Q&P PROCESS IN PRESS-HARDENING OF 42SICR STEEL

Dagmar Bublíková$^{1)}$*, Hana Jirková*$^{1)}$*, Štěpán Jeníček*$^{1)}$*, Josef Káňa*$^{1)}$
$^{1)}$*University of West Bohemia, RTI - Regional Technological Institute, Pilsen, Czech Republic*

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**Corresponding author: e-mail: dagmar.bublikova@seznam.cz, Tel.: +420 720 401 659, Laboratory of Experimental Forming, Faculty of Mechanical Engineering, University of West Bohemia, RTI - Regional Technological Institute, Univerzitní 22, CZ – 306 14 Pilsen, Czech Republic*

Abstract

One of today's advanced heat treatment routes for high-strength steels is the Q&P process which delivers high ultimate strengths combined with good ductility. The resulting microstructure is a combination of martensite and small fractions of bainite and retained austenite. Retained austenite has the form of thin needles adjacent to martensite laths. The use of this process in industrial practice is complicated by the need for holding at the partitioning temperature when retained austenite becomes stabilized by carbon migration from super-saturated martensite. Engineers therefore seek process routes in which interrupting the cooling process at a particular temperature and holding at that temperature do not pose technological problems. One of the available options is press hardening, often incorporated in the treatment of car body parts. 42SiCr steel, which is alloyed with manganese, silicon and chromium, was Q&P-processed using experimental sequences with various quenching and partitioning temperatures. The soaking time and temperature and cooling rates were identical to the parameters used in real-world processes. Correctly-chosen parameters led to martensitic-bainitic microstructures with a portion of retained austenite, ultimate strength of around 2000 MPa and A_{20} elongation of more than 10%.

Keywords: Q&P process, AHSS steels, press hardening

1 Introduction

A modern era's trend in the field of advanced steels is the combination of high strength and ductility. High strength is guaranteed in martensitic steels. The problem of low ductility can be resolved by stabilising retained austenite in the martensitic matrix. One of advanced heat treatment routes which lead to ultimate strengths of about 2000 MPa combined with elongations of more than 10% is the Q&P process [1 - 8]. It consists of heating to austenitizing temperature, quenching to a temperature between the M_s and M_f and reheating to partitioning temperature, when carbon diffuses from super-saturated martensite into austenite. As a result, austenite becomes stable in the martensitic matrix [9 - 11]. The difficulty with this heat treatment route lies in arresting the quench at the desired temperature and in subsequent holding at the partitioning temperature. One way to incorporate this route into real-world forming operations is press hardening [12 - 15]. Quenching from austenitizing temperature can be performed in a die which has the desired quenching temperature. As a result, the temperature of the workpiece does not decrease below the $M_{f.}$

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With regard to the intricacy of the Q&P process, in which a number of parameters need to be optimized, it is useful to employ material-technological modelling [16 - 19]. It is carried out in a thermomechanical simulator under laboratory conditions, which means that the target production lines need not be stopped. In addition, there is no risk of equipment overload due to, for instance, incorrect choice of parameters. Modelling in the thermomechanical simulator requires a small amount of material which is nevertheless sufficient for both metallographic examination and mechanical testing. The parameters of modelling are chosen so that they are close to real-world conditions [20].

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 material (wt. %)

	C	Si	Mn	Cr	Mo	Nb	P	S	M_s [^{0}C]	M_f [^{0}C]
42SiCr	0.43	2.03	0.59	1.33	0.03	0.035	0.009	0.004	294	170

2.1 Q&P process

Heat treatment schedules were designed on the basis of data collected in a real-world press hardening process. For the purpose of using various quenching temperatures, cooling curves for several tool temperatures were mapped.

The treatment comprised heating to 937°C, holding for 100 seconds, cooling down to the quenching temperature and subsequent reheating to the partitioning temperature. The critical parameter of the Q&P process is the quenching temperature. For this reason, two temperatures, 200°C and 230°C were used, as well as corresponding partitioning temperatures in **Table 2**, **Fig. 1**. The purpose of variation of the partitioning temperatures was to explore the potential for

Table 2 Treatment parameters and resulting mechanical properties

Schedule number	**T_A [°C]/t_A [s]**	**QT [^{0}C]**	**PT [°C/s] /t_{PT} [s]**	**HV10 [-]**	**R_m [MPa]**	**A_{20mm} [%]**	**RA [%]**
1	937/100	200	250/120	578	1865	9	10
2			250/600	575	1850	10	-
3			280/600	-	1698	10	-
4			340/600	-	1602	10	-
5			380/600	-	1515	10	-
6		230	250/600	-	1771	8	-
7			280/600	539	1675	9	-
8			340/600	529	1472	11	15
9			380/600	578	1468	9	14

improving strength without compromising elongation. For this reason, temperatures below the M_s – 280°C in **Table 1**, as well as those above it – 340°C and 380°C were tested. Additional goals were to determine whether an increase in the partitioning temperature raises elongation without significantly decreasing strength and whether carbides would precipitate along martensitic needles.

