NEW TREATMENT ROUTE FOR CLOSED-DIE FORGINGS OF STEELS WITH 2.5% MANGANESE

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Abstract
The requirements placed on closed-die-forged parts of advanced steels have been increasing recently. Such forgings demand an innovative approach to both design and heat treatment. It is important to obtain high strength and sufficient ductility in closed-die forgings. High strength, mostly associated with martensitic microstructure, is often to the detriment of ductility. Ductility can be improved by incorporating a certain volume fraction of retained austenite in the resulting microstructure. Among heat treatment processes capable of producing martensite and retained austenite, there is the Q&P process (Quenching and Partitioning). This process is characterized by rapid cooling from the soaking temperature to the quenching temperature, which is between Ms and Mf, and subsequent reheating and holding at the partitioning temperature. Thus, strength levels of more than 2000 MPa combined with more than 10% elongation can be obtained. This experimental programme involved steels with 2.5% manganese. Forgings of these steels were heat treated using an innovative process in order to obtain an ultimate strength of more than 2000 MPa combined with sufficient elongation. Thanks to a higher manganese level, the Mf was depressed as low as 78°C, and therefore quenching was carried out not only in air but also in boiling water. Holding at the partitioning temperature of 180°C, when carbon migrates from super-saturated martensite to retained austenite, took place in a furnace. The effects of heat treatment parameters on the resulting mechanical properties and microstructure evolution in various locations of the forging were studied.

Keywords: closed-die forgings, Q&P process, retained austenite, AHSS

1 Introduction

Closed-die forgings made by hot forming a steel stock are shaped with the use of plastic deformation [1]. Today's demands on the design solutions and mechanical properties of advanced closed-die forgings are increasing [2-14]. The process routes which are currently used with classical forging steels have been optimized over the years to a point where there is no more space for substantial enhancement and improvement of mechanical properties. This applies in particular to strength, service life and safety where the last-named aspect is provided mainly by the fracture behaviour of the particular steel. If progress is to be made in this field, new heat treatment and thermomechanical treatment technologies must be developed in the future, which

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entails continuous development of alloying concepts and the entire metallurgical production. This article introduces one of the available processes for achieving high strength and sufficient ductility: quenching and partitioning (Q&P). This advanced technique has a major weakness in that the quenching temperature must be controlled and kept above the Mf. In terms of practical implementation, Q&P processing is relatively straightforward with steel workpieces of constant cross-section where temperature field control and behaviour is substantially simpler than in intricate parts. Q&P processing leads to predominantly martensitic microstructures which typically contain 10 or more percent retained austenite [15-20]. With such microstructure, high-strength steels exhibit good ductility, with elongation values around 10% which is a relatively high value for martensitic materials.

2 Experimental programme

This experiment was carried out on the 42SiCr steel which is alloyed with manganese, silicon and chromium in **Table 1**. Manganese improves the solubility of carbon in austenite, ultimate and hardenability. Silicon prevents formation of carbides and facilitates saturation of martensite with carbon. Chromium increases hardenability and provides solid solution strengthening. The objective was to explore Q&P processing of this steel with various parameters using material-technological modelling and evaluate the effects of these parameters on the resulting microstructure and mechanical properties.

Table 1 Chemical composition of the experimental steel (wt. %)

AHSS	C	Mn	Si	P	S	Cu	Cr	Ni	Al	Mo	Nb	M_s	M_f
	0.419	2.45	2.09	0.005	0.002	0.06	1.34	0.56	0.005	0.04	0.03	209	78

