Data-Driven Prediction and Process Optimization of Deformation in Ti-alloy Casing

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Abstract: With the increasing demands of high-tech weaponry in the field of national defense on the yield and performance of parts, Ti-alloy casings are evolving towards more complex structures, such as thin-walled, large wall thickness differences, multi-crossing, rings, and blind holes. The complex structures make it extremely difficult to accurately predict and control deformation of casings during casting. Therefore, a data-driven deformation prediction and process optimization technique for Ti-alloy castings is proposed. First, a multi-source dataset is constructed. By building InteCast ERP system, the full-process quality big data of 54 casings in single-piece production investment casting, including molding, pouring, and heat treatment process parameters, are collected. The post-pouring and post-heat treatment shape point cloud data are obtained via 3D scanning, constructing a dataset with 21 types and 9,720 key dimensions, including distance, diameter, contour, and wall thickness. Second, data preprocessing is performed. Abnormal fluctuating data are removed, missing data are interpolated using regression and clustering algorithms, parameters are reduced by correlation and principal component analysis, and the processed parameters are normalized. Third, deformation prediction models are built and tuned, using pouring temperature, mold temperature, vacuum degree, heat treatment temperature and other key process parameters as decision variables to establish post-pouring and post-heat treatment dimensional deformation prediction models based on neural networks. Hyperparameters (1,0.1,0.01,0.001, etc.) and optimization algorithms (SGD, Adam, AdaGrad, etc.) are combined to optimize the models. The optimal model with minimum mean squared error is chosen, achieving prediction accuracy over 80%. Fourth, the multi-objective particle swarm algorithm (MOPSO) is used to realize the process parameter recommendation. The aim is to reduce the dimensional deformation of casing. The sum of the positive deviations of the predicted and theoretical values of all key parameters after heat treatment was taken as the objective function, and the upper and lower bounds of the decision variables were set to 105% of the maximum value and 95% of the minimum value of each parameter for actual, respectively. The goal of predicting dimensional deformation with an average value of less than 1 mm for 50 sets of recommended process parameters was achieved. This study proposes a data-driven technology based on accurate prediction of Ti-alloy casings dimensions and process parameter recommendation for multiple critical dimensional deformations, which realizes effective control of casings deformation.

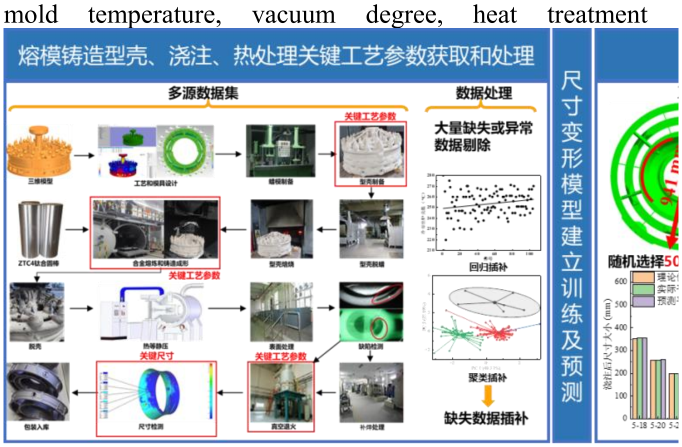

Figure 1 Investment casting parameter acquisition, model training, prediction and optimizing

Keywords: data-drive; Ti-alloy casing; dimensional deformation; prediction model; multi-objective optimization

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Achievement Awards in 2021 (ranked No.1), the first prize of Hubei Provincial Scientific and Technological Progress Award in 2022 and other first prizes at the provincial and ministerial levels. Guided the Challenge Cup Special Competition in 2021 to win the national special prize, and was personally awarded the Most Beautiful Science and Technology Worker of the National Foundry Industry in 2022 and other prizes. He serves as the executive secretary-general of Hubei Foundry Society, deputy secretary-general of China Foundry Association Mould Branch, senior member of China Mechanical Engineering Society, youth editorial board member of China Foundry, Special Casting Non-ferrous Alloys, and Foundry Technology.