Optimization of Controlled Cooling of Forgings from Finishing Temperature with the Use of Light and Electron Microscopy

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Customer requirements represent the driving force in the market, dictating the directions of development, production and processing of forged parts. Meeting these requirements is of paramount importance to forge shops as a precondition for their continuing operation and competitiveness. Consequently, optimization of manufacturing operations and their rapid response to market requirements are necessary for the forge shops to survive. However, any production stoppage for optimization results in extra costs. Forge shops thus strive to carry out optimization in as few steps as possible and within the shortest possible timeframe. A viable solution emerges in the form of material-technological modelling which involves laboratory-based optimization taking place away from the forge shop without any constraints on the production operations. This paper deals with selection of a material for a forged part to be controlled-cooled from the finishing temperature to substitute a C45-steel part treated by normalizing. One criterion was that the entire forged part should contain ferritic-pearlitic microstructure.

Keywords: material-technological modelling, 30MnVS6, 38MnVS6, controlled cooling

1 Introduction

Changes to the manufacturing route, substitution of forging materials and modification to forged part’s shape are among the most frequent technology-related causes of production stoppages. One available solution lies in laboratory-based design and optimization of new manufacturing routes and procedures [1, 2, 3, 4]. The production can thus be updated with optimized parameters and treatment routes without changing or slowing down the production rate, while eliminating stoppages. One of the approaches used in such cases is material-technological modelling. The materials-physical basis of this method makes it available for a wide range of interventions and for development of closed-die forging routes [5, 6, 7, 8].

One of their examples is the design and optimization of controlled cooling from the finishing temperature and a selection of steel for a forged part.

2 Experimental programme

The purpose of this experimental programme was to identify an appropriate material for a forging which was to be controlled-cooled from the finishing temperature (Fig. 1). The forging had been previously made of C45 steel. It was a part of a chassis of a heavy goods vehicle. The boundary conditions were that a ferritic-pearlitic microstructure must be achieved throughout the forging and the hardness must not exceed 240 HV10. The experimental programme was carried out on microalloyed 30MnVS6 and 38MnVS6 steels. The reasons for choosing these steels included the favourable effect of vanadium precipitates on controlling the grain growth after simulated forging and subsequent controlled cooling, and the possibility of precipitation hardening of the ferrite constituent. The steps involving optimization and the selection of an appropriate material were carried out for a critical location identified as P1 on the cross section. Material-technological modelling was employed to physically simulate the forging route with controlled cooling from the finishing temperature [9, 10, 11]. The data for developing material-technological models were obtained by means of FE simulations which were based on measurement of real-world operations in forge shops. Material-technological models were heated to the forging temperature of 1250˚C at which progressive forging with a true strain level of $\varphi = 2.8$ was simulated. Forging operations were followed by controlled cooling according to pre-defined curves.

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

The controlled-cooling curves were designed to enable the description of microstructural evolution vs. cooling rate in the critical range 900/300˚C (**Fig. 2**), i.e. in the range where undesirable hardening microstructure forms. Microstructure was examined using light and electron microscopes [12].