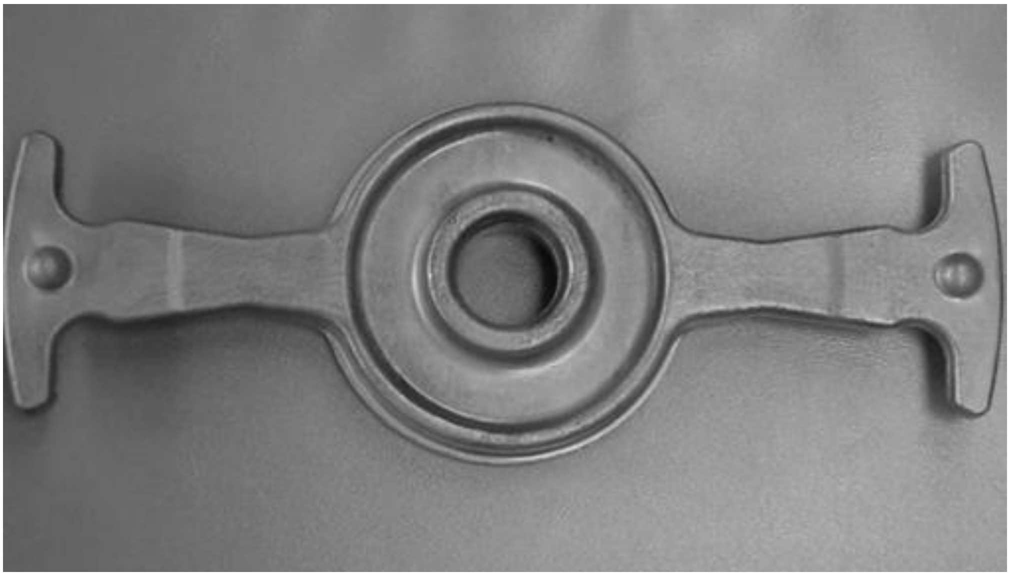

Fig. 1 Closed-die forging of AHSS steel used in the experiment

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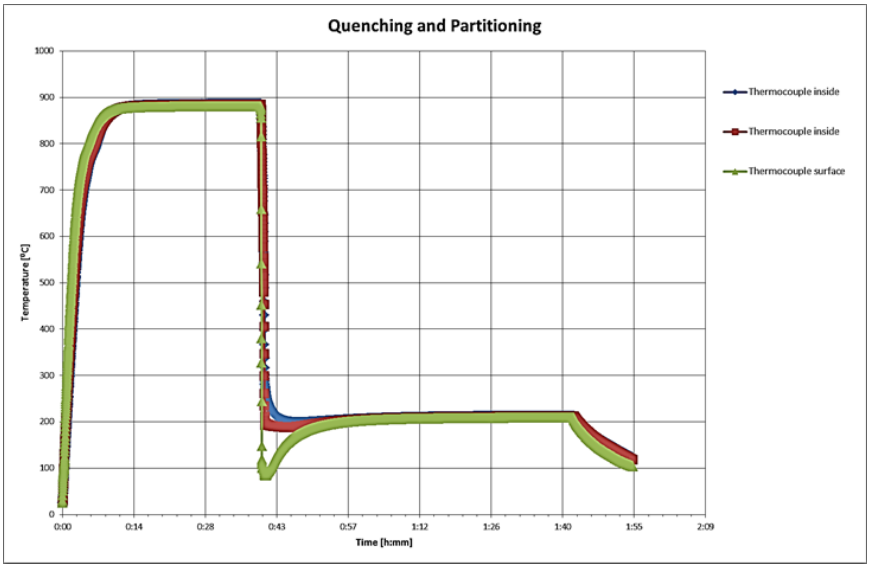


Fig. 2 Diagram of the heat treatment of closed-die forging incorporating the Q-P process

