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Unconventional Heat Treatment of Spring Steel by Q&P Process

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***Abstract*—Newly developed methods for heat treatments and any necessary thermomechanical working have led to the achievement of excellent properties for new types of multi-phase structures. One of these new methods is the Q-P (Quenching and Partitioning) process. The result is usually martensitic structure with a defined proportion of retained austenite. This process can be used for different kinds of steels with a tensile strength about 2000 MPa with retention of good ductility of more than 10%. The Q-P process was applied to experimental steel whose main alloying elements were silicon, manganese and chrome. The resulting specimens were evaluated metallographically, the proportion of retained austenite was ascertained by X – ray analysis and mechanical properties were found using tension tests.**

***Keywords*— *Q&P* process, 42SiCr, hig strengt steel, spring steel**

I. Introduction

The Q&P process is one of today's promising routes that, applied to steels with cost-effective chemistries, can deliver very attractive mechanical properties and combinations of material parameters which are otherwise difficult to achieve. [1,2] Yet, it is a relatively simple process which is technically feasible and, in addition, economical. Another advantage is that the Q&P process does not require workpiece materials of complex chemistries, and can be used for simple and affordable steels whose main alloy additions include silicon, manganese, and chromium. The results achieved so far on the 42SiCr steel which was optimized for the Q&P process have shown that this process can produce excellent combinations of mechanical properties: ultimate strength levels above 2000 MPa and A_{5mm} elongation in excess of 10 % [3,4]. Nevertheless, this 42SiCr steel is not ordinarily available. This is why attempts have been made to find a similar and readily commercially available steel for pre-commercial application testing and for verifying the performance of the Q&P process. For economic reasons, the available and affordable 54SiCr spring steel (Tab. 1) was chosen as a material similar to the 42SiCr grade. The largest difference and at the same a drawback is its higher carbon content. This complicates the Q&P process to some extent but one can still expect this steel to deliver good results, provided that the process parameters are chosen appropriately. The as-received microstructure of this steel consists of ferrite and lamellar pearlite. In its as-received condition upon hot forming, it had a yield stress of 560 MPa, ultimate strength of 960 MPa, elongation of 23 %, and hardness of 283 HV10.

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TABLE I Chemical compositions of 54SiCr and 42 SiCr steels [wt. %]

Steel	C	Mn	Si	Cr	Ni	Cu	P	S
54SiCr	0.5-0.6	0.5-0.8	1.3-1.6	0.5-0.7	max. 0.5	max. 0.3	max. 0.035	max. 0.03
42 SiCr	0.4-0.44	0.5-0.8	1.9-2.1	1.2 -1.5	-	-	max. 0.01	max. 0.004

In order to design the Q&P process route, relevant transformation temperatures had to be found. The most important ones for this process route are the M_s and Mf temperatures. They were found by calculation (**Error! Reference source not found.**) [5]. The M_s was 268°C and the M_f was 145°C. The transformation diagram indicates that the pearlite nose is relatively far on the left. This fact determines the limit cooling rates for preventing the austenite to pearlite transformation during quenching.

II. Experimental

Based on these findings, an experimental programme was designed and carried out using material-technological modelling. This is a procedure which enables process parameters to be determined using a small volume of material. What is even more important, it enables the thermal sequence to be controlled accurately as in real-world parts [6,7].

