INFLUENCE OF THE BH EFFECT ON THE HIGH-STRENGTH MATERIALS

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Abstract

The paper deals about determination the influence of BH effect on the high-strength steels mechanical properties in dependence on the chosen cutting technology. There is tested material with the martensite structure and alloyed with boron and manganese. Such materials are used in the automotive industry at the car-body design mainly for parts which provide the safety of the passengers. Thus to achieve and ensure these demands there is very important to know the deformation behavior of these materials already during cutting process and also after the thermal loading by which is car-body loaded during the painting process. For cutting materials there were used technologies of laser and water jet cutting. BH effect takes place as car-body passes through the painting line where materials mechanical properties are changed due to the elevated temperature in the heating device during own baking of the paint.

Keywords: BH effect, ultra-high strength materials, martensite structure, micro-hardness

1. INTRODUCTION

During the final production of the car-body there is the painting line where takes place the paint setting under the temperatures within 170 ÷ 180 °C with the holding time approx. 20 min. Because of elevated temperature there is necessary to know the influence of such process on the used material final properties. The major change of mechanical properties is caused by the effect that is termed as the BH effect (bake hardening). Such effect can have both positive and negative influence on the final product. During the paint setting there is strain and thermal hardening which causes the yield strength increase [1, 2]. Hardening process represents an accompanying process at the stamping and paint setting which arises from the deformation ageing during hot forming. Hardening mechanism is based on the diffusion of carbon and nitrogen atoms into the vicinity of dislocation which are created during stamping. BH effect is mainly used for the interstitials free (IF) steels where the basic structure is created mainly from the soft ferritic matrix. Thus car-body parts produced from the BH steels have higher maximal allowable loading and higher resistance against e.g. scratches [3]. On the other hand, for the ultra-high strength material this effect can have a negative influence and that is why there was carried out experiment which is described on the following pages.

2. TESTED MATERIAL

Material marked as 22MnB5 (manganese-boron steel) is an ultra-high strength material which, in its basic state, has a ferritic-perlite structure with ultimate strength R_m of 450 ÷ 550 MPa and ductility A_{80mm} min. 20 %. Boron steels belong into the steels suitable for quenching and tempering. They reveal perfect properties after the hot forming and high strength after the thermal treatment - quenching, which takes place right in the forming tool. Such material properties arise from its alloying by the small amount of boron and manganese with effort to improve hardenability. Micro-structure of the boron steels after the thermal treatment consists mainly from the martensite and residual austenite. For not so much demanding applications there is also acceptable the lower bainite [4]. Already small weight percent of boron is enough to prevent nucleation of ferrite on the boundary of austenitic grain and supports martensitic or lower bainite creation. The final structure is characteristic by its fine martensite dendrites (see **Figure 1**). To have such effect, there is necessary to prevent reactions of boron with the other elements e.g. with oxygen. This is done by alloying titanium or aluminium.

The own material processing for production different products then rests in heating up to austenitic temperature (approx. 950 °C) followed by its placing into the tool with the internal water cooling. By closing the tool there is firstly the heating of material and then in the closed tool it is followed by its quenching. As a condition about the full transformation onto the martensite there is necessity to cool down the part by the proper cooling rate in such manner that there is overrun the critical cooling rate [5].

Tested material was supplied from the producer as plates (sheets) with thicknesses 1, 1.5 and 2 mm. These sheets have already been thermally treated thus they revealed maximal strength values. To prevent creation of the flakes are these sheets covered by the protective layer from the AlSi (distribution 150 g / m^2).