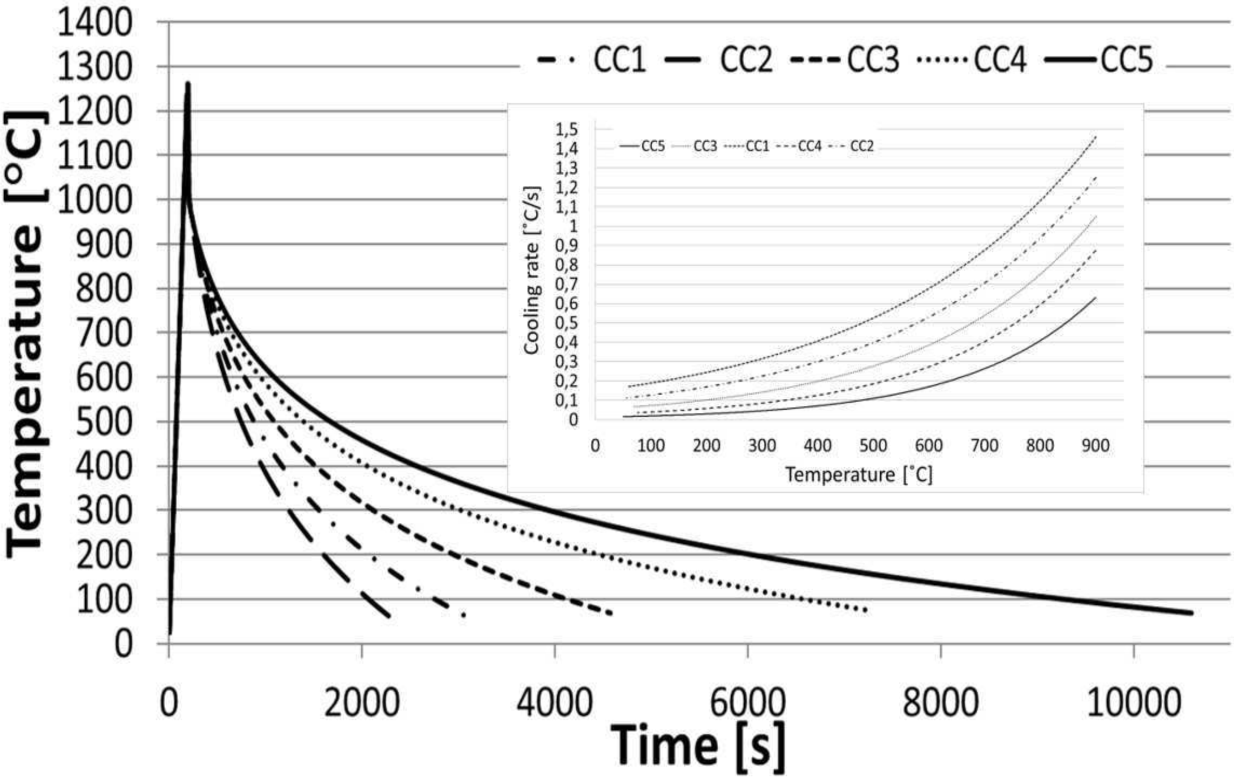

Fig. 2 *Experimental controlled cooling curves CC1-CC5*

3 Results and discussion

Material-technological models of both experimental steels, which cooled according to CC1 controlled-cooling curve with the highest cooling rate, contained allotriomorphic ferrite along grain boundaries, idiomorphic ferrite within grains, pearlite, and hardening microstructures (Fig. 3). The last-named constituents were identified using scanning electron microscopy as bainite with martensite islands (Fig. 4).

