100, 120, 130 and 140N normal loads. Loads were applied to the scratch indenter by means of a pneumatic cylinder through a lever arm, symmetrically pivoted on ball bearings. The pneumatic cylinder allowed a smooth and continuous increase of the load, irrespective of deflections of sample or sample holder. The samples were mounted on an X–Y table with stepper motor drives for positioning and scratching. The normal and tangential loads were measured with load cells attached to the pneumatic cylinder and the stylus holder, respectively. The loads and scratch displacements were continuously recorded via a microcomputer, which also controlled the X–Y table during each test. The speed was intentionally kept low at 1 mm s^{-1} to reduce frictional heating at the contact between the indenter and the sample. The alumina ceramic joint samples were ultrasonically cleaned in alcohol before testing and the stylus was wiped with ethanol before each scratch test. All experiments were performed in laboratory air at 25°C and a relative humidity of 50%. The scratches were subsequently examined by scanning electron microscopy (SEM, model - LEO S430i, LEO, UK). The surface roughness of the alumina substrate region and braze region was measured by a surface profilometer (ContourGT 3D optical microscope, Bruker, USA).

3. Results and discussions

Figure 2 (a-d) shows the normal load and frictional force versus distance graphs for the conventionally brazed joints at a normal load of 5, 50, 100 and 140 N. It was observed that frictional force slightly increased at the interfacial region with the application of a normal load of 5, 50,100 N. However, increment in frictional force was observed to be quite high in case of applying a normal load of 140 N. As the surface roughness of the interfacial region (R_a~0.35µm) was higher than that (R_a~0.15µm) of the alumina substrate region, frictional force slightly increased when the scratch indenter traversed the interfacial region. With increasing the applied normal load of 140 N the frictional force was observed to be quite high throughout the whole scratch track, noticeably at the interfacial region due to considerable amount of plastic deformation of the metallic braze region [12]. Smooth scratch track was noted in case of low load application. At higher loads, ceramic material was shattered and metallic braze region was plastically deformed. This is quite distinct from the SEM images of the scratch tracks of the conventionally brazed joint as can be seen from Figure 3 (a-d).

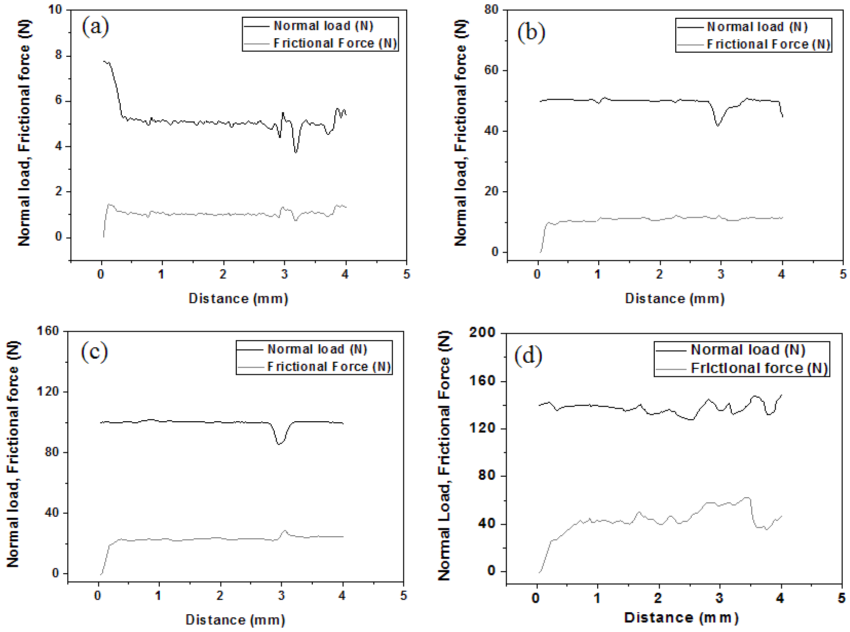


Fig. 2. Normal load and frictional force versus distance graphs for conventionally brazed joint at a normal load of (a) 5 N, (b) 50 N, (c) 100 N and (d) 140 N.

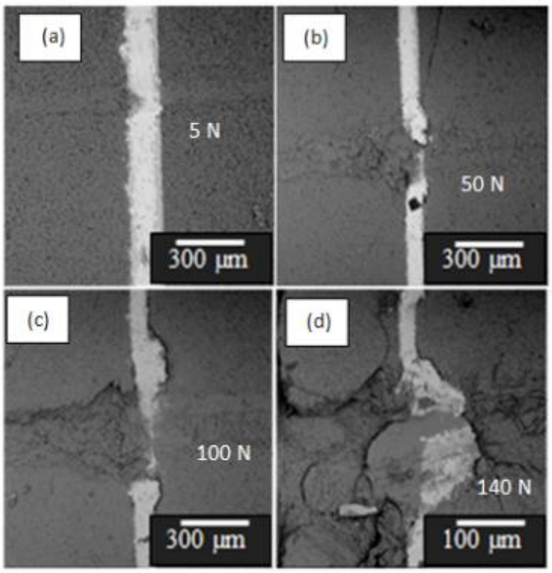


Fig. 3. SEM images showing scratch tracks for conventionally brazed joint at a normal load of (a) 5 N, (b) 50 N, (c) 100 N and (d) 140 N.