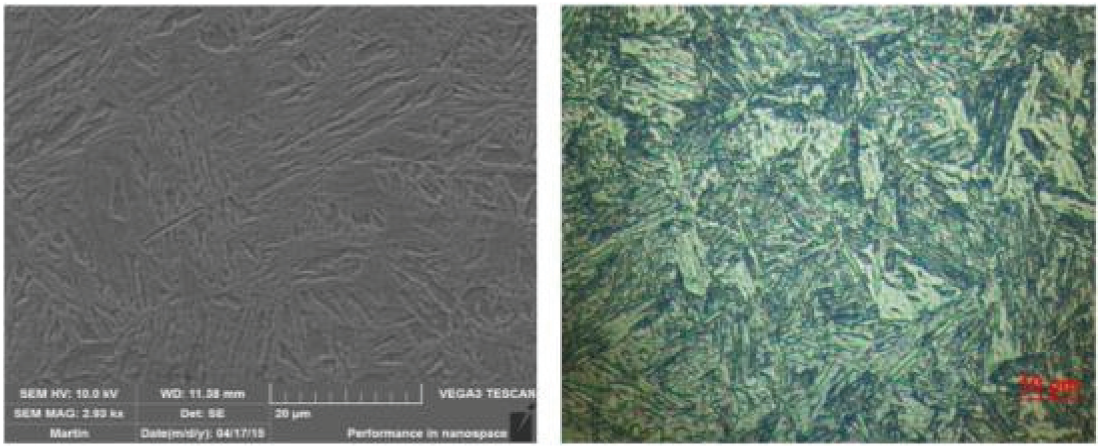

Figure 1 Micro-structure of the tested material 22MnB5, magnification 1000x

3. EXPERIMENTAL PART

Analysis of the BH effect was carried out with the testing samples from the material 22MnB5 that were prepared by means of the laser and water jet cutting with the subsequent grinding. Due to the different quality of the cutting edge and magnitude of the HAZ (heat affected zone) for the particular cutting technologies, there was necessary to determine influence of the cutting technology on the testing sample mechanical properties. Simultaneously there was done analysis for determination the change of the mechanical properties after material passing through the painting line. Own BH effect was simulated in the temperature chamber at temperature 180 °C and holding time 20 min.

3.1. Influence of the BH effect on the mechanical properties of the tested materials

As a basic experimental test there was carried out static tensile test acc. to standard EN ISO 6892-1 by the testing machine TIRAtest 2300 with the strain-gauge head sensor having range up to 100 kN. During the test was used length-gauge (initial length L_0 = 50 mm) and loading rate of 5 mm·min^{-1}. Testing sample was clamped between the hydraulic jaws of testing machine. Final results are compared in dependence on the material thickness and cutting technology.

In **Figure 2** are shown the proof yield strengths $R_{p0.2}$ for all material thicknesses which were cut by the water jet cutting. Samples without BH effect reveal certain inequality of the measured results. In the case of the samples which weren´t grinded is evident rapid increase of the yield strength before and after BH effect. The highest differences can be found for thickness 2 mm (116 MPa, increase by 10 %) and also for the thickness 1.5 mm (101 MPa, increase by 8.5 %). The same trend of increasing the yield strength after BH effect was observed for the grinded samples. Here the highest difference can be found for thickness 1.5 mm (101 MPa, increase by 8.3 %). On the contrary, for thickness 1 mm was yield strength increased only by 22 MPa. Generally it can be stated that after BH effect there is increase of the yield strength for all tested samples.

