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Material-Technological Modelling of C45 Steel Die Forgings

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Abstract

Material-technological modelling is based on thermo-mechanical treatment of a small amount of real material using a thermomechanical simulator. This is a procedure allowing quick and accurate changes to selected parameters of the thermomechanical treatment. Due to the high dynamics of the process, material-technological models and forming technologies with high strain rates and with steep gradients in temperature changes can be designed using this method. The current state of technology also allows the use of this method for die forging.

The paper is focused on the issues of material-technological modelling of die forgings made from C45 and the possibility of its application to designing changes and optimization of forming and heat treatment technology. The first phase of the solution is the creation of a material-technological model for a real forging. The objective of this phase was to achieve the desired agreement between the model and the real forging. In the second phase, this model was used to replace the conventionally processed material C45 by thermomechanical micro-alloyed steel 30MnVS6. The aim of the controlled cooling from the forging temperature was to achieve structures without heat treatment, which is currently a necessary part of the manufacturing process. Replacing conventional technology with controlled cooling results in a significant saving of production costs.

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Keywords: Material-technological modelling; 30MnVS6; simulations of real forging processes

1. Introduction

Production in die forgings is based on a combination of several successive operations which can be divided into three basic steps: heating to the forming temperature, progressive forming in the die and subsequent heat treatment,

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which serve to achieve the desired microstructure which gives the forging its mechanical properties. Heat treatment is a conventional method for achieving the desired properties, but it presents the producer with costs in terms of energy consumption and time and a number of other components of the manufacturing costs. This is why we have attempted to obtain the desired properties of forgings without the use of heat treatment. Material-technological modelling is a very effective tool when developing such procedures. This approach uses the processing of small volumes of material which are subjected to processing conditions very close to the real conditions of the actual technologies. This can effectively optimize most of the necessary details of the technology, without interrupting the production process, and without allocating time for research and innovation of production facilities by carrying out trial and error testing during operation.

2. Experiment

2.1. Material-technological modelling

Material-technological modelling is based on the idea of simulation of real conditions by processing on a model, which is a test sample made from the actual material. This can be used to design and optimize methods for the actual processing technology and the whole production line without disrupting production [1,2]. A C45 steel forging was selected for the pilot project of the material-technological model. It is a safety component, intended for application in the automotive industry (see Fig.1).

Fig. 1. Real forging from C45 steel.

Fig. 2. Model of real forging created using FEM simulation- cross section with reference point for material-technological mode.

The material-technological model of the forging was compiled based on data measured during real forging and from data obtained through FEM simulations (see Fig. 2) [3,4,5]. Point P10 was chosen for modelling. At this point FEM simulation achieved overall deformation reaching values of $\varphi P10 = 3.6$. The highest increase in deformation, approximately 67%, was observed in the first upsetting operation (see Fig. 3). Simulation of forming and heat treatment was carried out on a thermo-mechanical simulator, which allows us to achieve high deformation speeds and prescribed temperatures in very short times (see Fig. 4). Given the need to ensure the stability of the test model sample, while maintaining the overall deformation energy, the deformation was carried out in three increments using tension/compression (see Fig. 5)[6].

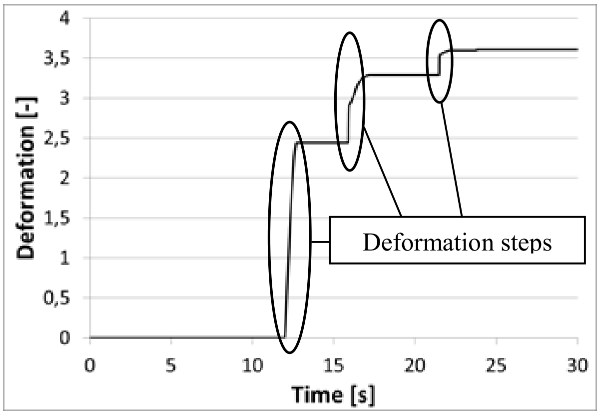

Fig. 3. Deformation during forming operation at P10.

Fig. 4. Sample used for material-technological modeling.

