LOW ALLOYED STEELS FOR HIGH STRENGTH PARTS WITH TAILORED MECHANICAL PROPERTIES

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Abstract

The QP process enables to achieve excellent combination of strength and ductility in low alloyed steels. However, the process itself is rather difficult to implement into a serial production of high strength parts as it is demanding precisely controlled temperature cycle for each part. Hot metal gas forming (HMGF) is a technology with potential to provide QP thermal treatment within tight constraints. Moreover, the tool for HMGF can be segmented from materials with different thermal conductivity. This results in different cooling rates, different microstructures and ultimately in different mechanical properties in different areas of the part which can be favourable for the for lightweight design. Three steels have been casted as 500 kg test batches and dilatometer analysis were performed to map the austenite decomposition. Steels 42SiCr, 38SiCr and 32MnB5 were subjected to the simulation of HMGF regime with two different cooling rates simulating the HMGF tool composed of two different materials. SICr steels proved to be able to preserve significant amount of austenite in the microstructure, up to 16 vol.%.

Keywords: quenching and partitioning, hot metal gas forming, retained austenite, high strength steel

1. INTRODUCTION

The experiment described in this paper is a first study of a large project aiming to develop QP hot metal gas forming (HMGF) process for automotive industry [1,2]. HMGF is a promising technology for fast paced production of high-strength and complex shaped parts [3]. In this case, HMGF will consist in enclosing a tube in a die, heating it by resistance heating into austenitic state and then expanding it into the shape of the die cavity by compressed gas. When the tube walls contact the die, they cool rapidly, the die opens, and the final complex-shaped product is removed. This paper investigates possibility of quenching and partitioning (QP) process integration into HMGF cycle for three experimental steels [4].

QP consist of quenching to the temperature T_Q above martensite finish temperature (M_f), leaving the martensite with a high amount of retained austenite (RA). A partitioning period than commence, when the material is maintained at the T_Q or slightly higher for usually several minutes. The intention is to give carbon in a freshly formed martensite time to diffuse into RA and stabilise it. This carbon rich RA should than remain stable even after cooling to the room temperature. QP structure consists of martensite and significant amount of RA (generally more than 10 vol.%). This microstructure excels in combination of strength and ductility with usually minimal demands on alloying (*i.e.* material cost) [5,6]. Drawback of the QP process is necessity of precise control of thermal treatment. Mainly the issue of interrupted quenching at certain temperature is quite difficult to solve in industrial processes.

This article focuses on the approximation of HMGH temperature regime applied for SiCr and MnB alloyed steels. SiCr steels proved to be very suitable for the QP process [7], whereas MnB type steel is widely used for the high strength components in automotive industry.

2. EXPERIMENT

Experimental steels were cast in a vacuum induction furnace. Chemical composition of the materials is in **Table 1**. Part of each of the 500 kg ingots was hot forged by hydraulic press into a flat bar 25 mm thick and let to cool in air. Rods 4 mm in diameter were cut out from the bars. Rods were cur to the length 10 mm to obtain suitable specimens for the quenching dilatometer.

Table 1 Chemical composition (in wt%)

Material	C	Mn	Si	Cr	B	Ti
32MnB5	0.33	0.62	0.60	0.32	0.0044	0.025
38SiCr	0.38	0.61	2.00	1.33	-	-
42SiCr	0.42	0.59	1.97	1.30	-	-

The thermal processing was performed on quenching dilatometer Linseys L78 R.I.T.A., where the specimen is heated by induction and cooled by the flow of nitrogen.

Austenitization was identical for all regimes – heating by 50 °C/s to the temperature 950 °C, 2 second hold and cooling. First, temperatures M_s and M_f were measured by cooling at rate 100°C/s to the room temperature. Then the QP regimes were set according to the M_s and M_f temperatures.

QP regimes had two different cooling rates in the martensite transformation temperature range, because the final tool for the HMGF will have inserts from two materials with significantly different thermal conductivity. The approximate cooling rates were determined by numerical simulation of the tube cooling at contact of the two insert materials. The faster cooling regime is labelled as “F” and the slower one as “S” regime. Then, the cooling is interrupted after 10 seconds and slow 240 sec rise to the partitioning temperature begins. This simulates taking out the processed tube out of the HMGF tube and putting it into the heated tunnel at the partitioning temperature. Then it cools down to the room temperature (**Figure 1**).

