A novel method for controlling the microstructure and performance of 3D printed human implants

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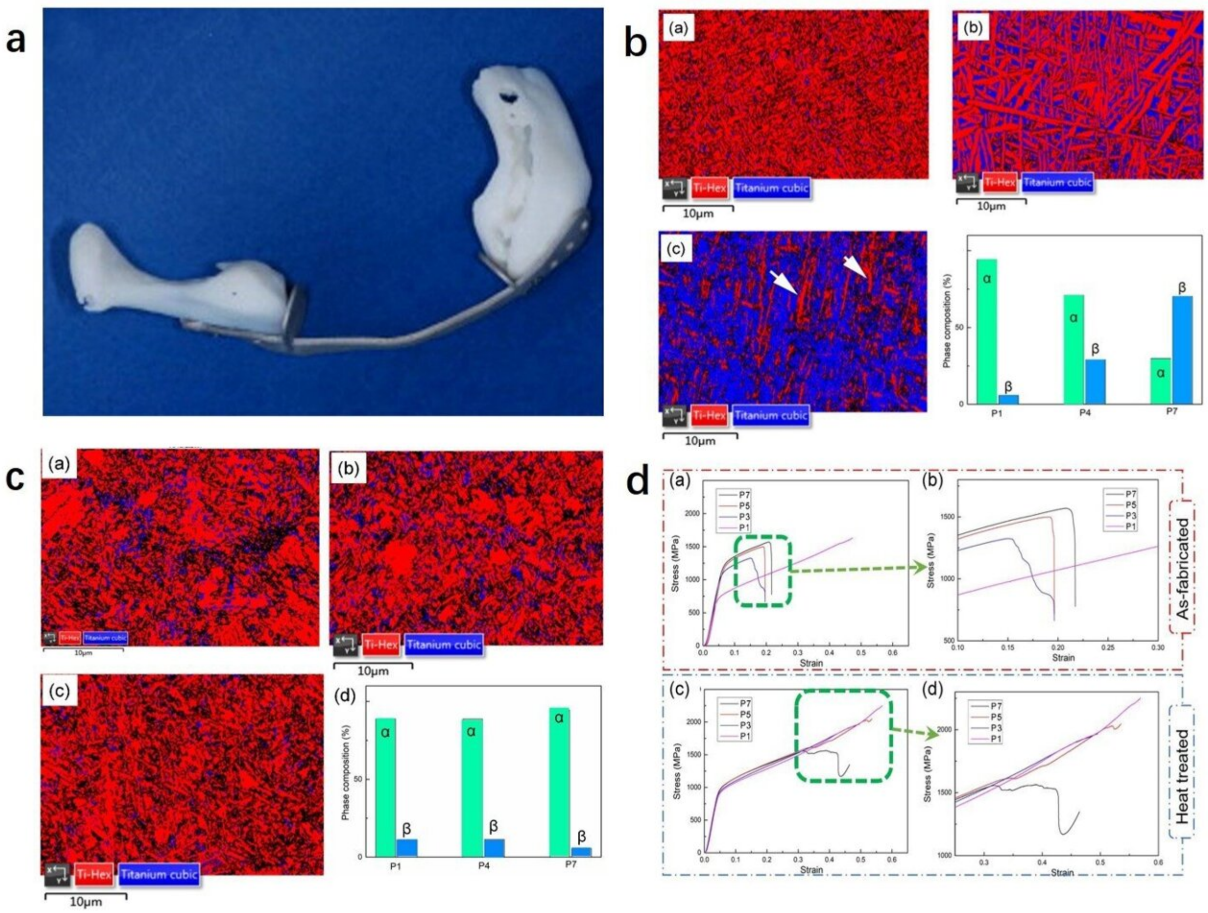

