NET SHAPE COMPOSITES USING SLA TETRACAST* PATTERNS

Vito R. Gervasi
Rapid Prototyping Center,
Milwaukee School of Engineering

ABSTRACT

Net-shape composites have been a focus of Solid Freeform Fabrication (SFF) for a number of years. A new method to achieve net-shape composites uses hollow Stereolithography (SLA) TetraCast* patterns. The TetraCast* pattern is injected with a filler material consisting of a matrix (typically epoxy) and reinforcement fibers, flakes, and/or particles. Upon solidification of the injected matrix, the net-shape composite is achieved.

Net-shape composites are ideal for custom manufacturing due to the virtually limitless geometry capabilities of SLA. Areas such as aerospace, medical, manufacturing, and others could someday benefit from this process.

Research to date has shown this composite structure to follow the "rule of mixtures." It has also been shown that heat-deflection, elastic-modulus, and tensile-strength can be enhanced and/or predicted in the composite material. Several areas of continuing research include: viscosity limitations, stair-step notch reduction, reinforcement combinations, shrinkage prediction, cooling methods, SLA skin removal, next-generation TetraCast* structures, wear-resistant coatings, process automation, and TetraCast* pattern fill methods.

Figure 1. Composite 3D Representation of the Klein Bottle

INTRODUCTION

Net-shape and near-net-shape composite parts are and continue to be a goal of Solid Freeform Fabrication (SFF) technologies. Several methods have been studied to achieve net-shape or near-net-shape composite parts using Laminated Object Manufacturing (LOM) [1,2], Stereolithography (SLA) [3,4,5,6], Fused Deposition Modeling (FDM) [7,8], and other SFF technologies.

Rather than producing the composite directly from SFF, a new method uses SLA TetraCast* [9] patterns to initiate the Rapid Composite Process (RCP**). 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, as the Klein bottle shown in Figure 1 suggests. This three-dimensional representation of a Klein bottle has internal features, nearly impossible to build any other way, and has a wall thickness of only 0.1 inch. This process may be especially suited for custom-manufacturing of complex, one-of-a-kind, components for aerospace testing, medical equipment, satellite structures, and others.

The goal of this paper is to introduce RCP**, describe the composite formulation, summarize early research findings, and suggest RCP** applications.

RAPID COMPOSITE PROCESS

Figure 2 illustrates the process of generating a net-shape composite using a TetraCast* pattern and composite filler materials. The process consists of 8 steps starting with a CAD drawing and ending with composite finishing as follows:

Step 1. A .stl file is created using the traditional CAD method or reverse engineering via 3D scans.

Step 2. The hollow TetraCast* pattern of the model is then built on the SLA machine.

Step 3. Trapped resin is drained from the TetraCast* pattern by drilling small holes in the skin.

Step 4. The drain holes are sealed followed by a leak check and full ultraviolet light cure.

Step 5. The fill tube is placed into the liquid composite filler material and the system is evacuated.

Step 6. The liquid composite is forced into the vacuum-filled TetraCast* pattern by adding air pressure to the system.

Step 7. After the matrix solidifies the composite is thermally post-cured.

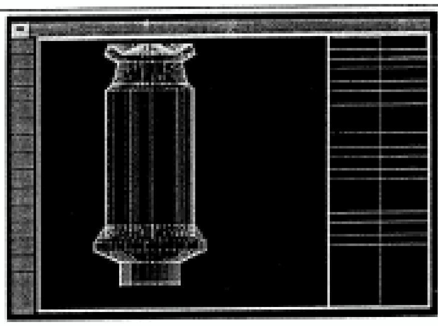
Step 8. Remove supports and finish the net-shape composite.

This process consists mainly of unattended curing time and can be completed in as little as 2 hours of labor including preparation, drainage, filling, and cleanup. In some cases this process can generate solid models in approximately half of the machine time of a solid ACES build (depending on wall thickness and other factors).

