DOI: 10.21062/mft.2023.105 http://www.journalmt.com

Influence of Thermomechanical Processing Parameters on Selected Properties of B-post Made of 22MnB5 Steel

Sylvia Kusmierczak (0000-0002-5135-4170), Radek Srb
Faculty of Mechanical Engineering, J. E. Purkyne University in Usti nad Labem. Pasteurova 3334/7, 400 01 Usti nad Labem. Czech Republic. E-mail: sylvia.kusmierczak@ujep.cz

With regard to the current economic situation, which deals primarily with energy prices, companies are trying to find reserves within individual technologies. The automotive industry is still a very important industry. One of the ways to improve the material properties of a body part is thermomechanical processing. This is how the B-pillar, which serves as a safety structural element of the car, was processed. The presented article aims to investigate the influence of selected thermomechanical processing parameters on the resulting properties of a B-pillar made of high-strength steel 22MnB5. At the same time, energy saving in the given production process should be used in such a way that it is not at the expense of the quality of the component. Three kinds of experimental production processes with different parameters of thermomechanical processing of steel were proposed for scientific investigation. Based on these proposed processes, several pieces of B-pillars were produced and subjected to further investigation. Changes in material properties were monitored using hardness measurements and subsequently the resulting microstructure of the material was examined for each experimental post.

Keywords: Thermomechanical processing, Steel 22MnB5, Analysis, Microstructure

1 Introduction

Car production still has an important position in the European Union, despite problems with energy prices. Due to the current economic situation, opportunities to save energy are also being sought in the car manufacturing process. Manufacturing a car is a demanding multi-stage process that is a complex set of construction, technology and material engineering. The automotive industry currently imposes often contradictory requirements on the structural parts of the car, and therefore on the car as a whole, such as requirements for weight savings, which is also related to the reduction of emissions, and on the other hand, increased resistance to breakage and fracture propagation, especially in safety body parts. For this reason, high-strength steels are used, which achieve both high yield strength and high ductility. [1, 2, 3, 4]

The presented article is specifically devoted to the issue of the production of one of the parts of the body of a passenger car, namely the B-pillar. The B-pillar is located in most passenger cars between the front and rear doors and serves to minimize the effect of frontal, corner and especially side impact on the vehicle. If we expose the car to a side impact in this part of the structure, the pillar will not be destroyed in any place. In this case, the largest part of the deformation energy is concentrated in the soft zone, which is located below the level of the driver or passenger. The soft part absorbs most of the energy, causing it to be damaged outside the body of the crew in the event of an impact. The hard zone is in the area of the middle part of the bodies of the road users occupying the front seats of the car. In the case where the largest part of the energy is transferred to the soft area of the post, the hard zone will no longer develop such a force that would be able to deform the hard and reinforced part and thus endanger the health or lives of the crew. The sequence of production operations is as follows: cutting of the so-called blank from a coil of steel, spot welding of the reinforcement, which increases the strength characteristics in the upper part of the B-pillar. The next step is the uniform heating of the blank in the furnace of the entire cross-section. The last step is the thermomechanical processing itself, after moving the blank and centering it in the form, when mechanical forces and hardening, or rapid cooling of the material, simultaneously act. Many companies currently use forms divided into two parts, the so-called hard zone and soft zone. [1, 4, 5, 6]

B-pillars can be formed either in one operation, the so-called direct procedure, or in two operations, where the first is cold forming (pre-pressing) and the second operation, hot forming, follows. Heating and subsequent hot forming can be carried out in several ways, namely: the blank is heated separately in a continuous furnace and forming is carried out in a non-tempered machine, heating separately and forming in a tempered tool, both heating and forming take place in a tempered tool. From the point of view of increasing the cycle time of the lines, reducing production costs and the overall utilization of the line, companies producing B pillars use the second method, i.e. heating the blank separately in a continuous furnace and subsequent forming and cooling in a tempered tool. The hard zone part of the form is no different from other forms. After the material is inserted into the mold, the upper part is closed and water begins to flow through the channels inside the mold, which leads to the hardening of the steel. The material formed in this part reaches the tensile strength limit Rm values of up to 1700 MPa. The part of the mold where the soft zone is located is not cooled, but rather heated. This means that the material will not be hardened, but only gently cooled. The material then reaches a strength Rm of approx. 600 MPa. [6-13]

One of the materials often used in the production of the B-pillar is steel 22MnB5 ČSN EN 10083 with the trade name USIBOR 1500. Steel 22MnB5 is suitable for high-temperature thermomechanical processing during pressing. Before heat treatment, the strength limit Rm is in the range of 500-700 MPa and the yield strength Re is greater than 350 MPa with a ferritic-pearlitic structure. A martensitic structure with a low proportion of austenite is manifested by high strengths, when it is possible to reach values of up to 1900 MPa and hardness according to Vickers above 425 HV. The 22MnB5 steel is treated with a surface layer of AlSi10Fe3, which protects the material from high-temperature oxidation during furnace heating. [10-18]

The aim of the article is to analyze the influence of thermomechanical processing parameters on the selected properties of a B pillar made of 22MnB5 steel using microscopic methods [16,18-24] and Vickers hardness measurement methods according to ČSN EN ISO 6507 1.

