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CHARACTERIZATION OF THE RESPONSE OF SYNTHETIC BONE SUBSTITUTE TO COMPRESSIVE LOAD

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ABSTRACT

Synthetic bone substitute has been used for bone implantation in humans. Chemical composition of this bone substitute is claimed to be close to that of human bone. The objective of this research is to characterize the response of synthetic bone substitute after subjected to compressive load. Compression test was carried out on INSTRON Universal Tester. The maximum load that the specimen can endure and stress-strain response were obtained from the compression experiment. Qualitative and quantitative characterization was done using scanning electron microscope and image analyzer. The response of the specimen showed multiple yield points during compression. Stress-strain response did not follow any of the response of either ductile or brittle materials. The response was rather strictly nonlinear throughout the test range undergone. In addition, the mode of failure is more to shear. The micrographs reveal porosity range, chemical composition and the smallest cell size sustained after compression. The results of this research can be useful for developing new synthetic bone or at least improving the properties of the current one.

Keywords: Synthetic bone, compression, material response, stress-strain

INTRODUCTION

The awareness of life-threatening injuries and degeneration problems in human bone has led engineers from various backgrounds to develop synthetic bone substitute which can duplicate enviable mechanical properties of human bone. Some of the developments are TCH synthetic developed by KASIOS, France and bioactive star gels introduced by Spanish researchers from the Universidad Complutense de Madrid and the Universitat Politècnica de Catalunya in Barcelona [1, 2, 3]. Synthetic bone substitute is a kind of biphasic ceramic in which hydroxyapatite and tricalcium phosphate are found as its constituents. Its evolution and application for bone implantation in humans have been well-recognized over few years as chemical composition of this bone substitute is believed to be close to that of human bone [1-5].

The primary intentions of the bone substitute are proper treatments for a range of bone degeneration problems, to help speed recovery of injuries, and potentially act as bone replacements. However in practice, there are several problems related to the type and structure of material used in synthetic. Some of the problems are permanent displacement of the implant relative to the bone, micromotion, and lack of fixation stability at the bone-implant interface [4, 5]. Principally, the material flexibility that can be adapted by the host bone structure is interrelated to the material characteristic when subjected to certain loads. This characteristic is also important to predict long-term behavior of the synthetic. Unfortunately, no sufficient report on such information has been found so far. Previous studies focus on finding out the properties of natural bone using experimental methods as well as computational methods [6-16].

The aim of this paper is to highlight some characteristics of synthetic bone substitute at macro and micro levels after subjected to compressive load using compression tester and scanning electron microscope. This research will provide useful information for development of new synthetic that can perform better than the existing ones, or at least for improvement of the properties of bone synthetic.

COMPRESSION TEST

The synthetic specimen was obtained from KASIOS. The specimen was cylindrical shape of 8mm diameter and 20mm length. Computerized universal testing machine INSTRON3369 with integrated software was employed to carry out compression test. Since the specimen was expensive and it is too costly to test on many, titanium specimens of the same size as bone specimen were tested several times to calibrate the machine as well as to get some clue on the appropriate load for the bone specimen. Titanium was used as a reference sample as it has some properties compatible with those of the bone. The specimen was prepared using CNC turning center, and the top and bottom surface that would touch the compression plates were fine-finished to ensure negligible friction. The test was repeated three times to confirm the computer-generated results. Figure 1 illustrates the deformation of titanium specimen subjected to a compressive load of 15 kN with the crosshead speed of 0.6 mm/s. Mode of deformation is conformed to shearing as the aspect ratio of the specimen is greater than 2.5 [17, 18]. The elastic limit was found to be 165.2 GPa. These results were agreeable with the published report. Thus the compression tester was calibrated.