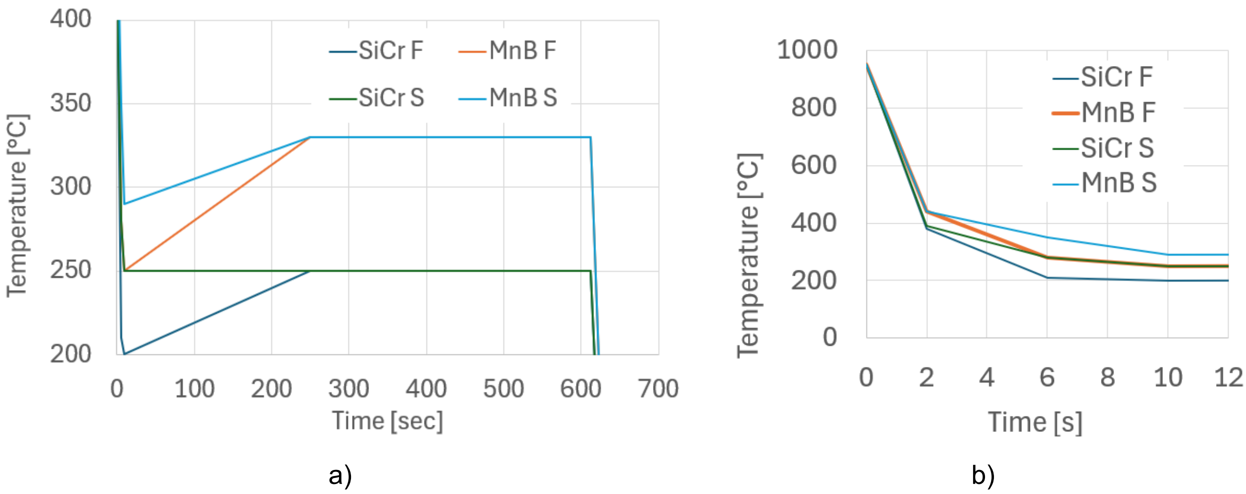

Figure 1 Regimes of the QP treatment. A) overall view of the quenching and partitioning; b) detail of the quenching period with fast (F) and slow (S) cooling rates.

Thermally treated specimens were mounted into resin at the room temperature and longitudinal metallographic sections were prepared by mechanical grinding and polishing. Final polishing was colloidal silica OP-S (supplied by Struers).

Retained austenite content was measured on the polished sections by diffractometer BRUKER DISCOVER D8. The diffractograms were analysed in BRUKER Topaz software by Rietveld analysis.

Sections were etched by 3% Nital solution to reveal the microstructure and observed by scanning electron microscope (SEM) JEOL IT500-HR at 12 kV acceleration voltage in secondary (SE) and backscattered (BSE) electrons.

3. RESULTS AND DISCUSSION

Temperatures M_s and M_f are stated in **Table 2**. Steels 38SiCr and 42SiCr exhibited almost the same interval of martensitic transformation due to their very close chemical composition. Martensitic transformation of the steel 32MnB5 takes place at significantly higher temperature. The QP treatment consists of quenching to the temperature slightly higher than M_f and in subsequent partitioning hold. QP regimes were set identical for the SiCr steels due to their similarity (see **Table 2**).

RA presence was detectable after quenching, however too low to accurately quantify by XRD measurement. No RA peaks were observable for 32MnB5 steel after the QP treatment. On the other hand, both SiCr steels exhibited significant amount of RA; notably more for the slower cooling rate and higher T_Q.

Table 2 martensite start and finish, quenching (T_{QS} and T_{QF} for slow and fast cooling) and partitioning (T_P) temperatures for the experimental materials. Results of XRD measurement of RA fraction (in vol.%) after the QP processing.

Material	M_s [°C]	M_f [°C]	T_{QF} [°C]	T_{QS} [°C]	T_P [°C]	RA_Q [%]	RA_F [%]	RA_S [%]
32MnB5	352	233	250	290	330	< 2	0	0
38SiCr	303	154	200	250	250	≈ 2	13	14
42SiCr	299	150	200	250	250	≈ 4	13	16

Microstructure has not visibly differed between the SiCr steels, therefore only the steels 42SiCr and 32MnB5 are shown for microstructure comparison.

