EFFECT OF THE POROSITY ON COMPRESSIVE PROPERTIES OF POROUS MATERIALS

Yilong Liao, Guibao Qiu*, Jian Xiao Chenguang Bai

College of Materials Science & Engineering, Chongqing University, China, 400044

*corresponding author, Email address: qiuguibao@cqu.edu.cn

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Abstract

Porous titanium and alloy can be used for structural materials and functional materials, which are applied to in all fields. The difference of characteristics has great influence on the mechanical properties. The effect of research on the pore characteristics has great significance on the mechanical properties of titanium foams, the purpose of which is to obtain porous titanium foams with excellent properties. The influence of the porosity of porous titanium on mechanical properties has been studied by the finite element analysis software of COMSOL Multiphysics and digital image analysis software of Image-J. The porosity of porous titanium increases from 28.30% up to 72.30%, resulting in that the elastic modulus decreases from 30.77GPa to 15.94GPa, which are consistent with experimental results obtained by powder sintering technique. It shows that the elastic modulus decreases with the increase of porosity.

Introduction

The porous titanium of the metallic foams is presently the focus of very active research and development activities. It has a good application prospect in many fields. Porous titanium materials can be used for structural material and functional material. On account of their excellent mechanical properties, light-weight and high specific strength, porous titanium are attractive for structure and biomedical application; as their vibration isolation, damping, sound-absorbing, sound insulation, heat dissipation, electromagnetic shielding, porous titanium are attractive for functional material application [1] [2]. Therefore, porous titanium is widely used both in the aerospace industry, biomedicine, electronics and communication, petrochemical, environmental protection, construction, automotive industry and the field of sports goods.

In the ninety of the 20th century, the titanium foam was attached importance to in the field of biomedical application, after that, many research institutions had been put into the study of porous titanium. The high porosity titanium foam via urea as pore-forming agent was successfully prepared by Martin Bram in the early 2000 years. In the 2001 years, Thieme used the titanium powder were directly sinter, which were prepared the porosity in 35%~60%, the bending yield strength in 5~190MPa, the elastic's modulus in 5~80MPa and add a certain amount of silicon in titanium powder to increase the porosity. From these research we can found that the mechanical properties was affected several factors, which include matrix materials, the characteristic of pore of the porous titanium and process parameters [3]. However, the foam metal material was researched very later. Furthermore, the preparation process and the parameters of process have greater influence on the structure, which influence the performance, and the detailed mechanism on process has not been study systematically. The fundamental theory of foam material mechanical properties was described by Gnet and Thomas in 1959[4] [5]. This theory laid a foundation for the mechanical properties of porous materials at later. The research on compression yield behavior of the aluminum alloy foam materials by Thornton in 1975,and the foam structure of the bending stress was considered as an important factor of the materials were damaged[6]. In addition, the relative relationship between a relative density of 0.05~0.07 zinc foam yield stress energy absorption capacity and temperature was also studied. Asmosa and Wiobaikcli used this method and numerical simulation to research the crushing behavior of closed–cell foam aluminum. A reflection of truncated cube model arrangement soma basic fold mechanism was proposed by them, the analysis results in according with deformation mechanism of numerical simulation and the results were in accordance with the deformation mechanism of numerical simulation compared with the experiment [7]. Amit Bandyopadhyay studied the porosity have influence on the mechanical properties [8]. In this work, the mechanical properties of porous titanium was study by the finite element analysis sfortware of COMSOL Multiphysics , in order to investigate the deformation mechanical of compressive deformation and stress distribution of porous titanium materials[9].

Experimental

<u>Preparations</u>

In this work, the powder metallurgy with space holder technique was used to produce porous titanium materials. There have the advantages of the method of powder metallurgy with space holder, which includes cost-effective, good controllability, etc [10] [11]. The processing steps for fabricating porous titanium can be seen from Fig1. The mainly steps contain ingredient, mixing, compacting and heat treatment [3]. Each process has strong influence on the structure and mechanical property of porous titanium.

