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Laboratory trials and design of industrial application of hot stamping of 22MnB5 tailored components by partition heating

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Abstract

Hot stamping of 22MnB5 by partition heating may represent an effective method to produce tailored parts of the car body-in-white to improve collision performances. This paper investigated its feasibility and applicability at both laboratory and industrial level. First, an M-shaped part was stamped using a specially-designed partition heating device, and its finite element model established and validated. Secondly, a partition heating device suitable for industry was designed for stamping tailored B-pillars. The hot stamping by partition heating to produce B-pillars was simulated, analysing major characteristics during and after stamping and quenching.

Keywords: Hot stamping; Partition heating; Tailored properties; 22MnB5; B-pillar

1. Introduction

In order to improve the collision performances, 22MnB5 parts of the car body-in-white produced by hot stamping should present areas characterized by different properties [1, 2]. Taking the B-pillar part as example, the upper section should present higher tensile strength but lower ductility to improve the intrusion resistance, whereas, the lower section

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should own higher elongation but lower strength so as to enhance the energy absorption capability [3].

Several methods based on the conventional hot stamping process have been developed to produce such components with tailored properties. Among them, to be cited the use of tailored welded blanks, the adoption of specific cooling strategies and annealing strategy on the basis of the component zones. Recently, hot stamping by partition heating has been also introduced to produce parts with tailored properties by adjusting the sheet austenitization degree during the heating process in order to obtain different microstructures after forming. Mori et al. [4] produced a hat-shaped part with tailored properties by hot stamping using bypass resistance heating. Mu et al. [5] optimized the partition heating parameters in order to produce a tailored M-shaped part.

As long as partition heating of 22MnB5 initial blank is well realized, the part can be produced with tailored properties, but without changing the hot stamping conventional procedure as well as the tool design. However, investigations on the applicability of such hot stamping process variation at industrial level are still very few. To this regard, the paper aims at further researching the laboratory and industrial applicability of hot stamping of 22MnB5 tailored components by partition heating making use of a combined experimental and numerical approach. The first part of the paper is devoted to the design and conduction of hot stamping by partition heating experiments to produce a simple laboratory part, namely an M-shaped part, as well as the development of the numerical model of the process. The second part instead proposes the design of a partition heating device to be applied to a component of industrial interest, namely the B-pillar of the car body-in-white, and the development of the numerical model of the process applied to this component.

2. Laboratory trials of M-shaped part hot stamping by partition heating

2.1. Experimental methods and results

A laboratory device was specially-designed to partition heat 22MnB5 sheets (see Fig. 1). The device consists of a clamping system, which makes use of two rectangular thick steel plates to clamp the sheet in the zone where its temperature must be guaranteed below austenitization, a furnace, whose temperature is kept at 900 °C to assure a complete austenitization of the region of the sheet not clamped between the two plates, and a temperature acquisition system, which uses a thermocouple to acquire the temperature of the sheet low-temperature region during furnace heating. When the temperature of the sheet in the low-temperature region reached to 700 °C as recorded by the thermocouple, the sheet was taken out of the furnace and transferred to the press to perform the hot stamping trials.

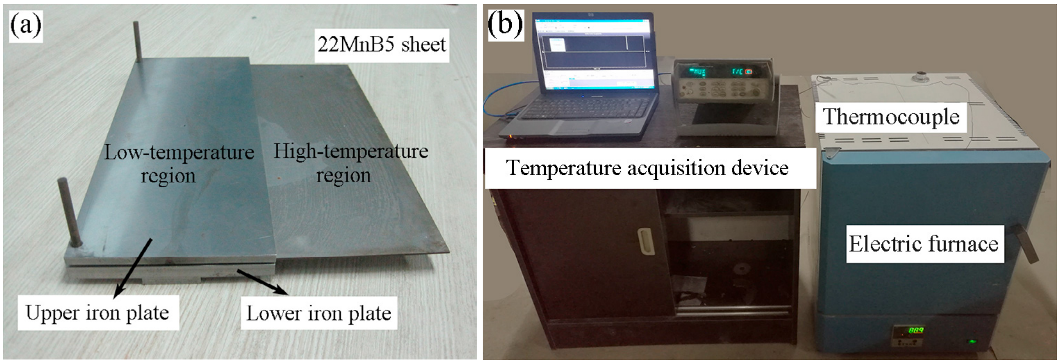

Fig. 1. Specially-designed device for partition heating: (a) detail of sheet clamping system; (b) overall equipment with indication of electric furnace and temperature acquisition system.

