氏　　　　名	ゆえ　しゅえじゅよん Yue　Xuezheng
所　　　　属	システムデザイン研究科　システムデザイン専攻
学位の種類	博士（工学）
学位記番号	シス博　第109号
学位授与の日付	平成30年3月25日
課程・論文の別	学位規則第4条第1項該当
学位論文題名	Mechanical Properties of Titanium Foams Having Disordered and Ordered Cell Structures (不規則及び規則セル構造を有するポーラスチタンの機械的特性)
論文審査委員	主査　教授　　北薗　幸一 委員　教授　　渡辺　直行 委員　教授　　筧　幸次 委員　准教授　鈴木　進補（早稲田大学理工学術院）

【論文の内容の要旨】

Metal foams are a class of materials with low densities and novel physical, mechanical, thermal, electrical and acoustic properties. They are known for their interesting combinations of physical and mechanical properties such as high stiffness in conjunction with very low specific weight or high compression strengths combined with good energy absorption characteristics. According to the pores structure, metal foam can be classified into open-cell metal foam and closed-cell metal foam. The open-cell one has network structure and all the cells are connected, while the structure in closed-cell metal foam contains many airtight bubbles and the bubbles are isolated. Their potential applications of metal foams were in different fields, such as high energy absorption, sound/thermal insulation, heat exchangers, filters, and catalyst carriers.

Titanium and titanium alloy are metal material with high tensile strength to density ratio, high corrosion resistance, fatigue resistance, high crack resistance and so on. Manufacturing titanium foams traditional method and additive manufacturing method are reviewed. Powder metallurgy is a term covering a wide range of ways in which materials or components are made from metal powders. The powder sinter process generally consists powder blending, die compaction, and sintering. Compaction is generally performed at room temperature, and the elevated-temperature process of sintering is usually conducted at atmospheric pressure and under carefully controlled atmosphere composition. This titanium foam of 60% porosity product was manufactured by powder metallurgy through compacting and pressure working. 3D printing is also known as additive manufacturing (AM). Additive manufacturing method builds a three-dimensional object from computer-aided design (CAD) model. Metal powder or wire is welded together using an electron beam as the heat source. Titanium foams made by laser or electron beam sintered titanium powder layer by layer. it has been widely expected to revolutionize the manufacturing of complex structure, from medical implants to aerospace engineering.

Outline of metal foam research obtained as followed：

Chapter 1：First chapter showed the introduction to physics properties of metal foams, applications of metal foam, many kinds of material（Al, Mg, Cu, Ti, Steel and so on）, Advantages of titanium, manufacture methods of titanium foam and comparison between traditional technology and additive manufacturing. Based on titanium foam, the motivation and objectives of this study are stated.

Chapter 2 : Investigates the strain rate sensitivity of commercial pure titanium foam at elevated temperature. Uniaxial compression tests were performed to investigate the effects of temperature and strain rate on the plastic deformation of titanium foams are with high temperature. Stress-strain curves showed line are elastic, plateau and densification regions which are typical characteristics of titanium foams. Both the flow stress and the energy absorption increase within creasing the strain rate and with decreasing the temperature. Apparent activation energy of the titanium foam was calculated. Apparent activation energy of the titanium foam was 603 kJ/mol, which is comparable to Commercial pure titanium with 746 kJ/mol. These results indicate that the thermally activated kinetics of the titanium foam mainly depends on the characteristics of the base material. In addition, XRD analysis showed the excellent oxidation resistance of the titanium foam.

Chapter 3 : This chapter aimed to clarify the effects of cell geometry on compressive deformation of open-cell titanium foams. Truncated octahedron and rhombic dodecahedron cells were used as different unit cell geometries by designing a commercial 3D-CAD software. The open cell titanium was printed of 10 kinds of pore structure for energy absorbing application by the electron beam melting process. The nominal porosities of both truncated octahedron cell and rhombic dodecahedron cell are plotted as a function of the normalized edge length. Relationship between the normalized porosity and normalized cell diameter are plotted as a function. The compressive behavior depended on the porosity, cell geometry and the cell orientation. Titanium foams with truncated octahedron cells showed high strength compared to those of rhombic dodecahedron cells. the parallel and oblique cell edges against the compression direction are effective to increase the compressive strength.

Chapter 4: Investigated influence of heat treatment on microstructure, mechanical properties and energy absorption capacities for Ti-6Al-4V foams with octahedron structure by additive manufacturing. Ti-6Al-4V foams were heat treatment at 1173 K and 1323 K (recrystallization annealing) for 1 h cooling by argon atmosphere in furnace. Titanium foams were subjected to different annealing in order to evaluate possibilities to the mechanical properties and energy absorption capacities. The apparent microstructure of Titanium alloy foams were studied through the SEM, XRD equipment. The Vickers hardness was discussion.

Chapter 5: summarizes the whole results in present. The remaining problems and future works are suggested in the fields of Titanium foam by powder metallurgy and additive manufacture