2 Experimental material and methods

The body B-pillar was used as an experimental sample. The production process consists of several types of operations. The first is a cutout of a so-called blank from a coil of Usibor 1500 steel (22MnB5 according to ČSN EN 10083-3) with a thickness of 1.4 mm. Furthermore, reinforcements are welded by spot welding, the function of which is to strengthen the strength characteristics and thereby increase the safety parameters for the crew. The next step is the heating of the semi-finished product in a continuous furnace, time approx. 400 s. At the end of the line, the semi-finished product reaches a temperature of 930 °C. The last step is the thermomechanical processing itself. Currently, companies use molds that have 2 parts: hard zone and soft zone see Fig. 1. In the hardzone there are channels where water flows, which leads to hardening of the material, which increases the tensile strength limit Rm value up to 1700 MPa. The part of the mold where the softzone is located is not cooled, but heated. In this part, there are heating segments that heat the mold to 560 °C. The material then reaches a strength Rm of approx. 600 MPa.

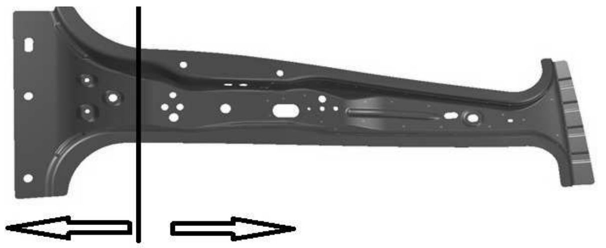

Fig. 1 *Characteristic parts of the B-pillar*

After this process, the pillar takes its final shape. After opening the mold, the "soft" part has a temperature of 560 °C and the "hard" part is cooled to approximately 350 °C. The pillar is then simply moved onto a steel conveyor belt, on which it cools down to ambient temperature. The B-pillar made in this way is therefore divided into two parts, namely a hard upper part, the strength of which is supported by a welded reinforcement (patch), and a soft part. Through this process, we produce a B-pillar that has a controlled deformation area.

2.1 Experimental material

22MnB5 steel with the trade name USIBOR 1500 was used for part B- pillar. 22MnB5 steel is suitable for high-temperature thermomechanical processing during pressing. The chemical composition is shown in Table 1.

Tab. 1 *Chemical composition of steel 22MnB5 according to the CSN EN 10083-3 standard*

Element	C	Si	Mn	Cr	Mo	P	S	Ti	Al	B
min. (wt %)	0.25	0.15 – 0.40	1.4	0.5	0.35	0.03	0.01	0.1	0.1	0.001 – 0.005

2.2 Conditions of thermo-mechanical processing

The heat treatment conditions were chosen with regard to reducing the economic demands of production using the CCT diagram of 22MnB5 and the parameters of the production line. Three technological processes were determined for the experiment, see Table 2. Process number 1 was determined as the starting point, which reflects the real production conditions of the B pillar. The blank was placed in a continuous furnace where it was heated to 930 °C for 400 s, the heating segments in the mold have a temperature of 560 °C. After the mold is closed, cooling takes place, which takes 10.7 s.

Tab. 2 *Conditions of thermo-mechanical processing*

Process No.	1	2	3
Conditions of heating	930 °C/400 s	930 °C/400 s	930 °C/600 s
Conditions of forming	560 °C/10.7 s	480 °C/10.7 s	560 °C/8 s

Process number 2 was chosen for the purpose of energy saving in production. The initial heating step remains the same as process number 1. The change only occurs in the forming phase. The heating segments were heated to a lower temperature of 480 °C. This temperature was determined from the CCT diagram for 22MnB5 steel. In the soft part B of the bridge, there is an undesirable martensitic structure, therefore, during pressing, the material must not be cooled below the Ms temperature, which is 420 °C. In the event of a greater decrease in the temperature of the segments, the Ms temperature could be exceeded and the subsequent formation of martensite, which is undesirable in the soft part B of the column.

Process number 3 was designed to reduce the economic complexity of production. However, this is not a change associated with the temperature of the heating segments seated in the mold, but a reduction in the time during hardening by pressing. The heating of the material in the furnace at a temperature of 930 °C takes 600 s, after the blank is placed in the mold; it is closed with the upper part. The mold is closed for 8 s, during which plastic deformation of the material occurs and at the same time it cools down.

3 Microscopic analysis

Microscopic analysis is important to determine the microstructure of the material, which changes either based on temperature or time of thermal exposure. The character of the microstructure will manifest itself during the deformation-stress states in the real loading of the structural element. Samples for microscopic evaluation of the structure were prepared by the classic metallographic procedure, i. e. material collection, preparation, grinding, polishing, etching - Nital 3%. An Olympus OLS 3100 confocal laser microscope was used to examine the metallographically prepared samples.

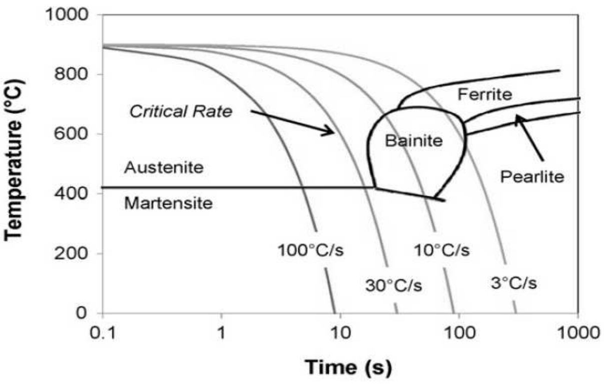

Fig. 2 *CCT diagram of Usibor 1500 stell*

The input material Usibor 1500 has a ferritic-pearlitic structure, which changes after thermomechanical treatment according to the diagram of anisothermal breakdown of austenite see Fig. 2 depending on temperature and cooling rate.

