Original Article https://doi.org/10.4322/2176-1523.20191506

EFFECT OF THE BLANK SURFACE CONDITIONS ON THE QUENCHING BEHAVIOR OF A HIGH THICKNESS 22MNB5 STEEL IN PRESSHARDENING PROCESS

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Abstract

Weight reduction in commercial vehicles is increasingly gaining importance, following an already well established trend in the modern car structures. However, the production of high thickness structural components using 22MnB5 steel requires a more profound knowledge of the effect of increased heat and cycle time on the quality of the final martensitic microstructure. The identification of new process parameters offers additional possibilities to control and stabilize the manufacturing process. In this study, the influence of the surface condition of 22MnB5 steel samples with 8.0 mm thickness on the mechanisms that characterize heat transfer by contact is discussed, as is the correlation of this parameter in the characterization of the martensitic transformation and hardness profile. For this, the test specimens with three different surface conditions (natural, ground and polished) were heated to austenitization temperature, and subsequently processed in an experimental tool provided with cooling channels. Through the results of the metallographic analysis and hardness profile, it was verified that the cooling rate is affected by the superficial condition of the specimens, as well as the resulting martensitic microstructure. Higher austenitization temperatures promote austenite grain growth and, thus, deteriorate properties such as toughness and crack propagation resistance.
Keywords: Hot stamping; Press-hardening; 22MnB5; Heat transfer rate; Surface preparation.

EFEITO DA CONDIÇÃO SUPERFICIAL DO BLANK NO COMPORTAMENTO DE TÊMPERA DO AÇO 22MNB5 DE ELEVADA ESPESSURA NO PROCESSO DE CONFORMAÇÃO A QUENTE

Resumo

A redução de peso em veículos comerciais está ganhando cada vez mais importância, seguindo uma tendência já bem estabelecida nas estruturas modernas de carros. No entanto, a produção de componentes estruturais de alta espessura usando aço 22MnB5 requer um conhecimento mais profundo do efeito do aumento do calor e do tempo de ciclo na qualidade da microestrutura martensítica final. A identificação de novos parâmetros de processo oferece possibilidades adicionais para controlar e estabilizar o processo de fabricação. Neste estudo, a influência da condição superficial de amostras de aço 22MnB5 com 8,0 mm de espessura nos mecanismos que caracterizam a transferência de calor por contato é discutida, assim como a correlação deste parâmetro na caracterização da transformação martensítica e do perfil de dureza. Para isso, os corpos de prova com três condições de superfície diferentes (natural, retificado e polido) foram aquecidos até a temperatura de austenitização e, posteriormente, processados em uma ferramenta experimental provida de canais de resfriamento. Através dos resultados da análise metalográfica e do perfil de dureza, verificou-se que a taxa de resfriamento é afetada pela condição superficial dos corpos de prova, bem como a microestrutura martensítica resultante. Temperaturas mais altas de austenitização promovem o crescimento de grãos de austenita e, assim, deterioram propriedades como tenacidade e resistência à propagação de trinca.
Palavras-chave: Estampagem a quente; Endurecimento por estampagem; 22MnB5; Taxa de transferência de calor; Preparação superficial.

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1 INTRODUCTION

Legal guidelines related to automotive vehicles weight reduction and to the increase of passenger safety have resulted in an increasing of use of steels with a higher level of strength [1,2]. In order to meet the requirements of the environmental legislation related to CO2 emissions in the atmosphere and, simultaneously, to increase the crash-test performance, the demand for press hardened (hot stamped) parts is constantly evolving [3]. In the commercial vehicle market, the economic and environmental advantages of reducing vehicle mass can be even more significant than in the automotive market, since it translates into an increase in the transported load capacity [4]. However, there is still relatively scarce literature dealing with the problem of modern processing of thick 22MnB5 sheets (a range of 3,00mm up to 10,00mm thick), aiming to obtain high strength parts without compromising toughness and crack propagation resistance.

The hot stamping process of 22MnB5 steel requires a thorough knowledge and control of the parameters involved in forming, in order to produce high strength components with desired properties. For the hot stamping process, equipment such as presses and tooling need to be radically modified and there is also a need for new elements such as furnaces, cooling and handling systems. In addition to the adaptation of these elements to the industrial environment it is necessary to combine knowledge in all phenomena involved: thermal, elasto-plastic, mechanical, microstructural and technological [5].

