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Procedia Engineering 207 (2017) 269–274

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on the Technology of Plasticity, ICTP 2017, 17-22 September 2017, Cambridge, United Kingdom

Numerical simulation of temperature field in large integral panel during age forming process: Effect of autoclave characteristics

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Abstract

As an advanced manufacturing technology, autoclave age forming (AAF) has been developed to form large integral panels. During the AAF, autoclave characteristics (air speed, heating rate and pressure) influence the temperature uniformity in panel, which lead to lower the precision of the formed panel. Temperature field of a large panel with a dimension of $2500\times1300\times17mm^3$, formed under a large frame mold, was computationally fluid dynamics simulated and experimentally evaluated. It is found that the simulation results tally well with the test results. Then, the effect of air speed (V), heating rate (H) and pressure (P) on panel's temperature field are investigated via simulation. It shows that increasing the air speed helps improve the temperature uniformity of the panel, while raising the heating rate and the pressure have the opposite effect. Additionally, the combination of the air speed and pressure (V&P) has a great impact on the panels' temperature field. The magnitude of effects on the panel's temperature field correspond to a sequence of V&P > H > V > P > H&V > H&P.

Keywords: Large integral panel; Autoclave age forming; Temperature difference; Air speed; Heating rate; Pressure;

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Peer-review under responsibility of the scientific committee of the International Conference on the Technology of Plasticity.
10.1016/j.proeng.2017.10.773

1. Introduction

Creep age forming process (CAF), with the advantage of using heat treatment cycle of metals to release stresses, has been developed as a new forming method to manufacture large integral panels [1]. Generally, large integral panels are fabricated by autoclave age forming process (AAF) [2]. However, besides the structure of mold and panel, the autoclave characteristics (air speed, heating rate and pressure) lead to an uneven temperature distribution in larger integral panel during the AAF, reducing the precision of the formed panel. Thus, it is essential to study the effect of autoclave characteristics on temperature field in the large aluminum panel during the AAF.

Recently, Huang et al. [3] carried out CAF and springback analysis for AA7B04 plates at 155 °C for 20 h. Huang et al. [4] carried out another simulation for single-curvature bending of AA2324 plate. Moreover, Guines et al. [5] modeled the CAF of integrally stiffened structures for AA6056. In views of above, the creep aging temperature is isothermal and uniform. Based on these, through Computational fluid dynamics (CFD) [6-7], Zhang et al. [8] studied the effect of different types of mold on mold's temperature field and proved that the temperature uniformity of T-duct mold is better than that of line-duct and cross-duct mold. Gan et al. [9] carried out a 2D mold to studied the effect of air speed and the types of mold on the mold's temperature field and found that the effect of air speed on the mold temperature field is slight, while the influence of length and cut-out size of mold is great. Obviously, the temperature field of the large aluminum panel during AAF should be further investigated. Furthermore, it is unclear that the effect of autoclave characteristics on temperature field in large aluminum panel during AAF.

The objectives of this work are (1) to develop and experimentally velidate a computational fluid dynamics (CFD) model for the AAF process of large integral panels, (2) to investigate the effect of autoclave characteristics on temperature field in large aluminum panel during AAF. The results have great action on making technology regulations and controlling the temperature uniformity of the large aluminum panel during AAF.

2. Autoclave age forming process and tests

2.1. Material, autoclave and tooling features

In this case, a large flat panel of 2219 aluminum alloy with dimensions of 2500×1300×17mm^3 was studied. The sketch of the autoclave depicting the airflow is shown in Fig. 1a. The circulation fan carries the burden of assuring temperature uniformity throughout the working chamber. Since the heat flows from the electric resistance into the circulating air stream, and then into the workload, the greater the airflow turbulence is, the better the heat transfer is, particularly with workloads that are heavy and dense. The effective working area of the autoclave used is a cylinder with a size of Φ2000×4000 mm^2 (Fig. 1b). The large frame type mold of Q235 with a size of 3200×1600×850 mm^3 was used and the mold concave radius is 1425 mm. Additionally, vacuum is formed between the panel and the mold through a vacuum bag assembly. Supplementary material layers including vacuum bag and ventilated felt is shown in section A-A (Fig. 1c).The temperatures inside the autoclave were measured using five thermocouples (K-type; Ni/Al-Ni/Cr) The locations of monitor points (M1#~M5#, blue) are shown in Fig. 1(b) and Table 1.

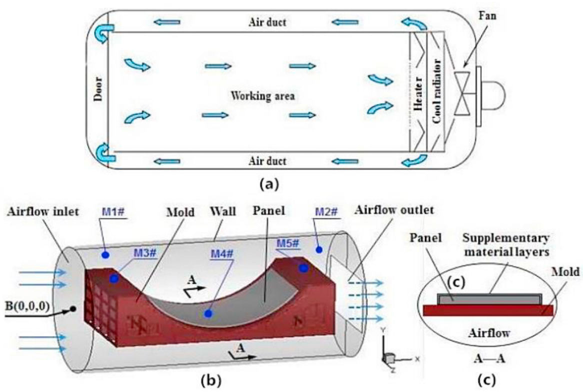

Fig. 1 The sketch of autoclave (a) and tooling characteristics (b) and section A-A of tooling (c).

Table 1 Locations of monitor points and validation results.

Points	Coordinates /mm	RMSE (℃)			
		Heating	Soaking	Cooling	Total
M1#	(400,820, -473.5)	8.76	1.17	10.98	8.43
M2#	(3600,0, -950)	9.37	5.55	14.64	11.03
M3#	(600,424.5, -400)	4.67	2.98	4.66	5.31
M5#	(3200,424.5, -400)	8.47	3.95	9.78	8.45
M4#	(2000,-217, -400)	9.86	2.2	7.24	5.68