COMPOSITES WITH GRADIENT PROPERTIES FROM SOLID FREEFORM FABRICATION

V.R. Gervasi, R.S. Crockett
Rapid Prototyping Center
Milwaukee School of Engineering, Milwaukee, WI

Abstract

TetraCast is a build style developed by Milwaukee School of Engineering involving stereolithography patterns produced with an open cellular structure inside a surface shell. Composites are created using this pattern as a host for a filler material, generally epoxy matrices loaded with various fibers or microspheres. Regions within a single object may be separated by thin barriers, allowing filling with different matrix materials to create regions of differing local properties. The internal structure can also be continually graded in thickness to produce composites with properties ranging from that of the filler material to that of the TetraCast material (currently stereolithography epoxy or FDM ABS).

Introduction

Functionally gradient materials (FGMs) transform from one material (part A) to another (part B), unlike traditionally bonded materials that have a distinctive seam. The goal of FGMs is generally to produce materials able to withstand extremely harsh environments. Examples include surviving temperatures as high as 2100 K and temperature gradients, within the FGM, as great as 1600 K over a very short region. FGMs also need to handle these temperatures while maintaining mechanical functionality. To accomplish this, the benefits of two or more materials are combined in a FGM to produce a non-traditional engineering material[1]. A good example is a FGM consisting of metal and ceramic, as illustrated in figure 1. The properties of the metal component are high strength, ductility, conductivity (electrically & thermally) and low chemical resistance. The properties of the ceramic are high hardness, insulating, brittle, chemically

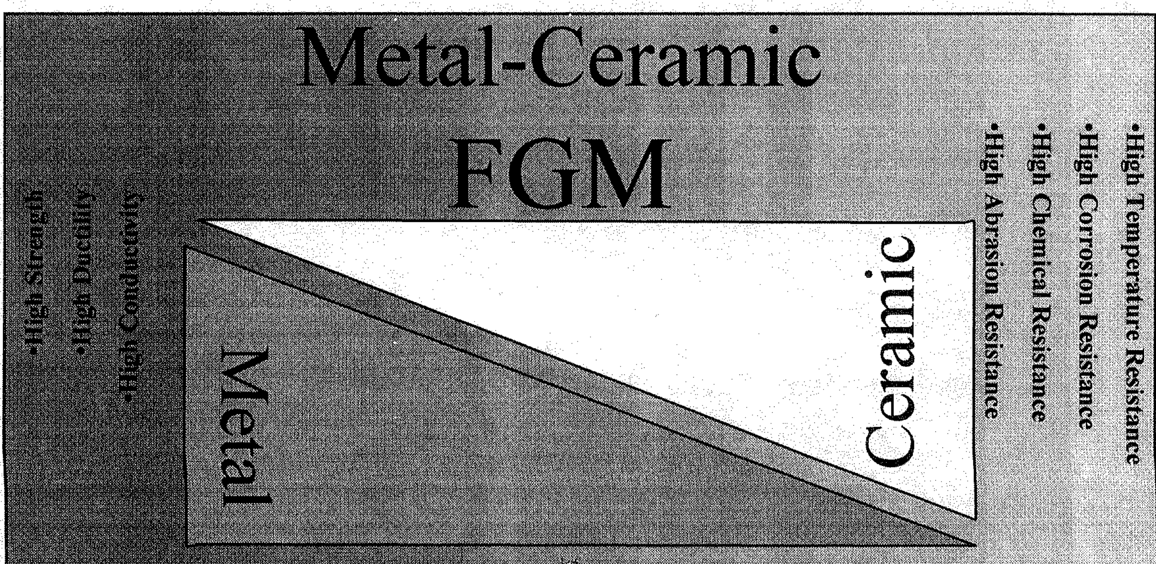

Figure 1. Metal-Ceramic FGM

resistant, and abrasion resistant. Now, if the advantages of both are combined in a FGM, the result is a material with high mechanical strength, conductivity, corrosion resistance, and abrasion resistance. Combinations being tested include: metal-ceramic, ceramic-ceramic, carbon-carbon, carbon-ceramic, and polymer-polymer.

Industries with applications for FGMs include aerospace, manufacturing, mining, nuclear power, architecture, automotive, biomedical, and electronics. In aerospace, leading edges and combuster cans could benefit from FGM properties. Whereas in manufacturing and mining, abrasive tools could be produced with a combination of wear resistant surfaces and shock absorbing surfaces such as those found in FGMs. Biomedically, bone implants could be generated with bio-compatible materials on one surface and mechanically functional materials on another surface.

