CUSTOM FABRICATION OF HARD TISSUE RECONSTRUCTIVE FRAMEWORKS

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Abstract

The feasibility of fabricating custom frameworks for tissue regeneration utilizing three-dimensional inkjet printing technology followed by slip casting was investigated. A CAD solid model of mold was created with structures within the mold cavity to provide variable, customized porosity in the cast framework. The polymer mold was printed using a 3D ink-jet printer. The mold was then infiltrated by an aqueous suspension of hydroxyapatite to produce porous frameworks that were tested for mechanical properties.

Introduction

Porous materials have been used as non-resorbable intermediate structures for bone repair and when pore size is properly controlled such repairs can integrate into new bone, even permitting the development of vascularity [1]. A promising approach for hard tissue reconstruction is the integration of a custom mechanical framework with biological agents to promote development of the desired tissue [2]. Such a structure must have three characteristics. It must fit the patient, thus requiring a unique structure for every repair. It must have specified mechanical properties to permit proper function during regeneration. Finally, it must be able to carry the required precursor cells and/or growth factors and direct their development. Thus it will require a controlled internal structure that will probably not be uniform if it is to guide development of all of the subcomponents of functioning bone or cartilage. These requirements make solid free form fabrication the best hope for cost effective fabrication of the required structures.

Research to date on rapid fabrication of tissue frameworks has utilized either selective laser sintering [3], laminated object manufacturing [4] or fused deposition modeling [5]. In each case, the part must be sintered after the polymer binders are burned out. The ink-jet based rapid prototyping technology proposed for this study is well suited to the fabrication of precision frameworks for reconstruction. The system prints a layer of build material using an ink-jet head and maintains accuracy in the z-direction by milling the layer to a precise height before the next layer is deposited. The result is one of the most accurate and affordable commercially available solid free-form fabrication system. Models with pore feature size of 0.5 mm repeatability accurate to 0.05 mm have been produced. This process is not suitable for very large parts that may be required in orthopedic reconstruction, but it is capable of producing many of the common components needed for maxillofacial work.

In this work, a CAD solid model of a mold is built with the inner surface created using imported surface data from a CT scan. Structures are created within the mold cavity to provide variable, customized porosity in the cast framework. The polymer mold is printed using a 3D ink-jet printer. The mold is then infiltrated by an aqueous suspension of hydroxyapatite mixed with binder. The part is dried then processed in an oven to burn out the polymer binder and then sintered to produce porous framework.

The ability of tissue growth into the framework is requires a well connected network of macropores. A number of different designs for the internal geometry were considered. A repeated hexagonal pattern of axial cylinders interconnected like a honeycomb was found to give the most uniform mesh as shown in Figure 1. The pattern is repeated at uniform axial increments throughout the structure. Cross section sizes ranging from 0.25 mm^2 to 0.7 mm^2 were used, the smaller sections showing a higher rate of damage in processing. These structures in the wax mold will provide predictable sized pores in the cast structure.

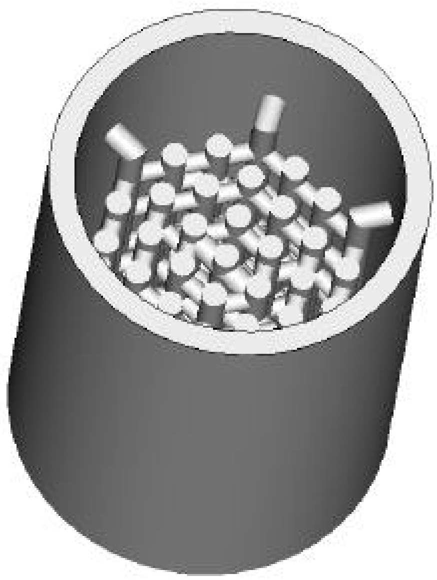

Figure 1. CAD model of mold with internal structure

Processing

Hydroxyapatite powder (Aldrich) was mixed with water and compressed to form coupons. Samples of the coupons were analyzed in a differential thermal analyzer (DTA).

