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ScienceDirect
Trans. Nonferrous Met. Soc. China 27(2017) 2415−2422
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Calculation and experimental study on heating temperature field of super-high strength aluminum alloy thick plate

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Received 15 July 2016; accepted 22 May 2017

Abstract: Stepped heating treatment has been applied to aluminum alloy thick plate to improve the mechanical performance and corrosion resistance. Accurate temperature control of the plate is the difficulty in engineering application. The heating process, the calculation of surface heat transfer coefficient and the accurate temperature control method were studied based on measured heating temperature for the large-size thick plate. The results show that, the temperature difference between the surface and center of the thick plate is small. Based on the temperature uniformity, the surface heat transfer coefficient was calculated, and it is constant below 300 °C, but grows greatly over 300 °C. Consequently, a lumped parameter method (LPM) was developed to predict the plate temperature. A stepped solution treatment was designed by using LPM, and verified by finite element method (FEM) and experiments. Temperature curves calculated by LPM and FEM agree well with the experimental data, and the LPM is more convenient in engineering application.

Key words: lumped parameter method; surface heat transfer coefficient; temperature field; aluminum alloy; thick plate

1 Introduction

The importance of temperature fields in heat treatment of aluminum thick plate is indisputable. The key parameters in any heat treatment are time and temperature, which ideally depend on the diffusion of alloying elements [1]. Due to the importance of temperature fields in microstructure, they influence the mechanical and corrosive properties of aluminum alloys directly. So, searching for a direct method to calculate the temperature fields of thick plates is important.

Nowadays, stepped heat treatment is a development trend of aluminum and paid more and more attention. Stepped heat treatment was first used in aging treatment, known as retrogression and re-aging (RRA), which was first applied to 7075 alloy in T6 condition, involving a short heat treatment in the temperature range of 200−280 °C followed by T6 re-aging [2,3]. Then, considerable research has been conducted on it, and it is proved as an advanced aging treatment leading to a favorable combination of good strength and stress-corrosion cracking resistance [4−7]. In recent years, stepped treatments in homogenization [8], solution [9] and quenching [10] have gradually become research hotspots. DENG et al [11] studied the two-stage homogenization scheme of 7085 alloy, and demonstrated that more homogeneous Al_3Zr particles may be nucleated at the grain boundary in the first low-temperature stage. CHEN et al [12] studied both the stepped homogenization and advanced solution of 7055 alloy, and revealed that a suitable pretreatment could enable a complete dissolution of η phase, leading to better mechanical properties. HAN et al [13] reported the advanced solution of 7050 alloy, which resulted in smaller sub-grains than the single-stage solution, and higher strength and fracture toughness. XU et al [14] used both advanced solution and RRA, and the obtained samples showed better mechanical properties for the higher volume fractions of η' and η precipitates.

Foundation item: Project (2012CB619500) supported by the National Basic Research Program of China; Project (51375503) supported by the National Natural Science Foundation of China; Project (2016YFB0300901) supported by the Major State Research Program of China; Project (2013A017) supported by the Bagui Scholars Program of Guangxi Zhuang Autonomous Region, China
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DOI: 10.1016/S1003-6326(17)60268-1

However, almost all these heat treatments strongly depend on the accurate control of the material temperature. In these studies, the temperature differences between the samples and the surrounding are ignored for the insignificant small size of the samples. But in practice, based on the measured single-stage surface heating curve of 7050 thick plate (180 mm in thickness) in our previous work (see Fig. 1), we found the heating speed of the metals may be far below the surrounding because of the low surface heat transfer coefficient and the large volume. And for the more complex stepped heat treatment, the traditional heating method would be completely inappropriate.