The Production of FGMs is quite challenging, and numerous techniques are being tested and used. A technique, such as vapor deposition, creates gradient materials at the atomic or molecular level. Other techniques, on the micro-scale, produce gradients by combining powders or laminates to produce FGMs. A new approach uses a meso-scale gradient morphology. This morphology, discussed in this paper, is called Gradient Tetracast.

Background

Before discussing the approach to this research, it is helpful to give some background on the TetraCast Build Style, the Gradient Tetracast Morphology, and the Rapid Composite Process.

TetraCast[2] is a SFF build style used to produce lattice-filled patterns for the Rapid Composite Process and investment casting. TetraCast patterns have many of the same benefits as QuickCast™ patterns. TetraCast uses an internal three-dimensional tetrahedron morphology modeled after the molecular bond geometry found in diamonds. The TetraCast internal lattice offers the outer surface or skin sufficient support with minimal density. Figure 2 illustrates the TetraCast Lattice.

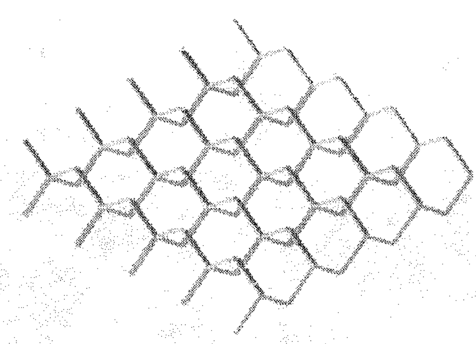

Figure 2. TetraCast Lattice

Gradient Tetracast (GTC) is a three-dimensional morphology, transforming from one material to another, in a controlled manner. This morphology can be likened to M.S. Esher art work in three dimensions. To create Gradient Tetracast, spacing between standard TetraCast units can remain constant while the branch thickness is increased in a controlled manner (as shown in figure 3). This controlled increase in branch thickness results in a proportional change in volume percentage of material combinations. In theory, this volume percentage will transform from 100 percent of material A to 100 percent of material B at any rate, in any direction. With Gradient Tetracast the transformation is three dimensional and mechanically interlinked. GTC becomes two TetraCast lattices with varying branch thickness. Part A is the mirrored negative of part B and GTC can be stacked as shown in figure 4.

