Simulation and Experimental Study on Asymmetrical Quenching Deformation of 7075 Al Alloy Thick Plate

Yuan Haiyang[1,2,a], Wu yun xin[1,2,b*], Lei Chen[1,2,c]

[1]College of Mechanical and Electrical Engineering, Central South University, Changsha, 410083, China

[2]Key Laboratory of Modern Complex Equipment Design and Extreme Manufacturing, Central South University, Changsha, 410083, China

[a]yuanhaiyang@csu.edu.cn, [b]103701016@csu.edu.cn, [c]597080827@qq.com

Keywords: 7075 Al Alloy, Thick plate, Asymmetrical quenching, Residual stress, Deformation

Abstract. Simulation and experimental study of asymmetrical quenching processes were carried out on 7075 Al alloy thick plates. Effects of heat transfer coefficient ratios, thicknesses, and widths on warping deformation by asymmetrical quenching were simulated, and an increasing heat transfer coefficient ratios and plate thickness would obviously deteriorate plate-shape quality while plate width has fewer influences on both residual stresses and warping deformation. Experiments on one-side water spraying quenching were carried out to evaluate detailed relationship between warping deformation and residual stresses under different supporting patterns. The maximum plate irregularities always occur around its supporting locations and then expand far away and more supporting locations could reduce quenching deformations. The warping deformation during quenching is essentially caused by internal residual stresses introduced by heterogeneous heat exchanging, and the external structural warping deformation would respond reasonably to the internal residual stresses distribution.

Introduction

The Al-Zn-Mg-Cu type 7075 aluminum alloy has been widely used in aeronautics and astronautics industries in recent years because of its high strength and high hardness [1,2]. The mechanical performance of 7075 made components has been always enhanced by quenching processes which refer to multi-dimensional physical fields and dimensional variation [3,4]. However, a high level residual stresses and a following severe machining deformations would inevitably introduce internal the thick plate when quenching processes enhance the mechanical performance [5]. Symmetric quenching processes of 7075 Al alloy plates have been widely studied for many years, and the processes always introduce a heterogeneous distribution of internal residual stresses which causing considerable deformation when the plates being shaped by machining or welding [6-8]. Obviously, asymmetrical quenching would introduce a much heterogeneous residual stresses distribution compared to traditional symmetric quenching, plate-shape deficiencies including warping or distortion deformation would occur. In this paper, the simulation and experimental study on distribution features of residual stresses and structural distortion caused by symmetric quenching were carried out to evaluate the effects of quenching processes to plate-shape quality.

Simulations

Modeling Parameters. The simulation was performed on 7075 aluminum alloy whose physical characteristics and mechanics performances coming from reference [9]. Rectangular specimens of 10000mm×2000mm×6/10/20mm were chosen. The equivalent thermo-mechanical treatment of the material consists of gradually elevated 373 K every one hour with heat preservation for 10 min, a solution heat treatment for 2 h at 753 K, and then water spraying quenching was carried out under room temperature with water pressure 0.4MPa and flow rate 2.5L/s. The asymmetrical quenching processes were featured by heat transfer coefficient ratio between one side and the other side, and the extreme case is 12 $N/s \cdot mm \cdot {}^0C$ to 0. For ideal situation the simulation modeling is simplified that material is continuously homogenous and isotropic, and material plastic deformations will be symmetrical in longitudinal and transverse directions.

Simulation Results. Fig.1 presents the quenching deformations in longitudinal direction under different heat transfer coefficient ratios, plate thicknesses and plate widths respectively, and the results in transverse direction show same variation trends.

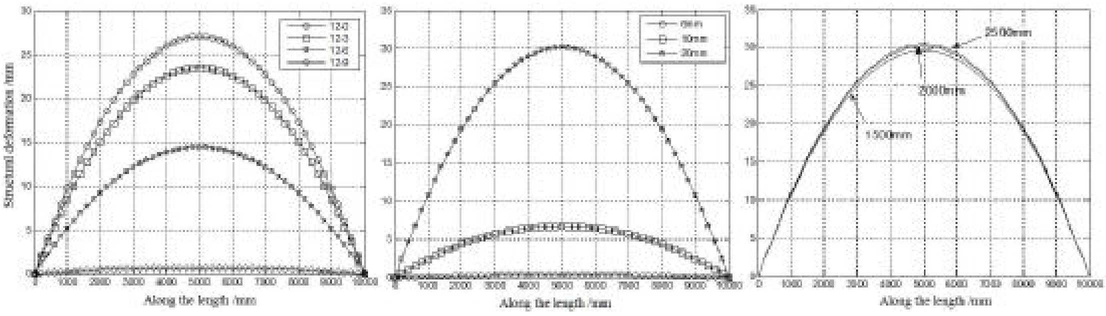


Fig. 1 Effects of heat transfer coefficient ratio, thickness and width on plate deformations in longitudinal direction