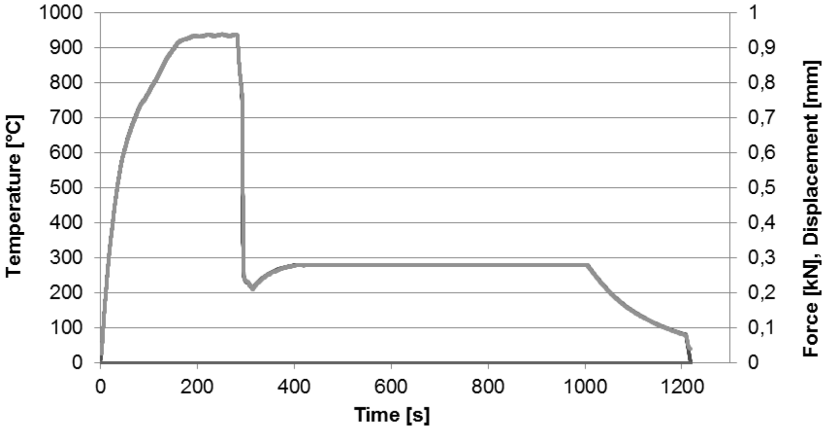

Fig. 1 Temperature profile in experimental press hardening with Q&P processing, tool temperature: 200°C

3 Discussion of results

All heat treatment schedules applied to 42SiCr steel led to martensitic-bainitic microstructures with small fractions of ferrite. The amount of retained austenite was measured by X-ray diffraction with results in the range of 10-15% (**Fig. 2** - **Fig. 5**).

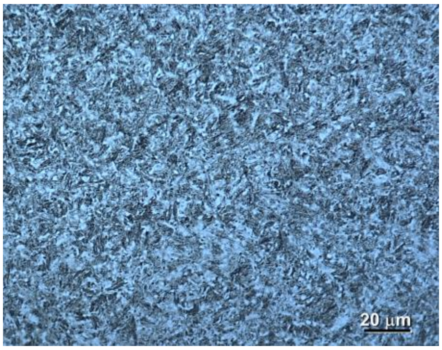

Fig. 2 Schedule 1 - 42SiCr, a tempered mixture of martensite, bainite and some amount of retained austenite

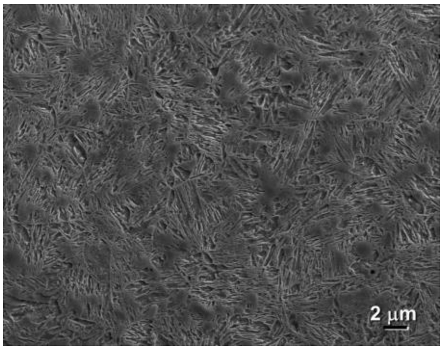

Fig. 3 Schedule 2 - 42SiCr, a tempered mixture of martensite, bainite and small amounts of ferrite and retained austenite, detail scanning electron micrograph

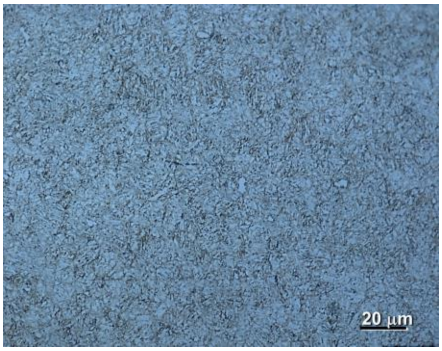

Fig. 4 Schedule 8 - 42SiCr, a tempered mixture of martensite, bainite and small amounts of ferrite and retained austenite

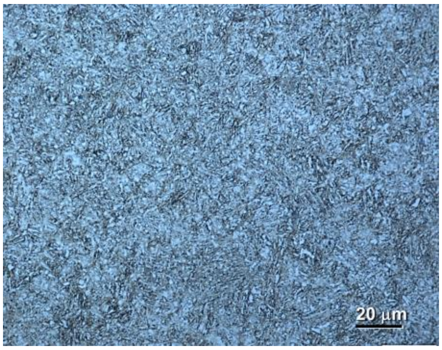

Fig. 5 Schedule 9 - 42SiCr, a tempered mixture of martensite, bainite and small amounts of ferrite and retained austenite

The first two schedules which involved the tool temperature of 200°C and a partitioning temperature of 250°C led to hardness levels around 578 HV10. The ultimate strength exceeded 1850 MPa and the A20 elongation value was 9% in **Table 2**. The prolonged partitioning in schedule 2 had no major impact on mechanical properties or resulting microstructure. Schedule 3 with its increased partitioning temperature (280°C) led to a lower ultimate strength (1698 MPa) and delivered no increase in elongation. The same trend was found upon additional increases in the partitioning temperature to 340°C and 380°C (schedule 4, schedule 5).

Schedules with the tool temperature of 230°C produced very similar microstructures. In this case, too, the highest ultimate strength of 1771 MPa and an elongation of 8% was obtained upon the partitioning temperature of 250°C (schedule 6). The increase in the partitioning temperature to 380°C, i.e. appreciably higher than the M_s, led to a lower ultimate strength of 1468 MPa and an elongation of 9%. Schedules with higher quenching temperatures led to retained austenite fractions of 14 and 15%. This increase in the retained austenite fraction when compared to schedules with the quenching temperature of 200°C is probably due to the fact that a smaller fraction of martensite formed during cooling because the cooling process was arrested at a higher temperature in **Table 2**.

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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