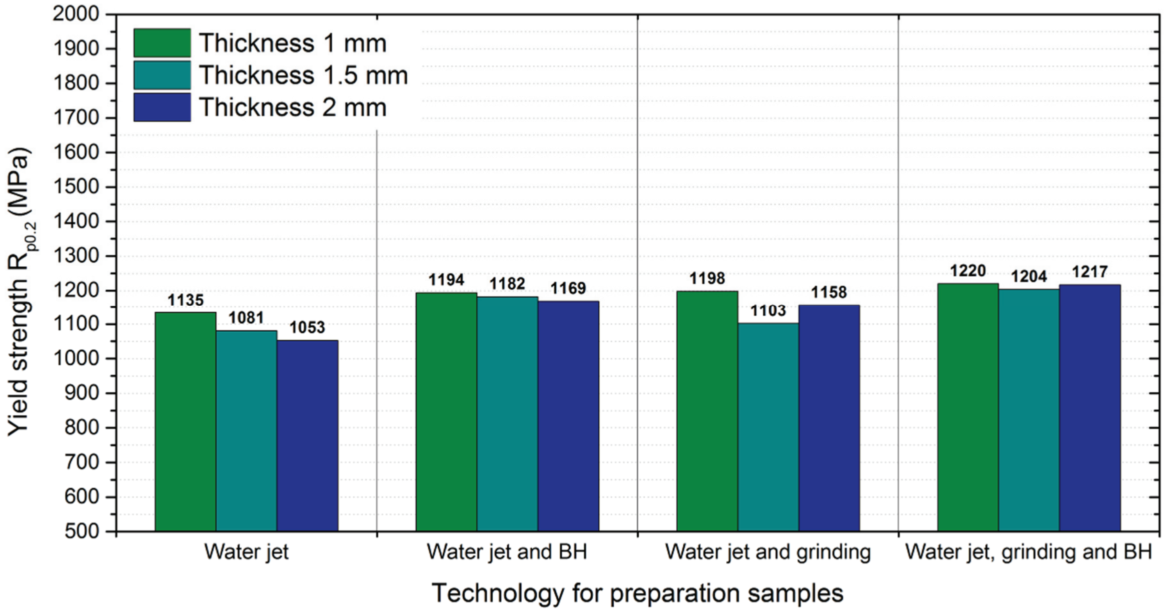

Figure 2 Comparison of the yield strength $R_{p0.2}$ for different thicknesses (material 22MnB5)

In **Figure 3** are shown the measured valued of the ultimate strength R_m. For all samples it is valid that ultimate strength is decreased after the BH effect. Basically, the non-grinded samples have the lowest decrease of the ultimate strength due to the BH effect at thickness 1.5 mm - only by 5 MPa. The highest decrease is obvious for thickness 2 mm where in the case of non-grinded state it decreased by magnitude of 46 MPa. Materials achieve the highest ultimate strength magnitudes in the case of grinded samples compared to the non-grinded samples. Because of that is seems that as optimal procedure there is water jet cutting followed by grinding of edges. Influence of the preparation technology (water jet cutting and following finishing machining) on the ultimate strength R_m is especially important for the tested material because the material 22MnB5 in the car-body design takes case about the safety of passengers.

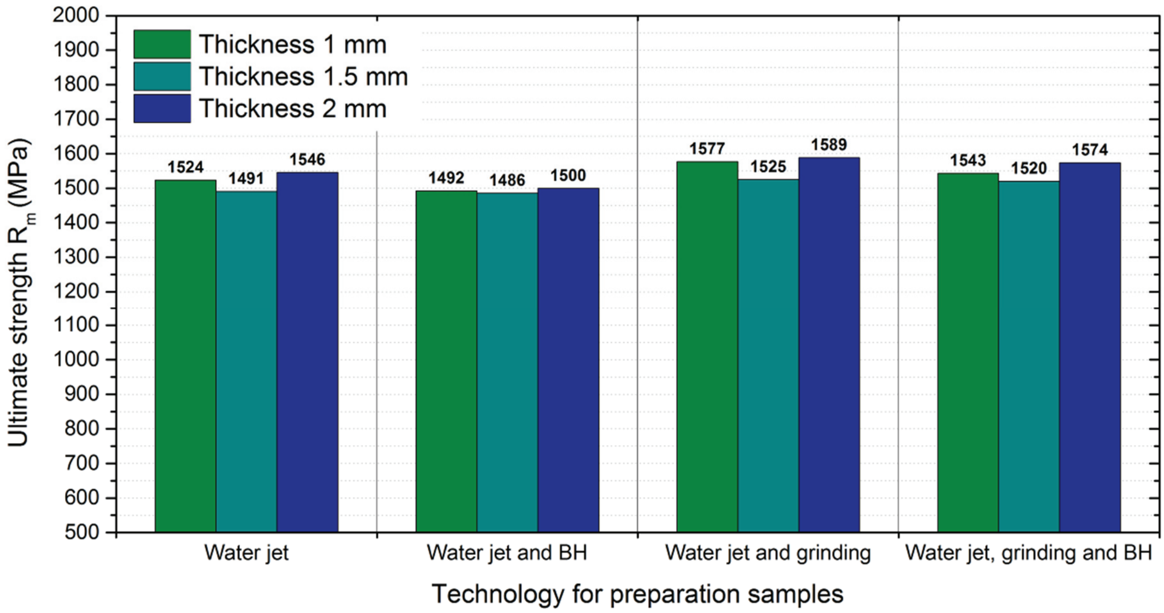

Figure 3 Comparison of the ultimate strength R_m for different thicknesses (material 22MnB5)