3.1 Microstructure of the B-pillar in the Hard Zone

In order for a fully martensitic structure to occur and a hardness of at least 400 HV10 to be reached, the critical cooling rate must be exceeded, which is about 30 °C$\cdot$ s^{-1}. After passing through the continuous furnace, the sheets remain in the air for about 10 seconds, where the temperature drops to 850 °C. At this temperature, the sheets are placed in the mold and the hardening process by pressing follows. After opening the mold, the sheets have a temperature of approx. 350 °C, which corresponds to a cooling rate of approx 38 °C$\cdot$ s^{-1}, thereby guaranteeing a fully martensitic structure. Below are images of the material microstructures of three selected samples, taken from the hard part of the B-pillar, Fig. 3-8.

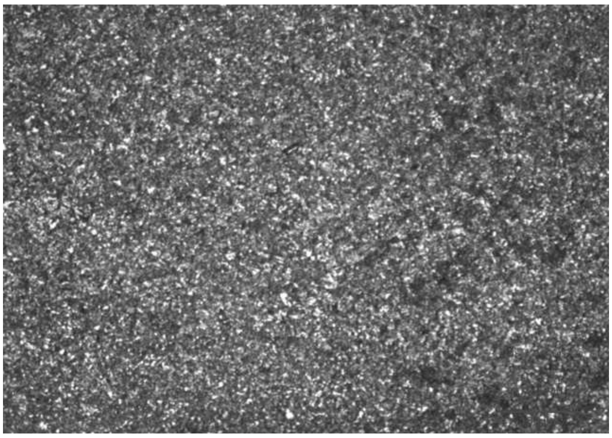

Fig. 3 *Sample 1, Hard Zone, magnification 100x*

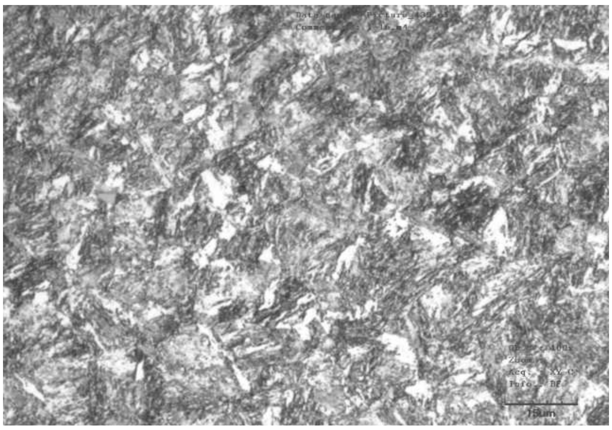

Fig. 4 *Sample 1, Hard Zone, magnification 1000x*

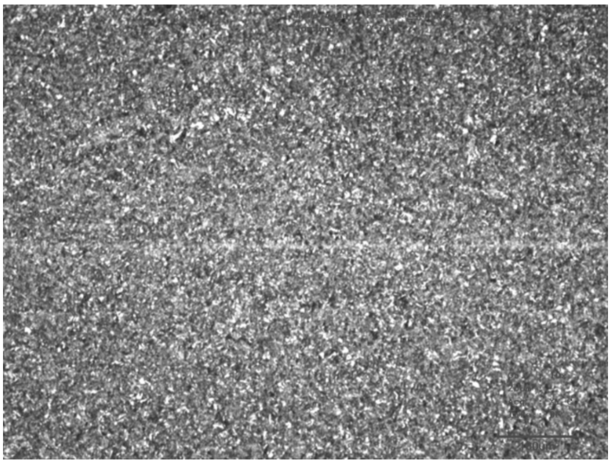

***Fig. 5** Sample 2, Hard Zone, magnification 100×*

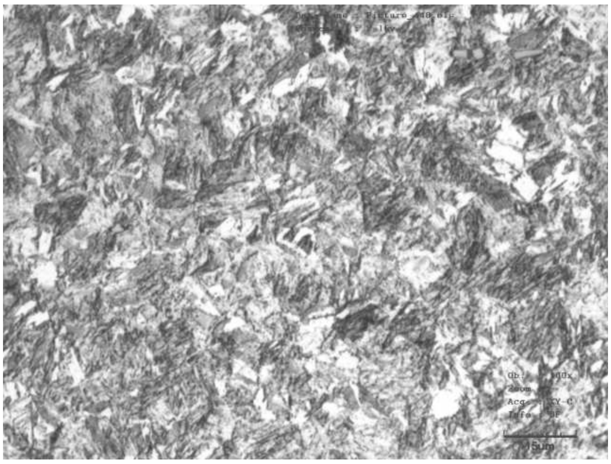

***Fig. 6** Sample 2, Hard Zone, magnification 1000×*

The selected microstructures represent changes in the resulting structures that determine the design of the resulting methodology. The microstructure of the analyzed material consists of fine needles of martensite and residual austenite. The structure of sample 2 (Figs. 5, 6) is almost identical to the structure of sample 1 (Figs. 3, 4). This is due to the fact that there is no change in parameters in the thermomechanical treatment process in the hard part between process #1 and #2. The structure of sample 2 thus consists of fine needles of martensite together with residual austenite. For process #3, the cooling time is reduced by 2.7 s, which results in a higher temperature of the molded post after removal from the mold. If the cooling rate is in the form 38 $°C \cdot s^{-1}$, then if we shorten the cooling time by 2.7 s, the resulting temperature of the pillar is not 350 °C, but approx. 