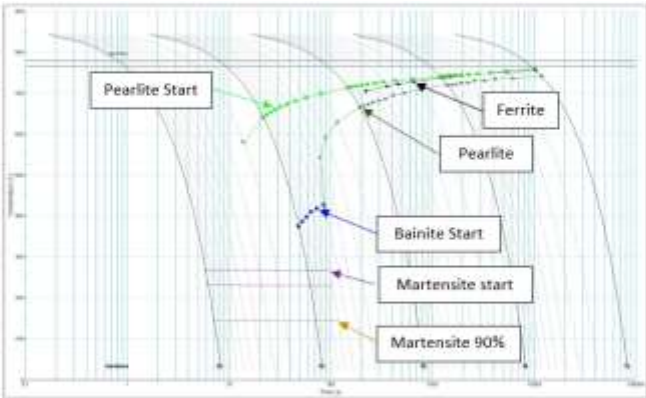

Figure 1 CCT diagram calculated for 54SiCr steel

The material-technological modelling was carried out in a thermomechanical simulator. It is a machine which can rapidly and accurately control temperature and deformation parameters and is therefore suitable for exploring the effects of processing conditions on microstructure evolution and mechanical properties in materials.
The test bars used has a gauge section of 16 mm length and 8 mm diameter (**Error! Reference source not found.**). The thermomechanical treatment included the Q&P process. The microstructure in the treated bars was examined using optical and scanning electron microscopy. HV10 hardness was measured. Tensile testing was carried out on miniature specimens with a gauge length of 5 mm and a cross-section of 2×1.5 mm.

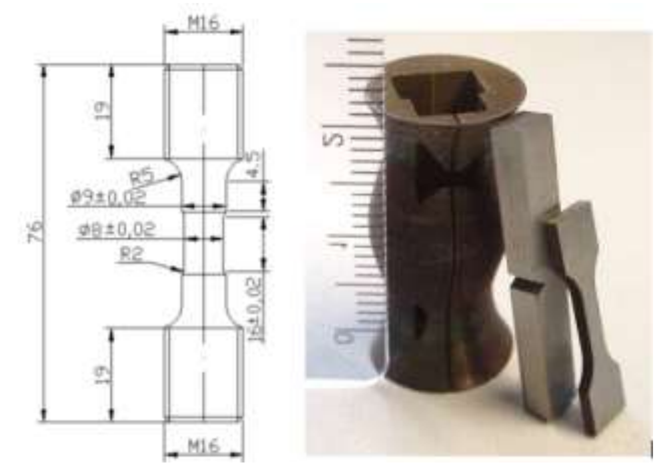

Figure 2 Shape of specimens for material-technological modelling and mechanical testing

III. Discussion of Results

The first material-technological modelling sequences, S-01 through S-04 described in Tab. 2, included the Q&P process and no deformation. The S-01 sequence included soaking at 900°C for 100 s, cooling at 16°C/s to the quenching temperature of 200°C, and holding for 10 s. The purpose of this holding stage was to homogenize temperature across the entire cross-section. It was immediately followed by reheating to 250°C and isothermal holding for 600 s to allow carbon to migrate from the super-saturated martensite to retained austenite (partitioning). The quenching temperature of 200°C was 55°C higher than the calculated M_f. The partitioning temperature of 250°C was 18°C lower than the M_s.

The resulting microstructure consisted of martensite and a small fraction of bainite (**Error! Reference source not found.**). Using X-ray diffraction analysis, the material was found to contain 13 % retained austenite. The ultimate strength reached more than 2000 MPa with the A_{5mm} elongation value being 7 %, and the hardness value of 670 HV10. Observation in a scanning electron microscope revealed that retained austenite was present along martensite and bainite needles. No polygonal retained austenite grains were found. The next two sequences (S-02 and S-03) involved different rates of cooling from the austenitizing temperature to the quenching temperature (Tab. 2) than in the S-01 sequence. In the S-02 sequence, the cooling rate was higher, 30°C/s, whereas in the S-03 it was reduced to 10°C/s. The increased cooling rate had no substantial effect on mechanical properties. The lower cooling rate led to a lower hardness (642 HV10) than the S-01 sequence (670 HV10). This was in agreement with the slightly higher bainite fraction (**Error! Reference source not found.**). Since one of the objectives here was to improve elongation, the last sequence, S-04, involved a higher quenching temperature (240°C) as well as higher partitioning temperature (290°C) (Tab. 2). The cooling rate of 16°C/s was the same as in the first sequence. The microstructure of the products consisted of martensite and a small fraction of bainite. When compared to the first sequence, the ultimate strength decreased slightly to 1905 MPa, and the A_{5mm} elongation value rose from 7 to 11 %. The resulting hardness of 589 HV10 was lower than in the S-01 sequence (670 HV10). Nevertheless, the S-04 led to a favourable combination of properties: A_{5mm} elongation of more than 10 % with the strength being 1900 MPa.