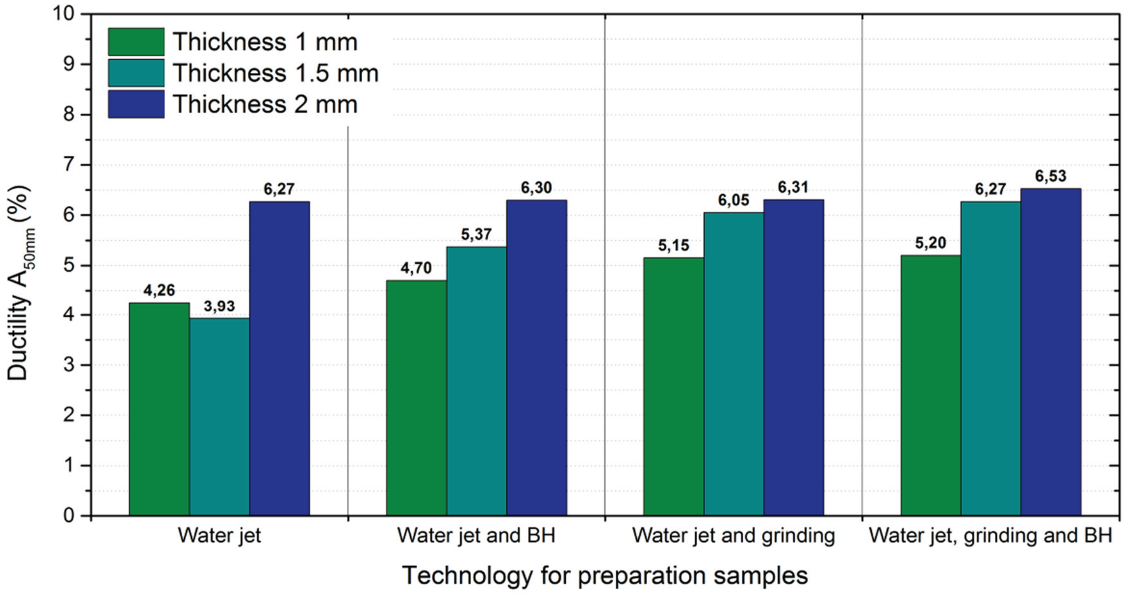

Figure 4 Comparison of the ductility A_{50mm} for different thicknesses (material 22MnB5)

Figure 4 illustrates the comparison of the measured ductility A_{50mm} for different thicknesses of tested materials. Values of ductility were increased after BH effect for all thicknesses. Steel of thickness 2 mm reveals the lowest range of the measured values. At the other materials there is (due to the grinding of the cutting edge) increase of the ductility in comparison with the non-grinded edge. It can be stated that the higher material thickness, the higher value of the ductility.

3.2. Influence of the BH effect on the micro-hardness of the tested materials

For evaluation the hardness in the area between the cutting edge and basic material was used measurement of hardness by Vickers. Its principle and testing conditions are defined acc. to standard EN ISO 6507-1. Measurement was carried out under RT (room temperature) and at loading of 0.98 N for 5 sec (thus there was measured micro-hardness). For the every material were evaluated 5 impressions - see **Figure 5**.

Evolution of the hardness in dependence on the distance from cutting edge into material is shown in **Figure 6**. Non-grinded samples reveal almost constant hardness profile and due to the BH effect there is mild increase of hardness. At grinded samples is in the close vicinity of the cutting edge obvious decrease of the hardness as it is measured for all grinded samples. Samples with the grinded edge achieved the higher hardness values than the non-grinded ones. Moreover there is hardness profile lowering after BH effect.

