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Optimizing Design of Two-dimensional Forging Preform by Bi-directional Evolutionary Structural Optimization Method

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Abstract

Preform is a step between blanking and finish forming. Design and optimization of the preform for forging would affect the material flow, forming load, dimension accuracy and tool wear. In this study, analysis, simulation and optimization process are carried out by utilizing MATLAB codes as well as using finite element analysis software (DEFORM-2D package) and CAD software as auxiliary tools. The results of this study are as following: using “Curve Fitting” method and two times of reference length are the better options for the boundary fitting method. Besides, the differences between using mean stress and normal pressure as an addition criterion were considered. In terms of strain, the average of effective strain is 0.643 and the standard deviation is 0.298 when using normal pressure as an addition criterion. These values are smaller than those using mean stress as an addition criterion, in which the values are 0.674 and 0.308, respectively. In terms of forming load, the value of the former is 70.616 tons. It is greater than value of the other criterion that forming load is 70.207 tons. Finally, in terms of shape, the results from normal pressure are more complex than those from mean stress.

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Keywords: forging; preform design; topology optimization; bi-directional evolutionary structural optimization;

1. Introduction

Forging may be defined as a manufacturing process by means of deformation in conjunction with heating, separating, and joining of a workpiece with permanent work hardening [1]. Forging is currently known as the oldest technology in the metal forming process. Prehistoric humans have found that by heating the sponge iron and

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knocking stone, its shape can turn into useful items [2]. Since the forging part is deformed by impact or extrusion, it has the following advantages [3]: (1) Less defects; (2) Continuous material flow, better impact resistance, good fatigue resistance and other mechanical properties; (3) Stability of geometric dimension, high reliability and suitable for mass production.

In general, forging method is difficult to manufacture the products with complex shape, die is expensive and it is not suitable for a few products. Nowadays, however, forging method is improved with high precision, complexity, and diversity. The manufacturers always want to reduce cost of forging products, and improve production efficiency. In the forging process, preform stages have the significant impacts on the quality, efficiency and cost. Therefore, the preform design has become one of the important key of forging process. In the complex shape forming, in order to avoid material failure and affect the mechanical properties, forming process is divided into multiple stages. Each stage is called as a preform design step. The preform gradually changes the shape of the billet into the desired preform, so the ultimate goal of any analytical method is to assist engineers in designing the preform stages [4].

The problems of most traditional structural optimization methods are implemented by using the evolutionary structural optimization method [5]. There are two methods, one is ESO and the other is BESO. The ESO method is to optimize the shape of the structure by gradually removing inefficient material from a structure. The stress of each part in the ideal structure should be quite similar and safe level. This concept leads to a rejection criterion based on the local stress level, where the low stress is assumed to be under-utilized and gradually removes the material. The BESO method can remove inefficient materials and add useful materials at the same time [6]. Furthermore, this method may start from designs that are much smaller than the full design domain and save time for the finite element analysis (FEA).

With the BESO algorithm, the computational efficiency and flexibility of the algorithm are improved [7]. In this study, the background meshes are created with an equally spaced grid. Each grid of background mesh can be defined as an element. The area contained in this grid is the design area of the ESO or BESO algorithm. Each element can be divided into active and inactive. The shape of the preform includes the active elements. However, the mesh boundary defined by the active elements is rough and cannot be used directly for FE simulations. A smooth contour which is acceptable for FE simulation can be obtained by extracting the boundary of active meshes and using surface approximation method to smooth the surface.

2. Research methodology

2.1. BESO method for forging preform design optimization

The BESO method has often been used for continuum structures under loading of elastic deformation. With this method, materials can be added or removed from structure simultaneously by using a certain criterion. In the forging preform design optimization, the same concept may be used: unnecessary materials can be removed while some materials can be added in the certain regions of forging structure. By the way, after some optimization iterations, the preform shape can be obtained the optimum structure for forging process. However, in the forging process, internal structure of workpiece is required to be continuum without a void, so optimization process can be only performed on the boundary of the workpiece. Before simulating FE using DEFORM-2D, curve of the boundary must be smoothed due to the complex contact conditions between workpiece and dies. Therefore, in this study, curve fitting method is used to interpolate the boundary of preform. After the FE analysis, a data tracking and an operation of interpolation process are carried out in order to track the information of meshes from final step to initial step and interpolate to background meshes. Then the activation and inactivation of background meshes can be determined in accordance with the criteria [7].

2.2. Optimization objective

The objective of this study is to obtain the best preform for forging process which enables sufficient filling of die cavity and minimum material consumption. This objective can be represented by the unfilled length and the flash length. The objective function can be calculated by performance index (*PI*), as shown in the following equation 1.