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Research on the process of multi-point forming for the customized titanium alloy cranial prosthesis

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Abstract

Titanium alloy cranial prosthesis can be formed with multi-point forming (MPF) technology. The 3D curved surface of prosthesis is realized by following processes, 3D reconstruction according to the sufferer's primary cranium CT data, transformation of model data, adjustment of the matrices of punches to curved surface, and forming of titanium alloy retiary sheet. Three forming modes, i.e., (i) titanium alloy retiary sheet is contacted with the element groups directly, (ii) titanium alloy retiary sheet is sandwiched by elastic cushions and contacted with the element groups indirectly, and (iii) titanium alloy retiary sheet is sandwiched by steel paddings and contacted with elastic cushions and the element groups indirectly with blank-holder device, were simulated by an explicit finite element software. Numerical simulation results show that dimples and wrinkles occur at the surface of titanium alloy cranial prosthesis in the first two forming modes, but are suppressed when the last forming mode is adopted. Meanwhile, the 3D curved surface of prosthesis with good quality can be acquired. Finally, the forming tests were performed and the results coincide with the simulation results quite reasonably.

Keywords: Multi-point forming; Cranial prosthesis; 3D curved surface; Numerical simulation; Titanium alloy

1. Introduction

The absenting cranium which is induced by the surgery or the wound is a common neurosurgery clinical case. For recent years, people have attempted many kinds of cranial mend materials, such as plexiglas, silicone glue and polymers. However, the application of the materials decreases gradually because they are usually prone to disfigurements, including subcutaneous effusion, rejection, inflammatory reaction and material aging [1,2]. The titanium alloy is considered as a better biomaterial because of its innocuity, corrosion resistance, low allergic problems, stable chemistry performance and satisfying biocompatibility. At present, it has been used extensively in clinical practice. Titanium alloy cranial prosthesis, which based on the shape and place of the absenting cranium is formed from titanium alloy retiary sheet. The forming is difficult by common forming modes because of the bad forming performance of titanium alloy and different shapes of different absent crania. Traditionally, the customized 3D curved surface is produced by pressing titanium alloy retiary sheet into mold or by handcraft, which needs a long time and high cost. Nowadays, this 3D curved surface is formed by hands or rapid prototyping techniques, whereas, sufferers are generally not satisfied with the 3D surface because it is not accurate. Therefore how to shape an eligible titanium alloy cranial prosthesis economically and efficiently is a difficult task for the medicine workers [3].

The application of multi-point forming (MPF) [4,5] technique enables this difficult problem to be solved. MPF is an advanced manufacturing technology for 3D sheet metal forming. Its main idea is dividing the curved surface of the traditional stamping dies into many pairs of matrices of elements. The position and movement distance of each element is controlled independently by the MPF system, and then the 3D shape of sheet metal is formed by the enveloped surface of the elements. Adjusting the relative positions of the elements, one can change the geometric shapes of forming surface freely and thus produce a variety of geometric shapes of products in a MPF system. Using the flexible characteristic of MPF, the 3D curved surface of prosthesis can be eligibly shaped by the MPF system.

In this paper, dynamic explicit finite element software, LS-DYNA is introduced to simulate the MPF of the titanium alloy cranial prosthesis. The reasons for the formation of defects in the forming process are analyzed and the corresponding controlling methods are proposed. Finally, the practical forming test was done to demonstrate the validity of the simulation results.

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2. Material and model

2.1. Material

At present, as a desirable embedded material, Ti–6Al–4V has been extensively applied in domestic and foreign hospitals, its yield strength is 830 MPa, tensile strength is 900 MPa and elongation at break is 15%. The yield strength and tensile strength of the alloy are high, but elongation is relatively low, implying its plastic deformation performance might be poor, and wrinkles and cracks will occur during deformation since the formability of metal sheet are generally determined by its material attribute and shape of part.

2.2. Model

Because the shape of the cranial prosthesis is not symmetry and complex, a whole model is adopted. In order to save the computational time of CPU, only the model of half spherical surface of elements is taken into account. Elements and blank-holder device are assumed not to be curved in modeling, adopting a rigid body model; the elastic cushion is adopted a linear–elastic model; metal sheet and steel padding are adopted an elastic–plastic model. The modeling steps include using the relevant software to adjust the elements to a 3D surface, introducing a suitable boundary condition, defining each attribute and computing. In this study, the retiary sheet is in dimensions of 152 mm × 152 mm, the thickness is 0.7 mm with 30 × 30 square holes in it. The application of sheet with square holes, on one hand it is need which the human body organization can grow in it, on the other hand the forming performance of it can be improved, the resistance to deformation can be reduced effectively in the forming process, and the wrinkle defects can also be suppressed effectively.