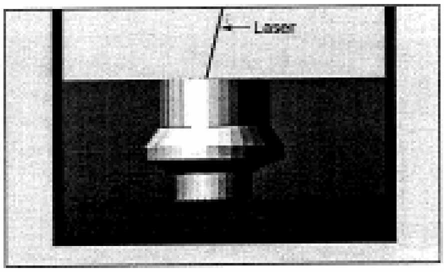
THE COMPOSITE MAKE-UP

The net-shape composite is made up of three main components including: the SLA TetraCast* pattern, resin matrix, and reinforcement. Typically, the resin matrix will be loaded to its limit, taking advantage of the resulting reinforcement mechanical properties.

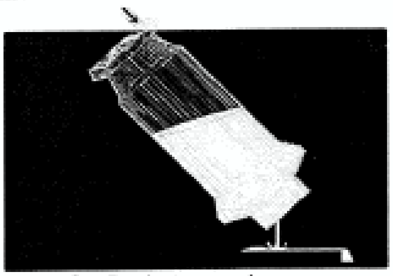
TetraCast* (Figure 3) is an SLA build style invented and developed for both RCP** applications and investment-casting applications. TetraCast* patterns have many of the same benefits and applications of QuickCast™ patterns. TetraCast* uses an internal three-dimensional tetrahedron structure modeled after the molecular bond geometry found in diamonds. The TetraCast* internal structure offers the SLA skin maximum support and



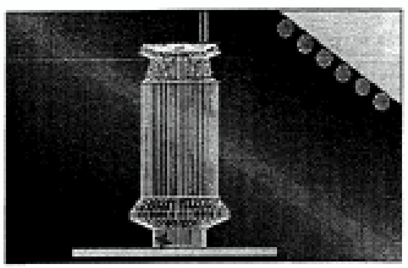
Step 1. Create .stl file



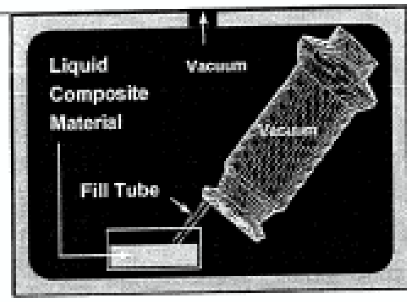
Step 2. Create Tetra Cast pattern on SLA



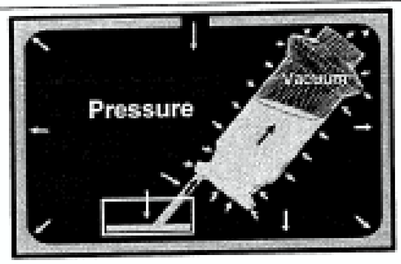
Step 3. Drain trapped photopolymer in T. C. pattern



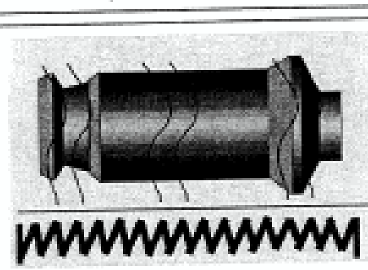
Step 4. Cure T. C. pattern with ultraviolet light and patch leaks



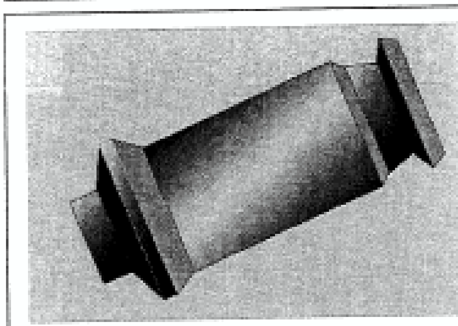
Step 5. Remove air from chamber and pattern to create a vacuum