The graph in Figure 2 shows the decrease in weight of the sample as the temperature increases. The initial downward slope is attributed to the loss of water from the specimen up to 600C.

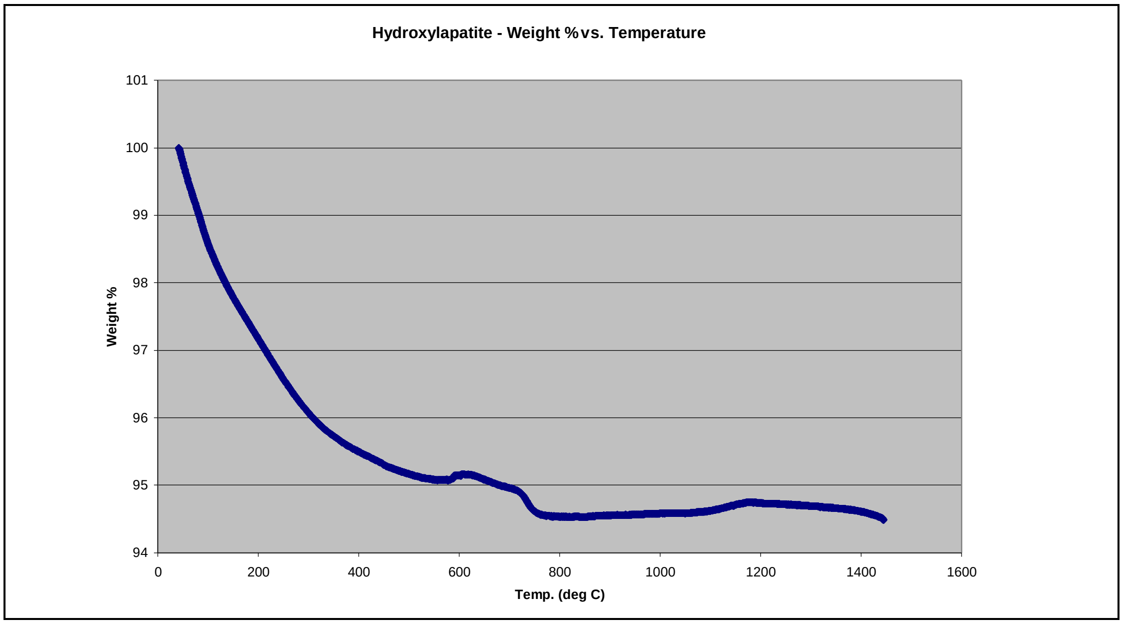

Figure 2. DTA weight loss analysis of HA

The graph in Figure 3 shows the temperature difference of the sample from the control pan in the chamber due to exothermic or endothermic processes. This shows that the loss of the water can be completed at below 600C, but that the sintering temperature can be set below 1200C.