453 °C. At this temperature, all phase transformations of austenite are not yet complete. The structure consists of martensite with a small proportion of residual austenite and bainite. The B-pillar is then gradually cooled in air. According to the CCT diagram, the perlite area will be crossed by the cooling curve, which is shown in Fig. 9, marked in red.

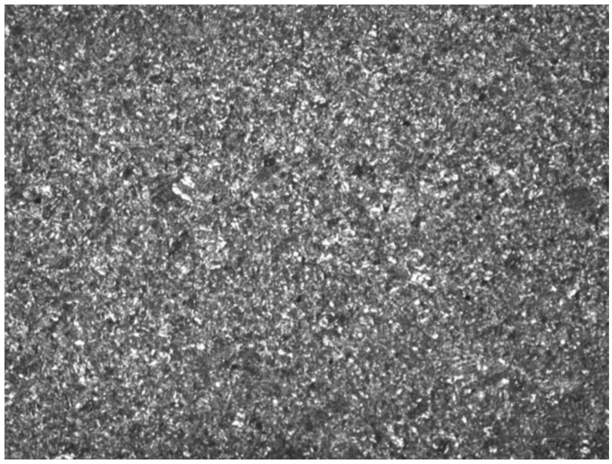

***Fig. 7** Sample 3, Hard Zone, magnification 100×*

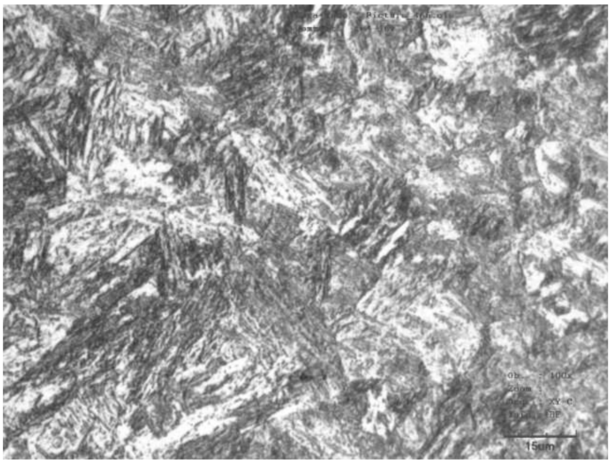

***Fig. 8** Sample 3, Hard Zone, magnification 1000×*

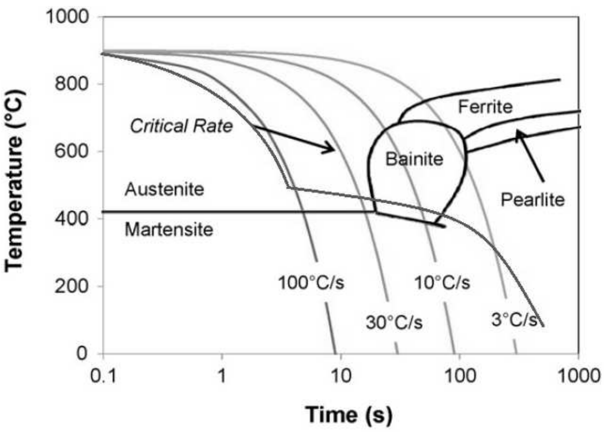

***Fig. 9** CCT diagram for process No. 3 in the hard zone*

3.2 Microstructure of the B-pillar in the Soft Zone

In the case of the Soft Zone, due to the influence of various process parameters, more significant changes in the microstructure occur. The initial temperature when inserting the sheet into the mold is the same as for the hard part, i.e. 850 °C. After the mold is closed, however, the material does not harden, as this part of the mold is not cooled, but heated. In process No. 1, the segments in the soft part of the mold are heated to 560 °C. After the mold is closed, the temperature of the material decreases from 850 °C to 560 °C for 10.7 s, which corresponds to a cooling rate of approx. 22 $°C \cdot s^{-1}$. After removal from the mold, the material is cooled in air. On (Fig. 10) at a magnification of 100x, the linearity of the microstructure can be observed, which could be caused by several factors, for example, heating before forming and the degree of deformation or during the steel production itself. The material produced by process No. 1 consists of ferrite and pearlite (see Fig. 11).