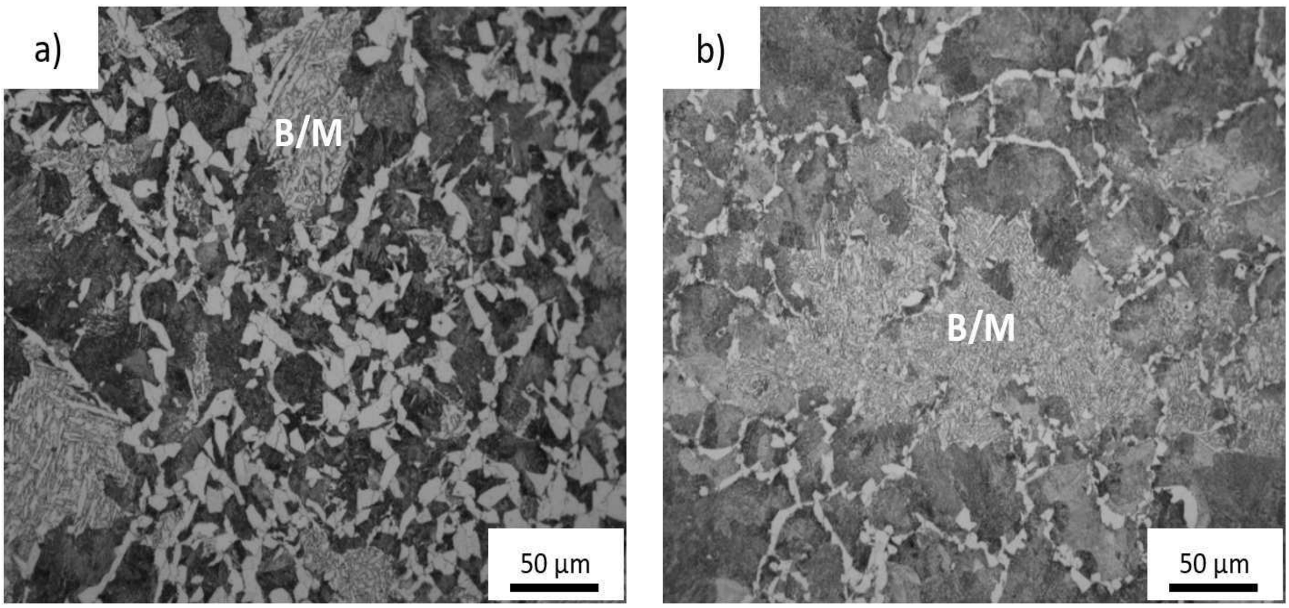

Fig. 3 *Micrographs of material-technological models which cooled according to CC1 curve a) 30MnVS6 – ferrite, pearlite, bainite b) 38MnVS6 – ferrite, pearlite, bainite*

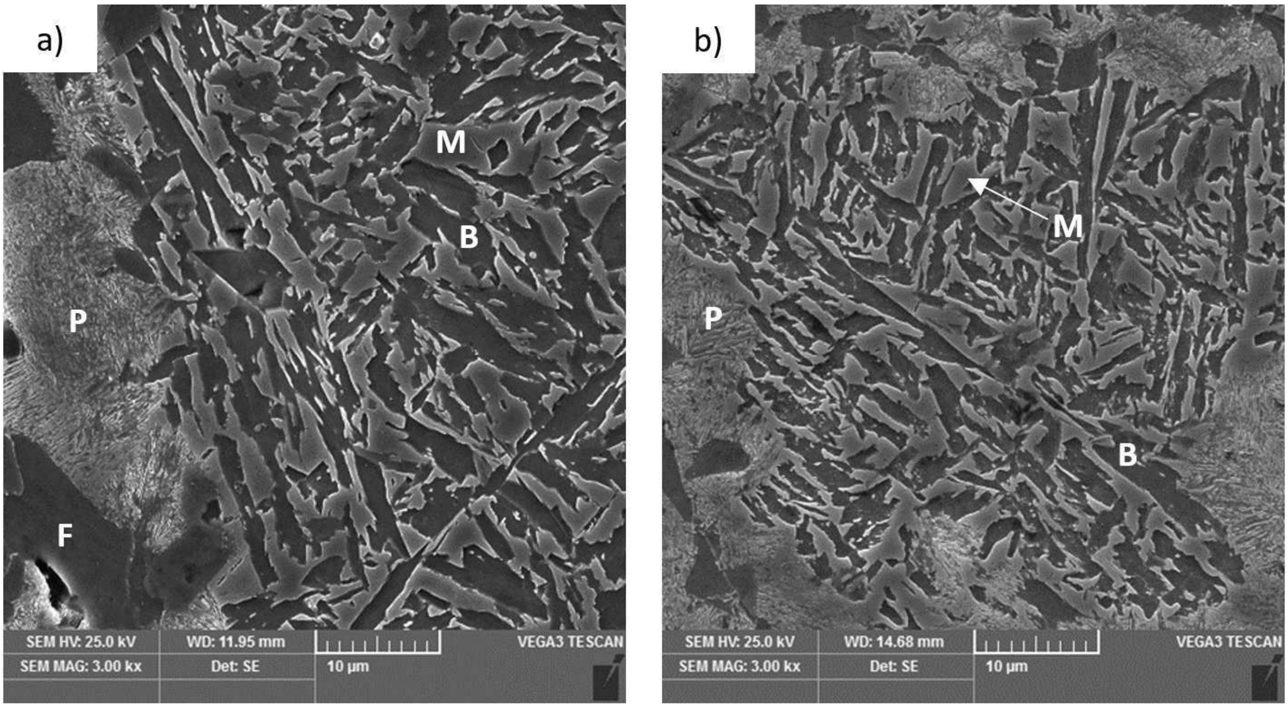

Fig. 4 *Detail scanning electron micrographs of material-technological models which cooled according to CC1 curve a) 30MnVS6 – ferrite, pearlite, bainite b) 38MnVs6 – ferrite, pearlite, bainite*