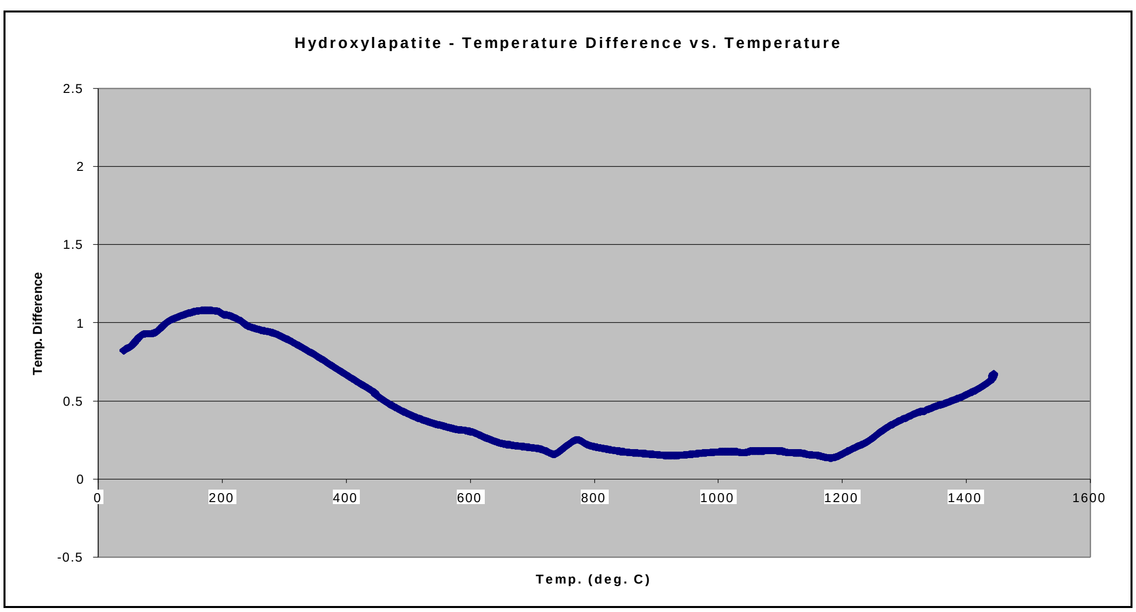

Figure 3. DTA temperature analysis of HA

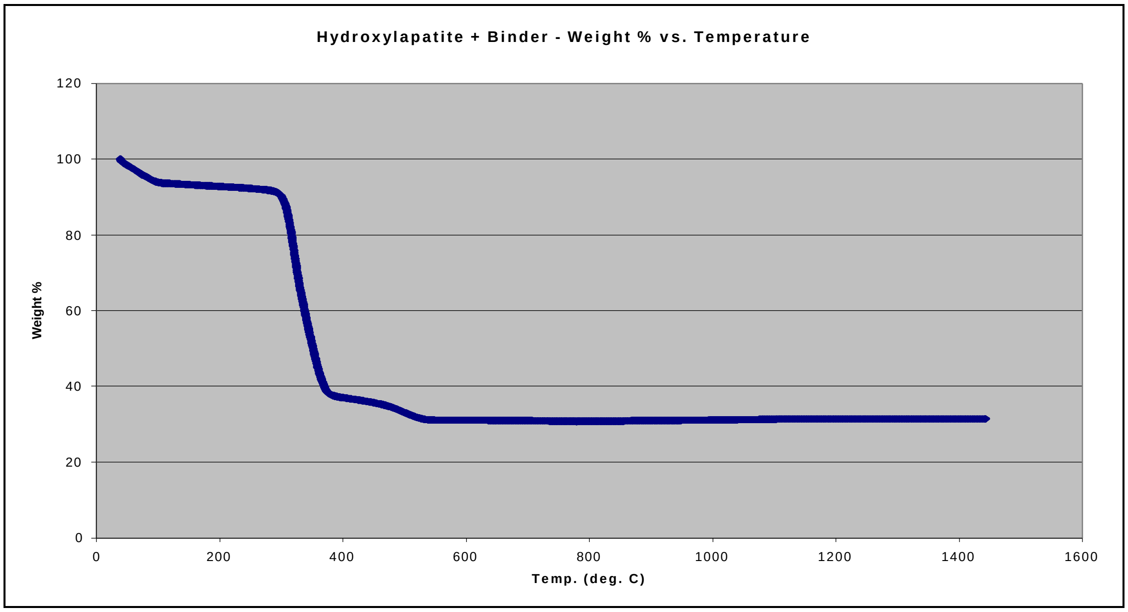

Figure 4. DTA weight loss analysis of HA with binder

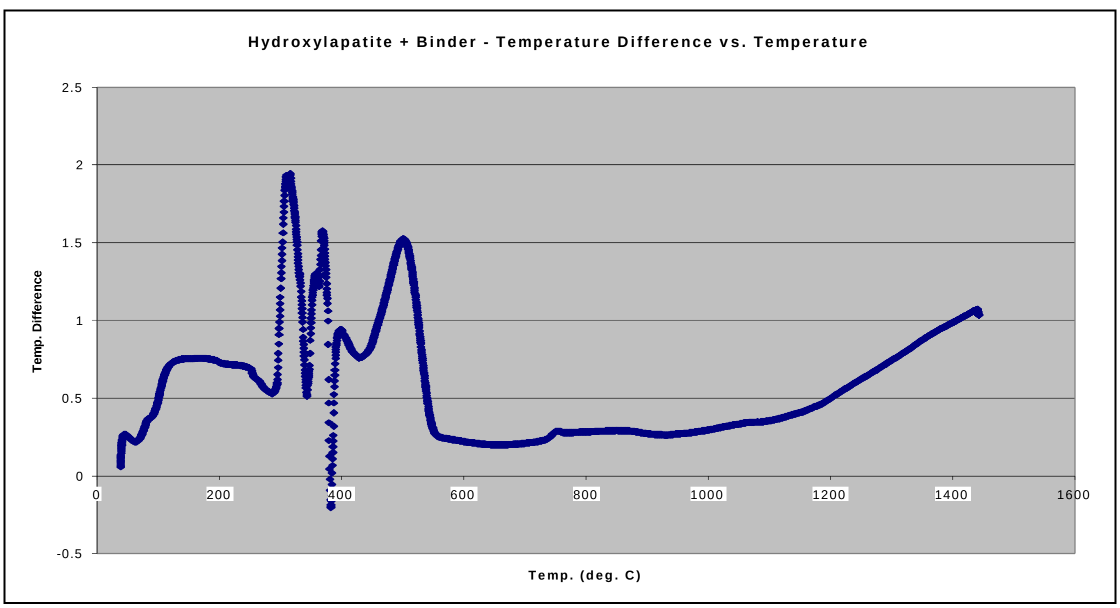

Figure 5. DTA temperature analysis of HA with binder

Figures 4 and 5 show the corresponding graphs for hydroxyapatite mixed with Duramax B-1020 binder. Figure 4 shows the loss of water from the specimen at 500C. The graph in

Figure 5 shows binder is burnt off at 700C. This establishes the burn off temperature at 600C followed by sintering at 1100C, thus the temperatures for processing the specimens have been identified.

Molds with the outer body of the mold and the internal structures for the pores all in one piece were built using the Sanders ink-jet printing machine. Hydroxylapatite powder was combined with Duramax B-1020 organic binder and water to make a slurry. The slurry was poured into the mold and the water allowed to seep out of the base to form solid ceramic specimens.