a, a typical human implant material application, which can be used as a bone plate to treat patients with transplant surgery. b, The distribution and morphology of α-hcp Ti and β-bcc Ti in different regions of Ti-Mo samples prepared by laser solid forming (a) P1-top; (b) P4 middle; (c) P7 bottom area; (d) phase composition statistics. The laser three-dimensional forming Ti-Mo alloy sample has an α+β dual-phase structure. The α phase content of the sample decreases from top to bottom, and the β phase of the sample gradually increases from top to bottom, showing a typical gradient structure. c, Distribution and morphology of α-hcp Ti and β-bcc Ti in different regions of the heat-treated Ti-Mo sample prepared by laser solid forming (a) P1-top; (b) P4 middle; (c) P7 bottom area; (d) phase composition statistics. The structure of the heat-treated Ti-Mo alloy sample from the top to the bottom is very uniform, and the structure is almost α mainly α. This shows that after the triple cycle heat treatment, the uniformity of the sample has been greatly improved. This transformation of the structure is due to the triple-cycle heat treatment process and the long holding time, and the non-equilibrium metastable β phase transforms into the equilibrium α phase, so that the structure from the top to the bottom of the sample tends to be thermodynamically stable. d, The compressive strain-stress curve of the sample prepared by laser three-dimensional forming after processing (a, b) and heat treatment (c, d). The heat-treated Ti-Mo alloy has higher strength and toughness than the deposited alloy. In addition, compared with the deposited samples, the heat-treated samples exhibited more uniform mechanical properties in terms of strength, ductility and fracture properties. Credit: Nan Kang, Kai Wu, Jin Kang, Jiacong Li, Xin Lin and Weidong Huang

With the rapid development of biomedical technology, the replacement of human skeletal elements with implants has become an application market with high technical content and huge benefits. In order to quickly customize human implants with complex structures, Chinese scientists use 3D printing technology to prepare Ti-Mo alloy human implants, and then adjust the microstructure and performance through subsequent heat treatment, so as to obtain products with excellent compatibility.

As the average life expectancy increases, there are more and more cases of human bone tissue disease. With the upgrading of treatment methods, more and more bone tissue issues can be treated with artificial implants for replacement. Due to the huge demand in the field of biophysical therapy, biomedical materials have very broad market prospects. In the past 10 years, the market growth rate of biomedical materials has remained at 20-25%, and the world population has approached 6.5 billion. Statistics show that there are close to 400 million disabled people and about 2 billion dental patients.

At present, there are only 35 million implanted biomaterial devices, and the annual joint replacement volume is about 1.5 million, which is far from the actual number of replacements needed. Therefore, the market demand for biomedical materials has great potential. At present, common metal materials such as 316 stainless steel, pure titanium, TC_4, cobalt-based alloys and precious metals are widely used in the production of human implants, such as dentures, bone plates and joints.

However, the elastic modulus of the above-mentioned materials is far greater than the Young's modulus of the human bone, and the mismatch between the Young's modulus of the metal implant and human bone will cause physical discomfort. Therefore, it is necessary to develop an implant material with good biocompatibility, low toxicity or even non-toxicity, resistance to friction and wear, corrosion resistance, and mechanical properties that match human bones. Titanium-molybdenum alloy is the preferred choice for human implants due to its non-toxicity and low elastic modulus. As an emerging manufacturing technology, additive manufacturing technology (3D printing) is very suitable for the manufacture of parts with complex shapes, and also very suitable for the preparation of customized human implants. However, the titanium-molybdenum alloy implants directly prepared by laser three-dimensional forming technology have poor uniformity in microstructure and performance.

In *Light: Advanced Manufacturing*, scientists from the State Key Laboratory of Coagulation Technology of Northwestern Polytechnical University proposed a way to control the uniformity of microstructure and performance through a heat treatment system, so that the tissue performance of 3D printed human implants can better match and enjoy better biocompatibility. Aiming at the problem of poor uniformity of tissue properties of directly using 3D printed Ti-Mo alloy human implants, these scientists proposed a new type of triple-cycle heat treatment system, based on the transformation of the heat treatment process, through long-term heat preservation and extraordinary low cooling rate, the non-equilibrium metastable β phase transforms into the equilibrium α phase, which makes the structure of Ti-Mo alloy sample from top to bottom tend to be thermodynamically stable. The change of microstructure improves the mechanical properties of Ti-Mo alloy while maintaining good stability.

Through triple-cycle heat treatment, the microstructure and performance of the 3-D printed Ti-Mo alloy are adjusted and controlled, so that the 3D printed Ti-Mo alloy human implant has better microstructure and performance stability, and thus better matches the performance of human bones. This makes 3D printed Ti-Mo alloy human implants more widely useful in the biomedical field.

More information: Nan Kang et al, Effect of cycling heat treatment on the microstructure, phase, and compression behaviour of directed energy deposited Ti-Mo alloys, *Light: Advanced Manufacturing* (2021). DOI: 10.37188/lam.2021.016

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