

Metallographic Observation for Evaluating Microstructural Evolution on Various Cross-Sections of Forged Part upon Air-Cooling from Finishing Temperature

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Utility properties of forgings, particularly the mechanical ones, are among the primary aspects of interest to the customers of forge shops. These properties arise from internal structure whose evolution depends predominantly on the combination of parameters of deformation processes applied during forging, on the temperature profile during cooling and on the shape of the forged part. As microstructural evolution depends on the shape of the particular cross section of the forged part, an appreciable inhomogeneity of mechanical properties occurs in forgings. This article deals with observation of microstructural evolution in a chosen forged part, depending on cooling profiles of its various cross sections. The experimental programme of mechanical working and treatment of the forged part was based on the material-technological modelling approach. Microstructural evolution was studied using light and electron microscopic methods. Results of this analysis provided a basis for outlining optimization steps for mechanical working and treatment of the forged part.

Keywords: material-technological modelling, C45, cooling rate, microstructure

1 Introduction

The manufacturing sequence for forged parts comprises soaking at the forging temperature, progressive forging and subsequent cooling [1, 2, 3]. Heating to the forging temperature typically takes place in devices which rely on electromagnetic induction. Their advantages are given predominantly by the high rate of heating to the forging temperature: several tens to several hundreds of degrees of centigrade per second. The forging temperature depends on the steel type and often exceeds 1200°C. Generally, forging operations take place at high temperatures at which considerable grain coarsening occurs. This is partially offset by recrystallization which is initiated in the workpiece by the plastic deformation energy introduced during forging. From this perspective, microstructural evolution within the workpiece is non-uniform due to the rate of cooling from the finishing temperature and due to the amount of working – the amount of deformation energy introduced [4, 5]. This non-uniformity has a profound effect on mechanical properties of forgings. Non-uniform microstructure can only be corrected by annealing above A_{c3} , typically by normalizing. Finding the heat treatment parameters which are appropriate for all cross sections is a complex task. Several approaches are available. One of them is material-technological modelling which is based on laboratory simulations of real-world physical-metallurgical processes [6, 7, 8]. Using this approach, treatment parameters are adjusted gradually and tested on a small volume of material without interfering with the actual manufacturing process.

2 Experimental programme

The purpose of this experimental programme was to assess the impact of forging and cooling parameters on microstructural evolution at selected points on a cross section of an actual C45-steel forged part of chassis of a heavy goods vehicle (Fig. 1). The experimental programme was based on material-technological modelling

[10, 11]. Material-technological models were constructed for selected points P1, P2 and P3 of the part's cross section. These models described the thermal-deformation processing of the actual forged part, i.e. forging and subsequent air cooling from the finish-forging temperature. The entire sequence consisted of soaking at the forging temperature of 1250°C, upsetting, preforming, finish-forging, trimming and subsequent air cooling. Results of these analyses were compared with material-technological models which comprised forging, air cooling and subsequent normalizing. The data for developing these models were obtained by means of FE simulations which were based on measurement of real-world operations in forge shops.

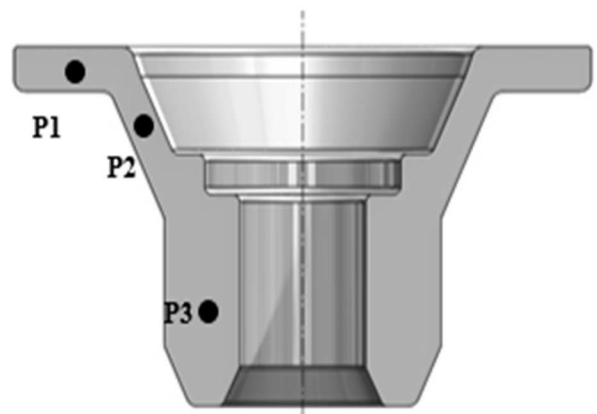


Fig. 1 Cross-sectional view of the experimental forged part

The P1, P2 and P3 points on the cross section of the forged part were chosen with regard to the area of the cross section and the magnitude of true strain applied during progressive forging. They were critical points on a cross section with a non-uniform wall thickness which therefore cooled at various rates (Fig. 2). Microstructures of material-technological models were examined using light and electron microscopes [9].