Step 6. Pressurize chamber to force liquid composite material into T. C. pattern



Step 7. Heat solidified composite material to complete matrix curing process



Step 8. Clean up and finish

The resin matrix serves two main purposes: 1) suspension of the reinforcement during transport into the TC pattern; 2) solidification around the reinforcement to complete the composite. Typically, a two-part epoxy is used for the matrix, although polyurethane and other two-part plastics can be used. Epoxy was selected for its low viscosity level, excellent wetting characteristics, and reinforcement bonding capabilities. Factors that influence the type of epoxy to be used include: viscosity level, gel-time, exothermic characteristic, heat-deflection-temperature, tensile-strength, elastic-modulus, availability, shrinkage, post curing requirement, and notch sensitivity.

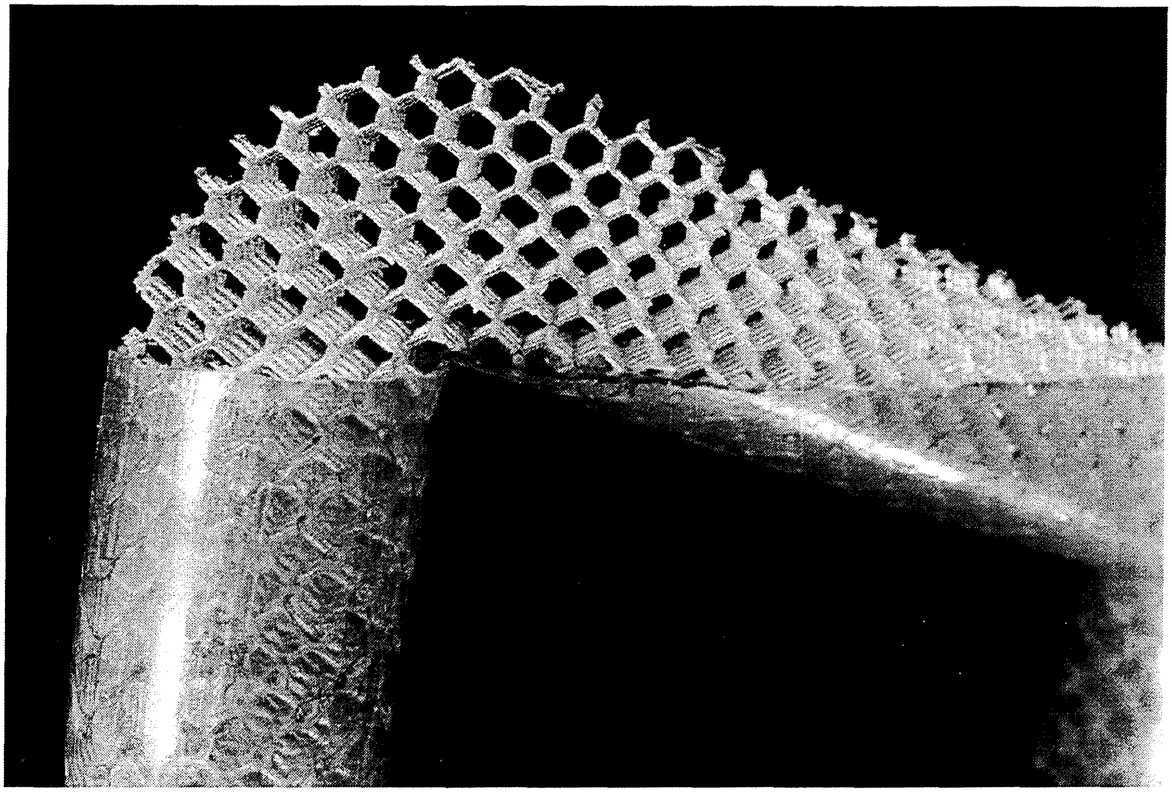


Figure 3. SLA TetraCast* Pattern with Exposed Tetrahedron Structure

By encapsulating various reinforcements in the epoxy matrix, enhanced mechanical properties can be achieved. These improved mechanical properties can exceed those of current SLA resins and also those of many engineering plastics. There are a large variety of reinforcement materials that can be used, but there are geometry limitations. Reinforcement materials include: glass, carbon, silicon carbide (whiskers), calcium carbonate, metal, aramid (Kevlar), and others. Those which are readily suspended in the liquid matrix material are ideal for RCP**. Reinforcement geometries include discontinuous fibers, flakes, particles and limited hand-placed filaments, as shown in Figure 4. Combinations of two or more of these reinforcement