The direct hot stamping process begins with the austenitization of 22MnB5 steel blank, usually in a continuous heating oven at a temperature of 950°C for a duration of 4 to 10 minutes. Immediately after the blank leaves the furnace, it is quickly transferred to a press with cooling systems integrated into the stamping tool, where forming and quenching takes place [6-8]. Advantages obtained with the process are: high mechanical strength of the final part and low springback after the process [9,10]. The mechanical strength of the material increases from approximately 340 MPa to 1500 MPa, a factor of approximately 4, which meets the needs of the current market demands [11]. The highest resistance is obtained when the final microstructure is completely martensitic [12]. Hardness and microhardness measurements can be used to verify whether fully martensitic microstructure is achieved. Lechler and Merklein [10] reported for a 22MnB5 that in order to obtain the martensitic microstructure, hardness should be approximately 470 HV minimum. For this, the cooling rate between 800 and 500°C should be at least 27°C/s [13,14].

The cooling rate can usually be accelerated by lowering the coolant temperature to increase the temperature difference between coolant and forming tool, or by increasing the contact pressure between sheet material and forming tool [15]. Especially for thick gages it is recommended to use optimized tool steel with high heat conductivity. In order to avoid immediate surface oxidation and decarburization when using uncoated 22MnB5 steel blanks, it is necessary to reduce the transfer time from the heating furnace to the press to the minimum possible [16]. According to Chen et al. [17], the oxidized and decarbonized layer on the blank surface is extremely hard and promotes accelerated wear of the stamping die.

Heat transfer rate is a determining factor in the hot stamping process, and uncontrolled temperature variations leads to changes in the microstructure and mechanical behavior of the material. It depends on the thermal resistance of the surfaces in contact, i.e. the resistance to the thermal flow between two surfaces due to the geometric irregularities of the surfaces. In turn, these irregularities cause the contact to occur at only a few points of the surfaces, thus resulting in a much smaller real contact area with respect to the apparent contact area. In this way, we can predict that the thermal contact resistance is mainly related to roughness effects of the material surface, where the thermal conductivity is low in the coexisting points of contact with voids or faults. According to Malinowski et al. [18] and Bakri et al. [19] the thermal contact resistance is dependent on the contact pressure in addition to surface roughness.

In this context, the effect of surface preparation on thermal behavior in the hot stamping processing was investigate. For this, the effect of the surface roughness of uncoated 22MnB5 steel blank with 8.00 mm thickness was evaluated using three different surface conditions: as received hot rolled surface from the steel supplier, ground and polished. Finally, a correlation was established between the surface roughness of the blank and the thermal behavior of the process. Results of hardness, cooling rate and metallography were used to characterize the quality of the test specimens.

2 METODOLOGY AND DESIGN OF EXPERIMENTS

In this study, the material used was the boron alloyed 22MnB5 steel with 8.00mm thickness. The dimensions of the specimen are shown in Figure 1 (values in millimeters).

The chemical composition of the material can be visualized in Table 1.

In order to carry out the experiments, an experimental tool set, shown in Figure 2, was designed and built. Punch and die inserts were produced using H13 hot work steel, widely used in hot working processes. The die (lower part) was designed with cooling channels to extract the heat of the test piece, similarly to real hot stamping dies.

To acquire temperature data, three K-type thermocouples with measuring range from 0°C to 1200°C connected to a Labview based data acquisition system were utilized. The thermocouples were installed as follows:

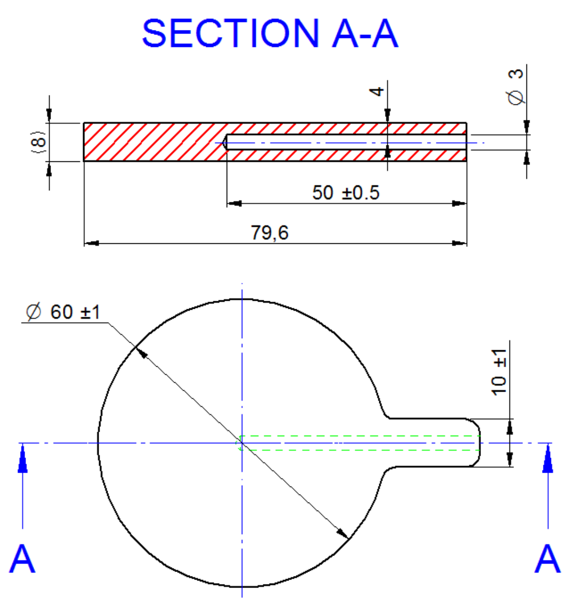

Figure 1. 22MnB5 test specimens geometry.