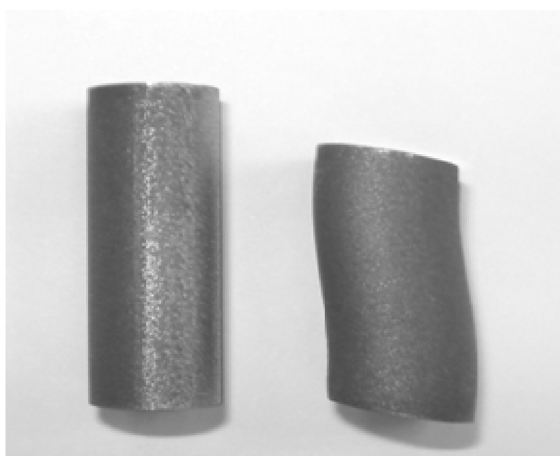
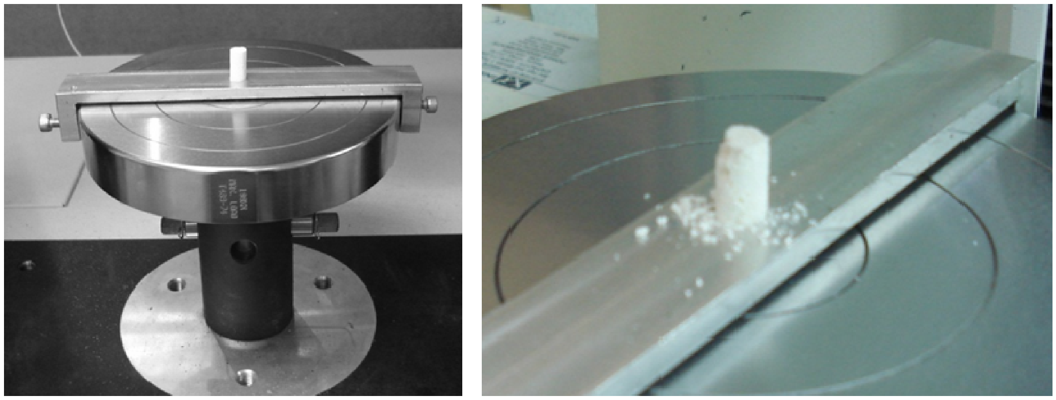


Figure 1. Deformation of titanium specimen after compression

For the synthetic specimen, the fixture was fabricated to hold it in order to do compression test as the specimen was very delicate. Figure 2(a) shows the bone specimen mounted on the fixture that is clamped onto the base plate of the tester. The maximum load to be applied was set to be 0.5 kN with the same crosshead speed used as with titanium. The deformed bone can be seen in Figure 2(b). The predominant mode of deformation is likely to be shearing at macro level [17].



(a) (b)

Figure 2. Response of bone synthetic specimen after compression

Figure 3 demonstrates stress-strain curve as response of the specimen subjected to maximum compressive load of 0.5 kN. The trend of the stress-strain response does not follow a typical compression test curve of conventional materials. Its behavior is like more conformed to that of brittle materials such as silicon and crushable concrete. Overall trend is also prevailed by nonlinearity with several yielding. The approximate elastic modulus was found to be 5202 MPa and first yield point to be 0.397 MPa. Elastic modulus was relatively low compared to natural bone [6, 8]. Also first yielding occurred very fast indicating low rigidity.

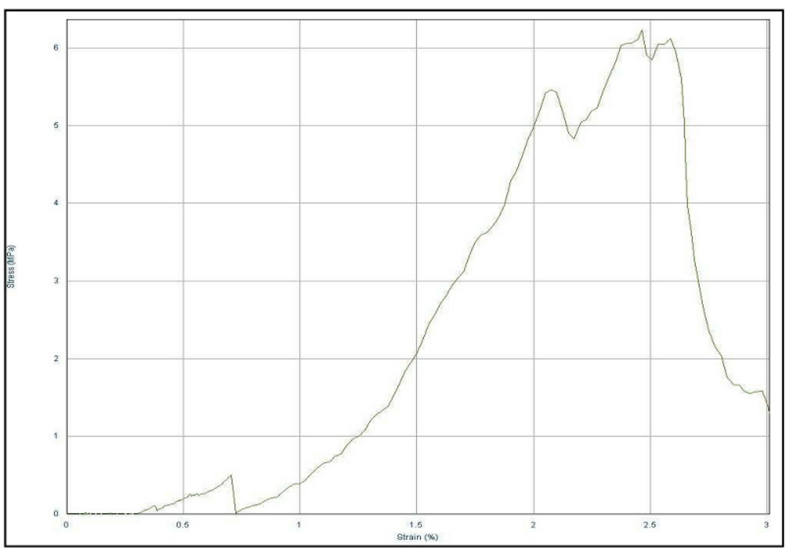
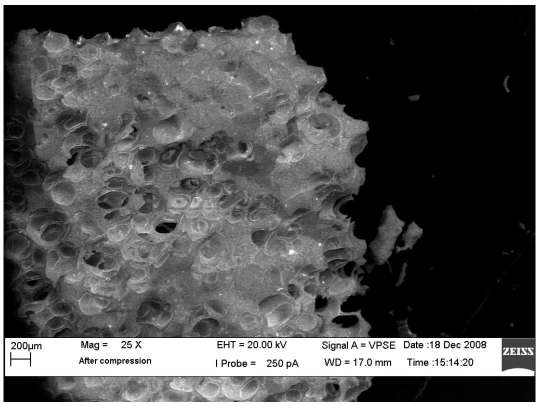