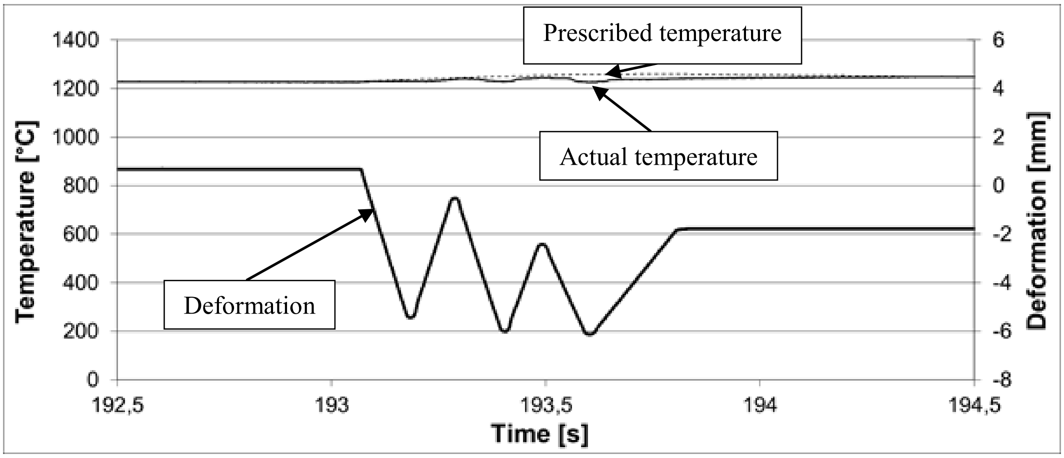

Fig. 5. Model solution of reduction in the first cavity for point P10.

2.2. Aims and the research plan

The aim of the research was the preparation and verification of the functionality of a material-technological model, created on the basis of measurements from real forging operations and then used for the design and optimization of controlled cooling of a real forging in order to optimize properties without the need for heat treatment (see Fig. 8). As part of the experiment, steel C45 was replaced by steel 30MnVS6. This is a vanadium microalloyed steel with high sulphur content. The reason for selecting this steel was also the possibility of precipitation hardening, which contributes to achieving the required mechanical properties. During the heating to forging temperature, the vanadium dissolves in the solid solution of austenite, and during cooling it precipitates out in the form of fine precipitates of V (C, N). This precipitation gives rise to both proeutectoid ferrite and pearlitic ferrite. The presence of higher concentrations of sulphur improves the machinability of the forgings.

A site was selected on the real forging which was important with regard to the forging's production technology and its resulting properties. Point P10 was chosen to demonstrate the modelling. At this point, based on the previous measurements and FEM simulation, a model was prepared for deformation and temperature, which was subsequently recalculated for a real sample in the form of a threaded test bar with a diameter of 8 mm and length 16 mm. Then it was processed using the specified parameters. The resulting structures were analysed. Correlation between the model and the real forging was evaluated by comparing the microstructures and hardness HV10.

3. Results and discussion

Microstructural evaluation of the model point P10 and the real forging showed significant concordance (see Fig. 6). In both cases there was a mixed ferrite-pearlite structure. Similarly, the evaluation of hardness HV10 showed a match between the experimental model of 226 HV10 and the actual forging of 221 HV10.

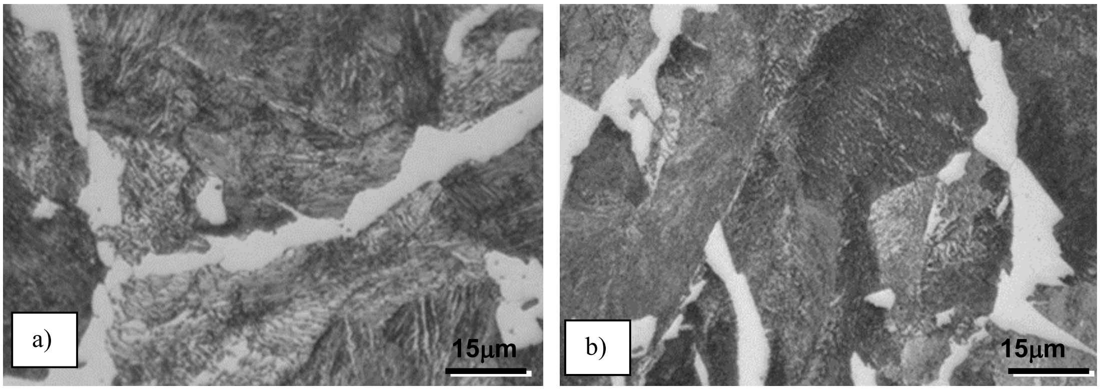

Fig. 6. Comparison of ferrite-pearlite structure (a) real forging and (b) model after forging operation.