Microstructures after quenching were composed of martensite and very similar among all three experimental steels (**Figure 2**). Martensitic crystals were clearly visible (**Figure 2a, b**). Fine carbides were present in large fraction of the martensite crystals in all experimental steels. The martensite in these steels exhibited auto tempering.

Microstructure after QP treatment differs significantly between 32MnB5 and the SiCr steels. 32MnB5 martensite is clearly tempered with tempering carbides present homogeneously in the microstructure (**Figure 2c, e**). There were elongated plates in the martensite crystals as well as areas with very fine globular carbides. On the other hand, SICr steels did not exhibit significantly more carbides in the microstructure after QP processing, compared with the quenching (**Figure 2d, f**). The carbon thus remained in the martensite and RA during the partitioning period.

Figure 3a shows clearly individual plates of transition carbides in the martensite crystals. Thin carbide films are also visible on several martensite crystal boundaries. **Figure 3b** shows by shading individual crystals of the martensite structure. The brightest areas of the BSE image with no internal structure are probably RA areas.

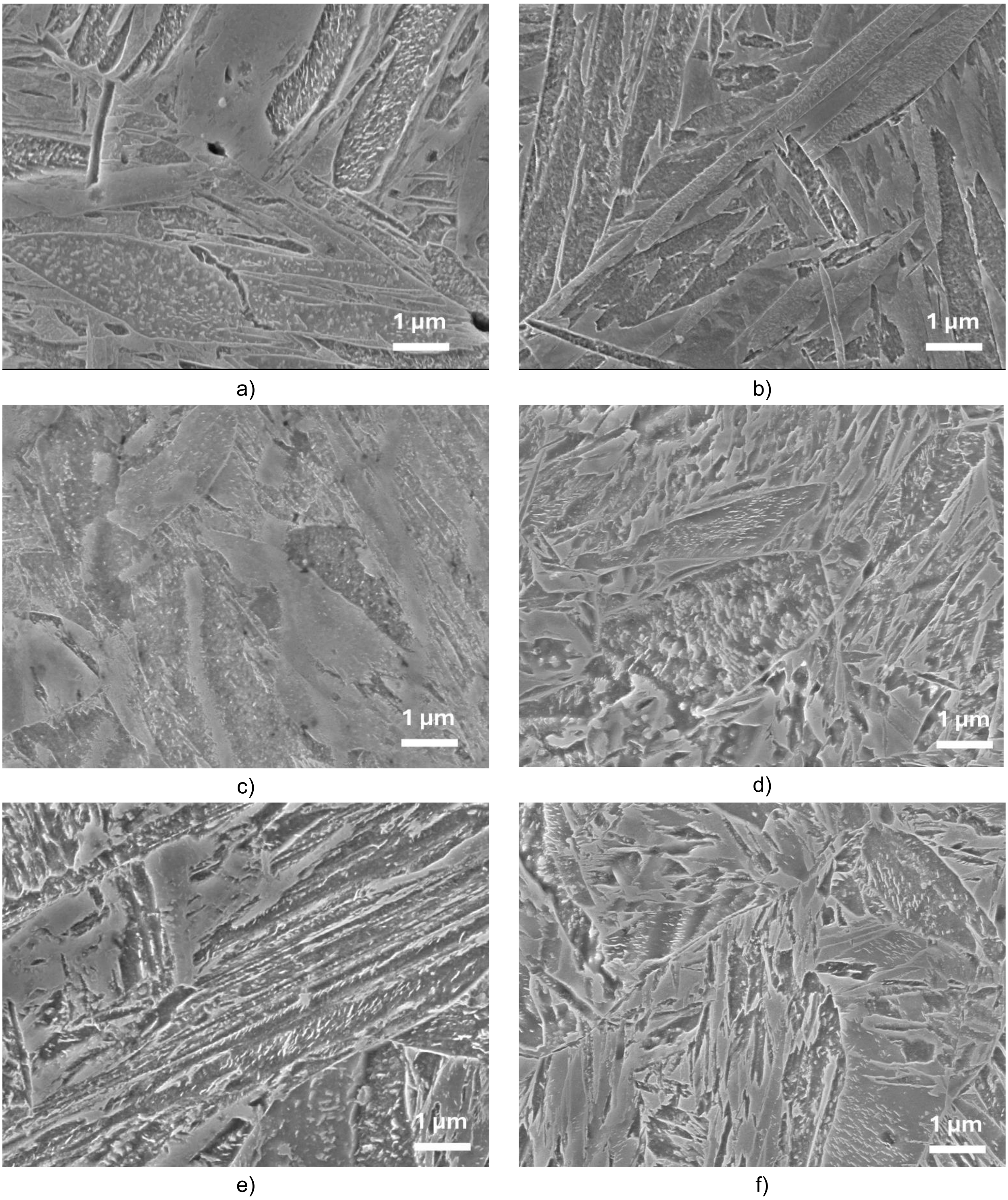

Figure 2 Microstructure of the specimens” a) 32MnB5_Q; b) 42SiCr_Q; c)32MnB5_F; d) 42SiCr_F; d)32MnB5_; f) 42SiCr_S.

The microstructure of 32MnB5 steel underwent tempering process and RA transformation during the partitioning period. It seems that the martensite formed during quenching grew tempering carbides in the crystal interior (and partially at the boundaries) and the RA transformed in a bainite-like structure – very fine ferrite plates with carbide particles.

SiCr steels retained significant amount of austenite during the QP processing. It is visible in the detail micrographs as films between the martensite crystals (**Figure 2c, d**). There was not found any RA in blocky form. The RA films were 100 nm thick at most, but usually thinner than 100 nm. RA was also very homogeneously spread within the microstructure. It was usually not present on the boundaries of martensite crystals with carbides in them, but these tempered martensite crystals altered with the RA-rich regions with spatial period of about 2 μm at most.