Figure 5 Measurement of micro-hardness by Vickers: Qness Q30A (left) and examples of impressions (right)

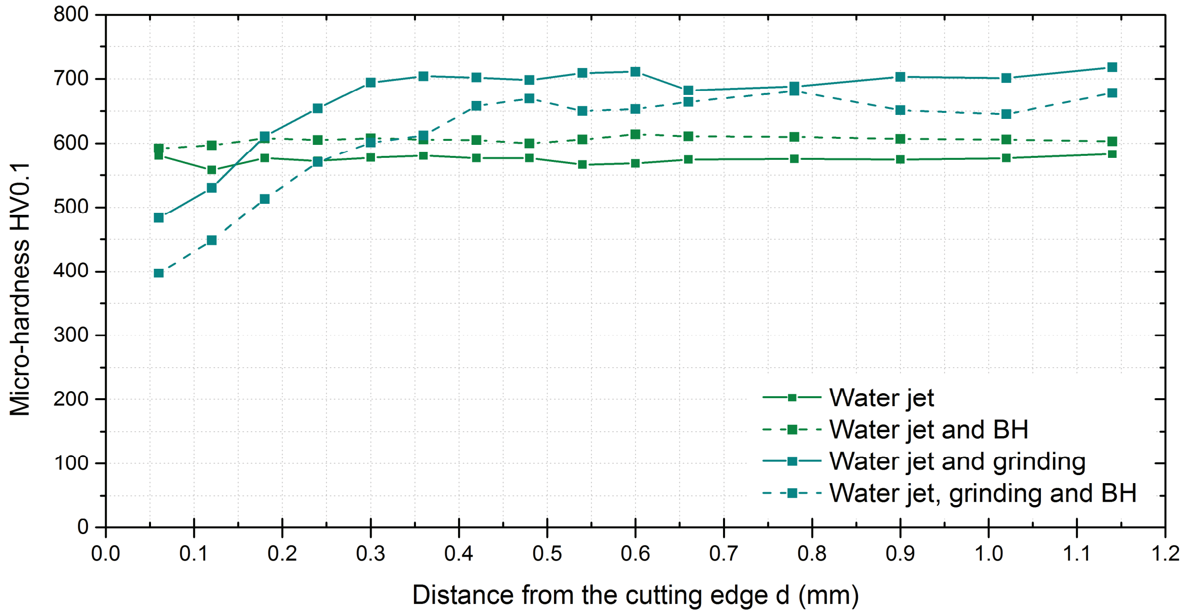

Figure 6 Micro-hardness values comparison (material 22MnB5) for tested preparation technologies

Comparison of the hardness evolution for samples prepared by the water jet cutting and laser cutting is shown in **Figure 7**. Samples prepared by the water jet cutting don´t have any HAZ and due to the grinding there is hardness decrease in the close vicinity of the cutting edge. By the BH effect there is hardness decrease approx. by 80 HV 0.1/5. Samples prepared by the laser cutting revealed significant influence of the HAZ because of the laser beam. Thus there is obvious rapid hardness decrease. Generally due the laser influence there is after the BH effect increase of hardness with the increasing distance from the cutting edge. As it is obvious from the results, such measurement is very important close to the cutting edge.