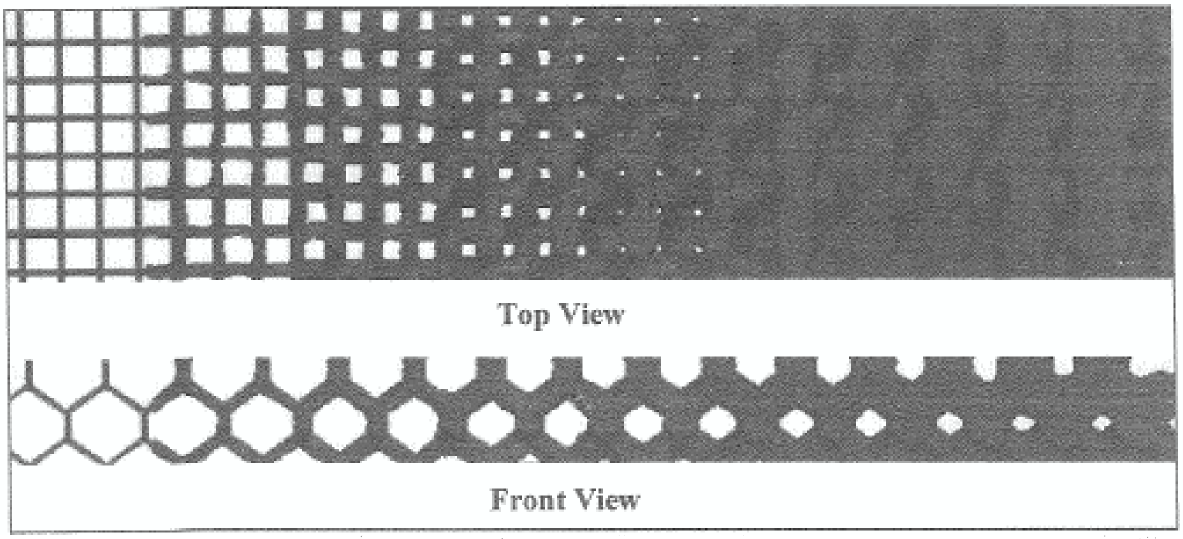

Figure 3. Gradient Tetracast

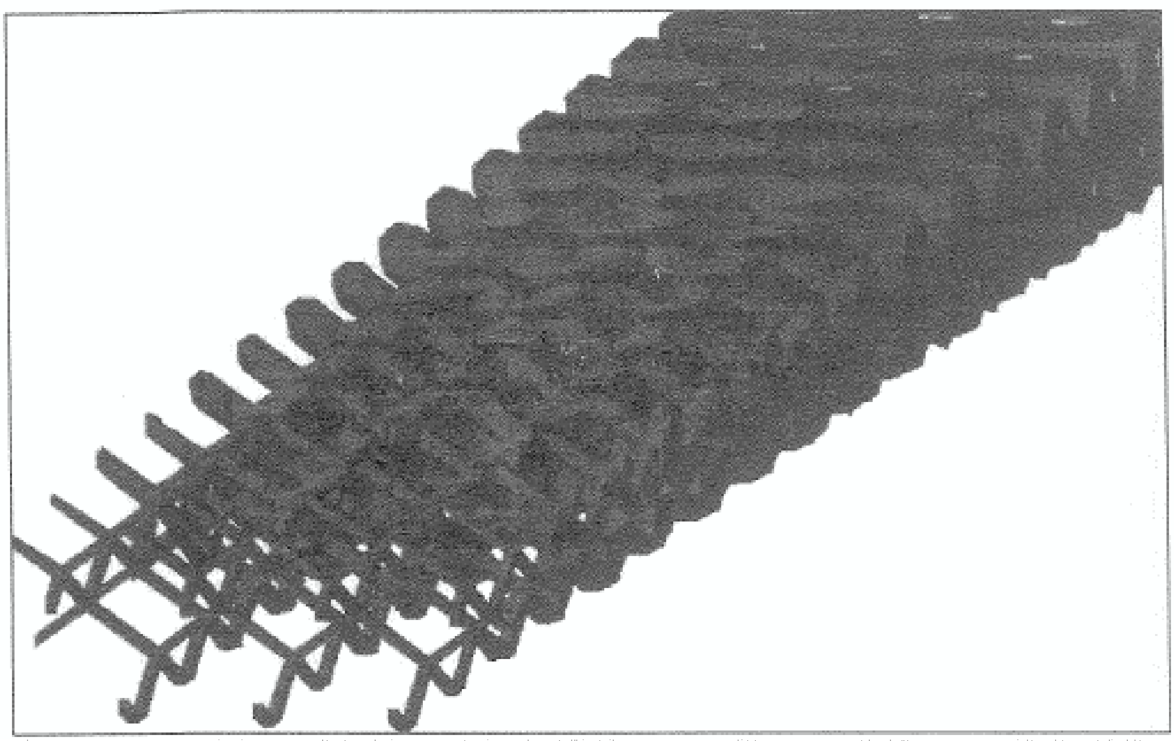

Figure 4. Stacked Gradient Tetracast

The Rapid composite Process[3] (RCP) is used to create composite parts from TetraCast patterns. With this method, the TetraCast pattern becomes part of the final composite, as it both defines the net-shape of the desired geometry and embodies the composite material during matrix solidification. The composite material is introduced into the TetraCast pattern as chopped fibers, flakes, and/or particles suspended in a liquid matrix (typically epoxy). After the TetraCast pattern is completely filled, the matrix solidifies, resulting in a net-shape functional composite part.

Through this method, the composite material properties can be tailored to meet application requirements of the composite. Parts of virtually any geometry can be produced. This process may be especially well suited for custom-manufacturing of complex, one-of-a-kind, components for testing or end usage. The Rapid Composite Process was applied to GTC for the first experiment. The Rapid Composite process functions well to fill small features such as those found in the first GTC samples.

Objective

The main objective of this research was to introduce a new gradient morphology that uses GTC as the transitional structure. To accomplish this a simple GTC material was produced consisting of part A (SLA photopolymer) transitioning into part B (glass filled epoxy). Sample Functionally Gradient Materials were produced within a class III tensile geometry profile.