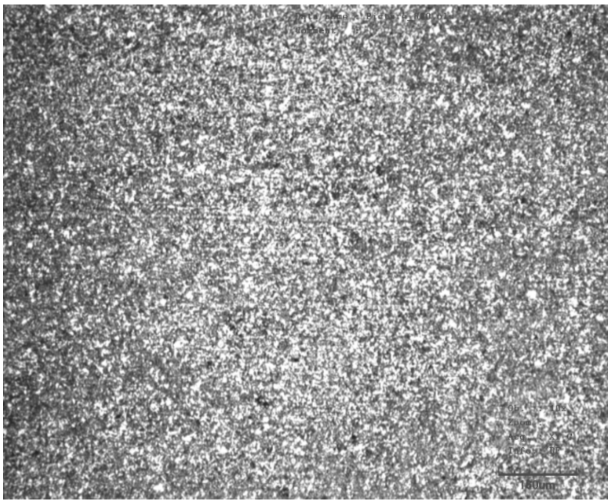

Fig. 10 *Sample 1, Soft Zone, magnification 100x*

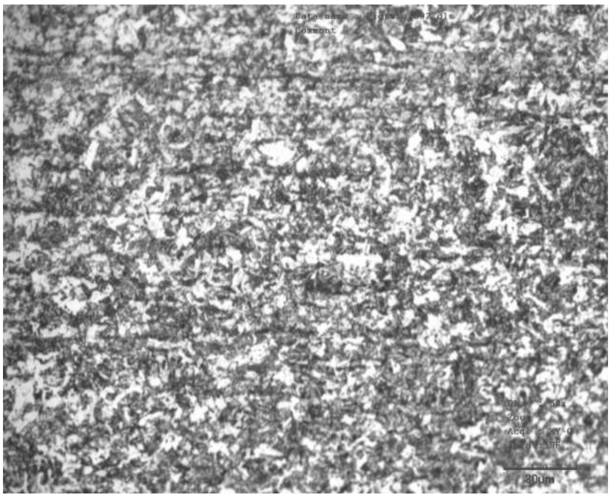

Fig. 11 *Sample 1, Soft Zone, magnification 500x*

Process No. 2 represents sample 2. The temperature of the mold is thus reduced to a temperature of 480 °C compared to the first process. A lower pressing temperature resulted in a higher proportion of pearlite and intermetallic phases in the structure, which is reflected in a slight increase in hardness, Fig. 12-13.

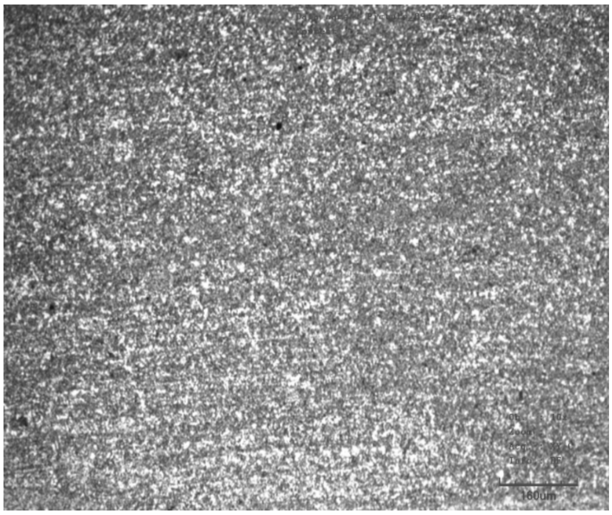

Fig. 12 *Sample 2, Soft Zone, magnification 100x*

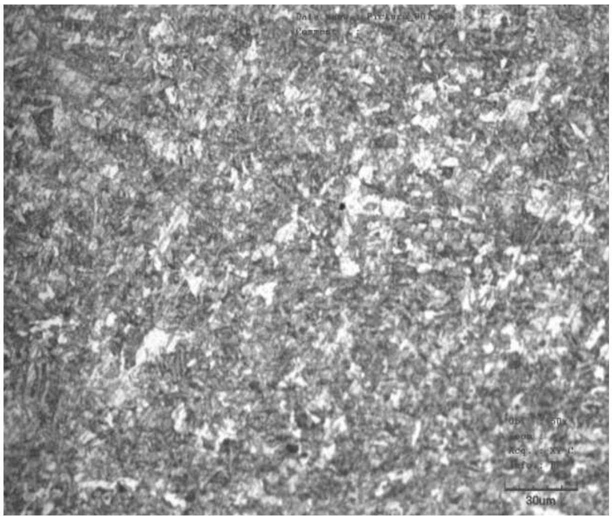

Fig. 13 *Sample 2, Soft Zone, magnification 500x*

When using the parameters of production process No. 3, a ferritic-pearlitic structure (Fig. 14-15).

