PLASMA ENHANCED MICROWAVE JOINING

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ABSTRACT

A new method for plasma enhanced microwave joining of high purity (99.8%) alumina has been developed, The controlled application of a plasma between the adjoining surfaces of two rods permits the initial heating of low microwave absorbing alumina to sufficiently high temperatures where they can efficiently absorb microwave energy. With this technology, the adjacent surfaces of alumina rods can be melted and welded together in less than three minutes using approximately 400 watts of microwave energy. Four point bending tests measured fracture strengths of up to 132 MPa at the joined interface.

INTRODUCTION

The use of microwaves to join materials has been successfully achieved;[1-4] however, joining very low absorbing ceramics is still a challenge. To significantly absorb microwaves, a material must have a large enough imaginary dielectric constant, ε'' (≥ 0.05). In general, ε'' increases with temperature and thus most materials are reasonably good absorbers of microwave energy at higher temperatures ($\geq 800°C$). However, materials must be heated from room temperature for commercial microwave processing of materials to be economical. Conventional microwave heating techniques attempt to process a material by first placing it at a high electric or magnetic field position in a microwave cavity depending on whether the material is insulating or conducting and then turning on the microwave power. Unfortunately, the electromagnetic field strengths attained, even for optimum power transfer conditions, are usually not sufficient to heat materials with low ε'' ($\leq$ 0.01). Furthermore, when many materials are heated to high temperature, thermal runaway effects may cause hot spots or internal melting that are detrimental to the microwave heating process. Although high power magnetron and hybrid heating techniques have been used,[5] these techniques are expensive, slow, and still are not able to join very low absorbing ceramics starting from room temperature. We have developed and tested a new plasma enhanced joining method that can supplement microwave heating starting at room temperature and also continue to heat the rod interfaces to high temperature.

EXPERIMENTAL PROCEDURE

Commercial available 99.8% purity alumina rods from Coors Ceramics Co. were used in this work. The samples were 3“ long with 0.2” in diameter. No further surface preparation was needed. In this study, we used a magnetron source to excite a rectangular waveguide cavity in the TE 102 mode at 2.45 GHz. This mode has electric field maxima along the lines defined by $z/L_z = 0.25$ and 0.75 and $x/L_x = 0.5$ (see Fig. 1). An alumina rod was placed along one of these maximum E field lines ($z/L_z = 0.75$ and $x/L_x = 0.5$) with its end inserted approximately half way down the y axis ($y/L_y = 0.5$). This experimental arrangement was chosen since a plasma is generally ignited at a high electric field position in a microwave cavity. Helium gas was flowed through the cavity to ignite the plasma around the tip of the rod. The temperature of the rod tip was measured using a non-contact Everest Interscience IR thermometer (range -30-11 00°C) and an Accufiber non-contact pyrometer (range 500- 3000°C). After the Helium plasma was ignited, a second rod was inserted through the opposite hole below the first rod as shown in Fig. 2. The new rod was positioned with ≈ 0.5” gap between the rods. The plasma surrounded the gap due to the concentrated microwave field in the gap. After a short time, both adjacent rod tips were preheated by the plasma to temperatures ≈ 1000”C. The Helium gas was then turned off allowing the heated rod tips to directly absorb microwave energy, and quickly reach their melting temperature (2072°C). The rods were then pushed together with a force-controlled hydraulic pump to form a joint and then cooled at a controlled rate by gradually reducing the microwave power. The 6“ long joined sample was tested using a four point bending method with outer span ≈ 3“, inner span ≈ 1.5” and crosshead speed 0.04"/min.

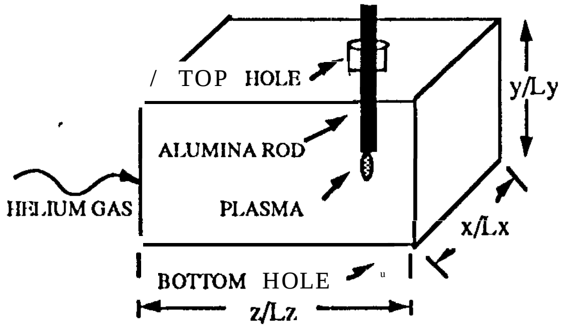

Fig. 1. TE102 Microwave cavity for plasma ignition on the alumina tip.