In accordance with the entire manufacturing process the cross-correlation between the model and the state of the forging after heat treatment was also investigated. Normalizing annealing at 860 ° C for 120 minutes is used, which is carried out in a continuous annealing furnace. The model of this technology was again based on data measured during real production. Comparison of the structures of the real forging and the model again showed good agreement (see Fig. 7). In both cases there was a ferrite-pearlite structure; in the real forging a hardness of 189 HV10 was measured, and in the model 192 HV10. Based on the results, it was then possible to use the model to design controlled cooling and replace the existing steel C45 with micro-alloyed steel 30MnVS6. The aim was to achieve similar properties without requiring heat treatment.

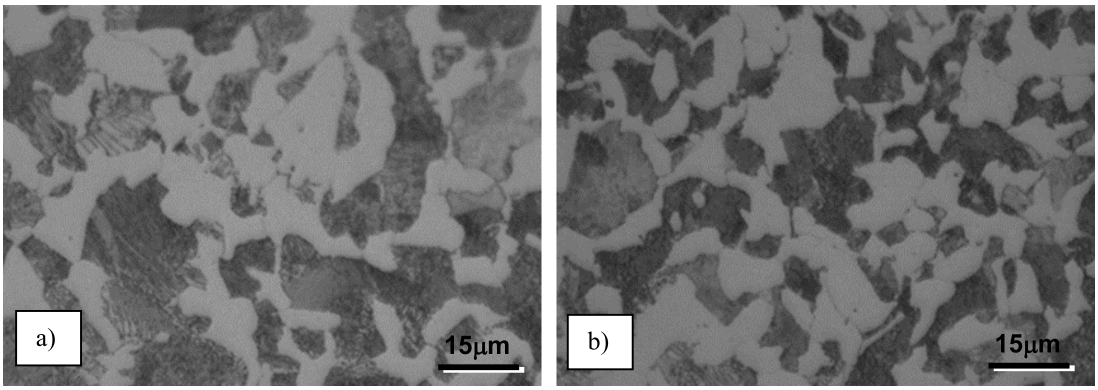

Fig. 7. Comparison of ferrite-pearlite structure (a) model after heat treatment (b) real forging.

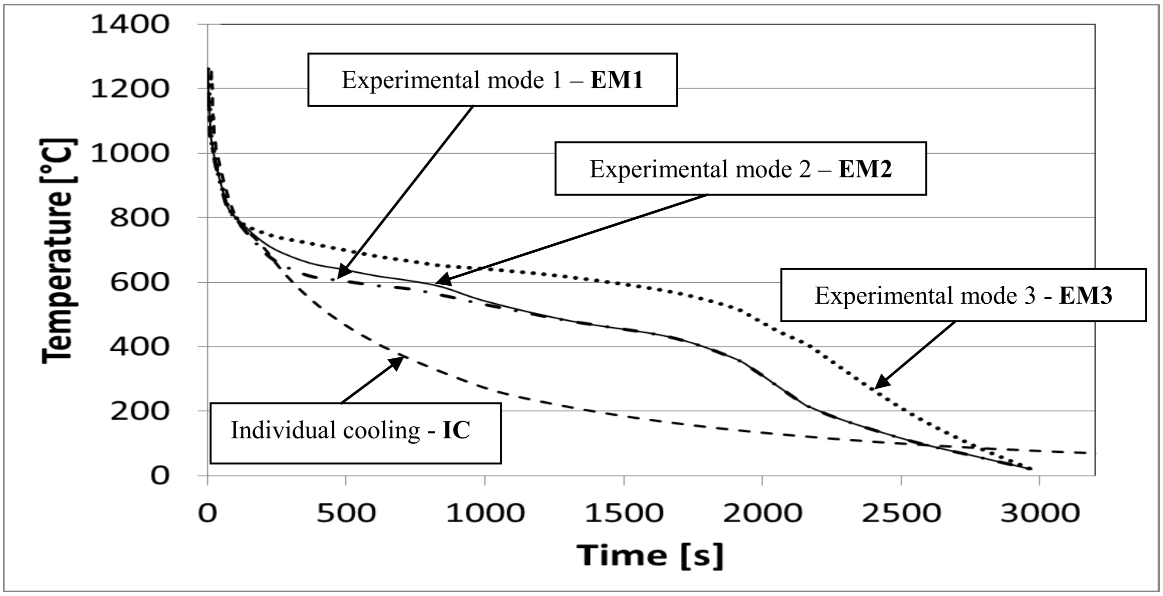

Fig. 8. Experimental cooling regime.

Evaluation of the microstructure of the model for processing steel 30MnVS6 with free cooling according to temperature curve IC (which corresponds to the curve of free cooling of the selected point of the real forging after forging) showed the presence of ferritic - pearlitic structure. Comparison with the original material C45 processed in the same way showed the expected significant difference of the structures.