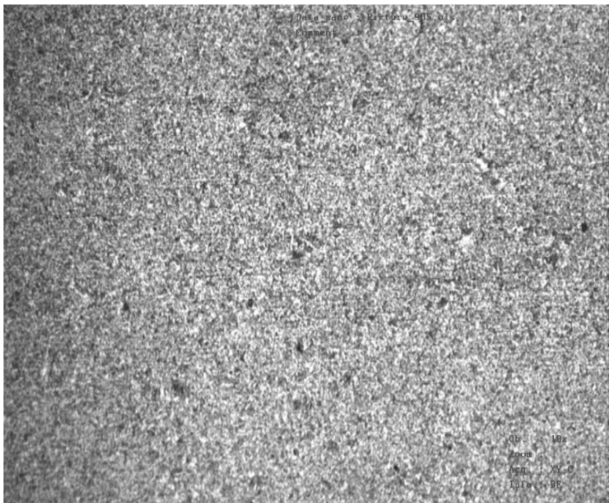

Fig. 14 *Sample 3, Soft Zone, magnification 100x*

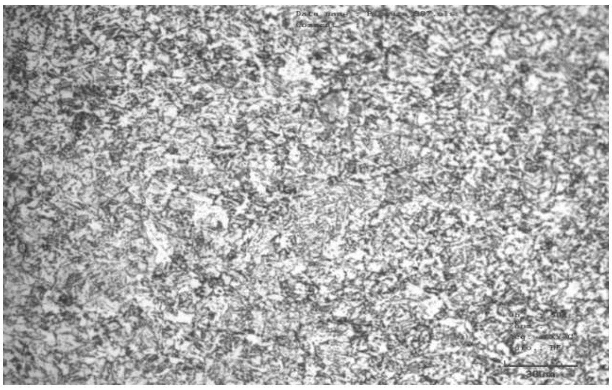

Fig. 15 *Sample 3, Soft Zone, magnification 500×*

3.3 Vickers hardness of the examined materials according to CSN EN ISO 6507 1

An important parameter that is reflected in the microstructure is the hardness of the material. Hardness evaluation was performed on Shimadzu HMV MICRO Hardness Tester, hardness measurement was performed under HV10 load, as it is a high-strength steel. Six measurements were made for each sample, the results are shown in Table 3. The hardness of HV10 in the soft area of the B pillar should be in the range of (175-275) HV10, in the hard area it should be HV10 ≥ 400.

Tab. 3 *Hardness in Soft Zone B-pillar according to ČSN EN ISO 6507-1*

Process No.	1	2	3
Average HV10	211	222	208
Standard deviation σ	2	3	2

Tab. 4 *Hardness in Hard Zone B-pillar according to ČSN EN ISO 6507-1*

Process No.	1	2	3
Average HV10	509	502	504
Standard deviation σ	4	4	5

The measured hardnesses confirmed this assumption.

3.4 Vickers hardness measurement in the transition area of the B pillar

Another criterion for evaluating the effect of thermomechanical processing on the resulting properties of the B-pillar is the evaluation of the transition area between the soft and hard parts. A distance of 1 mm was chosen between individual measurements. In total, 45 measurements were performed on each sample. In Fig. 16 shows the hardness of the transition region for samples of all three processes.

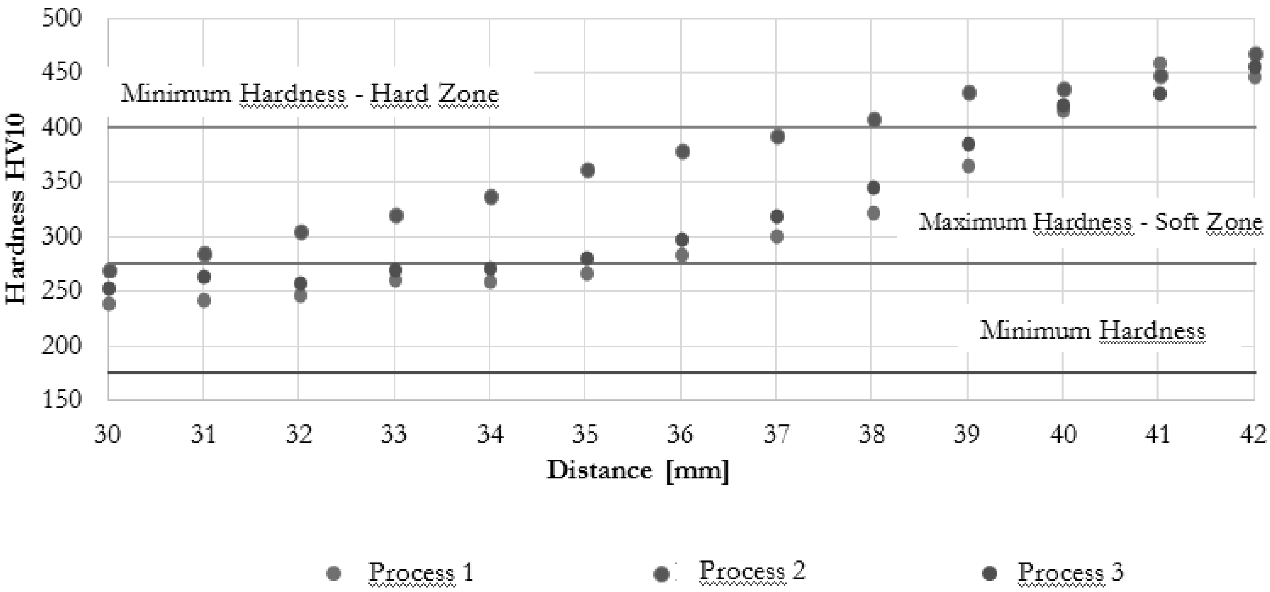

Fig. 16 *Hardness in the transition area of the samples*

The samples produced by processes No. 1 and 3 have the same hardness profile, unlike the samples produced by process No. 2, they differ significantly from the other experimental processes, both in the hardness profile and the size of the transition region in the given part. The transition part for the sample produced by Process No. 2 starts at a distance of 31 mm from the edge of the sample, the hardness then stabilizes at a distance of 41 mm. The hardness of all samples in the soft, hard and transition regions were within the minimum and maximum required values, as shown in Fig. 16. The indicated graph shows a significant influence of the temperature of the forming process of process 2, respectively the temperature difference, in the area of the soft zone, which was reflected in the microstructure and subsequently the evaluated hardness.