3. Brief introduction of the forming process

In this paper, the 3D curved surface is formed in a high accuracy MPF press with blank-holder device. It is realized by following processes: 3D reconstruction of the absenting cranium according to the sufferer's primary cranium CT data (Fig. 1(a)), obtaining the model data file of the absenting part, technologic computation by MPF special-purpose CAD software (Fig. 1(b)), adjusting the matrices of punches to curved surface by the shape measurement system based on the information generated by CAD, acquiring the convex–concave shape cavity (Fig. 1(c)), forming eligibly shaped 3D curved surface of prosthesis from titanium alloy retiary sheet in the MPF press.

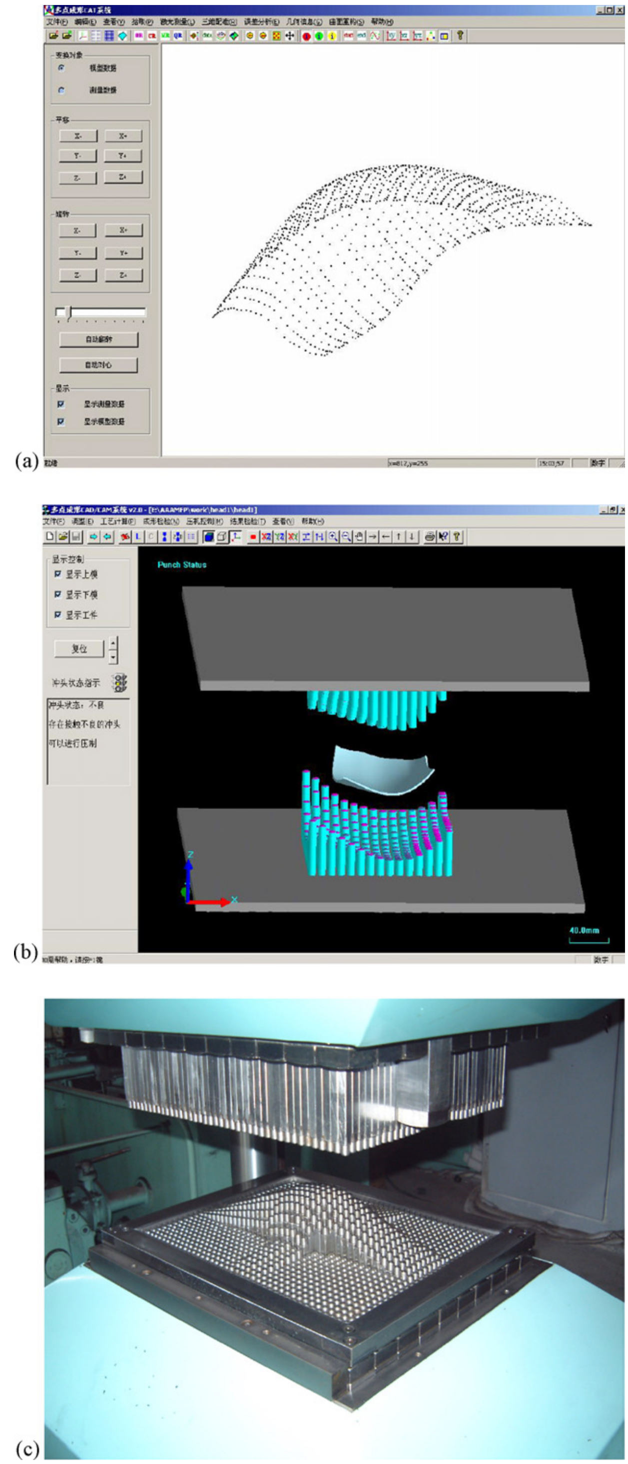

Fig. 1. Schematic diagram of the forming process. (a) 3D reconstruction; (b) technologic computation; (c) convex–concave shape cavity.

4. Forming result prediction and control of forming defects

Numerical simulation is an effective method to predict forming results, but the simulation of MPF process is much more complicated than that of conventional pressing. Here LS-DYNA with an explicit solver is introduced to simulate the MPF of titanium alloy cranial prosthesis, including the creation of FE model, the choice of material model, the establishment of boundary conditions and the treatment of contact friction. Forming defects such as wrinkles and dimples can be predicted by different forming technique modes with this software.

Fig. 2(a) is a schematic diagram that titanium alloy retiary sheet is contacted with the element groups directly in MPF press.