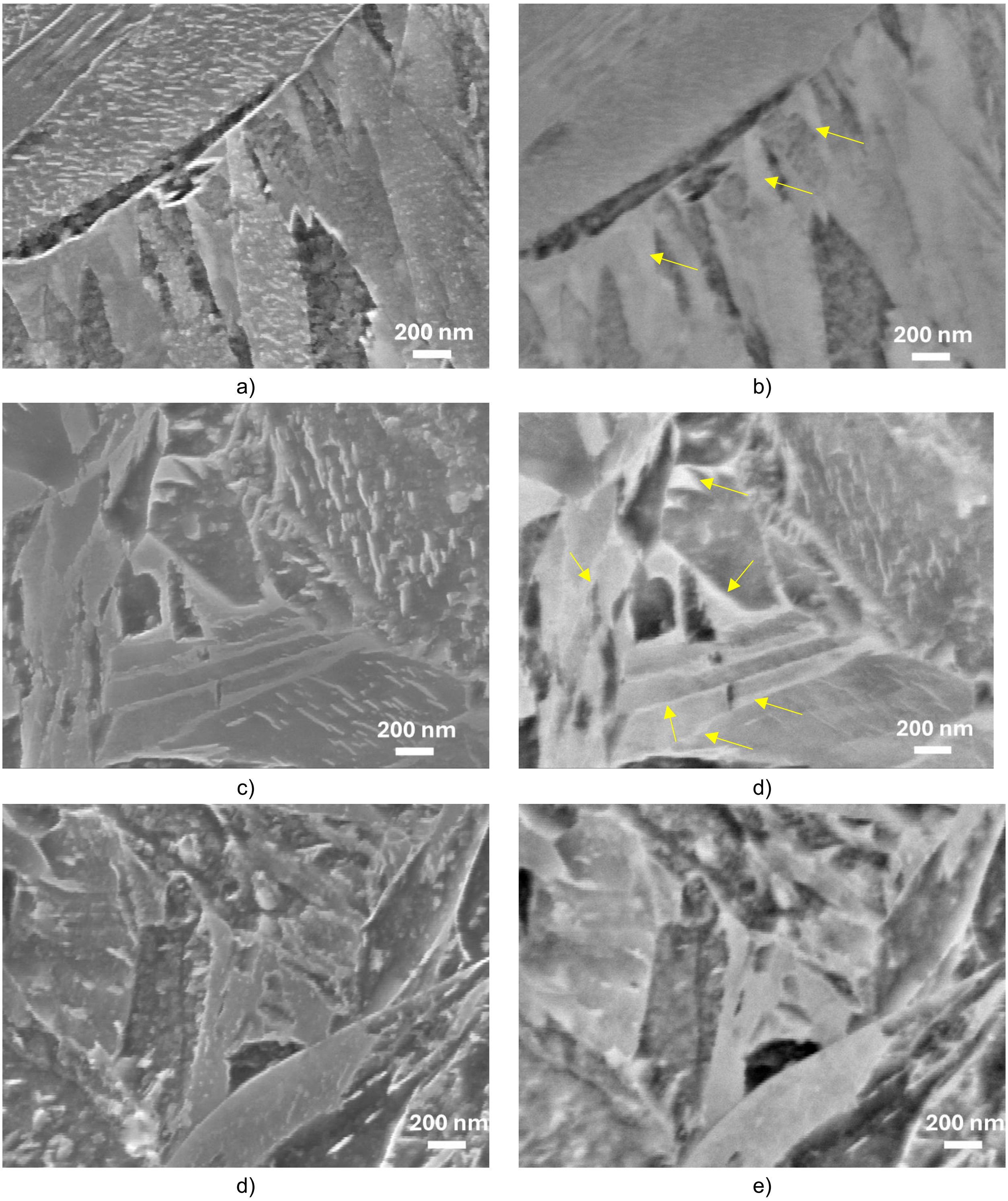

Figure 3 Microstructures in detail in SE (left) and BSE (right): a,b) 42SiCr_Q; b,c) 42SiCr_S; d,e) 32MnB5_S. Arrows point to the probable areas of RA (lighter areas).

4. CONCLUSION

The experiment proved, that 38SiCr and 42SiCr steels have excellent potential for the QP processing in the anticipated conditions of tube HMGF. Slight alteration of the carbon content did not have any notable influence on the microstructure and maximum RA content was 14 and 16 vol.%. It is remarkable, that the RA content was higher for quite high quenching temperature - closer to the martensite start than martensite finish. This shows that fine tuning of the thermal profile of the QP processing is not necessary for these steels. This is an important fact regarding industrial applicability.

32MnB5 has not retained any austenite during the partitioning period. The partitioning caused tempering of the martensite and formation of fine carbides within the martensite crystals and on their boundaries.

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REFERENCES

[1] BLALA, H., PENGZHI, C., SHENGLUN, Z., KHAN, S. Evolution of hot metal gas forming (HMGF) technologies and its applications: a review. *The International Journal of Advanced Manufacturing Technology*. 2024, Vol. 131, pp. 3441–3466.

