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Bending Strength of CO_2 Laser Welded Joints of 87%Al_2O_3 Ceramics†

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Ceramics generally have high melting points, so welding requires high energy density heat sources such as lasers. In order to develop a joining technique for thick ceramics, the authors investigated the welding characteristics of 87% Al_2O_3 under various welding conditions using a high power CO_2 laser. An assist gas nozzle was initially used to remove the plasma generated during welding, but it was found that the assist gas influenced the melting of the ceramics and many welding defects occurred. A coaxial gas nozzle was thus used to remove the plasma and reduce the influence on the melting ceramics as much as possible. Using a coaxial gas nozzle, the authors investigated the influence of the welding parameters on bead porosity and on the bending strength of the welded joint.

As the heat source for welding, a 15 kW CO_2 laser (beam outer diameter 70 mm, module 1.5) was used with the Arata A-type laser focusing system (F10, spot diameter 0.8 mm) and an a_b value of 1.006.

Helium gas was employed as the assist gas with a coaxial gas nozzle.

When ceramics are welded without preheating, complex cracks often form. The specimens were therefore preheated to 1300K before conducting furnace welding. After welding, the specimens were transferred to an electric furnace. The specimens were kept at 1300K for one hour and were then cooled at a rate of 100K/hour inside the furnace. The specimens consisted of 87% Al_2O_3 and measured 40 mm wide × 80 mm long, with a thickness of 4 mm.

Figure 1 shows the bead shape zone obtained using a coaxial gas nozzle at different laser powers and welding speeds for 4 mm thick plate. There are three different zones. In zone I there was only partial penetration due to the relatively low laser power for the speed of welding. In zone II a reinforcement bead was produced with full penetration. In zone III the bead surface was underfilled due to a great deal of spattering caused by excessive laser power for the welding speed.
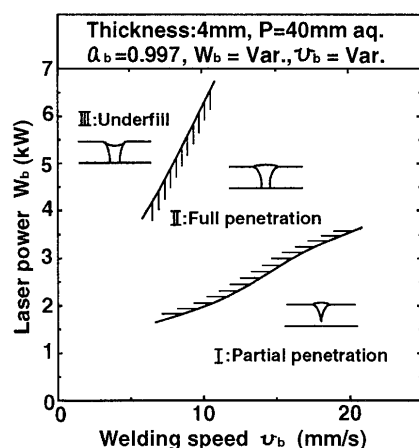

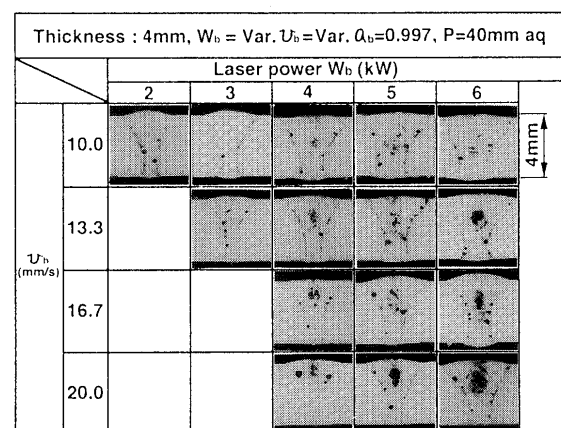Fig.1 Bead shape regions determined by the welding speed and laser power.

Fig.2 Full penetration bead cross sections at various laser powers and welding speeds.

Fig.3 Bead cross section porosity ratio at various input powers and welding speeds.