The stamping tools of M-shaped part were installed on the platform of a 250 t hydraulic press (See Fig. 2(a)). The formed M-shaped part after quenching time of 15 s is shown in Fig. 2(b). It is worth noting that the part does not present evident defects and that the oxidation in the high-temperature region is more severe than that in the low-temperature region, as expected.

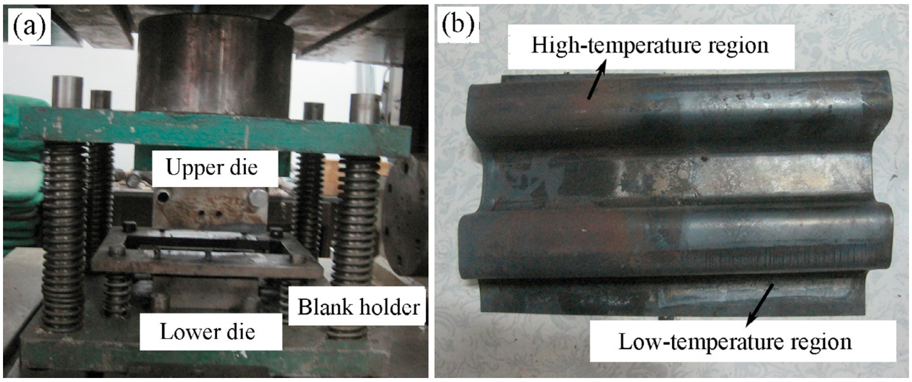

Fig. 2. Tooling system for hot-stamped M-shaped part (a); formed M-shaped part (b).

The tensile strength and elongation at fracture of specimens extracted at five different locations in the formed M-shaped part are shown in Fig. 3, which proves that tailored mechanical properties are well achieved through the process. In the low-temperature region, the average tensile strength and elongation are 626 MPa and 24.37%, respectively, whereas, the average tensile strength and elongation in the high-temperature region are 1565 MPa and 8.65%, respectively.

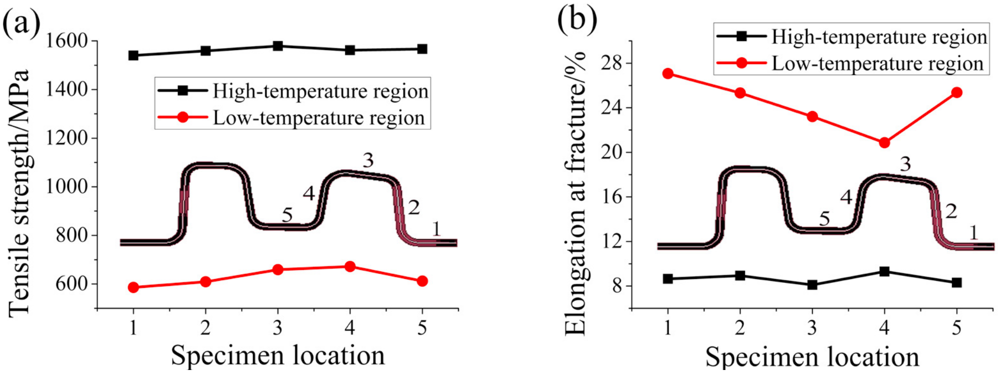

Fig. 3. Tensile strength (a) and elongation at fracture (b) of specimens extracted at different locations in formed M-shaped part.

2.2. Numerical modelling and analysis

The FE (Finite Element) model of the hot stamping process by partition heating to produce the 22MnB5 M-shaped part was established using the commercial code Pamstamp™ (Fig. 4). The blank initial high-temperature region was set at 900ºC with 100% austenite volume fraction, whereas the low-temperature region was set at 700ºC with no austenitization. The stamping velocity was set at 50 mm/s, the blank holder force 15 kN, the dwell pressure 10 MPa. The friction coefficient was set as 0.25 because of MoS_2 applied as lubricant, which is on the basis of literature records [6]. The 22MnB5 strain-stress curves at different temperatures and strain rates were obtained from a paper previously published by the Authors [7]. The 22MnB5 thermal properties as a function of temperature, the heat transfer coefficients with the tools and the environment, the phase transformation kinetics from austenite to bainite, ferrite+pearlite and martensite, as well as the micro-hardness as a function of the steel phase were set according to literature records [8-13].