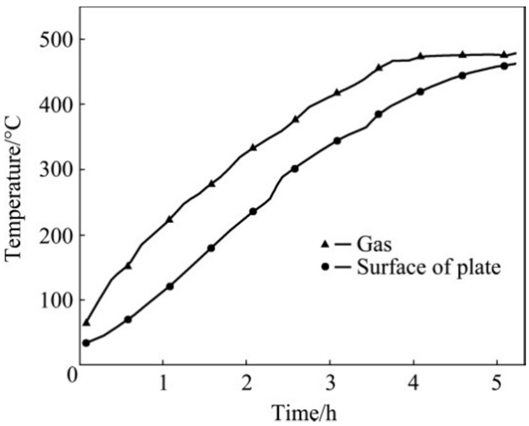

Fig. 1 Measured heating curve of 7050 thick plate (180 mm in thickness)

In this work, the heating manner was studied with a 7050 super-high strength aluminum thick plate. Based on the measured heating data, the temperature uniformity was discussed, and the variation of surface heat transfer coefficient along with the plate temperature was greatly concerned. Furthermore, the equation of thick plate temperature was given with the linear changing of the gas temperature. At last, a feasible heating method for stepped solution treatment was designed to verify the results.

2 Experimental

A 7050 aluminum alloy thick plate with a nominal composition of Al−2.2Cu−2.0Mg−6.5Zn−0.12Zr−0.05Ti (mass fraction, %) was chosen for the investigation. The dimensions were 1300 mm × 1100 mm × 180 mm. In order to measure the temperature in different thicknesses, drills were bored on the side face with the depth of 200 mm. The distances between the holes and the surface are 5, 15, 30, 60 and 90 mm, respectively. Then, K-type thermocouples were inserted into the bottom of the holes, which were filled with asbestos to prevent the heat flux. The temperature measurement facility is illustrated in Fig. 2.

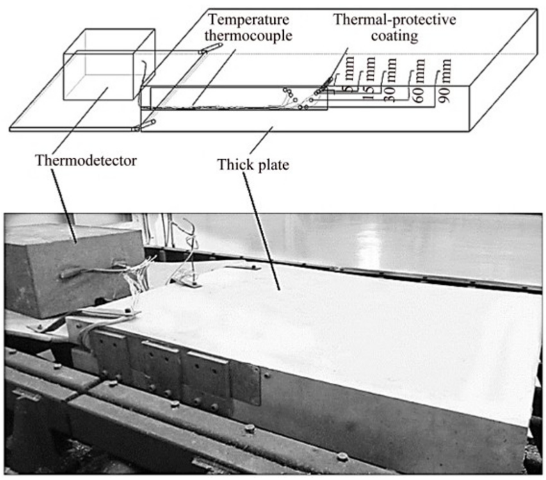

Fig. 2 Illustration of temperature measurement and real device

3 Results and discussion

Heating the gas to 470 °C directly in a resistance furnace, the heating curves in different thicknesses of 7050 plate with 180 mm in thickness are shown in Fig. 3, which reveals that the plate temperature is almost uniform in furnace heating condition, and this is quite different from steel. Temperature uniformity will be discussed in the following, and the actual surface transfer coefficient will be calculated based on it.

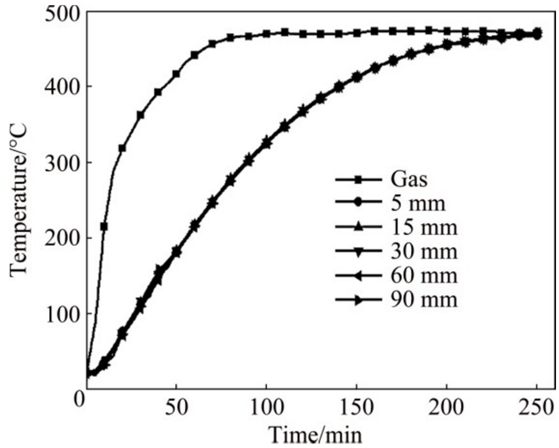

Fig. 3 Heating curves in different thicknesses of 7050 plate

3.1 Temperature uniformity

The temperature uniformity of the thick plate depends on the factors such as, plate thickness ($2l$), surface and center temperatures (T_w and T_c), gas temperature (T_f), surface heat transfer coefficient (h) and heat conductivity coefficient (k). Figure 4 shows the schematic diagram of the thick plate heating. The surface transfer heat flux is equal to the plate heat flux of conduction:

$$hA_{top}(T_f - T_w) = kA_{top}(T_w - T_c)/l \tag{1}$$

where A_{top} is the area of the top face.

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