Approach

The approach to studying GTC began with the production of plastic-composite GTC tensile samples. The material combination was 50 percent SLA photopolymer and 50 percent glass filled epoxy. The main objective was to produce a visual sample of GTC to be used for discussion and analysis. The modulus of elasticity as a function of percentage composition was also analyzed. The approach used to produce the first GTC sample consisted of: CAD modeling, SLA production, RCP, sample slicing, and Testing.

The GTC tensile bar CAD model was designed to include five distinctive TetraCast percentage combinations to form a gradient. The first TetraCast region was less than 10 percent by volume increasing to greater than 90 percent in the final region. Each TetraCast section was 0.45 inches in thickness to allow machine stock for later slicing and sanding. All five TetraCast regions were combined within a thin shell. One hundred percent SLA photopolymer and composite samples were produced separately.

Two GTC samples were produced on an SLA 250, using ACES build style. Uncured photopolymer was removed in a centrifuge, leaving a 50 percent graded air void and 50 percent graded photopolymer. SLA Photopolymer was chosen because of the fine detail, ease of uncured resin removal, clarity, and homogeneous mechanical properties (specifically Young's Modulus of Elasticity).

The RCP was used to fill the 50 percent graded void with glass filled epoxy as shown in Figures 5. Glass filled Epoxy was chosen for its high modulus and grey color.

Samples were sliced, polished, and tested for Young's modulus of elasticity. Figure 6 illustrates the sectioned GTC sample.

Results/Discussion

As shown in Figure 5, a gradient material was successfully produced using the GTC morphology. The tensile samples produced with GTC had a volume percentage range from 95 percent photopolymer/5 percent composite to 28 percent photopolymer/72 percent composite. Low volume percentage photopolymer sections collapsed during RCP filling and were not used. This section would have been 95 percent composite/ 5 percent Photopolymer.