The specimens fabricated above were all found to have cracks and internal cavities. These make compression strength tests unreliable. The cause of these defects appears to be uneven drying. Experimentation to eliminate these defects by modifying the binder content and controlling the humidity is continuing.

SEM scans of the surface reveal as shown in Figure 6. that the sintering process leads to relatively smooth surfaces. This may indicate that the surface needs to be etched to create micropores to enhance osteoinductivity.

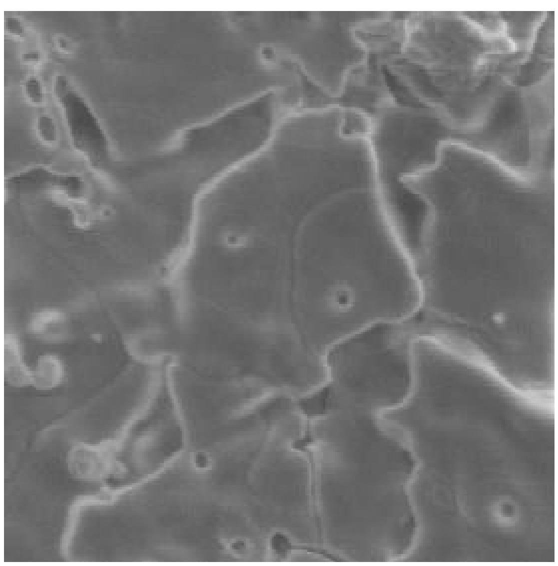

Figure 6. SEM picture of part surface 4000X magnification

Conclusion

The results of the studies conducted this year suggest that we can design molds for frameworks with specified pore size and distribution in a CAD system. These molds can be fabricated using ink-jet printing rapid prototyping technology. The materials to be used for casting of the frameworks in these molds have been selected and analyzed to identify the processing temperatures.

Bibliography

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