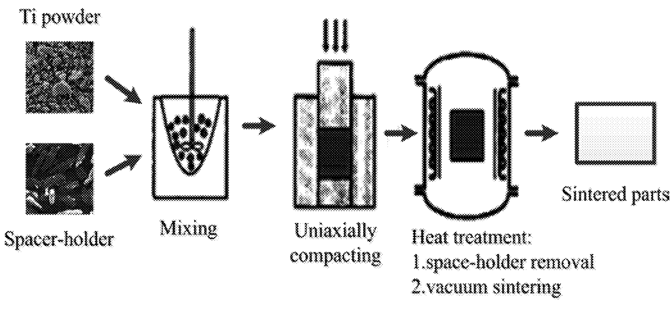

Fig1, Schematical illustration of the processing steps for fabricating porous titanium

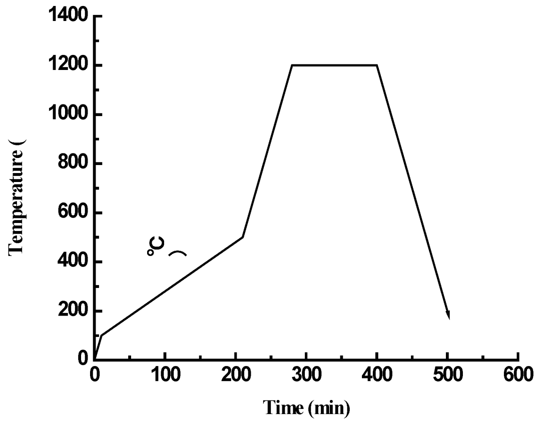

Fig2 Time dependent temperature for heat-treatment

The first, calculated the appropriate ratio of raw materials according to design the porosity, requirement of specimen size and the parameters of material, which the density of urea is 1.25 g/cm^3 and powder titanium is 4.51 g/cm^3. The samples were cylindrical dimensions diameter, ϕ=16.00mm and height, h=12mm. According to the volume fraction of raw material, weighing and mixing in the mortar. Then the specimen were prepared by uniaxially compacted with 100KN universal testing machine, the press force set 200MPa, the pressure maintaining time set one minute, dwell is conductive to the pressure sufficiently transmitted and to improve the suppression effect. The finally, the ZT-25-20 vacuum carbon tube furn ace can be used in the heat–treatment。The vacuum degrees $P_0 = 10^{-2}$ 。 The mainly factors need to be taken into consideration, which include evaporation of water, decomposition of urea and the sintering of powder. According to the differential thermal curve of urea, make the temperature curve of sintering as shown Fig 2. After natural cooling, the resulting porous titanium we need. The sintering of sample as Fig 3:

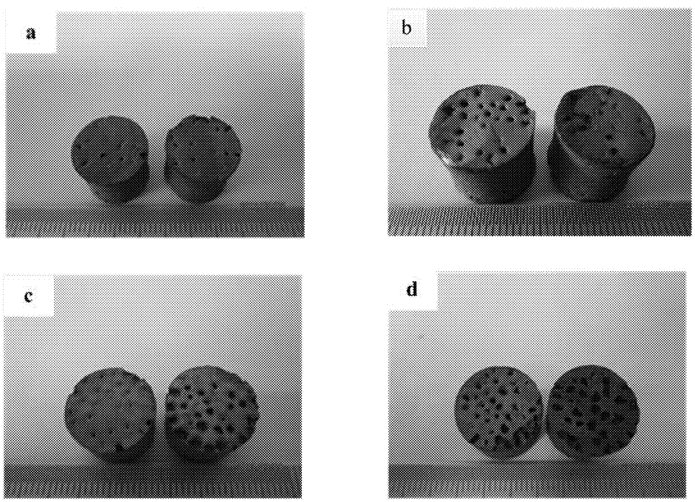

Fig3, porous titanium was made with different porosity (a-28.3%, b-41%,c-5.4%,d-72.3%).