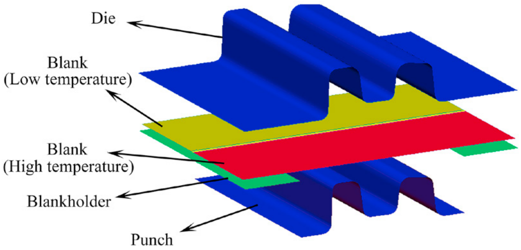

Fig. 4. FE model of hot stamping process by partition heating for producing 22MnB5 M-shaped parts.

The comparison between the experimental and numerical thickness and Vickers hardness distributions in the high- and low-temperature regions of the formed M-shaped part is shown in Fig. 5. The thickness in the high-temperature region is lower than that in the low-temperature region attributed to the decrease of stress value and strain hardening of the material deformed at elevated temperatures. In the high-temperature region, the Vickers hardness is about 490 HV, indicative of a fully martensitic microstructure. The Vickers hardness of material in the low-temperature region is about 162 HV, indicative of a mixture of ferrite and pearlite. The experimental results agree well with the numerical data, proving that the FE model can effectively reproduce the deformation behavior and mechanical properties of 22MnB5 during hot stamping by partition heating.

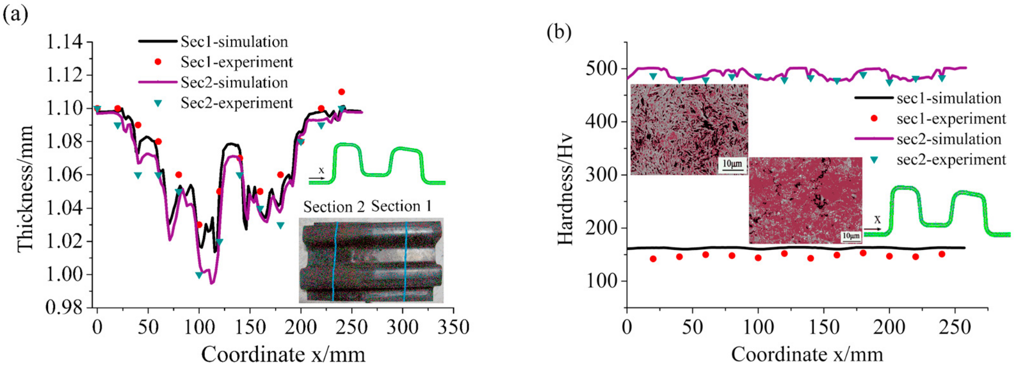

Fig. 5. Thickness (a) and Vickers hardness (b) distributions in high- and low-temperature regions of formed M-shaped part: comparison between experiments and simulations.

3. Towards industrial application of hot stamping of B-pillars by partition heating

3.1. Design of partition heating device of industrial interest

The partition heating device presented in §2 cannot be applied in industry to produce complex-shape components due to its inherent simplicity, therefore a different partition heating device was designed according to industrial requirements. The starting idea was the direct contact heating technique proposed by Ploshikhin et al. [13], which austenitizes the 22MnB5 sheet using two hot plates heated by magnetic induction, allowing the blank heating up to 1050 °C. Based on this research, the partition heating device shown in Fig. 6 was designed. Two heat conducting plates in the high- and low-temperature regions are heated and kept at above Ac_3 and below Ac_1, respectively, making use of induction coils. The temperature gradient region can be adjusted by changing the length of the sheet that is not in contact with the hot plates. After the two couples of plates have reached their set temperatures, the initial cold blank is put onto the lower heat conducting plates, then the upper heat conducting plates move down until coming in contact with the blank, and, finally, the clamping is kept at a certain contact pressure during which the blank heat up through conduction. The designed partition heating device can protect the sheet against oxidation and control the temperature distribution precisely [14], and it is more energy efficient and space-saving.

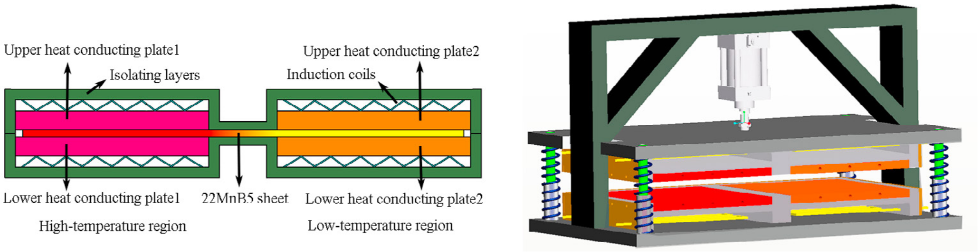

Fig. 6. Scheme and assembly of partition heating device using combination of induction and conduction heating means.

