S2–12

Manufacture of Gypsum Core Mold for Large Oxygen Plant Components using Fused Deposition Modelling

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At Kim Chaek Iron and Steel Complex, they are producing oxygen by using two 15000m3/h large oxygen plants for the oxygen–blast furnace. A wheel with the high speed rotating component that produces the cold, is the main component of a turbo–expander and it accounts for 80~90% in the whole process of producing the cold. The turbo–expander wheel of the large oxygen plant must have high dimensional accuracy and good dynamic stability. Because it transfers external work to the rotating shaft, it also must have enough strength and plasticity at room or cryogenic temperature. In general, there are three types of turbo–expander for oxygen plants; semi–open, enclosed and open type, it is important to increase the efficiency and quality of wheel and reduce the period and cost of manufacture as for operation of the large oxygen plant.

In this paper, we have designed the optimal profile by using the fluid analysis simulation tool and have manufactured the mold for making gypsum core according to this profile using Fused Deposition Modelling (FDM) equipment, so as to decrease the period of manufacturing products and save the cost. FDM is the most popular additive manufactureing (AM) technology and it is widely used in numerous sectors of economy, national defense and society such as aerospace, automobile, medicine, education, sports and so on.

Firstly, we designed the wheel's 3D model using Solidworks 2016 and determinded the optimal wheel's profile by using L27(313) orthogonal table and Solidworks Flow Simulation, simulation annealing. For the experimentation, the simulation was run 27 times with the average running time per simulation being about 15min. The model which predicts minimum temperature at the output is as follows.

$$y=-1.496\,5x_1-2.492\,2x_2+0.027\,447\,x_1^2-0.000\,411\,3x_1x_2-0.001\,6444x_1x_3-0.000\,483\,33x_1x_4+0.059\,556x_1x_5+0.003\,790\,\,x_2^2-$$
$$-0.019\,381x_2x_3+0.015\,41x_2x_4+0.257\,94x_2x_5+0.052\,841\,x_3^2+0.009\,734\,8x_3x_4-0.002\,976\,4\,x_4^2-0.593\,21x_4x_5$$

where y is the minimum temperature(°C) at the output, x_1 is the up profile radius1(mm), x_2 is the up profile radius2(mm), x_3 is the down profile radius 1(mm), x_4 is the down profile radius2(mm), x_5 is the blade thickness(mm).

The absolute error average value of this model is 0.127 65°C and its relative error average value is –0.067 878%.

Simulation annealing is applied to this model for optimization. The execution result show the minimum temperature at the output is –208.75°C.

Secondly, we made of gypsum core mold according to the optimal process parameter using FDM equipment. The material of the part is the PLA resin, FDM equipment is the Ultimaker 2. The nozzle temperature is 220°C, bed temperature is 65°C, layer thickness is 0.1mm, feed rate is 120mm/min, hatch spacing is 0.4mm, and forming speed is 100mm/min.

As mentioned above in this work, we determined the optimum profile type of streamline wheel grooves using fluid analyzing simulation tool and according to this manufactured the mold for making gypsum core with FDM equipment, so as to reduce the period of production of turboexpander wheel by 1/3 and decrease the cost by 1/2.

We should study further about the generalized theory model and experimental method to determine the optimum FDM process indices for products of various types precisely.