Material Testing

The software of Image-J was used to analysis the pore characteristic of porous materials. It can calculate area and pixel value statistics of user-defined selections. In this study, the software of Image-J was used for calculate porosity. By means of the metallographic, import the Image-J software. Adjust the contrast of color, then automatically calculated the thickness of the hole wall of area ratio of the whole cross section. The area ratio was defined by v_0. So the porosity is $v = 1 - v_0$. The average pore size also can be calculated.

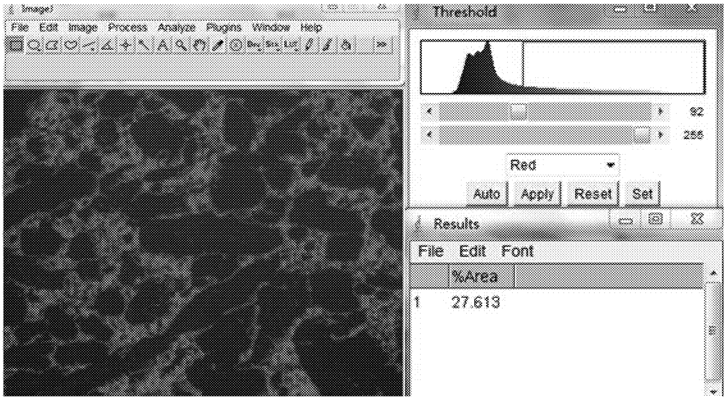

Fig4, calculate the porosity with Image-J

Test the performance to resist the compression of porous materials by the CMT-5150 electronic universal testing machine. The velocity of pressing is 0.1mm/s; after process data, we can get the stress-strain curve of porous materials by the software of Origin8.5. The results show as Fig5. However, compressed cylindrical specimens before the experiment to ensure that the upper and lower both are planar and parallel.

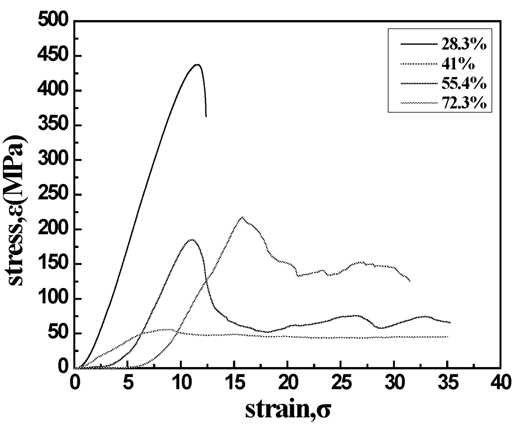

Fig5, the elastic modulus of porous titanium materials was manufacture with different porosity.

It can be seen from the Fig5, which the porosity has strong influence on elastic modulus and yield strength of porous materials. The porosity of porous titanium increases from 28.30% up to 72.30%, resulting in that the elastic modulus decreases from 38.28GPa to 8.4GPa. The elastic modulus and yield strength decreased with increase in porosity.

Simulation

Introduction of the COMSOL Multiphysics

COMSOL Multiphysics as senior finite element software was widely used [12]. Especially, it reflected greater advantage the coupling calculation in many physical situations. The simulation process contains several mainly steps, which include Establish the physical model, set the physical parameters and boundary condition, divide the finite element grid, solve computer and visualization post-processing.

The Physical Parameters and Boundary Condition

Mechanical properties of porous materials are mainly affected by the pore characteristics, porosity and material matrix. In this study, the porosity influence on elastic modulus of porous titanium can be considered. The table 1 list the physical parameters of titanium used in this study.

Table 1 Conditions for the numerical simulation of pure titanium

Matrix material	elastic modulus(Pa)	Poisson's ratio	Density(Kg/m^3)
Pure titanium	11×10^{10}	0.33	4.51

Load type: due to the compression force in the process of compression is not constantly, so the load was defined by the pressure velocity, fixed on the lower end side [13]. The upper pressing plate was pressed at a constant speed by v_0 = 0.01[mm/s]. The time was set 60 seconds. Then, the results shows that the distribution of stress and the strain morphology. At last, the elastic modulus can be calculated.