4 Conclusion

The aim of the article was to investigate the effect of selected parameters of thermomechanical processing on the resulting properties of the B-pillar made of 22MnB5 steel, with regard to reducing the energy consumption of production. Three types of experimental production processes were proposed, which had different thermomechanical processing parameters. Based on experimental processes, B-pillars were produced, for which the microstructure and Vickers hardness measurement according to CSN EN ISO 6507 1 were examined.

As the first part of the experiment, the influence of thermomechanical processing parameters on the resulting properties of the B-pillar was evaluated using microscopic analysis. In the soft zone of the B-pillar, a ferritic-pearlitic structure and intermetallic phases distributed in solid solution were observed in all samples produced by different experimental processes. In the hard zone of the B-pillar, where press hardening took place, the structure of all samples consisted of acicular martensite and residual austenite. Only the sample produced by process No. 3 contains pearlite in addition to martensite and residual austenite.

Furthermore, the hardness was measured in the soft, hard zone and the transition area of the post. In the soft zone, the hardness of the samples was around 210 HV10, only sample 2 produced by process no. 2 had a hardness of 222 HV10. In the hard zone, the hardness of all measured samples was almost identical. The average hardness value in the hard part is 503 HV10. The transition area is identical for samples produced by processes No. 1 and No. 3. These are transitional areas that are only 6 mm long, so between the soft and hard zones, an area with a sudden increase in hardness was created in all samples. In contrast, the B-pillar produced by process No.2 has a transition area length of 10 mm, and the hardness transition between individual parts of the post is smooth and uniform.

After comparing the hardness values and microstructures of the experimentally produced B-pillars, it is possible to state that all the investigated properties are the same for the samples produced by process No. 1 and 3 are the same, they have slight differences in the microstructure. This is determined both by the amount of material transformation and by the content of phases dissolved in the solid solution.

B-pillar made by process No. 2 was the only one that showed slight deviations from the other experimentally produced posts during all tests and measurements. In the soft zone of the column, the hardness increased by 11 HV10, but the highest difference is in the transition area. The B-pillar made with this process had the longest and smoothest hardness transition between soft and hard. This is the most important safety parameter for the B-pillar, as only the long and smooth transition area ensures that the pillar does not break and deformation energy does not pass into the interior of the car. The B pillar produced by process No. 2 is the only one that meets the requirements described above. After the introduction of process No. 2 into production, there will be a reduction in production costs associated with a lower energy requirement for heating the segments, which is 80 °C lower, compared to the existing process. Furthermore, the heating time of the segments is reduced by approx. 30 minutes. An unmissable advantage is the reduction of costs associated with mold maintenance, as the lower temperature of the heated segments will have a more positive effect on the loosening and wear of the mold. Recommended process parameters No. 2 will also ensure an increase in B-pillar safety due to the smooth transition line.

Acknowledgement

Supported by the project SGS 48207 15 2027 01 at Jan Evangelista Purkyne University in Usti nad Labem.

References

[1] CHANG, Y., ZHENG, G., LI, X., JIN, C., WANG, C.,DONG, H. (2021). Evaluation on the formability of the third-generation automotive medium-Mn steel based on experiment and simulation. In. *International Journal of Advanced Manufacturing Technology*, Volume 117, Issue 3-4, Page 1015-10, ISSN 0268-3768.

[2] JANDA, T. (2018). Use of Metallographic Analysis for Evaluating Microstructures in Quenched and Tempered High-Strength Steel. In. *Manufacturing Technology*. Vol. 18, No. 1, ISSN 1213–2489.

[3] RAZMPOOSH, M. H., MACWAN, A., BIRO, E., ZHOU, Y. (2020). Microstructure and dynamic tensile characteristics of dissimilar fiber laser welded advanced high strength steels. In. *Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing*. Volume 773, ISSN 0921-5093.

[4] YUAN, CH., LI, S., HUANG, J., LIN, X., BIAN, X., CHEN, J. (2021). Effect of hierarchical martensitic microstructure on fatigue crack growth behavior of ultra-high strength hot stamping steel. In. *Materials Characterization*. Volume 174, ISSN 1044-5803.

[5] KRAWCZYK, J., et al. (2021). State of Strain and Development of Microstructure of 22MnB5 Steel and Al-Si Coating during Deep Drawing of Automotive B Pillar. In: *Arch. Metall. Mater.* 66, 2, pp. 601-608. ISSN 1733-3490.

[6] PACKO, M., YOU, K. H., KIM, H.-K. (2021) A Study on the Effect of Process and Material Variables on the Hot Stamping Formability of Automotive Body Parts. In: *Metals 2021*, 11, 1029. eISSN 2075-4701.