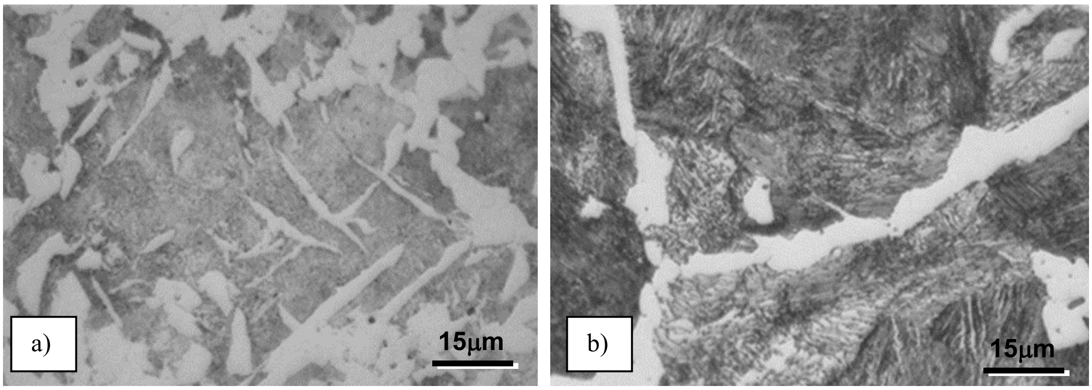

Fig. 9. Comparison of ferritic-pearlitic structures (a) model with 30MnVS6 steel (b) real forging from C45 steel after forging and free cooling.

In the original C45 material, the structure is formed from a relatively thin network of ferrite along the grain boundaries, while for the steel 30MnVS6 there was a massive ferritic network with sharp protrusions into the surrounding perlite (see Fig. 9). The hardness of the model 30MnVS6 was 245 HV10, for the forging from material C45 it was 221 HV10. The difference in hardness was 24 HV10. With regard to the carbon content which differs by 0.15%, the origination of the hardening is primarily from precipitation hardening of the matrix. Comparison of the microstructure of the 30MnVS6 steel model freely cooled from the forging temperature according to curve IC with the forging from steel C45 after normalization annealing showed in both cases the presence of a ferritic-pearlitic structure with a very similar morphology of massive ferrite network along the grain boundaries (see Fig. 10).

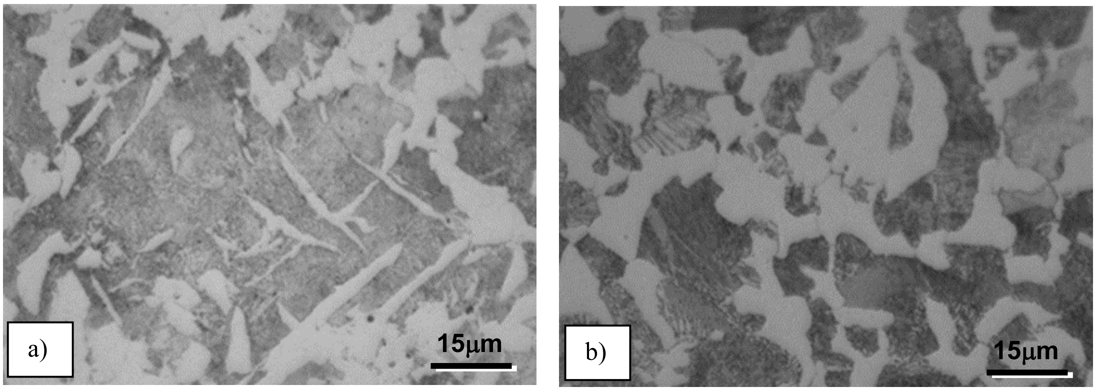

Fig. 10. Comparison of structures of models from 30MnVS6 steel after free cooling without heat treatment and the real forging from C45 steel after forging (a) model, (b) real forging.

In the case of cooling according to the curve EM1 the microstructure of the model from steel 30MnVS6 was composed of ferrite and pearlite (see Fig. 11a). Ferrite content increased in comparison to the free cooled forging cooled in air. During this process, acicular morphology did not occur. Hardness reached values of 226 HV10.