The Physical Model

The physical model must be coinciding with the actual sample [14]. According to the actual sample section Fig.5, a two-dimensional physical model of different pore characteristics was established by COMSOL Multiphysics software. The shape of pore was taken as the roundness of the pore.

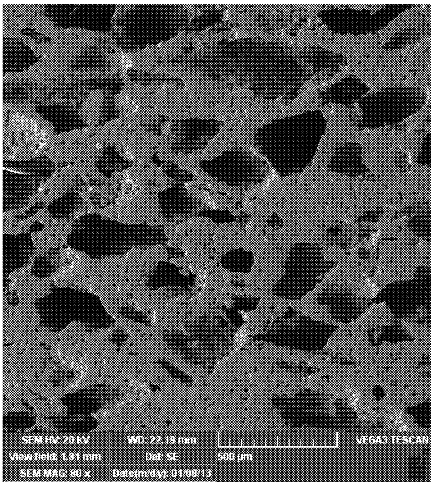

Fig6, Cross section morphology of porous titanium viewed by SEM

The first, the solid mechanics module was opened in the two–dimensional, and then the time dependent was chose. The second, According to the preset porosity and the requirement, the two–dimensional physical model was drawn by graphical selection, conversion and Boolean operation, etc. The third, the materials were chose in the material browser or directly input the parameters of material in the process of setting boundary condition. Divide mesh is the key to simulation of the finite element compute, the simulation results are affected both extra fine and extra coarse, may be lead to fail converge or cannot get the accurate calculation. Finally, set the solver and compute.

Simulation Results and Analysis

In the Fig7, Fig8, Fig9andFig10, the four pictures are described with different porosity of porous titanium, which include 28.3%, 41%, 55.4%, 72.3%. The simulation results were showed that the plane strain of porous titanium after compression deformation. The black contour in the photograph represent of geometric model before compression. Color part of diagram is the Von Mises stress distribution and Morphology of the materials after compression. It can be seen from the pictures, the maximum stress distribution between the two pores, the deformation increased with increasing the stress.

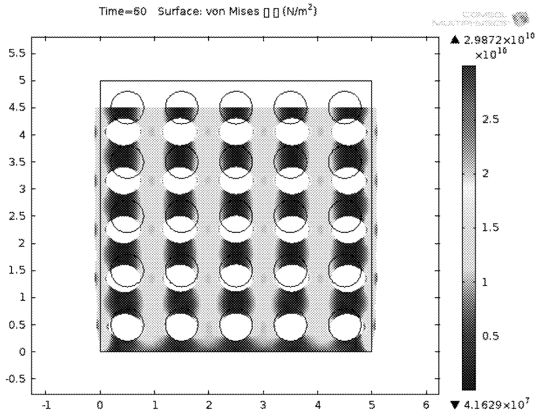

Fig7, Von Mises Stress distribution and compression deformation in the porous structure with porosity of 28.3%

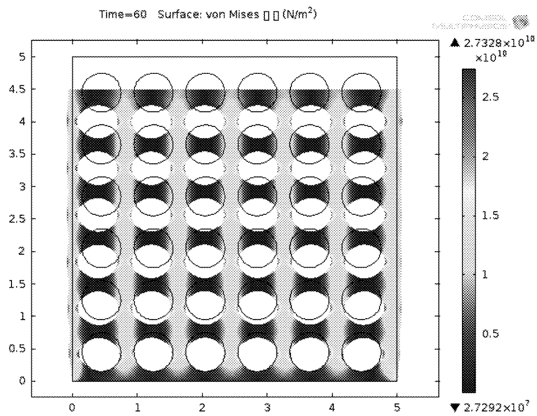

Fig8, Von Mises Stress distribution and compression deformation in the porous structure with porosity of 41%