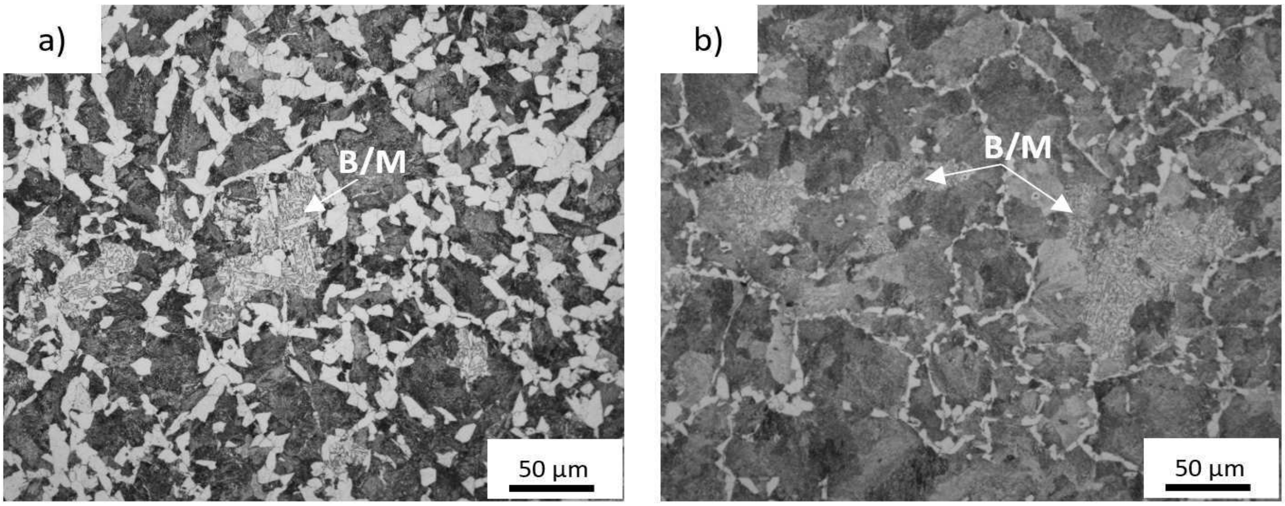

Fig. 5 *Micrographs of material-technological models which cooled according to CC2 curve a) 30MnVS6 – ferrite, pearlite, bainite b) 38MnVs6 – ferrite, pearlite, bainite*

Idiomorphic ferrite was identified in areas where inclusions were present. The hardness of the material-technological model of 30MnVS6 steel was 261 HV10 and that of the model of 38MnVS6 steel was 293 HV10. The difference in hardness levels of the models of controlled cooling which cooled according to CC1 curve was most likely down to the higher volume fraction of pearlite in the model of 38MnVS6 steel and the higher fraction of the bainitic constituent.

A similar trend in microstructural evolution was also observed in the material-technological models of controlled cooling according to curve CC2 (Fig. 5). In both experimental steels, the microstructure consisted of allotriomorphic and idiomorphic ferrite, pearlite and bainite whose fraction was lower than in CC1 models. Hardness of the 30MnVS6 material treated according to CC2 model was 257 HV10. In the 38MnVS6 material, it was 290 HV10.

In 30MnVS6 steel, a further reduction of the controlled cooling rate in the critical interval of 900/300°C, as represented by the CC3 curve, led to a microstructure consisting of no other constituents than allotriomorphic and idiomorphic ferrite and pearlite; with a hardness of 243 HV10 (Fig. 6). 38MnVS6 steel contained the above-named constituents and bainite. This was reflected in higher hardness: 280 HV10.

In 30MnVS6, the cooling rate in the material-technological models according to curves CC4 and CC5 led to a rise in the proeutectoid ferrite fraction (Figs. 7, 8). As a result, the hardness for the CC4 controlled-cooling curve decreased to 236 HV10 and that for the CC5 curve reached 232 HV10.