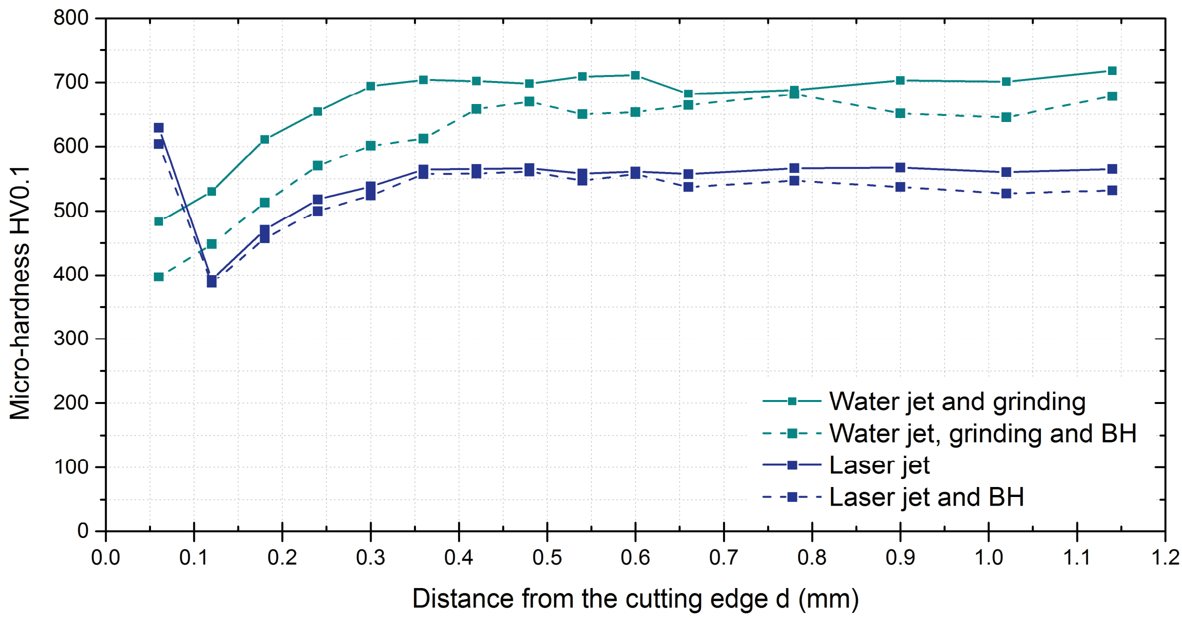

Figure 7 Micro-hardness values comparison (material 22MnB5) for water jet and laser jet cutting

4. CONCLUSION

The main aim of the experimental part was to determine the change of the mechanical properties for the material 22MnB5 after passing through the painting line in dependence on the used cutting technology. For all types of samples preparation was measured that BH effect has a positive influence in light of the proof yield strength $R_{p0.2}$ as there is its increase. The highest change is observed for material of thickness 2 mm where such increase is almost by 10 %. On the other hand, the BH effect decreases the ultimate strength R_m for all tested samples. The highest decrease was measured in the case of thickness 2 mm. Ductility A_{50mm} was increased for all tested samples. Lowering of the ultimate strength and increasing the ductility is probably resulting from the material low-temperature tempering.

Micro-hardness was subsequently measured from the cutting edge in direction into the basic material. The minimally influenced cutting edge was in the case of the water jet cutting without grinding. Here is hardness profile almost constant (see **Figure 7**). On the contrary, both at using the laser cutting and the water jet cutting without grinding there was rapid change of the hardness profile on the cutting edge. The hardness decrease was resulting from the influence of the higher temperature both from laser beam and from grinding wheel.

Based upon the results it can be for cutting ultra-high strength materials in light of the mechanical properties (more precisely change of their mechanical properties) recommended utilization of the water jet cutting followed by grinding the cutting edges. By such treatment there is improved material homogeneity which has a direct influence on the increasing mechanical properties. Despite the fact that there is hardness decrease on the cutting edge, in light of the ultimate strength and ductility such procedure reveals the highest values.

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REFERENCES

[1] JACOB, A. FLAXA, V. FREIER, K. Karosserienleichtbau und die umfassende Verwendung höherfester Stahle In *Leichtbau durch Umfortechnik*, Chemnitz, 2000, pp. 119.

[2] KVAČKA, T. MAMUZIC, I. Hardening Effect by Plastic Deformation and Annealing Conditions. *Metalurgija 45,* 2006, ISSN 0543-5846, pp.51-55.

[3] BALLARIN, V. SOLER, M. PERLADE, A. LEMOINE, X. FOREST, S. KERSE, C. S. *Mechanisms and Modeling of Bake Hardening Steels*. The Minerals, Metals & Materials Society and ASM International *2009,* vol. 40A, pp 1367-1374.

[4] SCHWEDLER, S. JÜTTNER, S. *Formhärten im Automobilbau*. Wolfsburg, *Wissenschaftliche Grundlagen* 2013

[5] NADERI, M. Hot *Stamping of Ultra High Strength Steels*, Institut für Eisenhüttenkunde Dissertation RWTH Aachen 2007