materials and/or geometries can be used to achieve desired physical or mechanical properties. Due to the random orientation of the reinforcement, composite structures will be nearly isotropic. Sizing can be used to enhance the bond between the reinforcement and the matrix.

PRELIMINARY RESEARCH FINDINGS

Beyond developing the RCP** process, we have studied the mechanical properties of simple composite combinations and confirmed that the rule of mixtures does apply. Mechanical properties including elastic-modulus, tensile-strength, and heat-deflection-temperature, have been investigated.

An early goal of developing RCP** was to determine whether the rule of mixtures does apply to this composite make-up. It was shown that the rule-of-mixtures [10] does apply to this composite system through two experiments (both experiments are shown in Figure 5). The earlier experiment included two composite volume ratios and two 100% samples of each material (epoxy photopolymer and straight epoxy). The later verification experiment included one composite sample and two 100% samples of each material. Both experiments showed this composite material to follow the rule of mixtures.

Another early goal was to find a composite with a high elastic-modulus, well suited for rigid sand casting patterns. This goal was achieved by adding glass micro-spheres to the tensile samples [11, type III]. The first composite fillers included 10%, 17.5%, and 25% glass-in-epoxy by volume. These composite fillers were injected into the TC pattern and later tested. Figure 6 illustrates that the elastic-modulus is increased by increasing the volume ratio of glass. The elastic-modulus shown for 37.5% and 50% are predicted values.