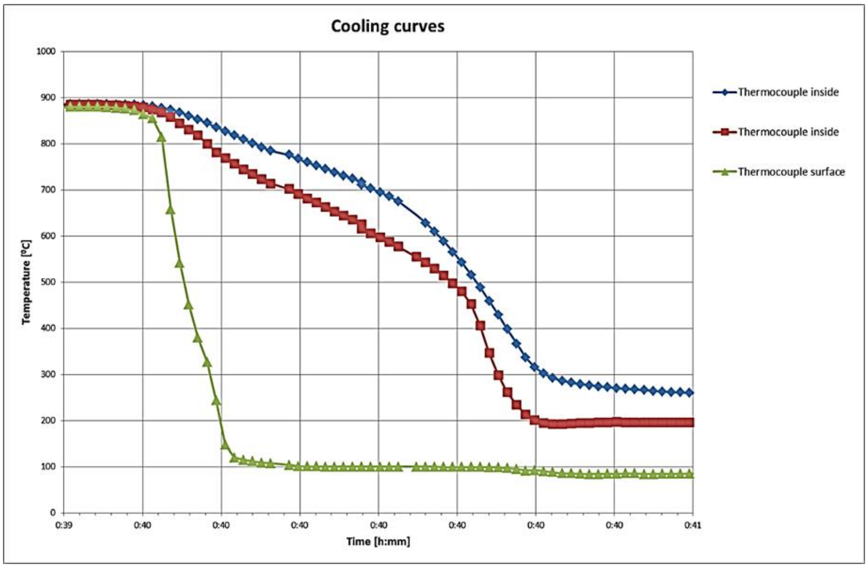


Fig. 3 Cooling curves of the forging's surface and interior during cooling in boiling water

3 Discussion of results

Experimental treatment which included the Q&P process led to mostly fine martensitic microstructure with retained austenite and a small fraction of bainite in all parts of the forging (**Figs. 4 – 8**). The surface and interior hardnesses of the forged part were about 591 HV10 and 519 HV10, respectively. The fact that the surface of the forging showed higher hardness was due to a larger fraction of martensite in the final microstructure and the higher speed of its formation.

In the core, owing to its higher temperature, complete martensite transformation and subsequent stabilisation of retained austenite in the martensitic matrix did not take place. Examination by X-ray diffraction revealed 10 vol. % of retained austenite in the martensitic matrix and fine-grained structure (**Fig. 8**). This retained austenite is likely to exist as thin films along martensite lath boundaries.

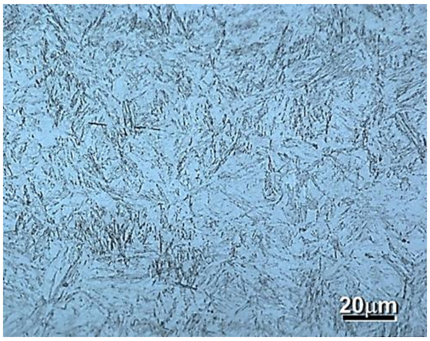


Fig. 4 Martensite with certain fractions of bainite and retained austenite, optical micrograph, interior of the forging

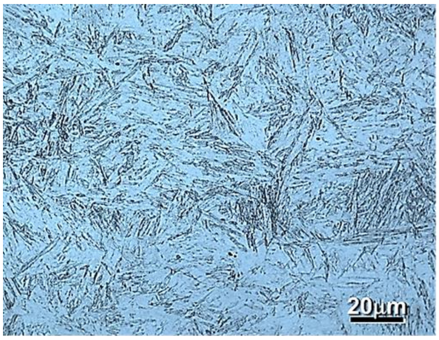


Fig. 6 Martensite with certain fractions of bainite and retained austenite, optical micrograph, interior of the forging

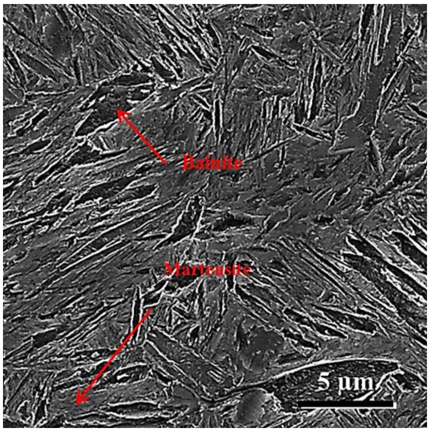


Fig. 5 Fine martensite with certain fractions of bainite and retained austenite, detail scanning electron micrograph, surface of the forging