Fig.1 shows that heat transfer coefficient ratio plays a very important role during quenching deformations, the warping deformations in both longitudinal and transverse directions would be more severe when the ratio increasing and in the extreme case the deformation reaches to maximum. Plate thickness plays a second important role since heat transfer would be relatively more heterogeneous in thicker plates causing slower heat exchanging, thickness directly influences internal residual stresses distribution in other words. Since the length of modeling specimen is much larger than its width, the structural warping deformation in longitudinal direction is more severe. Relatively, the width plays a not obvious role in plate warping deformation, but increasing the width would decrease bending rigidity and then easier deformation in transverse direction.

Experiments

Specimen Preparation. The experimentation was performed on 7075 aluminum alloy whose composition (*wt*%) was 1.6 Cu, 2.5 Mg, 0.23 Cr, 5.6 Zn and remainder Al. The rectangular specimen dimension and the residual stress measuring locations were shown in Fig.2, whose thermo-mechanical treatments refer to simulation parameters. For results accuracy the specimen transfer time in air is controlled in 10s, and a 60s water spraying quenching was carried out on the one side. Moreover, three different supporting patterns including one-end supporting, supporting in the middle and supporting both in two-ends and middle were chosen to evaluate the detailed deformation features, showed by Fig.2.

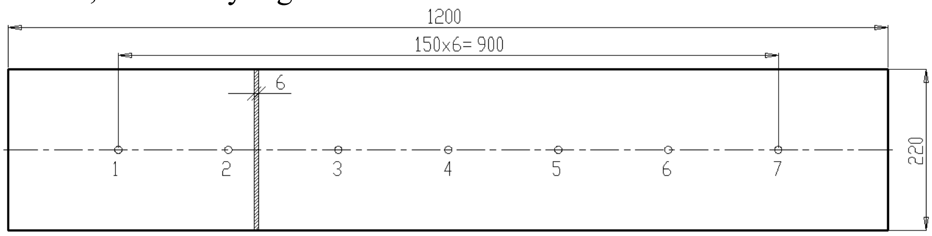
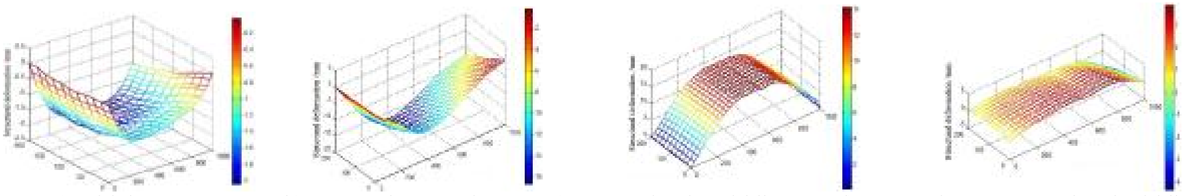


Fig. 2 7075 aluminum alloy specimen and the stress measuring locations (unit: mm)

Fig. 3 Water spraying quenching experiments

JTRX20-6 type resistance furnace was used for solution heat treatment, Global Status575 type three-coordinates measuring instrument was used to measure plate shape, and Proto iXRD diffraction device was used to measure surface residual stresses.

Experimental Results. Fig.4 presents the structural quenching deformations both in longitudinal and transverse directions, since the plate fluctuation is much smaller than plate dimensions the illustrating proportion in Fig.3 was restricted to 20(in length direction) : 10(in width direction) : 1(in thickness direction).



a) Initial state b) One-end supporting c) Supporting in middle d) Supporting at two-end and middle

Fig. 4 Structural deformations under different supporting patterns in spraying quenching

Here I_d was introduced to represent plate-shape straightness, which could be expressed as:

$$\begin{cases} \frac{\Delta L}{L} = \frac{p^2 l^2}{4} \\ I_d = 10^5 \times \frac{\Delta L}{L} \end{cases} \quad (1)$$

where l is the irregularity along a specified line, L is straight line of the waving curve, and ΔL is subtract value between the waving curve and L.