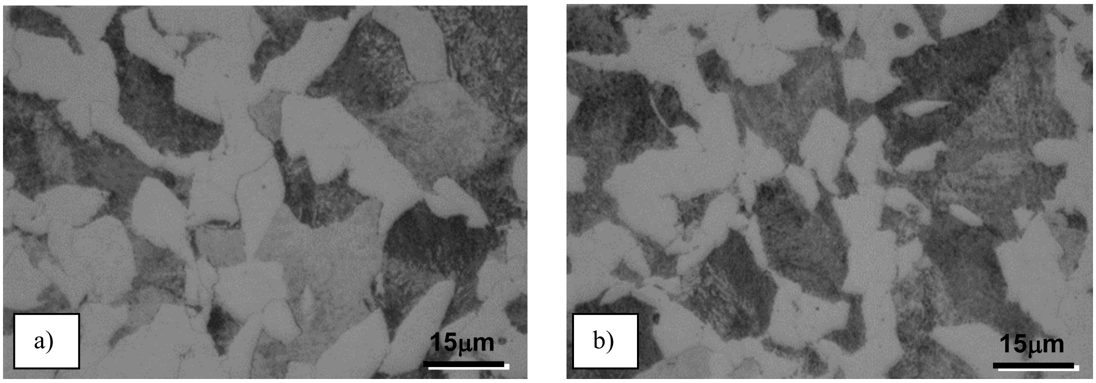

Fig. 11. Comparison of structures of model from 30MnVS6 steel after controlled cooling (a) regime EM1 (b) regime EM2 – cooling speed EM1>EM2.

In the model which was slowly cooled according to cooling curve EM2 after simulation of the forging operation, a ferritic - pearlitic structure was again identified (see Fig. 11b). Hardness was, however, in this case 213 HV10. Cooling of the experimental model according to experimental curves EM3 and thus the lowest cooling rate, led to creation of a structure consisting of ferrite and pearlite having a hardness of 212 HV10 (see Fig. 12).

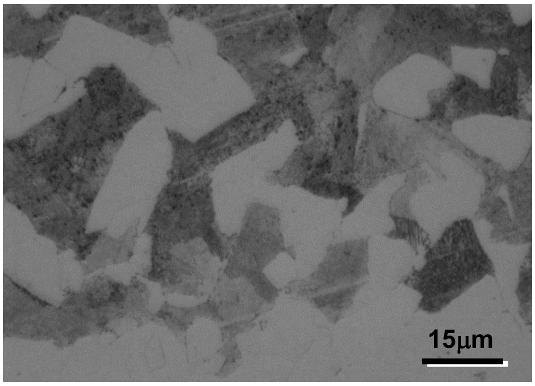

Fig. 12. Structure of model from 30MnVS6 steel after controlled cooling without heat treatment, experimental regime EM3, cooling speed EM3<EM2<EM1.

Conclusion

Material-technological modelling was used to develop a new procedure for thermomechanical processing. Using data taken during the production of die forgings a material-technological model was created, simulating a real forging process and heat treatment. The functionality of this model was verified by comparing with a real forging. To verify the agreement of the model with reality separate forging operations and heat treatments were used.

Comparison of microstructures after the forging operation showed an excellent match in both the model and the real forging. In both cases there was a ferrite-pearlite structure with very similar morphology. For the model the hardness was 226 HV10, for the real forging it was 221 HV10. A similar agreement was obtained even with the heat treatment operation. In the experimental model and the real forging the structure was composed of ferrite and pearlite. Hardness in the model reached values of 192 HV10 and for the real forging 189 HV10.

The functionality of the material-technological model was thus demonstrated. This procedure was then used to design and optimize a new process with controlled cooling of the forging, which was designed as a substitute for heat treatment. For this purpose the existing material C45 was replaced by 30MnVS6 steel. For experimental purposes four modes of cooling from the forging temperature were subsequently designed so that it was possible to determine the development of the microstructure in relation to the cooling profile.

When the modelled cooling from the forging temperature of steel 30MnVS6 according to the free cooling curve of the real forging was compared with the forging after heat treatment a ferrite - pearlite structure with very similar morphology was observed in both cases. Hardness of the real forging after heat treatment reached values of 189 HV10, in the model it was 245 HV10.This significant difference in hardness values can be attributed to the effect of precipitation hardening achieved for the model from steel 30MnVS6. Reducing the cooling rate led to an increase in the proportion of ferrite in the structure and a decrease in hardness to 226 HV10 compared to the state in the model from steel 30MnVS6 after free cooling from the forging temperature. Further reduction of the cooling speed did not lead to significant changes in the proportion of ferrite in the structure, but led to a reduction of hardness to 213 HV10 and 212 HV10. Controlled cooling from forging temperature together with substitution of the existing material C45 by 30MnVS6 managed to achieve structures and properties approaching the state of C45 after heat treatment. Conditions were thus found for a technological process for manufacturing forgings without the need for heat treatment with the potential for significant cost savings.

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