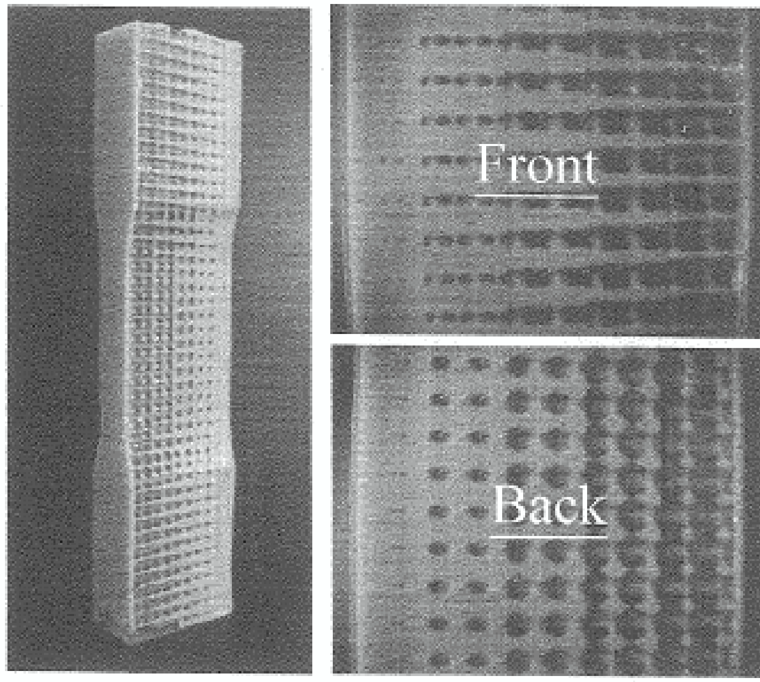

Figure 5. Filled Gradient Tetracast

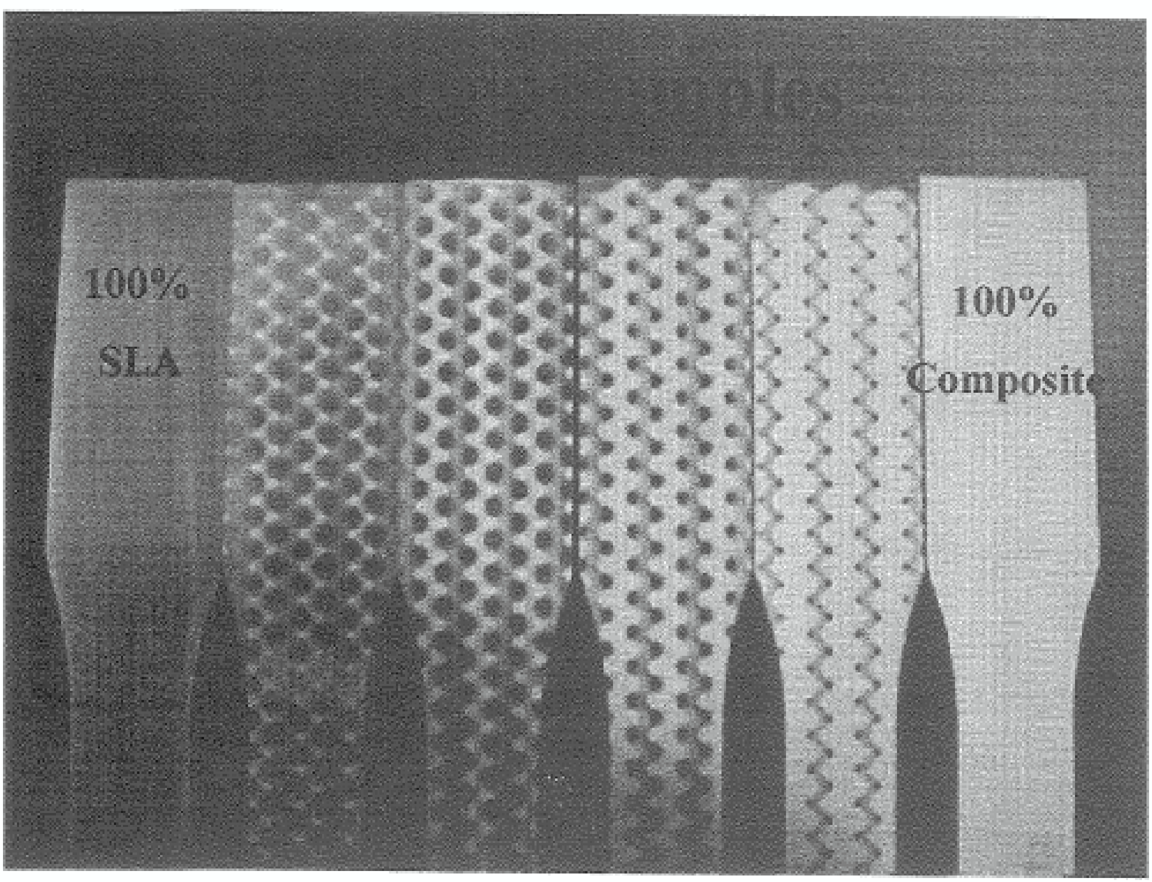

Figure 6. Sliced Samples

After sample slicing (figure 6), tensile testing was performed to determine the modulus of each section. Figure 7 illustrates the resulting stress-strain curves, clearly displaying an increase in stiffness as percentage volume of composite increased. Figure 8 illustrates the change in modulus as a function of material composition. The samples were expected to act similar to that of a particulate composite. The Upper Limit shown is the predicted moduli applying the rule of mixtures. The Lower Limit is what would be expected if the composite was loaded in the weakest possible direction, GTC fell below the Lower Limit. One reason for this could be a weak photopolymer-composite interface caused by uncured photopolmer between the two materials.

