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Short fiber reinforced 3d printed ceramic composite with shear induced alignment

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ABSTRACT

This paper accounts for utilization of shear induced alignment method during ceramic stereolithography. Lateral oscillation mechanism, combined with 3d printed wall pattern, was employed to generate necessary shear to align fiber in desired direction. First, semicircular channel pattern was printed to assess the effect of difference between wall direction and oscillation direction on the fiber alignment. Then, flexural strength of ceramic matrix was tested with nickel coated carbon fiber and ceramic fiber reinforcements. The results demonstrated that the shear induced alignment further improves the flexural strength compare to randomly distributed samples. Flexural strength of aligned samples with 1.0 wt% carbon fiber loading was improved by ~90% compared to randomly orientated samples and by ~333% compared to unreinforced samples. Finally, fracture surface morphology of the flexural strength test specimens was evaluated. The main fracture mechanism was observed as fiber pull-out.

1. Introduction

Traditional ceramic forming techniques, such as slip casting, shell casting, dry pressing; are not capable of producing complex parts with high accuracy without expensive mold or fixtures, or time consuming post-sinter machining [1]. Therefore, there is a demand and interest for alternative methods to produce complex ceramic pieces without the use of expensive tooling. Three dimensional printing (3DP) methods of ceramics and ceramic composites can directly produce complex parts from 3D computer-aided design (CAD) files without the use of any tooling. Fused deposition modeling (FDM) [2], selective laser sintering (SLS) [3], ceramic jet printing (CJP) [4], and stereolithography (SLA) [5] are some of the common 3DP methods which are used for additive manufacturing of ceramic and ceramic composite materials. During these processes, 3D complex objects are fabricated by rendering each layer according to CAD file and stacking them on each other.

SLS method involves the use of high power laser beam to bond ceramic particles to each other locally [6,7]. Localized temperature gradient during sintering process can generate high internal stresses which might cause lots of defects and micro cracks. FDM, CJP, and SLA ceramic processing methods use a mixture of a ceramic powder and a polymeric binder to fabricate green parts without high energy input. Fabricated green part must be sintered to remove polymeric binder and to fuse the particles. However, extrusion of precursor filament is often disturbed by buckling failures and powder volume fraction is limited by extrusion pressure at the nozzle for FDM and CJP processes [2]. On the other hand, SLA of ceramics utilizes photosensitive resin as a binder to produce the green parts without any nozzle and high energy laser beam. Without any nozzle and high energy input, internal stresses, buckling failures, and extrusion pressure are avoided. Therefore, SLA method was used for this study.

The use of pure ceramic materials as a structural material has been limited, due to its overall low toughness and thermal shock resistance [8,9]. As a result, additive of reinforcement such as whiskers [10,11], short fibers [12,13], particles [1,14], and nanotubes [15,16] into ceramic matrix attracted a lot of research interest in order to enhance desired properties. These enhancements are influenced by the material, dimensions, and orientation of the reinforcement [12,17]. Therefore, fiber alignment can be used to tailor the material properties of 3D printed composite pieces, such as mechanical [18] and electrical [19]. We demonstrated shear induced alignment during SLA 3DP for reinforced polymer composites (RPC) at our previous study [20]. In this work, same approach was utilized for 3DP of ceramic composites. Micro scale alumina, silica, and nickel coated carbon fibers (NCCF) were used as reinforcement. Respond of reinforcement to patterned wall direction and enhancement of flexural strength of the composite material with fiber orientation were discussed.

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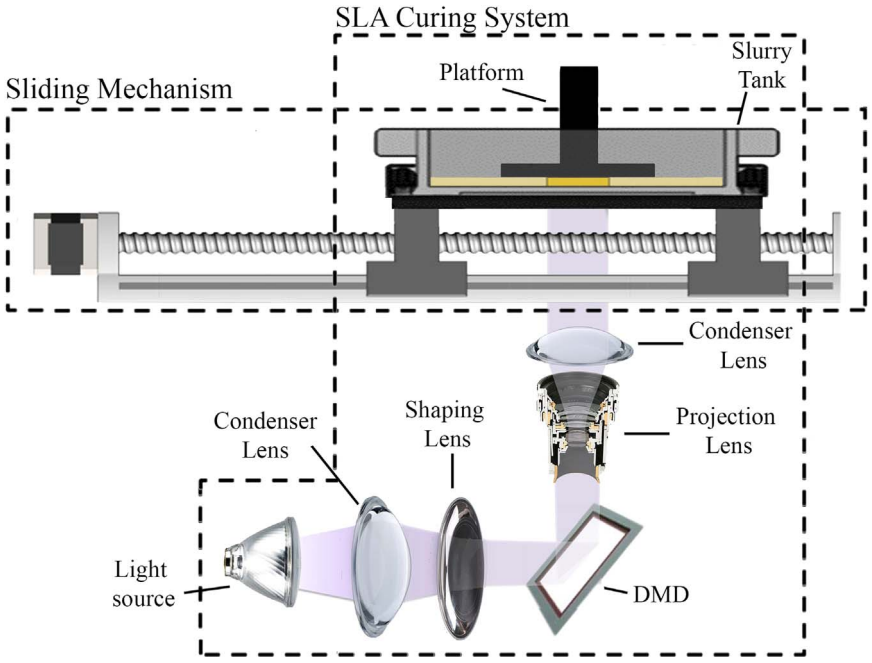

Fig. 1. System setup of SLA Ceramic 3DP with sliding mechanism.