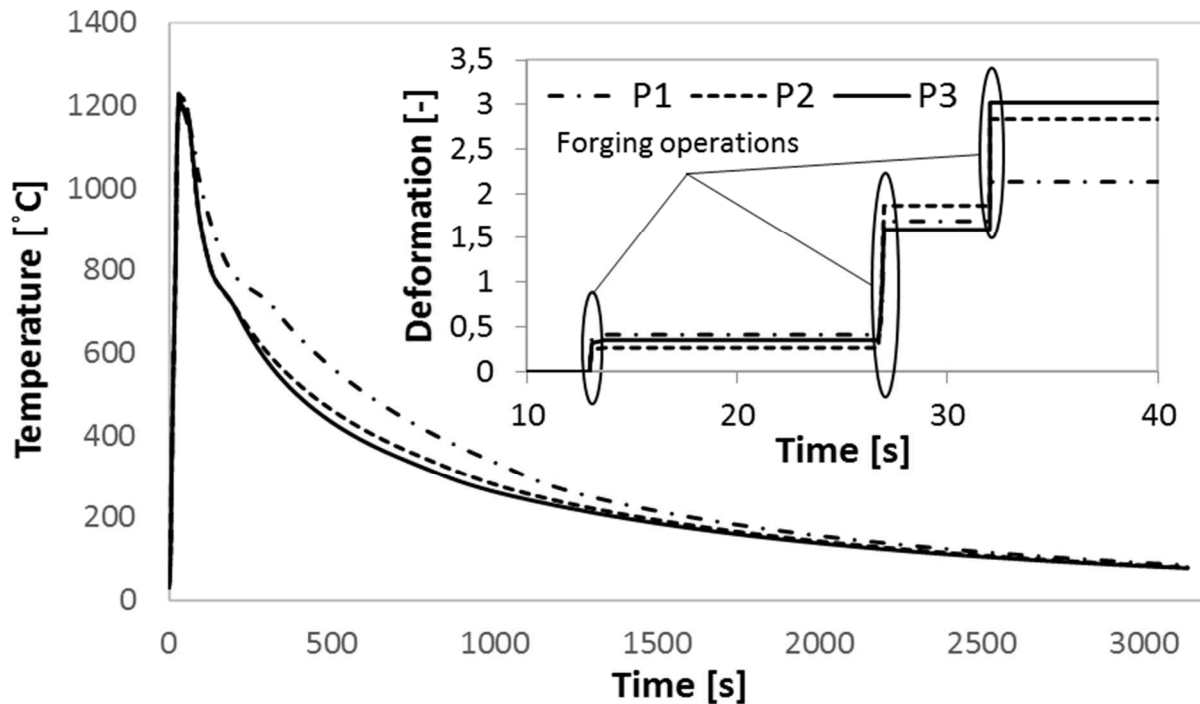


Fig. 2 Experimental curves of air cooling at selected points P1, P2 and P3 on the cross section

3 Results and discussion

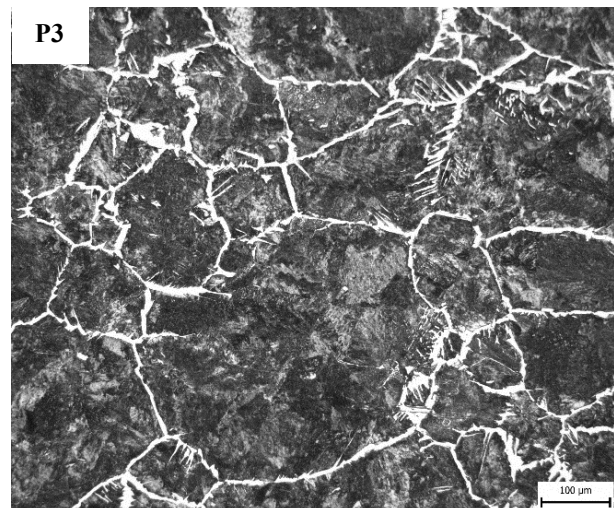
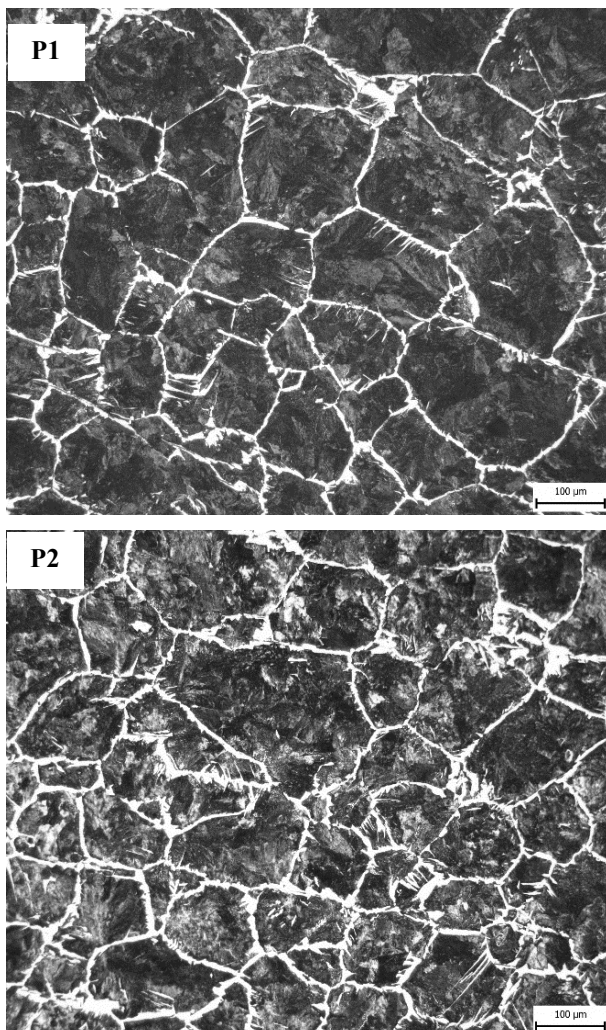