[7] BUBLIKOVA, D., JIRKOVA, H., STEHLIK, A, JENIČEK. Š. (2023). Effect of Temperature and Deformation on the Stability of Retained Austenite in Closed-Die Forgings from High-Strength Martensitic Manganese-Silicon Steels. In. *Manufacturing Technology*. Vol. 23, No. 3. ISSN 1213–2489. e-ISSN 2787–9402

[8] BURDOVÁ, K., JIRKOVÁ, H., KUČEROVÁ, L., ZETKOVÁ, I., MACH, J. (2022). Effects of Heat Treatment on Additively Manufactured 316L Stainless Steel. In. *Manufacturing Technology*. Vol. 22, No. 3, pp. 261-266, ISSN 1213–2489.

[9] LI, S., ZHOU, L., WU, X., ZHANG, Y., LI, J. (2016). The Influence of Thermal Conductivity of Die Material on the Efficiency of Hot-Stamping Process. In. *Journal of Materials Engineering and Performance*. Volume 25, Issue 11, Page 4848-4867, ISSN 1059-9495.

[10] PARK, A., NAM, J. H., KIM, M., JANG, I. S., LEE, Y. K. (2020). Evaluations of tensile properties as a function of austenitizing temperature and springback by V-bending testing in medium-Mn steels. In. *Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing*. Volume 787, ISSN 0921-5093.

[11] SHUO-SHUO, L., HAI-WEN, L. (2021) Medium-Mn steels for hot forming application in the automotive industry. In. *International Journal of Minerals, Metallurgy and Materials*. Volume 28, Number 5, May 2021, pp. 741–753, ISSN 1674-4799,

[12] SINGH, A. K., NARASIMHAN, K. (2021). Effect of strain rate on formability of 22MnB5 steel during hot stamping process. In. *International Deep-Drawing Research Group Conference*. Volume 1157, ISSN 1757-8981.

[13] ZHUANG, W., WANG, P., XIE, D., SHI, H. (2019). Experimental study and a damage model approach to determine the effect of hot forming deformation on the service performance of 22MnB5 steel. In. *Journal of Manufacturing Processes*. Volume 47, Page 10-21, ISSN 1526-6125.

[14] KUSMIERCZAK, S., SLAVIK, M. (2018). Analysis of Al-Si layer on steel sheet during thermo mechanical processing using microscopic methods. In: *Manufacturing Technology*, Vol. 18, No. 5, pp. 769-774. CZ, ISSN 1213–2489.

[15] MIN, J. LIN, J. MIN, Y., LI, F. (2012). On the ferrite and bainite Transformation in isothermally deformed 22MnB5 Steels. In. *Materials Science and Engineering A-Structural Materials Properties Microstructure and Processing.* Volume 550, Page 375-387, ISSN 0921-5093.

[16] OKAYASU, M., YANG, L. (2019) Influence of microstructure on the mechanical properties and hydrogen embrittlement characteristics of 1800 MPa grade hot-stamped 22MnB5 steel. In. *J Mater Sci.* Vol. 54, pp. 5061–5073, ISSN 0957-4522.

[17] ZHOU, P.W., YAN, Z.I., WANG, K., LIU, T. et al. (2023). The influence of adding niobium and vanadium on hydrogen diffusion in 22MnB5 hot stamping steel. In. *Journal of Iron and Steel Research International*. ISSN 1006-706X, eISSN 2210-3988.

[18] ZHOU, Q., GUO, P., QIN, F. (2022). Stress Response Behavior, Microstructure Evolution and Constitutive Modeling of 22MnB5 Boron Steel under Isothermal Tensile Load. In. *Metals*. Volume 12, Issue 6, eISSN 2075-4701.

[19] CAVUSOGLU, O., CAVUSOGLU, O., YILMAZOGLU, A. G., UZEL, U., AYDIN, H., GURAL, A. (2020). Microstructural features and mechanical properties of 22MnB5 hot stamping steel in different heat treatment conditions. In. *Journal of Materials Research and Technology*. Volume 9, Issue 5, Page 10901-10908, ISSN 2238-7854.

[20] HORN, A., MERKLEIN, M. (2021). Investigation of the Microstructural Evolution during Hot Stamping of Carburized Complex Phase Steel by Laser-Ultrasonics. In. *Materials*. Volume 14, Issue 8, eISSN 1996-1944.

[21] JANDA, T. (2018). Use of Metallographic Analysis for Evaluating Microstructures in

Quenched and Tempered High-Strength Steel. In. *Manufacturing Technology*. Vol. 18, No. 1, ISSN 1213-2489.

[22] KUČEROVA, L., JANDOVA, A., RUBEŠOVA, K. (2019). Microstructure Analysis and Mechanical Properties of Low Alloyed Steel with Retained Austenite Obtained by Heat Treatment. In. *Manufacturing Technology*. Vol. 19, No. 2.pp.243-247, ISSN 1213–2489.

[23] KUSMIERCZAK, S., NAPRSTKOVA, N., MICIAN, M. (2020). Usage of Microscopic Methods in Analysis of Non-Conforming Nickel Alloy Products. In. 19th *International Scientific Conference Engineering for Rural Development*, pp. 1208-1213, ISSN 1691-3043, eISSN 1691-5976

[24] TAVODOVA, M., NAPRSTKOVA, N., HNILICOVA, M., BENO, P. (2020). Quality Evaluation of Welding Joints by Different Methods. In. *FME Transactions*, Volume 48, Issue 4, Page 816-824, ISSN 1451-2092, eISSN 2406-128X.