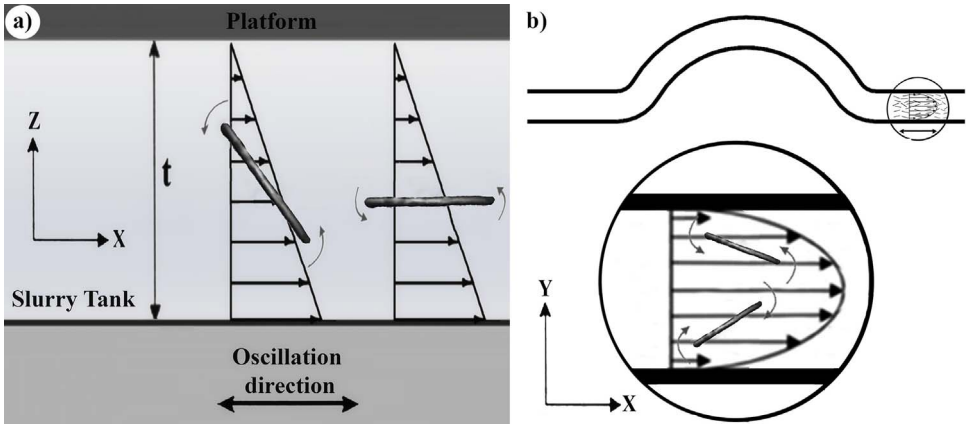

Fig. 2. Fiber alignment process: (a) Fiber alignment in a simple shear flow as a result of linear oscillation; (b) fiber alignment in a 3d printed wall pattern.

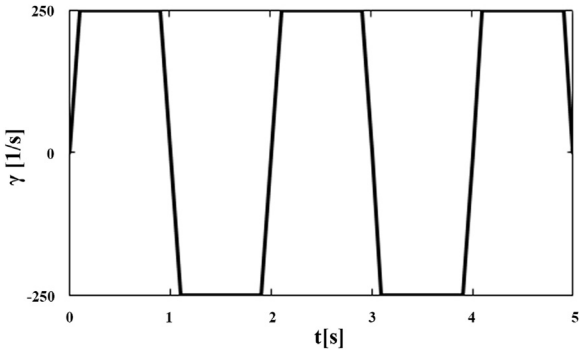

Fig. 3. The time dependent-shear rate profile which was used during fiber alignment process.

2. Materials and methods

2.1. Slurry preparation

The ceramic photocurable resin used in this paper is a mixture of both ceramic powders and liquid photocurable resin. Powder part contains silica powder, Feldspar powder, Kaolin clay powder and Ball clay powder (all from Axner Co.), and liquid resin part is a mixture of Laromer 8765 (BASF Co.), Laromer HDDA (Hexane-1,6-diol diacrylate, BASF Co.), and lauryl acrylate (Esstech Inc.). Irgacure 754 (a mixture of Oxy-phenyl-acetic acid 2-[2-oxo-2-phenyl-acetoxy- ethoxy]-ethyl ester and Oxy-phenyl-acetic acid 2-[2-hydroxy-ethoxy]-ethyl ester) and Irgacure 4265 (a mixture of Diphenyl (2,4,6-trimethylbenzoyl-phosphine oxide and 2-Hydroxy-2-methyl-1-phenyl- propan-1-one)) from BASF Co. was used as photoinitiators. 0.2 wt%. Tinopal OB (BASF Co.) is used as a UV absorber. 60 wt% of silica content was added within the resin as the ceramic filler and mixed with shear mixer for 24 h to provide homogeneity. During the mixing process, the viscosity of the slurry was reduced as result of shear thinning behavior of the fluid. After the mixing, if the slurry was not used for 8–10 h, ceramic fillers would settle to the bottom of the slurry as sediment and then slurry would require remixing.

While silica particles were used as the matrix, NCCF, alumina, and silica fibers were used as fiber reinforcement for the ceramic matrix composite. Carbon fiber is inclined to oxidation at temperature 500 °C and higher, as a result it requires protection from atmosphere to preserve its superior properties [21]. Nickel coating was used as the protection in our study. NCCF with 7 μm diameter and 1 mm mean

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