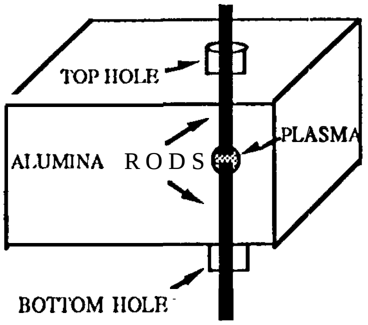

Fig. 2. TE102 Microwave cavity with plasma locked between two alumina rods.

RESULTS AND DISCUSSION

The enhancement in heating a low absorbing alumina rod using a plasma is illustrated in Figs, 3-6. In each case, the experimental arrangement corresponds to that shown in Fig. 1. Typical temperature and transmitted heating curves for the rod tip are shown in Fig. 3 with no Helium plasma gas in the cavity. We see that the sample temperature rose very slowly as the transmitted power increased in steps up to approximately 500 watts, The maximum temperature attained with no plasma was ≈ 65°C. When Helium gas was flowed through the cavity (≈ 100 ml/min.) and the microwave power was slowly increased, we obtained the temperature and transmitted heating curves shown in Fig. 4. The Helium plasma was excited suddenly using only ≈ 60 watts of transmitted power, The initially excited plasma quickly heated the tip of the rod to a temperature of ≈ 900°C. Once the plasma was initially excited, lower rod temperatures could be attained by decreasing the transmitted power. The Helium plasma was extinguished when the transmitted power was reduced below ≈ 15 watts which corresponded to a rod tip temperature of= 700°C.

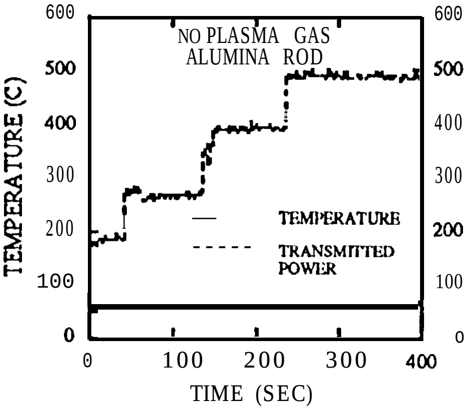

Fig. 3. Temperature and transmitted power curves with no plasma,

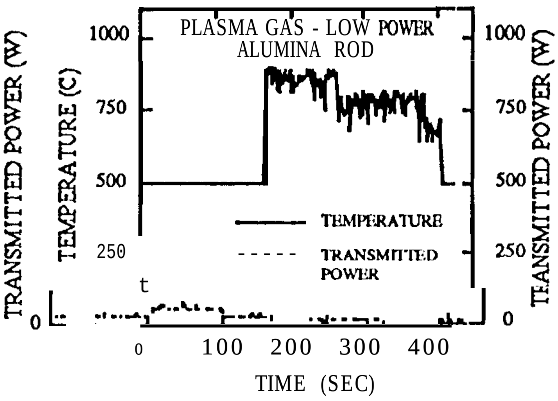

Fig. 4. Temperature and transmitted power curves with Helium plasma (low power).

High purity alumina has a room temperature imaginary dielectric constant of ε" ≈ 0.004, This is a very low value and high microwave power levels are required to initially heat this material. Figure 5 shows the heating curves when the transmitted power was increased to higher levels in the presence of the Helium plasma, The initially excited plasma again heated the rod tip to ≈ 900°C (ε" ≈ 0.09). The temperature of the rod tip was increased further to ≈ 1550°C by increasing the transmitted power to ≈ 430 watts. When the microwave power was turned off (at the end of the 1550°C plateau) the rod tip temperature cooled very quickly. While the Helium plasma could quickly heat the alumina rod tip to relatively high temperatures (≈ 1600°C for 500 watts), it could not heat the tip to melting (≈ 2072°C) without using significantly high transmitted power (> 500 watts). As the transmitted power was increased, the rod began to absorb microwave energy, However, the plasma surrounding the rod tip absorbed most of the microwave energy in the cavity and also partially shielded the rod from the remaining microwave energy, In order to heat the alumina rod tip to melting, we extinguished the Helium plasma by turning off the Helium gas after the rod was initially heated to ≈ 900°C. Figure 6 shows how this plasma enhanced technique was applied. For this demonstration, the transmitted power was initially set to 200 watts. After= 45 seconds, the plasma was excited and the sample reached a steady state plateau of= 900°C after 120 seconds. The Helium plasma gas was then turned off at ≈ 200 seconds and the rod tip quickly heated to above 1600°C by directly absorbing microwave energy. Further increases in the transmitted microwave power to ≈ 300 watts heated the tip of the alumina rod to melting(22072”C).