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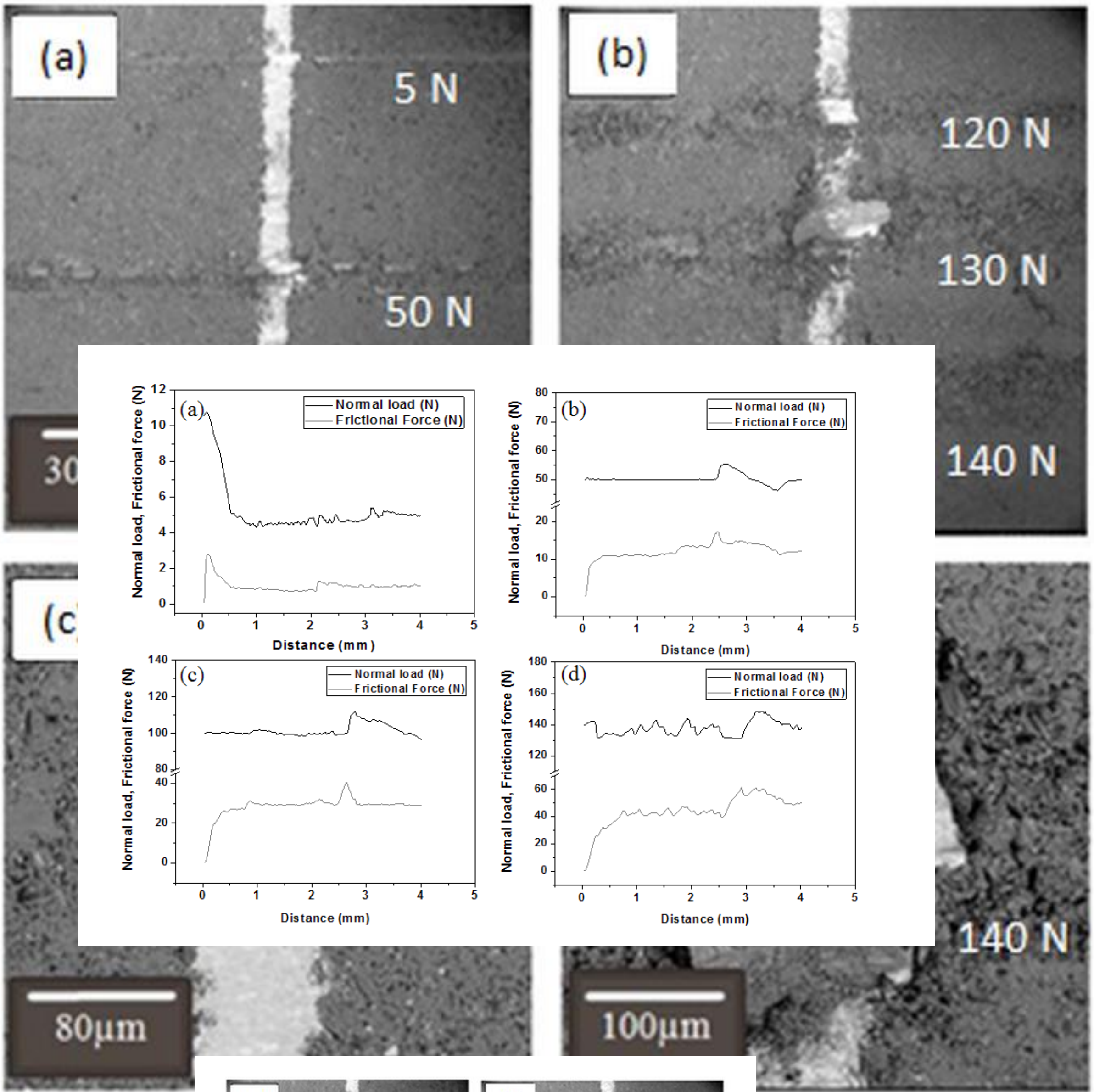

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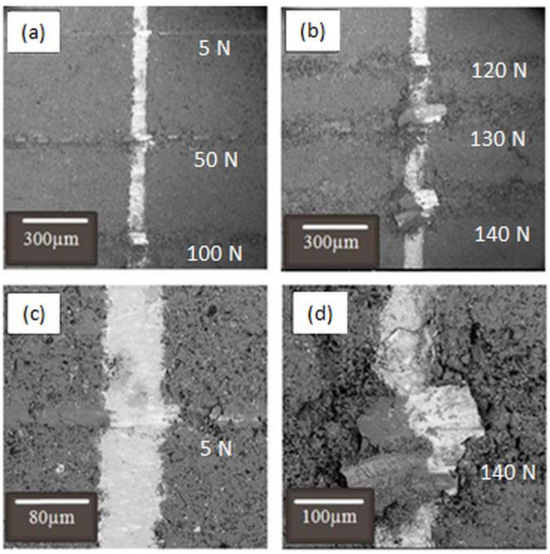

Fig. 5. (a) SEM images showing scratch tracks for microwave brazed joint at a normal load of (a) 5 N, (b) 50 N, (c) 100 N and (d) 140 N.

Scratch test data showed lower amount of plastic deformation in the braze region in case of conventionally brazed joint compared to that of the microwave brazed joint and thereby, indicating grater amount of interfacial joint strength of the microwave brazed joint. Therefore, greater amount of plastic deformation enhanced the reliability of the microwave brazed joint in terms of reducing the crack formation at the interfacial region leading to separation of substrate and braze region.

4. Conclusions

Scratch test analysis showed the superiority of the microwave brazing technique compared to conventional brazing technique for improving interfacial joint strength of alumina ceramic joints and subsequently, reducing the chance to brittle fracture.

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