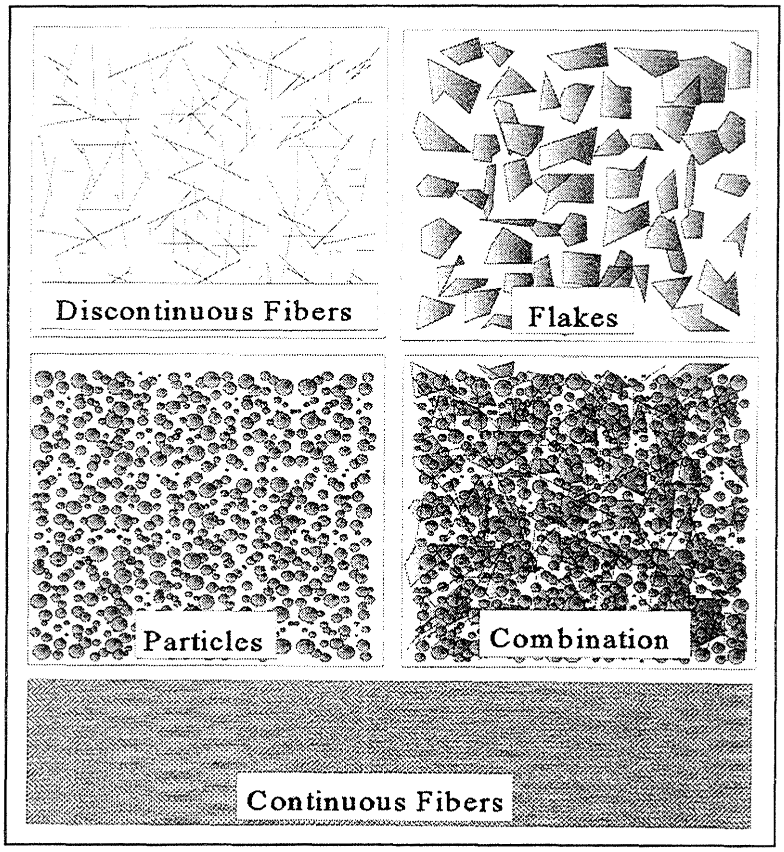


Figure 4. Reinforcements

Another research goal was to seek increased tensile-strength. It had been shown that by adding continuous-carbon-fiber as the reinforcement material, the tensile-strength can be increased to 30,000 psi (elastic-modulus of 2.0 M-psi). While this increased tensile strength is desirable, continuous fibers are not easily added. Discontinuous chopped-carbon-fiber additions increase viscosity making RCP** difficult. Milled-glass-fiber has shown much promise with up to 33% volume ratios achieved to date (not yet tested for mechanical properties). Particles and flakes have not been used to increase tensile-strength, but may be considered in the future.

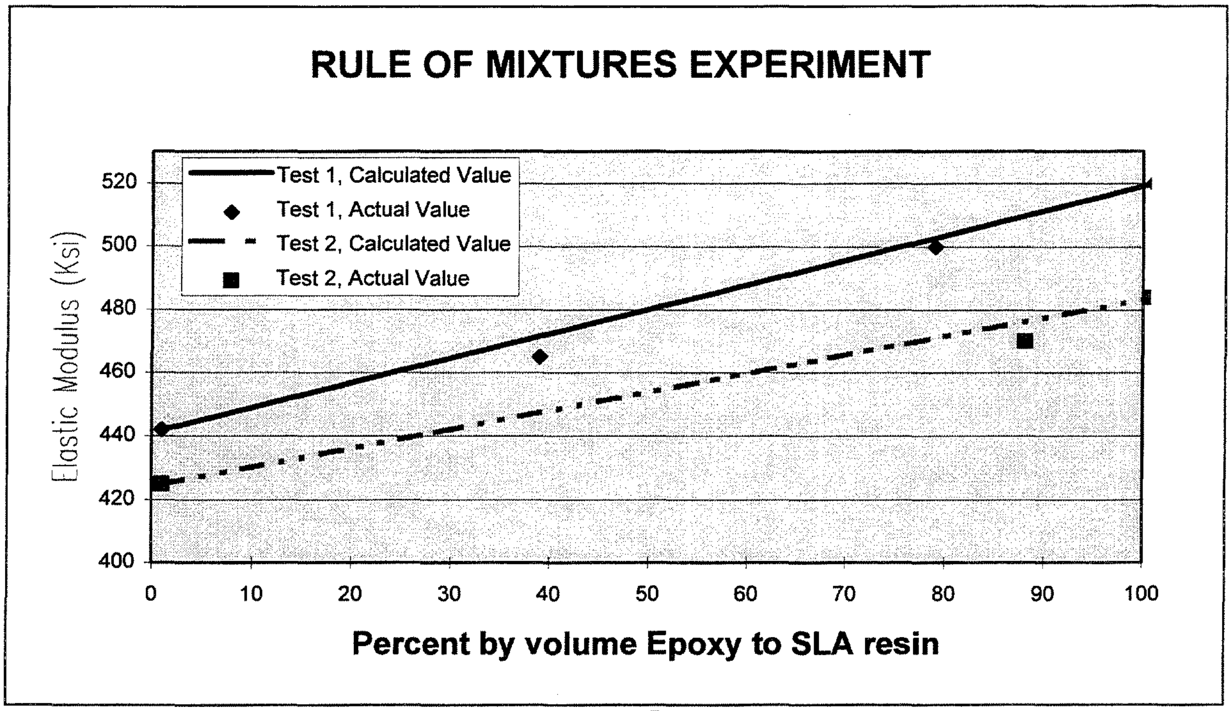


Figure 5.