3.2. Numerical modelling of partition heating process

The numerical model of the partition heating process of a 22MnB5 blank devoted to the production of a B-pillar was developed using the FE commercial code Abaqus™, as shown in Fig. 7. The temperature of the plates in the low-temperature region was set at 700 °C, whereas the plates in the high-temperature region were at 900 °C. The length of the temperature gradient region was set equal to 0 mm. The contact pressure between the upper and lower plates was set as 0.01 MPa, and it can be adjusted according to the magnitude of the clamping force. The conductivity was set based on published literature [8], which is related to gap and contact pressure between tools and blank. Heat exchange with air was not considered due to the existence of isolating layers (see Fig. 6).

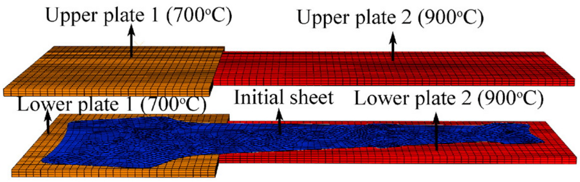

Fig. 7. FE model of B-pillar initial blank partition heating.

The blank temperature distribution after heating and temperature evolution with time in the blank high- and low-temperature regions are shown in Fig. 8. It can be seen that the required temperature distribution in the high- and low-temperature regions is well realized and the region characterized by a temperature gradient between 700 and 900 °C is very narrow (about 12mm). The blank temperature in the high-temperature region reaches 900 °C after about 20 s, whereas the blank in the low-temperature region, characterized by lower heating rate, is close to 700 °C after approximately 15 s. It is worth noting that the blank heating rate can be increased by increasing the contact pressure between the upper and lower hot plates.

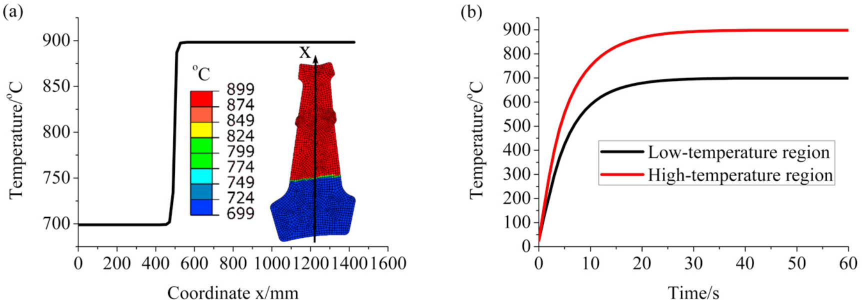

Fig. 8. Blank temperature distribution after heating (a), and time-temperature curves in high- and low-temperature regions (b).

3.3. Numerical modelling of hot stamping of B-pillars by partition heating

Since B-pillars with tailored properties are widely used parts of the car body-in-white, the industrial applicability of hot stamping by partition heating to produce them is here explored by means of numerical modelling of the process. The FE model developed for simulating the process and the tools used for it are shown in Fig. 9. The blank, with initial thickness of 1.2 mm, was set at 850°C with 100% austenite volume fraction in the upper segment, and at 650 °C with no austenitization in the lower segment. The temperature gradient region of the blank was not considered in this study. The temperature of the tools was set at 50 °C. The blank holder force was 100 kN and the dwell pressure 20 MPa. The other parameters were set equal to the ones of already set for the FE model of the M-shaped part hot stamping by partition heating. All the tools, namely the die, punch and blank holder, were designed consistent with the traditional hot stamping facilities (see Fig. 9(b)).