Fig. 3 Microstructure of the material after treatment by means of the material-technological model for P1, P2 and P3; air cooling from the finishing temperature – allotriomorphic ferrite, pearlite, Widmanstaetten ferrite

Metallographic examination showed that all material-technological models, P1, P2 and P3, contained proeutectoid allotriomorphic ferrite, Widmanstaetten ferrite and pearlite (Fig. 3, 4). Widmanstaetten ferrite probably formed as a consequence of substantial grain coarsening which in turn was caused by thermally-activated recrystallization processes after simulated forging.

As far as the total logarithmic strain applied during simulated forming (φ P1= 2.1; φ P2 = 2.8; φ P3 = 3) is concerned, it can be said that with decreasing logarithmic strain, grain size upon cooling from the finishing temperature increases. Mean grain sizes found by image analysis and by the intercept method according to ASTM E112

in the material-technological models P1 and P2 were G1 and G2, respectively. In P3 model, the mean grain size

was G1.

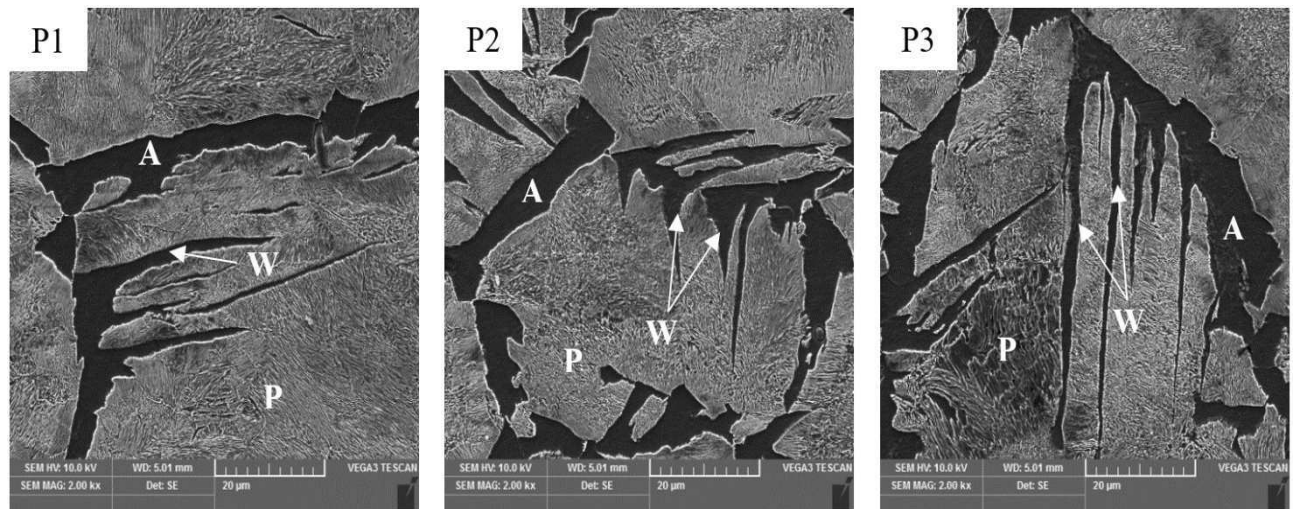


Fig. 4 Detail micrographs of material-technological models P1, P2 and P3 after air cooling

In material-technological models which represented progressive forging, air cooling to room temperature and subsequent normalizing at 900°C for 2.5 hours, the microstructure consisted of ferrite and pearlite and no Widmanstaetten ferrite (Fig. 5). Notable grain refinement was achieved in all material-technological models. Normalizing led to higher volume fractions of ferrite.

