Finite Elements in Analysis and Design 131 (2017) 17–24

Contents lists available at ScienceDirect

Finite Elements in Analysis and Design

journal homepage: www.elsevier.com/locate/finel

Stress generation during the quenching of large AA2618 forgings: Finite element computations and validation against neutron diffraction measurements

N. Chobaut[a], J.N. Wagner[b], D. Carron[c], P. Saelzle[d], T. Pirling[e], M. Hofmann[f], J.-M. Drezet[a,*]

[a] Ecole Polytechnique Fédérale de Lausanne, Laboratoire de Simulation des Matériaux, station 12, 1015 Lausanne, Switzerland
[b] Paul Scherrer Institut, Materials Science and Simulation, ASQ/NUM, 5232 Villigen PSI, Switzerland
[c] Univ. Bretagne Sud, FRE CNRS 3744, IRDL, F-56100 Lorient, France
[d] ABB Turbo Systems Ltd, Bruggerstrasse 71A, 5401 Baden, Switzerland
[e] Institut Laue-Langevin, 6 rue Jules Horowitz, 38042 Grenoble, France
[f] Forschungsneutronenquelle Heinz Maier-Leibnitz (FRM II), TU München, Lichtenbergstr. 1, 85747 Garching, Germany

ARTICLE INFO

Keywords:
Aluminium alloys
Quenching
Residual stress
Neutron diffraction
Strain gauges

ABSTRACT

Solutionising and quenching are key steps in the fabrication of heat treatable aluminium parts such as AA2618 compressor impellers for turbochargers. Quenching not only dictates the mechanical characteristics of the product but also induces residual stresses that can cause unacceptable distortions during machining and unfavourable stresses in service. Predicting and controlling stress generation during quenching of large AA2618 forgings is therefore of great interest. Since possible precipitation during quenching may affect the local yield strength of the material and thus impact the level of macro-scale residual stresses, consideration of this phenomenon is required.

A phenomenological material model accounting for precipitation in a simple way is used instead of modelling in detail precipitation that occurs during quenching. The required model parameters are identified using a limited number of tensile tests achieved after representative interrupted cooling paths in a Gleeble machine. This model is used in FE computations of stress generation during quenching of large massive AA2618 forgings for compressor impellers. The residual strain and stress profiles are compared with neutron diffraction measurements carried out at SALSA and STRESS-SPEC diffractometers in as-quenched and in T6 conditions. It turned out that the residual stress predictions by FE modelling might be wrong if precipitation is not taken into account properly in the material model.

1. Introduction

In heat-treatable aluminium alloys (AA), quenching from the solutionising temperature is of prime importance to control the final properties of the part. From a metallurgical viewpoint, the ideal quench must be fast enough to avoid the formation of precipitates during quenching, i.e. to obtain a supersaturated solid solution. However, ideal fast quenching cannot be achieved in the centre of large massive components where the quenching rate can be more than ten times lower than at the surface. This leads to the possible formation of coarse precipitates which are detrimental to the final yield strength. Indeed, coarse precipitates decrease the hardening potential by pumping solute atoms during quenching and influence the as-quenched residual stresses (RS) that depend also on the magnitude of the cooling rates and on the component size and shape.

The Al-Cu-Mg-based AA2618 alloy is a wrought alloy that is widely used for the compressor impellers in turbochargers for combustion engines owing to its high creep resistance [1]. The impellers are typically machined directly out of a forged blank, which has undergone a T6-heat treatment involving solutionising, quenching and artificial ageing. In order to reduce residual stresses, quenching is performed in boiling-water rather than in cold-water. In the artificial ageing step only a modest reduction in stresses is expected [2].

The prediction of internal stress build-up during quenching involves the determination of the transient heat transfer in the part and requires an adequate material model for finite element (FE) calculations accounting for the appropriate material properties.

A material model, based on interrupted quench tests in a Gleeble machine and validated upon constrained cooling (blocked-jaws) tests, has been developed by the authors [3]. In this model the impact of

* Corresponding author.
E-mail address: jean-marie.drezet@epfl.ch (J.-M. Drezet).

http://dx.doi.org/10.1016/j.finel.2017.03.004
Received 30 August 2016; Received in revised form 22 March 2017; Accepted 24 March 2017