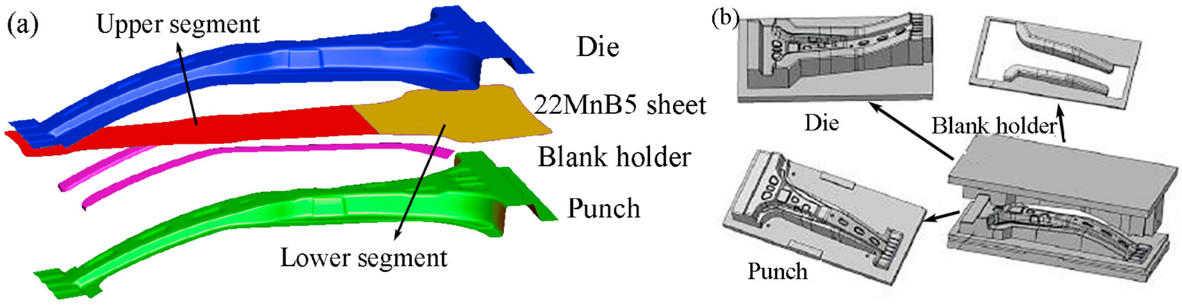

Fig. 9. FE model (a) and drawings of tools (b) of B-pillar hot stamping by partition heating.

Fig. 10 shows the stress and strain fields within the formed B-pillar part. The average stress in the lower segment is apparently larger than the one in the upper one, since the material at lower temperatures owns higher strength. The average strain in the upper and lower segments is similar, since, even if the material is harder in the lower segment, the depth of drawing is larger and therefore the strain level is similar.

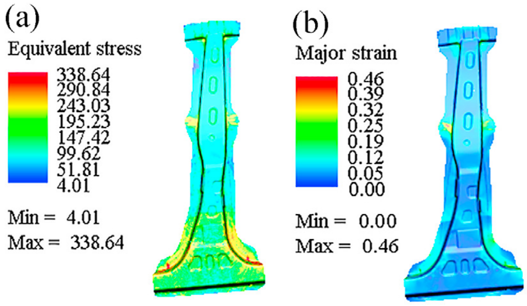

Fig. 10. Stress (a) and strain (b) fields within formed B-pillar.

The thickness field and thickness distribution along the section 1, section 2 and section 3 are shown in Fig. 11. The values of thickness in the whole formed part are between 0.99 and 1.46. The average thickness in the upper segment is lower than the one in the lower segment, because thinning of the material deformed at lower temperatures is harder due to the increase of stress level and strain hardening. Thickening occurs at the rounded corner in the upper and lower edge regions, as there are no blank holders in these two areas.

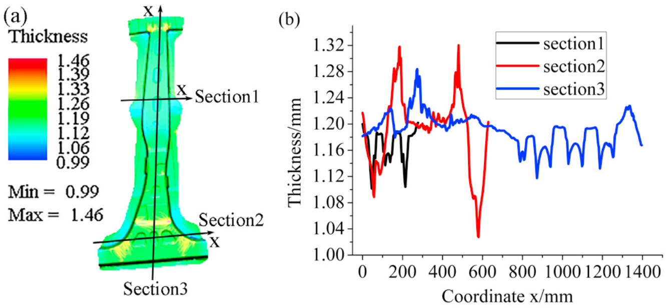

Fig. 11. Thickness field (a) and thickness distribution in different sections of formed B-pillar (b).

The temperature fields within the formed B-pillar after quenching times of 5 and 15 s are shown in Fig. 12. The temperature in the sidewall region is higher due to the larger gap and less contact pressure between the blank and the tools. After a quenching time of 15 s, the temperatures of the top surface of blank in the lower and upper segments are about 140 and 180 °C, respectively.

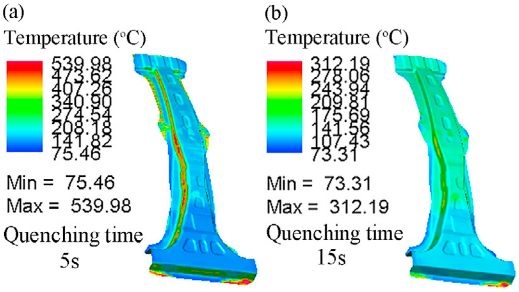

Fig. 12. Temperature fields within formed part after quenching time of 5 s (a) and 15 s (b).

Phase transformation gradually occurs within the B-pillar during cooling, which determines the microstructure and mechanical properties of the part in different regions. Martensite volume fraction and Vickers hardness distribution along section 3 of the B-pillar after a quenching time of 7 s are shown in Fig. 13. It can be seen that the martensite volume fraction in the lower segment is null as no austenitization occurred during heating. Whereas, in the upper segment, the volume fraction of martensite in the blank holder and top surface regions reaches near to 1, whereas martensite fraction in the sidewall region is less because of a lower cooling rate. It is worth noting that tailored properties are well realized as the hardness values in the upper and lower segments are about 490 and 165 HV, respectively.

