Preparation and mechanical property of polymer-based biomaterials

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Abstract. The porous polymer-based biomaterial has been synthesized from PLGA, dioxane and tricalcium phosphate (TCP) by low-temperature deposition process. The deformation behaviours and fracture mechanism of polymer-based biomaterials were investigated using the compression test and the finite element (FE) simulation. The results show that the stress-strain curve of compression process includes linear elastic stage I, platform stage II and densification stage III, and the fracture mechanism can be considered as brittle fracture.

1. Introduction
Biomaterial is essentially a material that is used and adapted for a medical application. For instance, biomaterials can be used in joint replacements, bone plates, bone cement, artificial ligaments and tendons, skin repair devices, etc. Up to now, many types of biomaterials have been developed and used widely [1-6]. In general, materials options for synthesis biomaterial include metals, ceramics and polymers. Unfortunately, metallic and ceramic biomaterials are not suitable to replace soft tissues because of markedly different mechanical properties. Polymer-based biomaterials may be a good candidate for replace soft tissue, because synthetic polymers that have various properties can be produced by changing the amount or kind of reactant and used according to its purpose. Poly-lactic acid is a kind of polymer which make from lactic acid as the main raw material and has good thermal stability, solvent resistance, mechanical properties, physical performance, biodegradability. So it is an ideal green polymer material [7-11].

In this paper, the polylactic-co-glycolic acid based biomaterials were fabricated by the low-temperature deposition forming process. For investigating the mechanical properties of the porous material, the deformation behavior in load process of the prepared biomaterial and the mechanism of fracture were analyzed by using compression experiment and FE simulation.

2. Experiments
2.1. Experimental materials
Experimental materials were polylactic-co-glycolic acid (PLGA) and dioxane. In the polylactic-co-glycolic acid, the ratio of LA and GA is 5 to 5, molecular weight is 25 myriad. The ratio of weight of PLGA and volume of dioxane is 0.10. Solid powder is tricalcium phosphate (TCP). The ratio of TCP and PLGA is 3 to 7.
2.2. Experimental equipment and forming process

The low-temperature deposition equipment developed by Tsinghua University was used [12]. The flow chart of forming process can be shown as Fig.1.

![Figure 1. Flow chart of forming process](image)

Firstly, according to the structure design of parts, CAD model can be built. Then, relevant process file and NC code file used to numerical control machining can be generated through data processing software. Secondly, according to the proportion of materials components, the selected polymer materials were dissolved in liquefier. Thirdly, NC code file can control the sprayer ejecting the slurry and scanning movement. The extrusion materials can solidify and bond rapidly in low temperature room. The designed part can be formed through the pile-up process. At the same time, porous structure can be obtained due to the phase separation. Fourthly, the formed parts were dried in dehydrator. The structure of formed part can transform to microporous structure due to the sublimation of dissolvent.

2.3. Mechanical property test

The compression mechanical properties of test samples were measured using Instron 5569 electronic universal testing machine. The size of the round sample was \( \phi 16 \text{ mm} \times 10 \text{ mm} \). The load velocity was 1 mm/min.

3. Results and Analysis

3.1. Porous patterns

Fig.2 shows that in the prepared porous materials, there are lots of pores with uniform thickness of wall and most of the pores are connected and distributed homogeneously. It can also be found that TCP powders have been distributed homogeneously on the surface of wall.

![Figure 2. SEM image of porous material](image)

3.2. Stress-strain curve

The stress-strain curve of compression process shown in Fig.3 includes linear elastic stage I, platform stage II and densification stage III, which is the typical compression curve of porous structure.
Flow stress is the most important material parameter. Usually, flow stress is the function of equivalent effective strain and equivalent effective strain rate, and which can be described by the expression (1).
\[
\bar{\sigma} = \bar{d} (\bar{\varepsilon}, \dot{\varepsilon})
\]  

(1)

Where \( \bar{\sigma} \), \( \bar{\varepsilon} \), \( \dot{\varepsilon} \) are flow stress, equivalent effective strain and equivalent effective strain rate respectively.

According to difference of the yield rule, the flow stress datum of porous materials can be considered as the yield stress of porous body or compact body. Then, the flow stress regression model of porous materials can be fitted as
\[
\bar{\sigma} = 0.314 + 0.007 \varepsilon^{3.541}
\]  

(2)

3.3. Analysis of compression process

FE simulations of porous materials can disclose the flow and densification rule, and predict the defects generated during the plastic deformation process. Fig.4 shows the equivalent effective strain nephograms of compression process. It can be seen that the pore walls of porous materials can be crumbled under the pressure with increasing of the compression strains, then the block porous material become more and more compact. Porous materials have the characteristics of variability of volume, lateral flow, inhomogeneous deformation and compaction due to the porous pattern distinction, which leading to the complexity of deformation regularity.

![Stress-strain curve of compression process](image)

**Figure 3.** Stress-strain curve of compression process

(a) 1step  (b) 40step  (c) 60step

![Equivalent effective strain nephogram of compression process](image)

**Figure 4.** Equivalent effective strain nephogram of compression process

3.4. Analysis of fracture mechanism

Fig.5 shows the damage nephogram of compression process. It can be seen that with increasing of compression the surfaces of porous materials contact with the dies were collapsed firstly, then the
collapse range enlarged gradually. During the compression process, porous materials generate certain lateral deformation. SEM image of fracture pattern shown in Fig.6 indicate that external section has been compacted and inner section of fracture is still with porous structure. The fracture pattern is tearing shape, so the fracture mechanism can be considered as brittle fracture.

(a) 1step                                      (b) 40step                                (c) 60step

Figure 5. Damage nephogram of compression process

Figure 6. SEM image of fracture pattern

4. Conclusions

(1) The compression curve of the prepared porous biomaterial includes linear elastic stage, platform stage and densification stage. The porous materials have the characteristics of variability of volume, lateral flow, inhomogeneous deformation and compaction due to the porous pattern distinction, which leading to the complexity of deformation regularity.

(2) After compression test, the external section of fracture is compacted and the inner section of fracture is still porous.

(3) The fracture pattern is tearing shape and the fracture mechanism can be considered as brittle fracture.

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