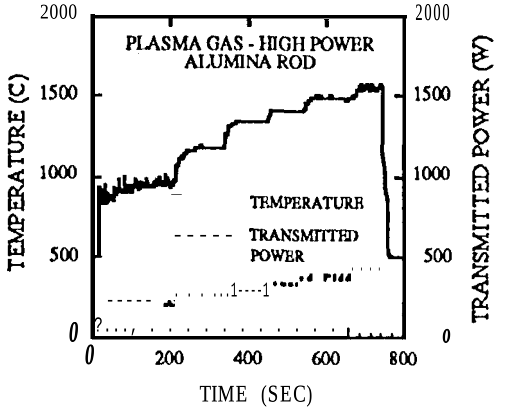

Fig. 5. Temperature and transmitted power curves with plasma gas (high power).

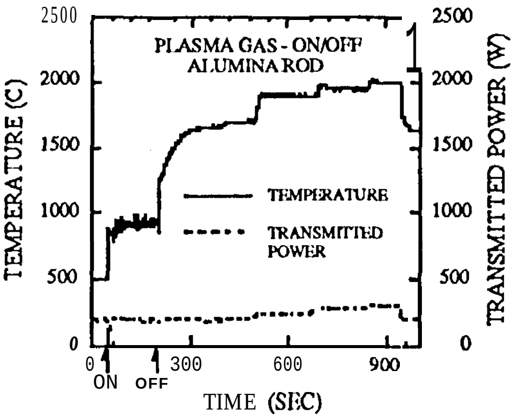

Fig. 6. Temperature and transmitted power curves with gas on and off.

Figure 7 shows the typical temperature and transmitted power heating curves for joining two alumina rods. The temperature was measured near the tip of the top alumina rod. The plasma was ignited immediately after the power was turned on, then a second rod was inserted through the bottom hole in the cavity after the plasma ignited,

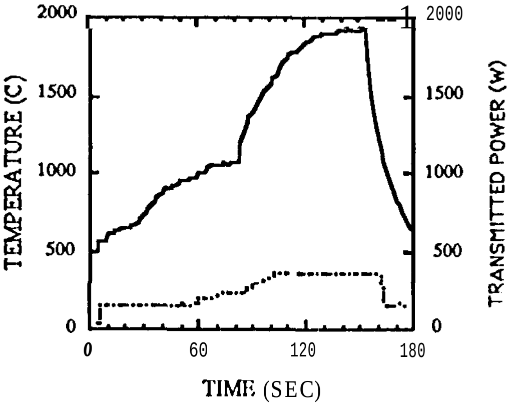

Fig. 7. Temperature and transmitted power curves during plasma enhanced microwave joining of 99.8% pure alumina.

After inserting the second rod (≈ 30 seconds), the plasma was positioned between the gap (≈ 0.5”) between the two rods. The temperature then increased further. To improve the preheating of the rod tips, the transmitted power was increased after 60 seconds until the temperature reached ≈ 1000”C. The plasma was turned off after 80 seconds. The temperature of the rod tips then increased rapidly to the melting point of alumina (2072°C) due to the onset of thermal runaway. The two rods were then pushed together after molten alumina droplets formed at the tips (at ≈ 150 seconds). The rod interface temperature then dropped quickly due to a sudden impedance mismatch.

CONCLUSION

In conclusion, the novel plasma enhanced microwave joining technique described here can lead to more efficient joining of low absorbing ceramics, This approach could also permit the joining of many more low absorbing materials that have high commercial value.

ACKNOWLEDGMENT

The authors wish to acknowledge Mr. O. Iny and Mr. R, Zanteson for the technical support, The research described in this article was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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