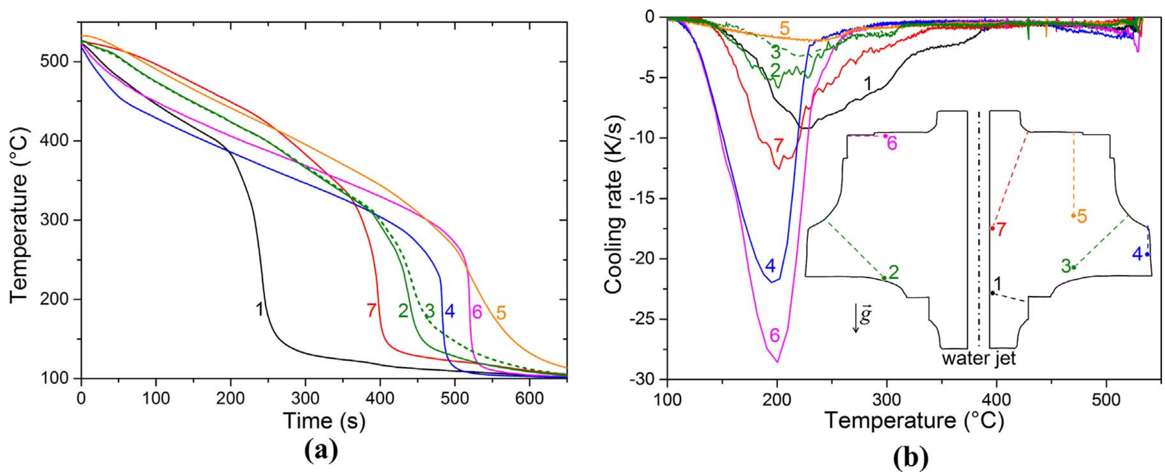

Fig. 1. (a) Measured cooling curves in boiling-water quenched forging A and (b) corresponding cooling rates. Inset: position of thermocouples with drillings in dashed lines.

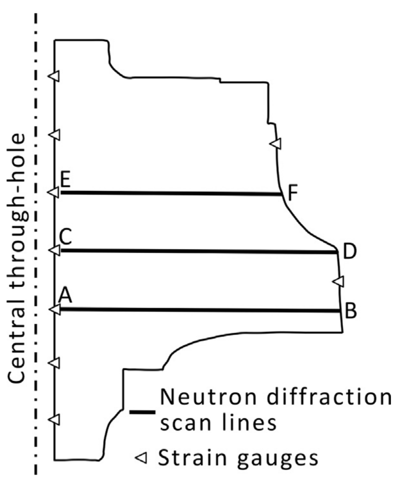

Fig. 2. Positions of rosette strain gauges and neutron diffraction scan lines [AB], [CD] and [EF].

precipitation during cooling is considered through temperature dependent yield strength thus avoiding a complex and fastidious characterisation of precipitation during quenching. The material model is now applied to quenching simulations of large impeller forgings which experience unconstrained cooling. This is more complex than uniaxial blocked-jaws tests as it requires an accurate knowledge of the complex transient thermal field for stress-strain FE simulations.

Temperature measurements during the entire heat treatment followed by RS measurements in T6 state using neutron diffraction (ND) and subsequent dissection method with strain gauges have been executed on one forging with central hole. Temperature measurements were used in an inverse modelling to calculate the position and temperature dependent heat fluxes (HFs). On a second forging with central hole of identical geometry and with the same heat treatment, RS measurements by ND were conducted in as-quenched and then in T6 states in order to quantify the amount of relaxation during artificial ageing and to check the reproducibility of the quench on both forgings. Based on the determined HFs and the validated material model, the stress generation during quenching has been simulated by FEA for the given forging with hole, and the therewith predicted as-quenched strains and stresses are compared to the RS measurements. Finally the results are compared to similar calculations performed on a forging of almost identical outer geometry but without a central axial through-hole, which decelerates the cooling speed in the center [4], in order to discuss the effect of cooling on precipitation and residual stress.

2. Experimental procedure

Two identical axisymmetric AA2618 forgings of about 0.5 m in diameter, with a central axial through-hole of 6% diameter of the outer diameter, and a total weight of about 110 kg were used:

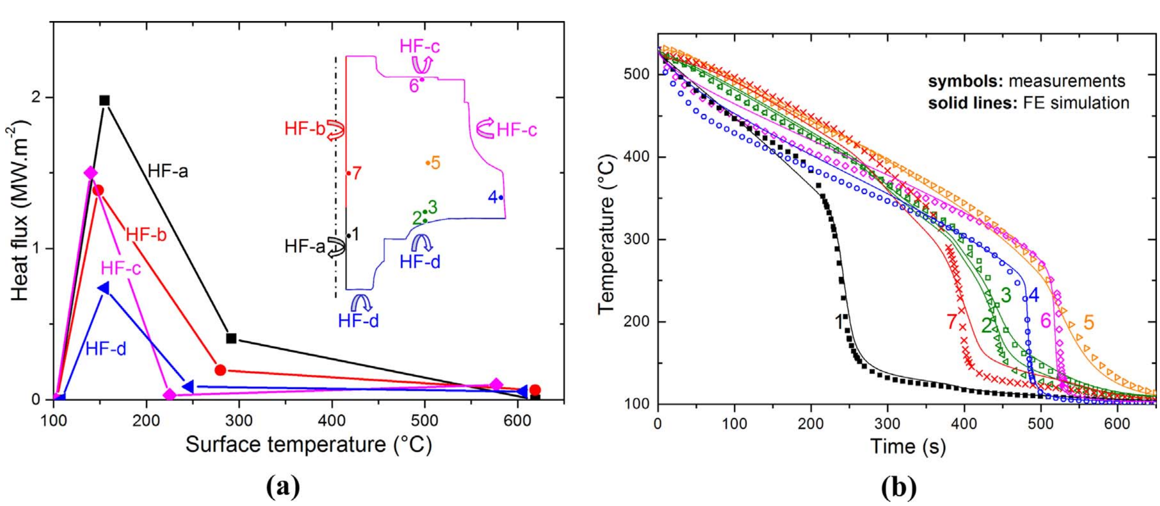

Fig. 3. (a) heat flux vs. surface temperature obtained by inverse method using an axisymmetric model of quenching in boiling water. The lines between the symbols correspond to the linear interpolation performed in-between the optimised heat fluxes in the FE simulation. (b) comparison between temperature measurements and simulation.