I. Conclusion

A heat treatment sequence involving the Q&P process with a suitable quenching rate was successfully used to obtain more than 10 % retained austenite in a martensitic-bainitic microstructure of a spring steel with 0.54 % carbon and 1.5 % silicon. The quenching process stopped at 240°C. Using a short carbon partitioning step, the stress within austenite was reduced, and a favourable combination of properties was achieved. These included the A_{5mm} elongation of more than 10 %, with the ultimate strength being 1900 MPa.

TABLE II Q&P process sequences used for material-technological modelling, and the mechanical properties

Schedule	QT/Qt [°C / s]	Quenching rate [°C/s]	PT/Pt [°C / s]	$R_{p0.2}$ [MPa]	R_m [MPa]	A_{5mm} [%]	HV10 [-]	RA [%]
S-01	200 / 10	16	250 / 600	1475	2029	7	670	13
S-02	200 / 10	30	250 / 600	1515	1919	4	680	14
S-03	200 / 10	10	250 / 600	1234	2018	5	642	12
S-04	240 / 10	16	290 / 600	1215	1905	11	589	14

Martensitic microstructure with a fraction of bainite obtained by Q&P processing with quenching from 900 °C to 200 °C and subsequent partitioning at 250 °C for 600 s, SEM micrograph

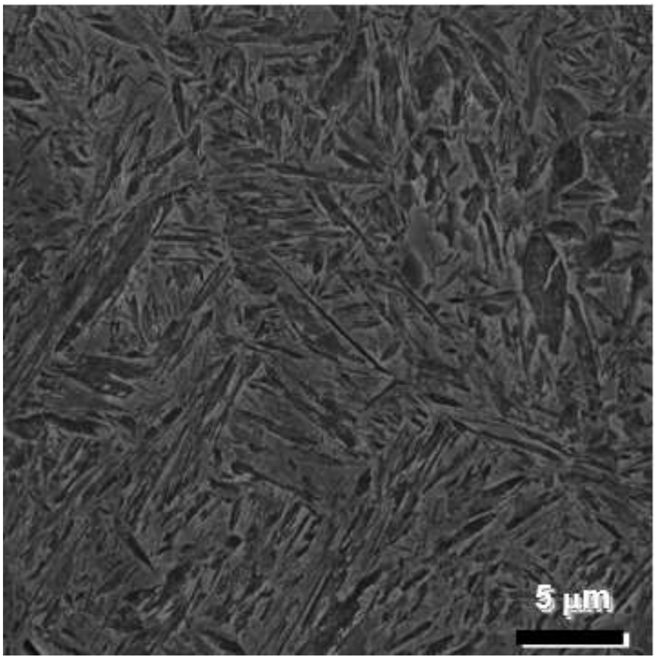

Figure 3 Quenching rate of 16°C/s (S-01)

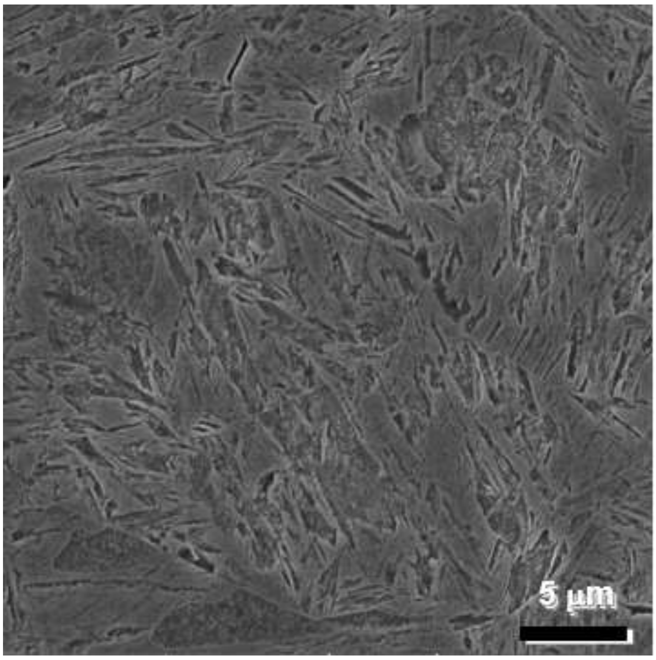

Figure 4 Quenching rate of 10°C/s (S0-3)

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About Author (s):

[of high-strength steels and unconventional methods of production and processing of forming parts]