Tab. 1 *Hardness values of material-technological models of 30MnVS6 and 38MnVS6 steel swhich cooled according to experimental curves CC1 – CC5*

Cooling curve	30MnVS6	38MnVS6
CC1	261 HV10	293 HV10
CC2	243 HV10	290 HV10
CC3	261 HV10	280 HV10
CC4	236 HV10	275 HV10
CC5	232 HV10	270 HV10

In 38MnVS6 steel, a further reduction in the cooling rate according to curves CC4 and CC5 led to elimination of bainite, unlike with the previous cooling rates. The resulting microstructure consisted of proeutectoid ferrite and pearlite. The hardness of the microstructure treated according to CC4 material-technological model was 275 HV10. The value for the model CC5 was 270 HV10 (Tab. 1).

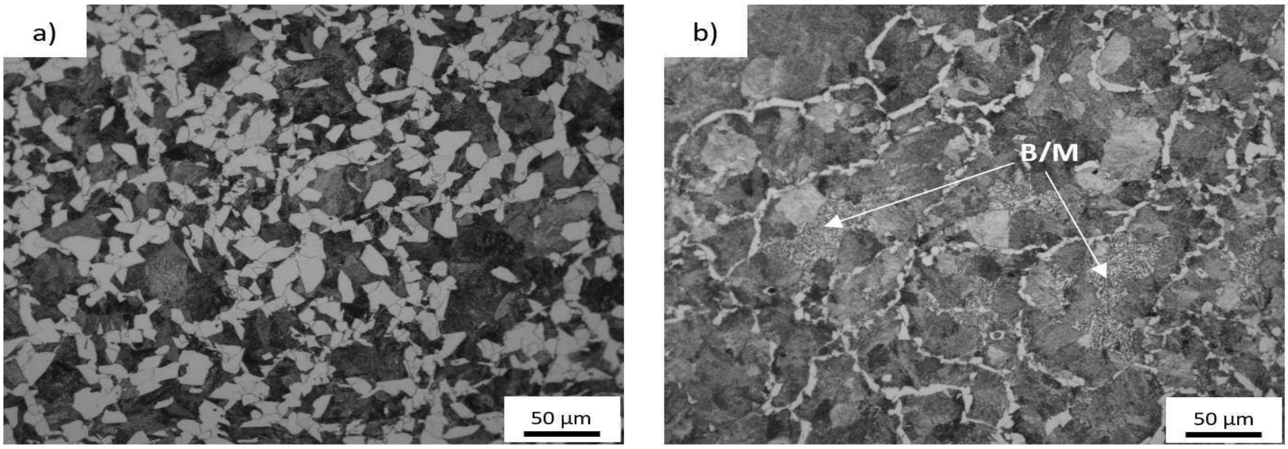

Fig. 6 *Micrographs of material-technological models which cooled according to CC3 curve a) 30MnVS6 – ferrite, pearlite b) 38MnVs6 – ferrite, pearlite, bainite*