Fig.4 shows that the plate is basically flat under initial state when quenching wasn't introduced, the warping deformation occurs in the two ends and the irregularity only is 35.67 I_d. In one-end supporting pattern there is a severe warping deformation just at the supporting end, the irregularities in longitudinal and transverse directions are 161.89 I_d and 52.61 I_d respectively. In supporting in the middle pattern there is a severe warping deformation just in the middle, the irregularities in longitudinal and transverse directions are 113.42 I_d and 47.67 I_d respectively. Supporting both in two-ends and middle pattern there is a severe warping deformation both at the two-ends and in the middle, and the irregularities in longitudinal and transverse directions are 170.69 I_d and 75.56 I_d respectively. In other words, supporting pattern has a very important influence on plate deformation during spraying quenching on one side, and the maximum plate irregularities always occur at the supporting location. Because of displacement limit at the supporting locations the plate begins to warp around the locations and then expand far away, and reasonably adding supporting locations should be a better choice during quenching.

The warping deformation during quenching is essentially caused by internal residual stresses, that is, the deformation is the external phenomenon while residual stresses are the incentive. Fig.5 presents the measured surface residual stresses in longitudinal direction. It can be seen that the asymmetrical spraying quenching processes always introduce compressive residual stresses on the surface, and the distribution of residual stresses agrees with the structural warping deformation very well. The external structural deformation should be responded reasonably to the internal residual stresses distribution.

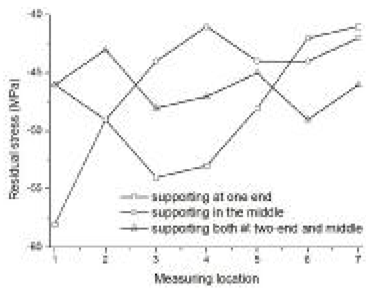


Fig. 5 The measured residual stresses in longitudinal direction

Summary

According to the simulation and experimental study of asymmetrical quenching processes on 7075 Al alloy thick plates, the effects of heat transfer coefficient ratios, thicknesses, and widths on warping deformation were analyzed. Multi-dimensional interactions during quenching processes play an important role in the internal residual stresses distribution and the external structural deformations. Asymmetrical quenching would always cause severe warping deformation. Moreover, increased heat transfer coefficient ratios and thicker plate would furtherly deteriorate plate-shape quality. Plate width has fewer influences on both residual stresses and warping deformation but its influence degree would be considerable when it increases too much. One-side spraying quenching processes under different supporting pattern were carried out experimentally which shows that the maximum plate irregularities always occur around its supporting locations and then expand further, the deformation should be improved by adding supporting locations and flat-plane supporting is the best choice in theory. The warping deformation during quenching processes is essentially caused by internal residual stresses, and the external structural warping deformation would go well with the internal residual stresses distribution.

Acknowledgements

This research is supported by the National Basic Research Program of China (973 Program, Grant No. 2012CB619505 and No. 2010CB731703).

References

[1] D.J. Smith, G.H. Farrahi, W.X. Zhu, et al: International Journal of Fatigue, Vol.23 (2001) No.4, pp.293-302.
[2] Yonghui Hu, Yunxin Wu, Guangyu Wang, et al: Advanced Materials Research, Vol.160-162(2010), pp.241-246.
[3] LIAO Kai, WU Yun-xin, GONG Hai, et al: Trans. Nonferrous Met. Soc. China, Vol.20 (2010), pp.789-794.
[4] GONG Hai, WU Yun-xin, LIAO Kai: J. Cent. South Univ. Technol., Vol.18 (2011), pp.285-289.
[5] GONG Hai, WU Yun-xin, LIAO Kai: Journal of Central South University (Science and Technology), Vol.41 (2011) No.4, pp.1354-1359. (In Chinese)
[6] WU Yun-xin, LIAO Kai, ZAHNG Shuyuan: Hot Working Technology, Vol.37 (2008) No.6, pp.50-52, 55. (In Chinese)
[7] LIN Gaoyong, ZHENG Xiaoyan, FEN Di, et al: Materials Review, Vol.22 (2008) No.6, pp.70-74. (In Chinese)
[8] DENG Yunlai, GUO Shigui, XIONG Chuangxian, et al: Journal of Aeronautical Materials, Vol.30 (2010) No.6, pp.21-26. (In Chinese)
[9] GONG Hai: Research on Evolution and Evaluation Model of Residual Stress in Aluminum Alloy Thick Plate, Thesis, Central South University, Changsha, Hunan, 2011. (In Chinese)