[2] ZHENG, K., ZHENG, J., HE, Z., LIU, G., POLITIS, D., WANG, L. Fundamentals, processes and equipment for hot medium pressure forming of light material tubular components. *International Journal of Lightweight Materials and Manufacture*. 2020, Vol. 3, No. 1, pp. 1-19.

[3] LANZERATH, H., AND TUERK, M. Lightweight Potential of Ultra High Strength Steel Tubular Body Structures, *SAE. International Journal of Materials and Manufacturing*. 2015, Vol. 8, No. 3, pp. 813-822.

[4] WINTER, S., WERNER, M., HAASE, R., PSYK, V., FRITSCH, S., BÖHME, M., WAGNER M. Processing Q&P steels by hot-metal gas forming: Influence of local cooling rates on the properties and microstructure of a 3rd generation AHSS. *Journal of Materials Processing Technology*. 2021, Vol. 293, 117070.

[5] BAI, S., CHEN, Y, SHENG, J, LI, D. LU, H., BAI, P., HUANG, Z., LI, Y., ZHAO, C. A comprehensive overview of high strength and toughness steels for automobile based on QP process. *Journal of Materials Research and Technology*. 2023, Vol. 27, pp. 2216-2236.

[6] BUBLÍKOVÁ, D., JIRKOVÁ, H., BEHÚLOVÁ, M., KRAJČOVIČ, J. Determination of Transformation Temperatures of Advanced High-Strength Steels and Their Use in Designing Q&P Process Routes. *Manufacturing Technology*. 2019, Vol. 19, No.1, pp. 18-22.

[7] HÄRTEL, S., AWISZUS, B., GRAF, M., NITSCHE, A., BÖHME, M., WAGNER, MF-X., JIRKOVÁ, H. Influence of Austenite Grain Size on Mechanical Properties after Quench and Partitioning Treatment of a 42SiCr Steel. *Metals*. 2019, Vol. 9, No. 5, 577.