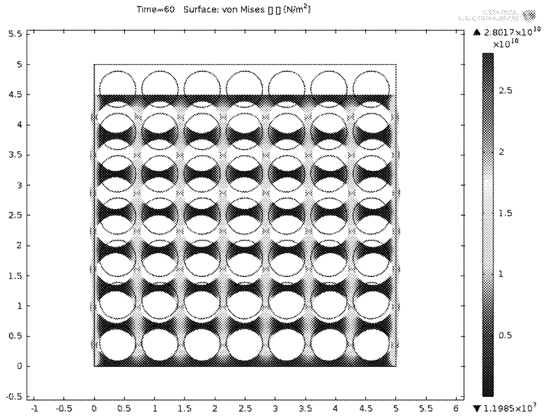

Fig 9, Von Mises Stress distribution and compression deformation in the porous structure with porosity of 55.4%

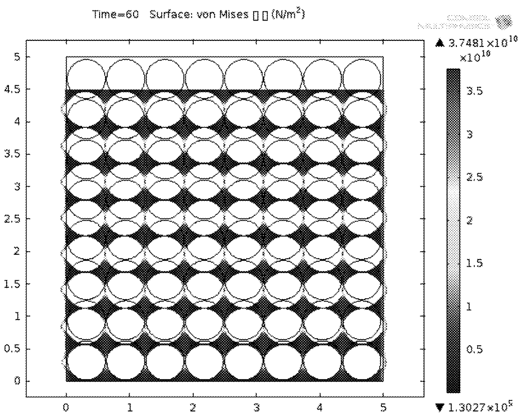

Fig 10, Von Mises Stress distribution and compression deformation in the porous structure with porosity of 72.3%

In the post-procession stage, elastic modulus can be effectively expressed by the formula as follow:

$$E = \frac{F/l}{\delta/h} \quad \text{.....................} \ (1)$$

Where E is elastic modulus of porous material; F is stress of porous material, and computed as $F = \int_0^l \delta_y dx$; δ is displacement; l and h are respectively the length and height of geometric model[10][15]. At constant aperture of 0.3mm, the result as table 2 of simulation values with different porosity.

Table 2, the simulation result of elastic modulus of porous titanium for different porosity

Porosity	0.283	0.41	0.554	0.723
Elastic modulus(GPa)	30.77	28.54	25.02	15.94

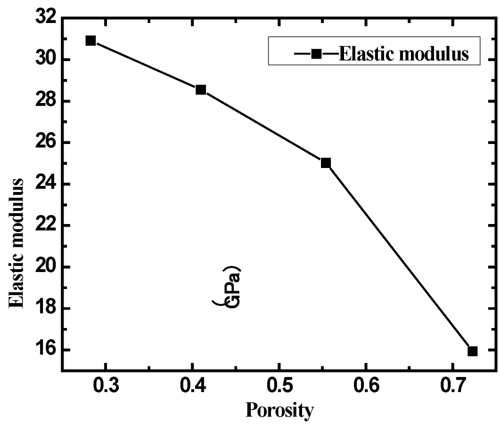

Fig11, Elastic modulus changes with porosity

The materials matrix, the characteristic of pore of the porous titanium and technology parameters have effected on performance of porous titanium materials [16][17]. It can be seen from the picture, the simulation results show that elastic modulus changes with porosity at constant aperture. The elastic modulus decreased with increase in porosity. The porosity of porous titanium increases from 28.30% up to 72.30%, resulting in that the elastic modulus decreases from 30.77GPa to 15.94GPa. However, thickness of pore wall was found to have strong influence on mechanical property, the porosity increased with decreasing the average thickness of pore wall [18].

Conclusions

This work confirmed that the elastic modulus decreased with increased in porosity of porous titaniu. Therefore, the control of porosity is necessary in order to optimize the mechanical properties of porous materials. By means of numerical simulation and experiment researched on the influence of porosity on mechanical properties, it can be seen that the porosity has great influence on elastic modulus. Through tailored the porosity, the excellent mechanical properties of porous materials can be get. The simulation results show that the porosity of porous titanium increases from 28.3% up to 72.3% that it result from the elastic modulus decreased from 30.77GPa to 15.94GPa. In addition, the experiment results show that the elastic modulus decreased from 32.28GPa to 8.4GPa.Not only the porosity have great influence on compressive properties, but the distribution of pore and microscopic porous also take effect.

Acknowledgements

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