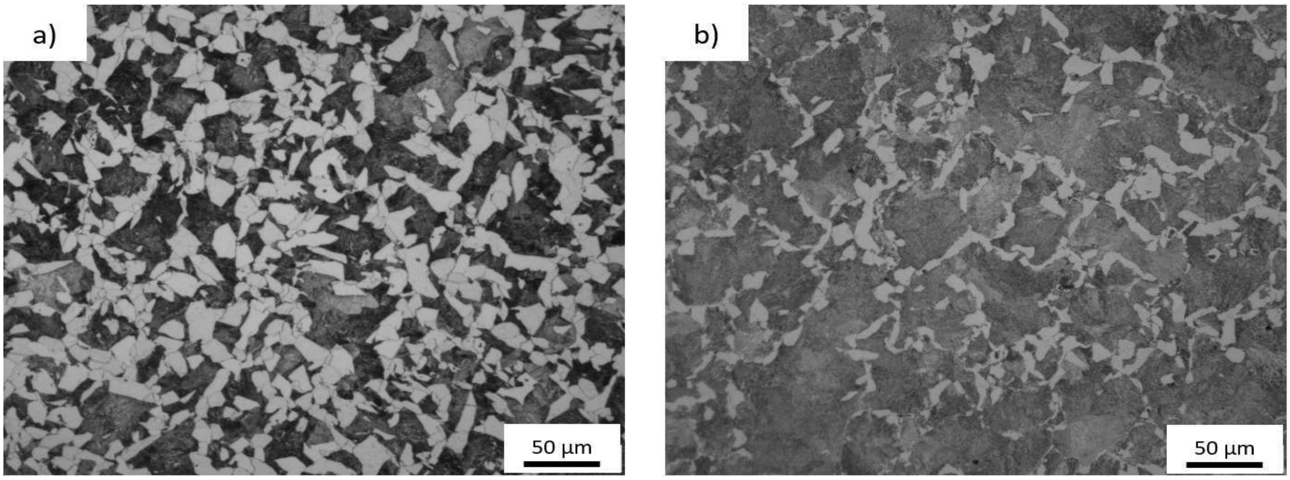

Fig. 7 *Micrographs of material-technological models which cooled according to CC4 curve 30MnVS6 – ferrite, pearlite b) 38MnVs6 – ferrite, pearlite*

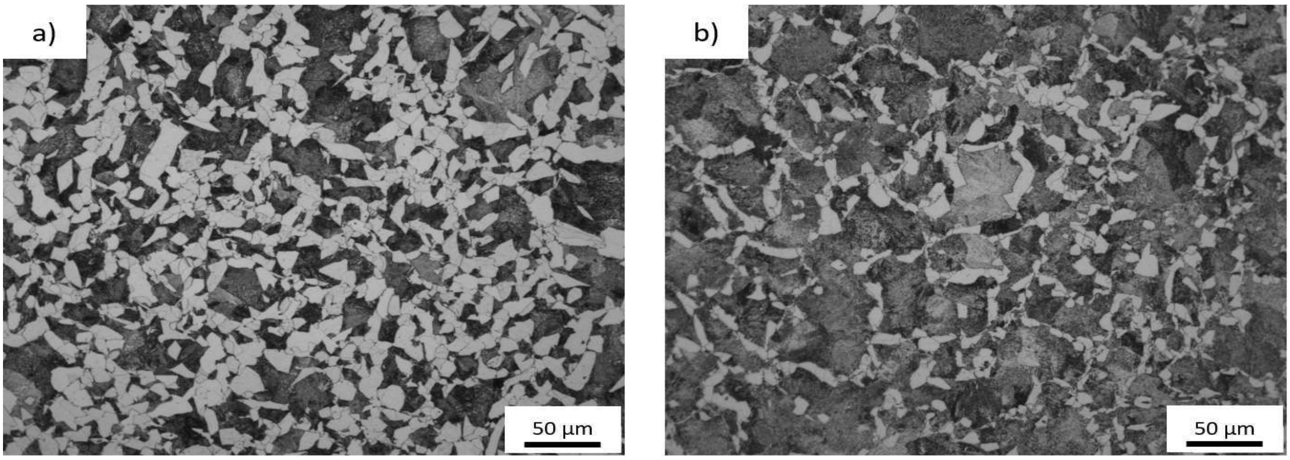

Fig. 8 *Micrographs of material-technological models which cooled according to CC5 curve a) 30MnVS6 – ferrite, pearlite b) 38MnVs6 – ferrite, pearlite*

4 Conclusion

Material-technological modelling was employed to explore controlled cooling of a specific forging from the finishing temperature and select an appropriate material. The experiment was carried out for a chosen critical cross-section of the forging which was expected to undergo the fastest cooling. For this cross section, several material-technological models were constructed which involved progressive forging and controlled cooling. Microstructural evolution was tracked in the critical interval of 900/300˚C. 30MnVS6 steel or 38MnVS6 steel were proposed as experimental materials. The boundary conditions for the solution were formulated as a resulting microstructure of ferrite and pearlite and a hardness of no more than 240 HV10. The experiment showed that with 30MnVS6 steel, these requirements can be met at the forged part's controlled cooling rate of less than 0.8˚C/s. With 38MnVS6 steel, it was found that although ferritic-pearlitic microstructure formed at cooling rates lower than 0.8˚C/s, the resulting hardness was 270 HV10 or higher. Consequently, the viable substitute for the current material which is treated by normalizing is 30MnVS6 steel treated by controlled cooling. Elimination of subsequent heat treatment leads to time and energy savings in production.

Acknowledgement

The present contribution has been prepared under project LO1502 'Development of the Regional Technological Institute' under the auspices of the National Sustainability Programme I of the Ministry of Education of the Czech Republic aimed to support research, experimental development and innovation.

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DOI: 10.21062/ujep/69.2018/a/1213-2489/MT/18/1/149