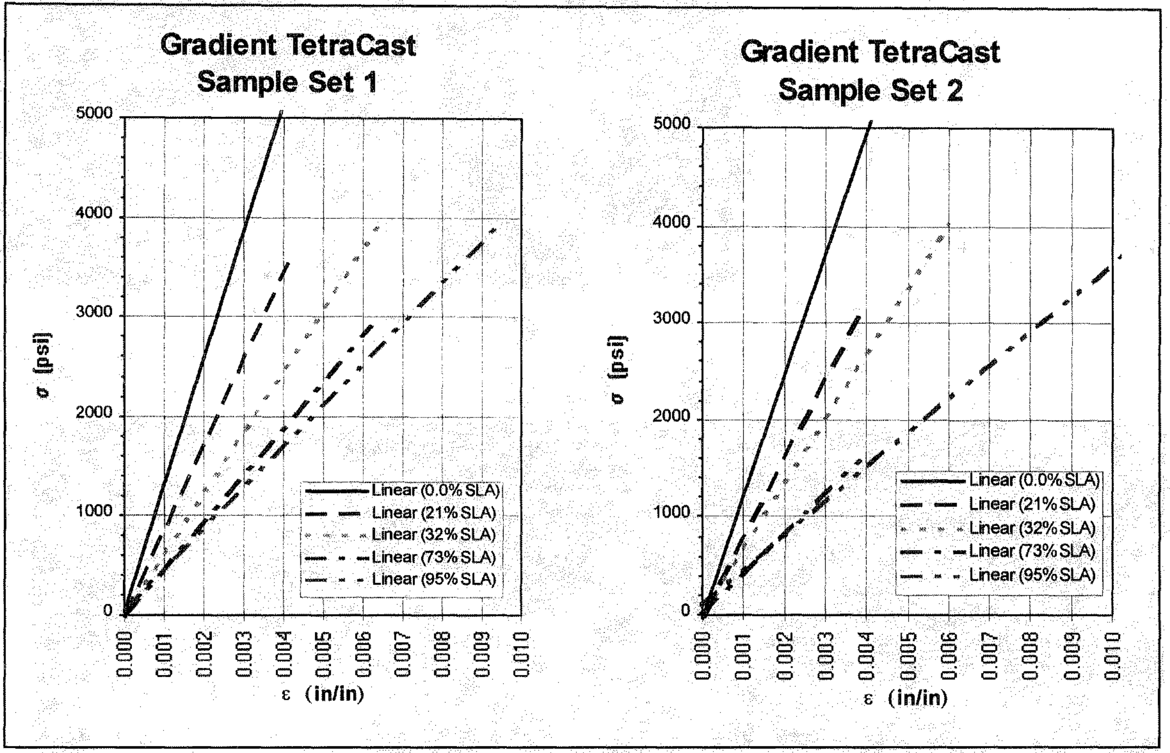

Figure 7. Stress Strain Curves for Gradient Tetracast Samples

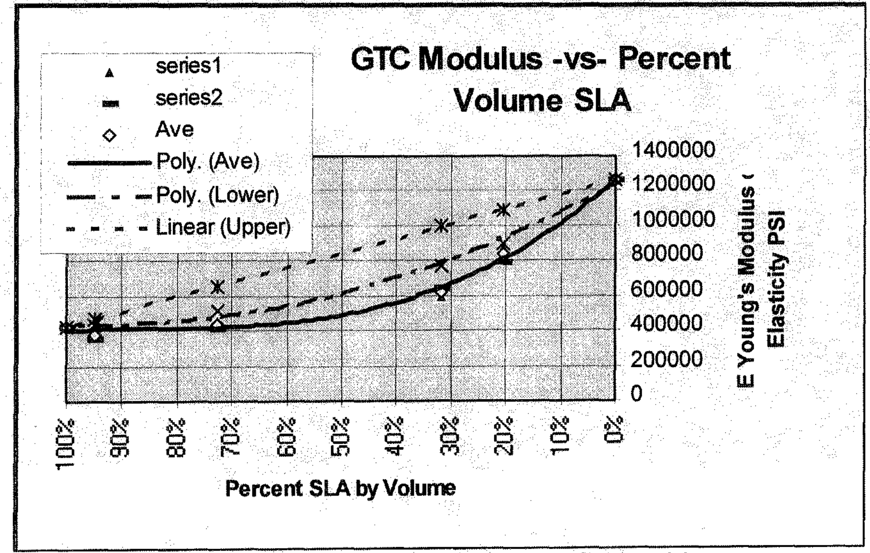

Figure 8. Modulus as a Function of Composition

Conclusions

Functionally Gradient Materials can be created using Gradient TetraCast as a transformational morphology. Gradient TetraCast has the potential to be stackable, allowing for two or more materials in Functional Gradient Materials. Gradient TetraCast is a continuous structure providing thermal and electrical conductivity through metallic portions of Functional Gradient Materials.

Future Work

Much work is required before the usefulness of Gradient TetraCast for Functional Gradient Materials is determined. In the future, metal-ceramic Functional Gradient Materials will be attempted along with other suitable material combinations. Applying Finite Element Analysis (FEA) to both the mechanical analysis and Gradient TetraCast unit design will also be considered for optimizing design and production. The production of simple to complex shapes will be attempted.

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