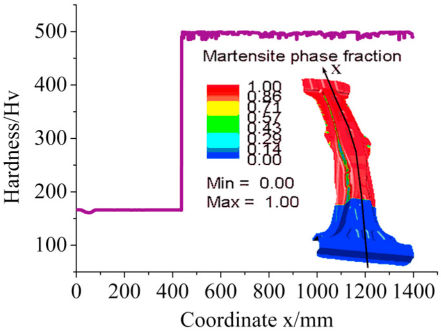

Fig. 13. Martensite volume fraction field and Vickers hardness distribution along section3 of formed B-pillar after quenching time of 7 s.

4. Conclusions

(1) Laboratory trials on hot stamping of M-shaped part using a specially-designed partition heating device were performed, producing tailored parts with average tensile strengths of 1565 MPa and 626 MPa in the high- and low-temperature regions, respectively.
(2) A FE model of the hot stamping process of M-shaped parts by partition heating was developed and validated through comparison between numerical and experimental outcomes in terms of thickness and hardness distributions.
(3) A partition heating device using a combination of induction and conduction was specifically designed to be suitable for industrial production, in order to partition heat 22MnB5 blanks for hot stamping of B-pillars.
(4) An FE model of the hot stamping process of B-pillars by partition heating was developed, and the characteristics of the part during and after stamping and quenching were analyzed.

Acknowledgements

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References

[1] M. Merklein, M. Johannes, M. Lechner, A. Kuppert, A review on tailored blanks - Production, applications and evaluation, Journal of Materials Processing Technology, 214 (2014) 151-164.
[2] K. Mori, P.F. Bariani, B.A. Behrens, A. Brosius, S. Bruschi, T. Maeno, M. Merklein, J. Yanagimoto, Hot stamping of ultra-high strength steel parts, CIRP Annals – Manufacturing Technology, 66 (2017) 755-777.
[3] M. Merklein, M. Wieland, M. Lechner, S. Bruschi, A. Ghiotti, Hot stamping of boron steel sheets with tailored properties: A review, Journal of Materials Processing Technology, 228 (2016) 11-24.
[4] K. Mori, T. Maeno, K. Mongkolkaji, Tailored die quenching of steel parts having strength distribution using bypass resistance heating in hot stamping, Journal of Materials Processing Technology, 213 (2013) 508-514.
[5] Y.H. Mu, B.Y. Wang, J. Zhou, Y. Kang, X.T. Li, Heating parameters optimization of hot stamping by partition heating for tailored properties, ISIJ International, 57 (2017) 1442-1450.
[6] P. Hu, D.Y. Shi, L. Ying, G.Z. Shen, W. Q. Liu, The finite element analysis of ductile damage during hot stamping of 22MnB5 steel, Materials and Design. 69 (2015) 141-152.
[7] Y.H. Mu, B.Y. Wang, J. Zhou, X. Huang, X.T. Li, Hot stamping of boron steel using partition heating for tailored properties: Experimental trials and numerical analysis, Metallurgical and Materials Transactions A, 48 (2017) 5467-5479.
[8] H. Warlimont, Metal forming data of ferrous alloys-deformation behavior, Vol. 2C1, Springer Berlin Heidelberg, 2009.
[9] ESI Group, PAM-STAMP 2G 2012 User's Guide (2012).
[10] M. Avrami, Granulation, phase change, and microstructure kinetics of phase change. III, The Journal of Chemical Physics, 9 (1941) 177-184.
[11] D.P. Koistinen, R.E. Marburger, A general equation prescribing the extent of the austenite-martensite transformation in pure iron-carbon alloys and plain carbon steels, Acta Metallurgica, 7 (1959) 59-60.
[12] H.H. Bok, M.G. Lee, E.J. Pavlina, F. Barlat, H.D. Kim, Comparative study of the prediction of microstructure and mechanical properties for a hot-stamped B-pillar reinforcing part, International Journal of Mechanical Sciences, 53 (2011) 744-752.
[13] D.V. Doane, Application of hardenability concepts in heat treatment of steel, Journal of Heat Treat, 1 (1979) 5-30.
[14] V. Ploshikhin, A. Prihodovsky, J. Kaiser, R. Bisping, H. Linder, C. Lengsdorf, K. Roll, New heating technology for furnace-free press hardening process, Tools and Technologies for processing ultra-high strength materials, Graz, Austria, 2011.