(a) v_b = 10.0mm/s
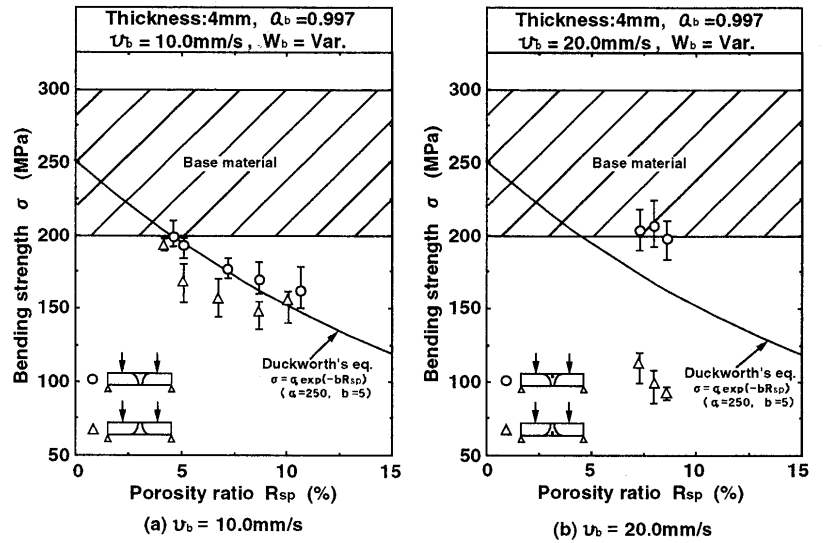
(b) v_b = 20.0mm/s

Fig.4 Relation between bending strength and porosity ratio.

Compared with a conventional assist gas nozzle, when a coaxial gas nozzle is used, zone I shifts to a higher laser power with a shallower penetration depth. On the other hand, at low welding speeds a zone II bead can be obtained at higher laser powers, widening the zone in which a full penetration reinforcement bead can be obtained.

Figure 2 shows the full penetration bead cross section obtained in zone II at various welding speeds and laser powers. In addition to porosities near the weld bond, shrinkage cavities can be seen at the center of the bead at a high welding speed and high laser power. At a lower welding speed and lower laser power, no shrinkage cavities or large-size blowholes occur near the weld bond.

Figure 3 shows the relationship between the input power and the porosity ratio in full penetration beads without underfill in zone II using a coaxial gas nozzle. Although the porosity ratio is over 10% using an assist gas nozzle, significantly fewer porosities occur when a coaxial gas nozzle is used. Also, the porosity ratio is lower at lower input powers, and there is a tendency for the porosity ratio to further decrease as the welding speed decreases at the same input power.

The strength of the welding joint was evaluated using the JIS four-point bend test. Both face and root bend tests were carried out to take into consideration the different bead shapes and porosity distributions.

Figure 4 shows the relationship between the porosity ratio and bending strength at welding speeds of 10 and 20 mm/sec. The strength of the base material is 200-300 MPa, and the line shows the bending strength predicted by Duckworth is equation ($\sigma=\sigma_0\exp(-bR_{SP})$: σ_0=250MPa, b=5). The bending strength decreases as the porosity ratio increases. There is no difference
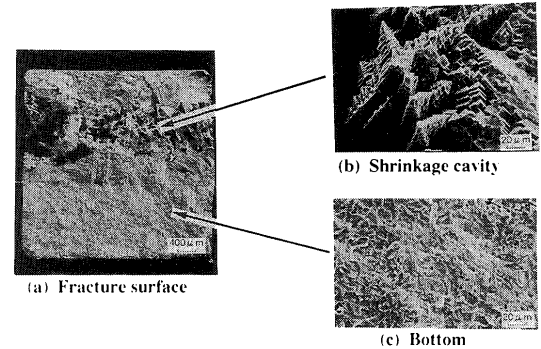

Fig.5 SEM photograph of fracture caused by bending test.

between the face and root bending strength at a welding speed of 10 mm/sec. The tendency for the bending strength to decrease as the porosity ratio increases is similar to the tendency shown by Duckworth's equation. However, there is a great difference between the face and root bending strengths at a welding speed of 20 mm/sec. The root bending strength is the same value as the base material, but the face bending strength is only half the root bending strength.

Figure 5 shows an SEM photograph of the fracture caused by the bending test. The welding speed was 20 mm/sec at a laser power of 5 kW. The large cavity visible in the upper fracture surface is a shrinkage cavity caused by a deficiency in melted ceramics when they solidified after welding. There are no large porosity at the bottom of the fracture surface, and there is a fine structure without welding defects. Thus, the concentration of strength caused by the shrinkage cavity at the upper part of the bead lowered the face bending strength. In this way porosities, in particular shrinkage cavities, were found to greatly influence the bending strength of welded joints of alumina ceramics.