Approaches to increasing heat-deflection-temperature is another area of preliminary investigation [9,12]. It has been shown that the composite materials have a significantly higher heat-deflection-temperature when compared to pure SLA epoxy. Figure 7 shows an increase of almost 50% when TC patterns loaded with calcium carbonate (CC) filled epoxy were tested. The epoxy matrix was the limiting factor in this experiment. If epoxy designed for higher

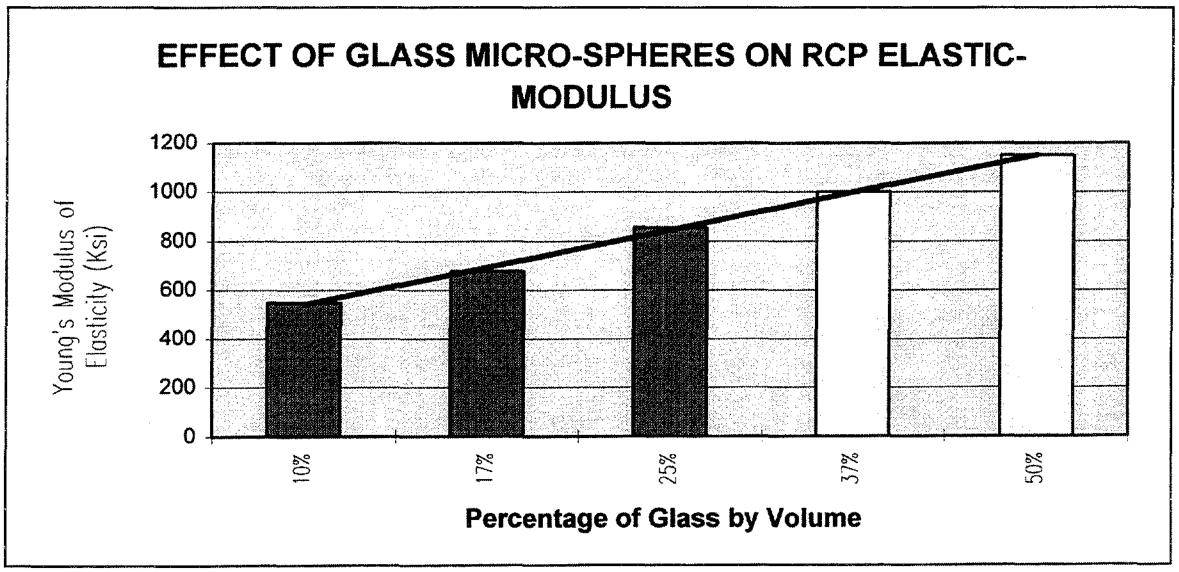


Figure 6.

temperature applications were used, the heat-deflection-temperature could be increased further. The SLA resin used has temperature limitations. Several new high temperature resins are being introduced which may extend the heat-deflection-temperature of RCP to above 300° F.

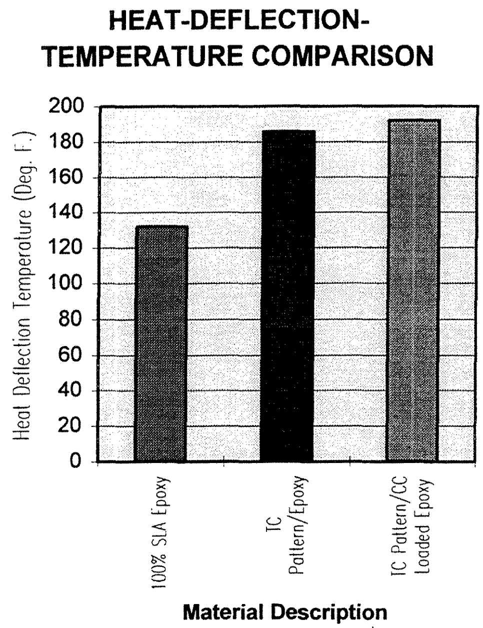


Figure 7.