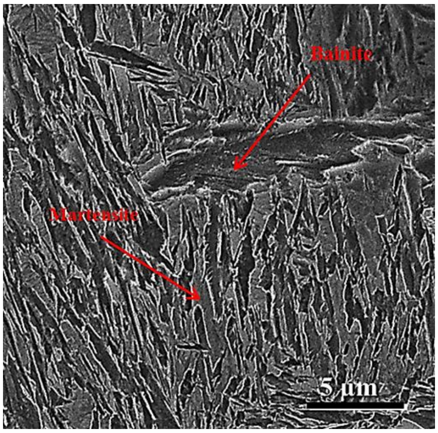
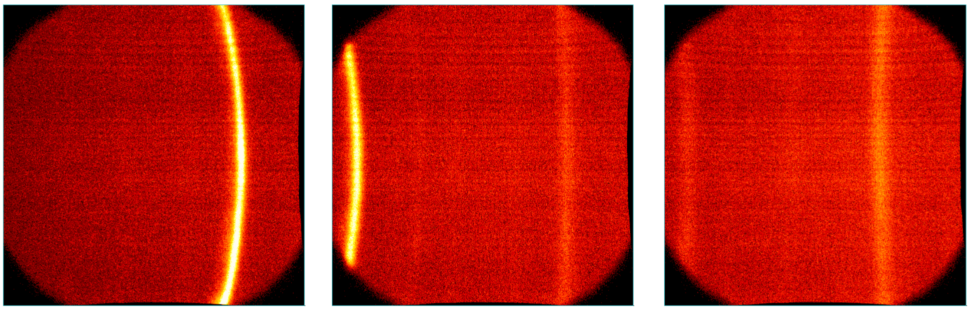


Fig. 7 Martensite with certain fractions of bainite and retained austenite, detail scanning electron micrograph, interior of the forging



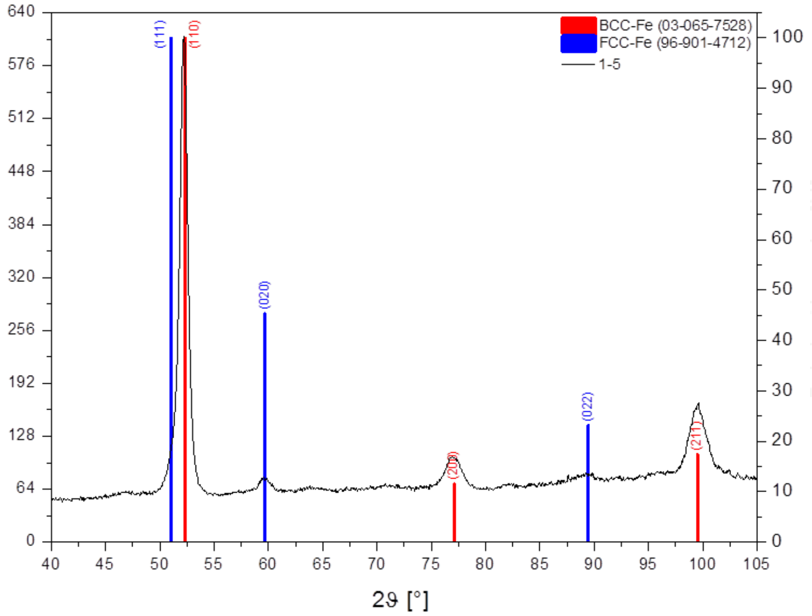


Fig. 8 A diffractogram of a specimen with identifiable phases, continuous spectrum – fine-grained structure

4 Conclusion

Integration of press hardening and Q&P processing was tested by means of material-technological modelling on 42SiCr steel which was alloyed with manganese, silicon and chromium. The goal was to find whether these two processes can be combined at all and whether this particular steel is suitable for such processing. The resulting microstructures contained martensite, bainite and small amounts of ferrite and retained austenite. With correctly-chosen process parameters, strengths of more than 1850 MPa and A20 elongation of 10% were obtained.

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