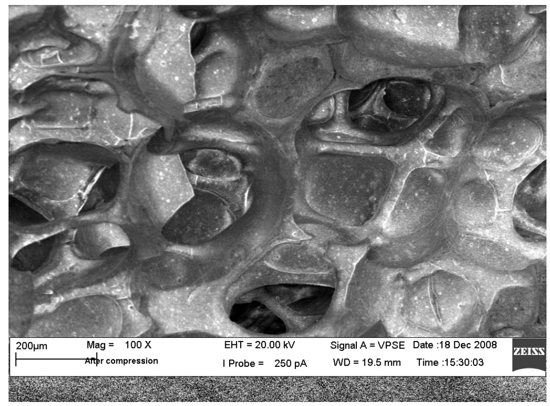
Figure 3. Stress-strain response of bone synthetic after compression

MICROGRAPH STUDY

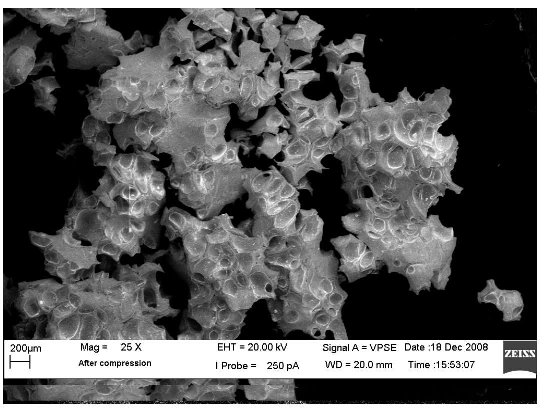
Figure 4 shows scanning electron micrographs of synthetic specimens after compression test. Figure 4(a) and (c) illustrate the specimen at macro scale while 4(b) and (d) at micro scale. Pores can be clearly seen at macro level; however the distribution of porosity is not uniform even at crushed state as shown in (c). In some region, it seems like no presence of porosity. Additionally, some void is formed instead of porosity. These voids can be defect in the specimen which degrades the strength. At micro scale, a lot of microcraks and breakage are present. The close-up views of the specimen reveal these damages. After compression, part of the specimen becomes like powder. The smallest size was found to be about 100 μm in average.



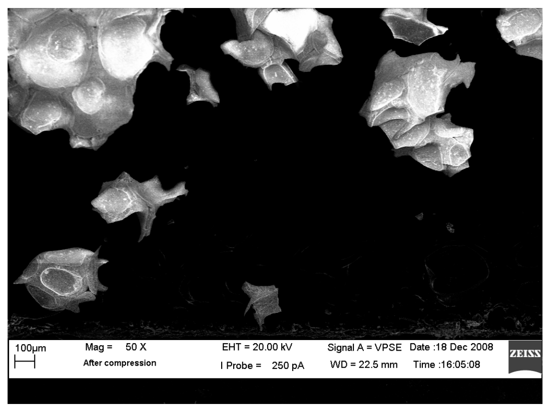
(a)



(b)



(c)



(d)

Figure 4. Scanning electron micrographs of the synthetic specimen after compression

CONCLUSION

The response of the synthetic bone specimen has been characterized with compression tester and scanning electron microscope. With reference to the experimental results, the following conclusions can be drawn:

- The specimen is able to sustain its strength under a range of external load.
- However as a whole it has low fracture resistance and poor strength.
- The principle factors that reduce the specimen strength are presence of many voids and non-uniform distribution of pores at micro scale.

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