Characterization of Joined Alumina Components Manufactured via Digital Light Processing

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Summer Program(s): 2024 Cornell Center for Materials Research North Carolina Agricultural & Technical State University (CCMR NC A&T) Summer Program, 2024 Cornell NanoScale Science & Technology Facility Research Experiences for Undergraduates (CNF REU) Program

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Primary Source(s) of Research Funding: Cornell Center Materials Research NC A&T 2024, National Science Foundation under Grant No. NNCI-2025233, Empire State Development, Air Force Research Laboratory Regional Network, Fuze Hub, Cornell Atkinson Center for Sustainability

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Primary Tools Used: Instron 5569, Admaflex 130

Abstract:

This study demonstrates effective strategies for overcoming print volume limitations in 3D printing of ceramics, offering insights into joint design and material performance critical for advancing large-scale ceramic manufacturing applications. The utilization of large-scale additively manufactured ceramic parts is constrained by print volume limitations. To address this challenge, this study investigates the mechanical performance of joined alumina ceramic beams created with the Admaflex 130 via Digital Light Processing (DLP), a method involving photosensitive resin and ceramic particles. Various joint designs are evaluated: Flat, Mouse Door, Notch, and T-slot; to discover their efficacy in joining these ceramic beams. Experimental tests included ambient flexural testing and thermal shock flexural testing, involving rapid cooling in a water bath after heating. While the standard alumina beam has a flexural strength of around 300 MPa, strength significantly decreases when joining. The T-slot joint, exhibited superior performance, over all geometries, as it achieved 88 MPa in ambient conditions and 55 MPa under thermal shock conditions. Comparatively, the Mouse Door joint showed a performance of 75 MPa in ambient flexural strength and, 30 MPa in thermal shock, surpassing the Notch joint which achieved 55 MPa in ambient flexural strength and 20 MPa under thermal shock.

Summary of Research:

Print volume constraints of digital light processing (DLP) printers, such as the Admaflex 130, limit the ability to print complex parts on larger scales. DLP is a mask-based technique of integral image transfer to the photopolymerizable liquid surface by exposing the light source through a patterned mask once only [1]. Previous research has explored the relationships between joint strength and cure time, as well as joint strength and sintering temperature. However, all tests were conducted using the same joint geometry. The findings indicated that strength was not significantly affected by curing time but was highly dependent on sintering temperature [2]. The different geometric designs compared, also ranked by surface area are Flat, Mouse Door, Notch, and T-slot — which can be seen in Figure 1. These interfaces are used to find the best configuration for strength and load-bearing capacity. These geometric interfaces were created to investigate how to get proper alignment while minimizing strength reduction and ensure proper alignment which is essential for complex shapes. It is hypothesized that the larger surface area will result in greater strength.

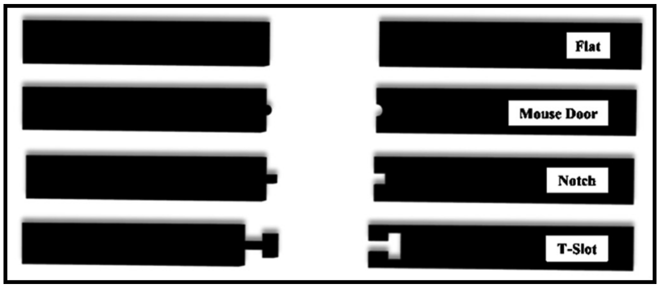


Figure 1: Types of interfaces used to join ceramic beams-Flat, Mouse Door, Notch, and T-Slot.

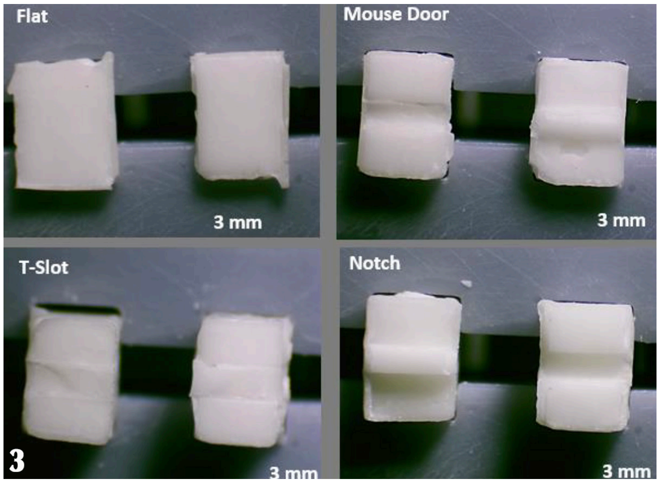
To create the ceramic beams, the Admaflex 130 machine is used, with a limiting build plate size of 54 × 96 × 110 mm. After printing, the ceramic beams are removed from the plate and cleaned with water and isopropyl alcohol to get rid of any leftover slurry. The beams are dried and then joined using a pea-sized amount of slurry followed by each face of the beam being exposed to UV light near 405 nm at 46 mW/cm^2 for one minute. The parts are then debound and

$$S=\frac{3PL}{2bd^2}$$

Figure 2: Equation used to calculate strength when ambient flexural strength tests are done. In this equation, P represents the break force, L denotes the outer support span, b indicates the specimen width, and d signifies the specimen thickness.