CURRENT AND FUTURE RESEARCH

Several areas are currently being studied to better understand the limitations of RCP** and the parameters to work within. Areas currently being investigated include: viscosity limitations, stair-step notch reduction, shrinkage prediction, reinforcement combinations, cooling methods, and TC pattern fill methods. Areas of future study include next generation TC structures, process automation, SLA skin removal, wear-resistant coatings, and reinforcement sizing.

FUTURE APPLICATIONS

With any new technology, it is important to identify possible applications. Custom manufacturing of complex net-shape composites could be one application of this composite fabrication method. This would include areas such as aerospace, medical, prototyping, and manufacturing. With this method, composites of virtually any shape could be quickly produced with a wide spectrum of tailored physical and mechanical properties. Aerospace mechanical components could be rapidly and accurately produced at a significantly reduced cost. Applications ranging from custom test parts to custom ergonomic components could be produced using this process .

One-of-a-kind satellite and space-exploration components could be produced in line with NASA's 'Better, Faster, Cheaper' slogan. Housing components for miniaturized satellites might also find this process beneficial.

The medical applications of this process could include prosthetics, facial plates, and limited-production-equipment components. A RCP** vertebrae generated from a CT scan is shown in Figure 8.

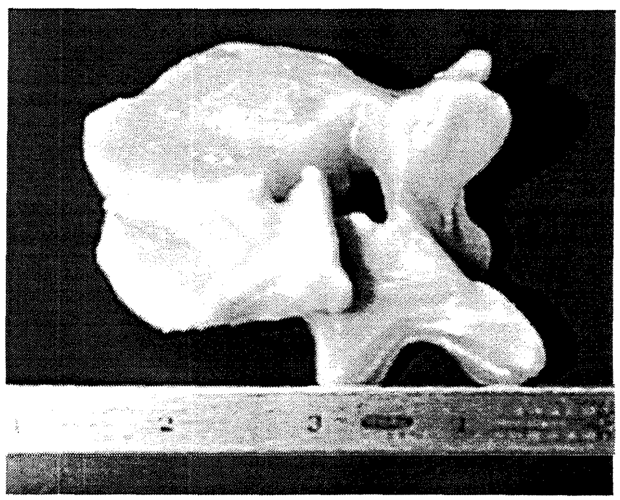


Figure 8. RCP** Vertebrae

Mechanical components that might be used on a prototype or manufacturing system could also be produced (Figure 9).

As this technology evolves, the applications will be extended, perhaps making new composite structures possible.

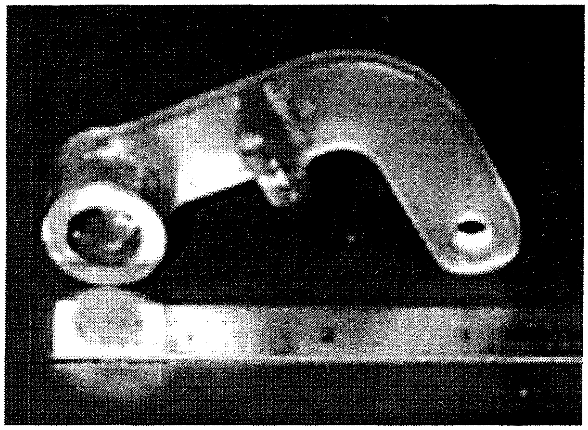


Figure 9. RCP Lever**

CONCLUSIONS

Net-shape composites can be achieved by using SLA TetraCast* patterns filled with a reinforcement loaded matrix. It has been shown that the rule of mixtures does apply to the resulting composite and that elastic-modulus, tensile-strength, and heat-deflection-temperature can be increased and/or predicted. Much research needs to be completed before the widened use of this process is realized.

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* TetraCast was developed at the Milwaukee School of Engineering Rapid Prototyping Center in October, 1995

** The Rapid Composite Process is similar to Rapid Composite Prototyping developed at the Rapid Prototyping Center at the Milwaukee School of Engineering in July of 1994