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CFD-supported optimization of flow distribution in quench tank for heat treatment of A357 alloy large complicated components

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Abstract: The flow distribution in quench tank for heat treatment of A357 alloy large complicated components was simulated using FLUENT computational fluid dynamics (CFD) software. The flow velocity and the uniformity of flow field in two types of quench tanks (with or without agitation system) were calculated. The results show that the flow field in the quench tank without agitation system has not evident regularity. While as for the quench tank with agitation system, the flow fields in different parameters have certain regularity. The agitation tanks have a distinct advantage over the system without agitation. Proper process parameters were also obtained. Finally, the tank model established in this work was testified by an example from publication. This model with high accuracy is able to optimize the tank structures and can be helpful for industrial production and theoretical investigation in the fields of heat treatment of large complicated components.

Key words: A357 alloy; flow distribution; quench tank; computational fluid dynamics (CFD) simulation

1 Introduction

A357 (Al−7Si−0.6Mg) alloy has been widely applied in aerospace industries, automotive applications and other aspects due to its good corrosion resistance, excellent castability and high specific strength in the heat-treated condition [1−3]. Many large thin walled complicated components (e.g., frame, wall panel and thin walled beam) used in aeronautic and astronautic industries have been cast using this alloy [4]. In order to obtain an adequate mechanical property, the Al−Si−Mg cast alloys are generally heat-treated to the T6 state (solution heat treatment, quenching and artificial aging) [5,6]. As for A357 alloy large complicated components, inhomogeneous distortion of the large complicated components occurs due to the stresses and strains caused by quenching treatment. Enough quench speed must be provided so as to inhibit the formation of Mg−Si precipitates of A357 alloy [7]. Therefore, for the large complicated components, suitable flow velocity should afford in the quench tank. But an increase in quench speed will lead to large residual stresses for quenched components. Good control of quench process for A357 alloy large complicated components will obtain better result of solid solution treatment and will be helpful to control the part distortion [8]. Therefore, it is very important to optimize the flow uniformity in quench zone and to predict the flow rate of quenching medium.

Computational fluid dynamics (CFD) is widely used for calculating the flow velocity and uniformity of quenching medium in quench tank [9]. CFD can be used to solve the complex problems of fluid flow and predict the performance of fluid-thermal process that is often too difficult to be solved with experimental or analytical techniques [10]. The non-uniformity of medium flow in quench tank was investigated by using the CFD modeling [11,12]. Using the CFD analysis, HALVA and VOLNY [13] investigated the relationship between the homogeneity of fluid flow and agitator placement. GARWOOD et al [14] researched the fluid flow in an agitated quench tank by using the CFD code and the

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experiments. The effect of the placement of submerged spray educators on quench non-uniformity was researched by CFD method [15].

As shown in the above, many researchers used the high fidelity CFD to investigate the medium flow distribution in the quench tank. But there are a few reports about the investigation of medium flow in the quench tank with different structures. In the present study, two types quench tanks (with or without agitator system) were selected as the objects. FLUENT CFD software was selected as a simulation tool. The influence of various parameters on flow field in the tank was studied. The correctness of the quench tank model established was testified by a numerical example from a publication.

2 Typical large complicated component

Figure 1 shows three-dimensional model of A357 alloy large complicated thin-wall component. As can be seen in Fig. 1, the structural characteristics of this large complicated component are as follows: four visual windows, distribution of strengthening bosses in the inside wall of the component, strengthening plates along radial and axial directions, and four grooves on the bottom end side. The schematic of thin-wall component with dimensions is shown in Fig. 1(c). The height, the wall thickness, the diameter of bottom face and the cone angle of this component are 700 mm, 8 mm, 600 mm and 3°, respectively.

3 Modeling of quench tank

3.1 Modeling of quench tank without agitation system

Figure 2 shows the sketch maps of heating furnace (Fig. 2(a)) and quench tank without agitation system (Fig. 2(b)) for heat treatment of aluminum alloy large component. The heating furnace is a cuboid with dimensions of 3.2 m × 2.2 m × 2.4 m. The quench tank is a cuboid with dimensions of 2.5 m × 2.5 m × 3 m. The inlet diameter is 0.2 m, and the outlet is overflow. As shown in Fig. 2(a), the heating furnace includes furnace chamber, two hooks, heating system, large basket and baffle plate. As shown in Fig. 2(b), the quench tank includes inlet, outlet, distributary nozzles, overflow channel, top cover and base plate. During the heating

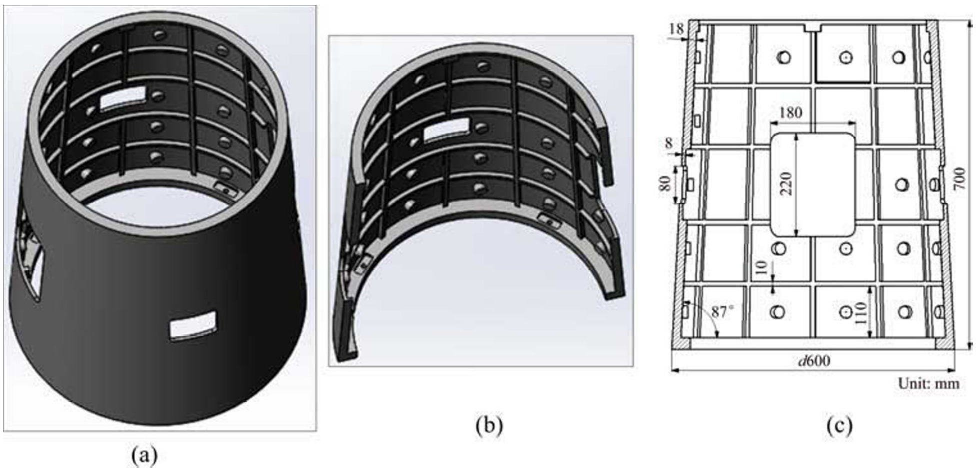

Fig. 1 Typical A357 alloy large complicated component: (a) 3D model; (b) Section view of model; (c) Dimensions of model

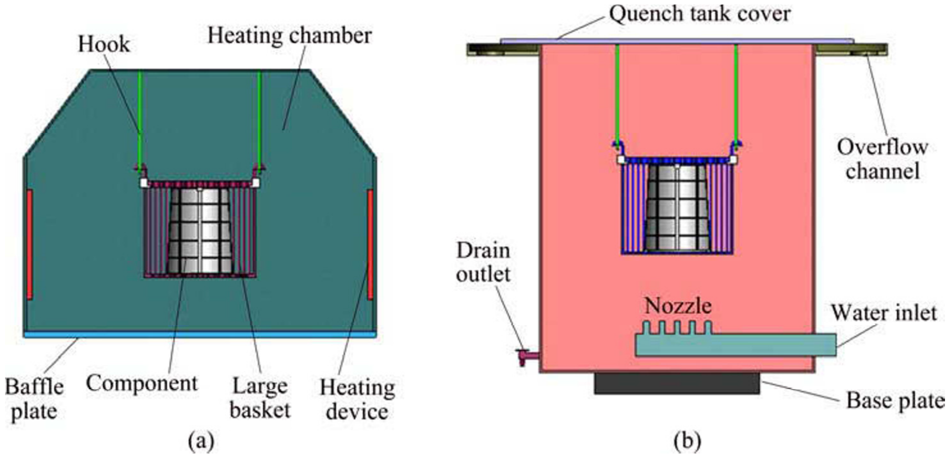

Fig. 2 Heating furnace (a) and quench tank (b) of aluminum alloy large complicated component