sintered. Debinding involves soaking the ceramic beams in a heated water bath (40°C) for 24 hours to remove the water-soluble resin. Then, a thermal debind is performed at 1000°C, resulting in brittle, chalk-like parts. Then sintering is done, at 1625°C, fully densifying the beams and shrinking them to the desired size of 3 mm × 4 mm × 45 mm. To test the strength of these joints, ambient flexural strength tests are conducted according to ASTM C1161-18 standards. The strength is calculated according to Figure 2, where S is strength, P is breaking force, L is outer support span, B is specimen width, and D is specimen thickness. Upon ambient flexural strength testing, the ceramic beams are broken. As seen in Figure 2, for all joints except the T-slot, failure occurs due to the joint slurry, as no breakage occurs through the joint geometry. This implies that the weakness of the joint is coming from the procedure of ceramic beam joining. It is also important to note that although the T-slot breaks in half, the other joints break but keep their geometry.

The results of this testing indicate that the Mouse Door and T Slot joint, with slurry, offer superior strength, making them preferable in mechanical strength applications. Notably, the T-Slot is two times stronger than the Flat. All complex geometries with slurry outperform the flat joint, suggesting the complexity of the joint improves strength. Next, joint performance under thermal shock was assessed, per ASTM E1225-20 guidelines. Here, samples are rapidly cooled after being heated to 400°C above bath temperature for fifteen minutes. The results shown in Figure 4 indicate that the T-slot joint with slurry remains the highest strength, while the Flat joint has the lowest strength. Interestingly, for ambient flexural testing, the Mouse Door joint is stronger than the Notch joint, contrary to initial expectations. The results suggest that T-slot joints are stronger than Flat joints. However, thermal shock tests reveal that ceramic joints can lose significant strength after sudden temperature changes. For the flat, 29.4% of strength is lost, 27% for Mouse door, 45.3% for notch, and lastly 62.9% for T-Slot with slurry and 69.5% without slurry.



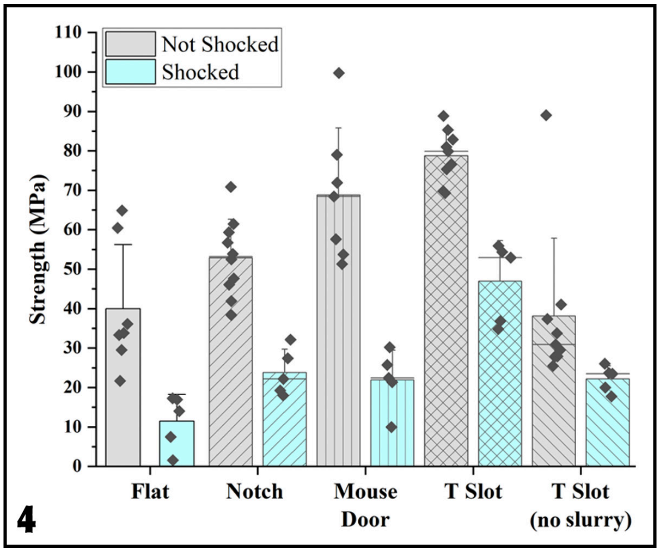


Figure 3, top: The ceramic beams upon ambient flexural strength testing. Figure 4, bottom: Types of interfaces used to join ceramic beams-Flat, Mouse Door, Notch, and T-Slot.

Conclusion and Future Work:

This research offers valuable insights into ceramic joining, helping to standardize and quantify the effects of these joints. Among all the joints compared, the T-slot joint demonstrated significantly greater strength, both in ambient flexural strength testing and after undergoing thermal shock procedure. Future work will explore joint orientation, and joint strength on conductivity testing because that could impact our current observed data. This research offers valuable insights into ceramic joining to help standardize and quantify the effects of these joints. Thermal conductivity affects not only joint strength but also the introduction of new interfaces which can influence thermal shock behavior. Lastly, it is important to explore new materials like zirconia and cordierite to assess the impact of less understood materials on joining behavior. While Alumina is a very commonly studied and mature material, zirconia and cordierite are much more experimental and may not have the same reproduceable shrinkage, post-curing, and sintering morphology. Understanding joint behavior with these materials will allow for a more robust understanding of the effect of joint geometry on strength as well as allow for broader impacts of this work in the additive manufacturing field.

References:

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