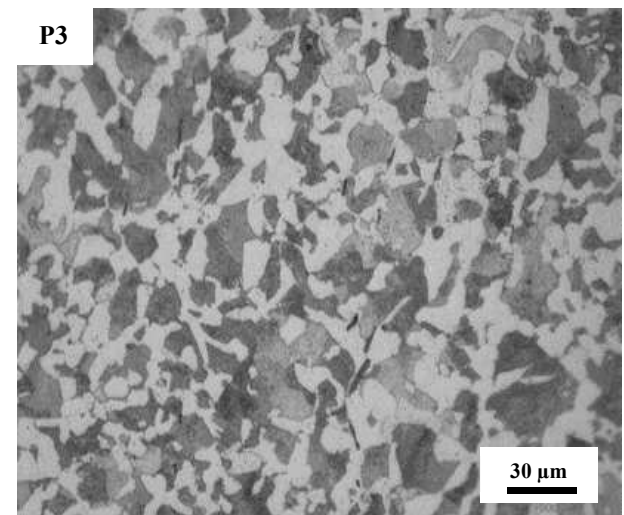
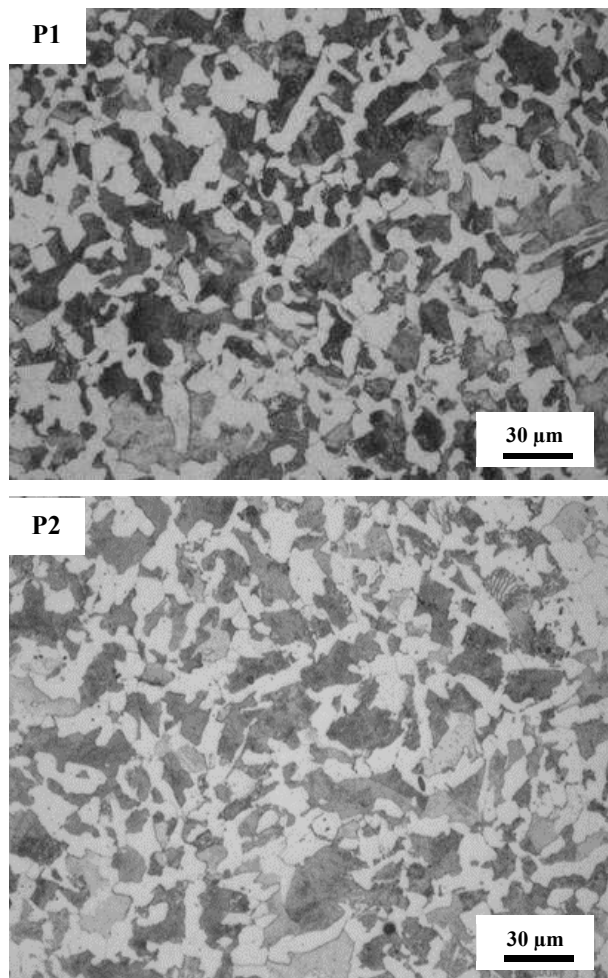


Fig. 5 Microstructures of material-technological models P1, P2 and P3 after normalizing – allotriomorphic ferrite, idiomorphic ferrite, pearlite

4 Conclusion

Material-technological modelling was used for studying the effect of air cooling from the finishing temperature on microstructural evolution in a forged part of C45 steel. Material-technological models for critical points P1, P2 and P3 on a cross section of an experimental forged part were constructed using data from real-world production in forge shops and from FE simulation. Results of this experiment showed that considerable grain coarsening takes place at critical points of the cross section after forging. It is likely that undesirable needle-like Widmanstaetten ferrite forms as a consequence of this grain coarsening. Widmanstaetten ferrite nucleates at the phase interface between allotriomorphic ferrite and untransformed austenite. In order to remove Widmanstaetten ferrite, it was necessary to use normalizing which led to overall refinement and to an increase in the ferrite volume

fraction. Upon comparing the microstructures at critical points on the cross section of the forged part after normalizing, it can be said that the proposed normalizing led to partial removal of microstructure inhomogeneity.

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