Table 1. Chemical composition of the 22MnB5 samples

Chemical composition	
Carbon-C(%)	0.22 - 0.25
Manganese-Mn(%)	1.20 - 1.40
Silicium-Si(%)	0.20 - 0.30
Sulfur-S(%)	0.005 MÁX
Aluminum-Al(%)	0.020 - 0.050
Chromium-Cr(%)	0.11 - 0.20
Boron-B(%)	0.0020 - 0.0035

- One thermocouple fixed to the die, positioned one millimeter below the die surface (see Figure 2).
- One thermocouple attached to the punch surface (see Figure 2).
- One thermocouple placed on a hole drilled in the half thickness of the blank (see Figure 1).

Figure 3 shows a picture of the experimental tool mounted in the press with the thermocouples. It is worth mentioning that the die was designed and built in such a way that it is supported by a spherical contact base, which guarantees a uniform contact pressure between the die, punch and test piece.

Figure 4 shows the experimental set up, consisting of a 100T hydraulic press model CNC VP Matic from manufacturer Dan Presse, a high temperature muffle furnace model BF 51848A from manufacturer Lindberg/Blue and a water chiller model R134 from the manufacturer Maqtermo.

In order to discriminate the influence of surface preparation on the cooling rate and to correlate the results with hardness and microstructure, three surface conditions were used in the test specimens: natural surface, as received from the steel mill, ground surface and polished surface. Three samples were prepared for each surface condition. Other control parameters such as soaking temperature, soaking time, specimen transfer time, coolant flow rate, contact pressure and coolant temperature was determined experimentally through the preliminary tests, and were kept constant. The contact pressure, for exemple was measurented through a load cell with the acquisition of the results through Labview software. Table 2 summarizes the process parameters used in this study.

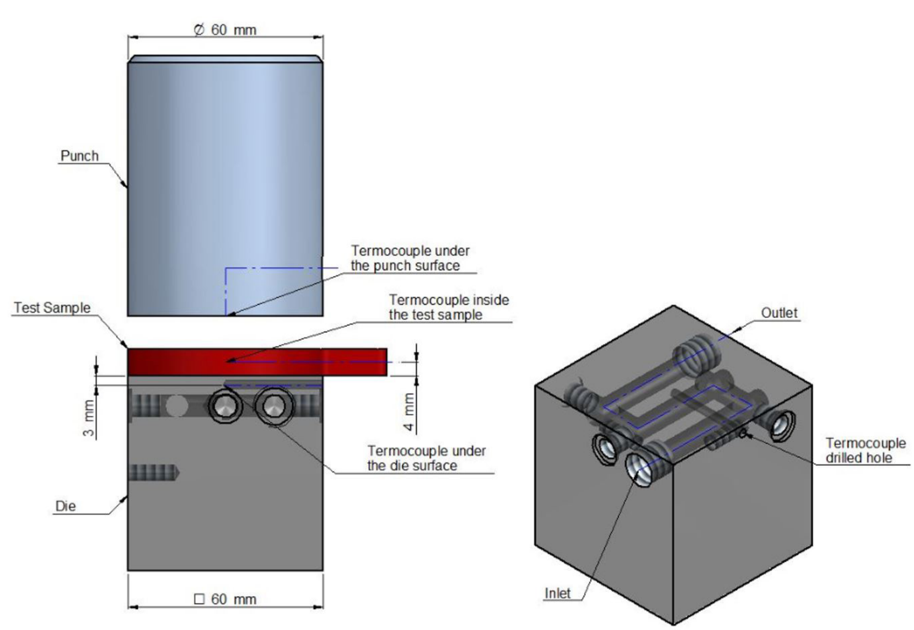

Figure 2. Experimental tool set used in the investigation, showing the position of the termocouples (on the left) and the cooling channels (on the right).

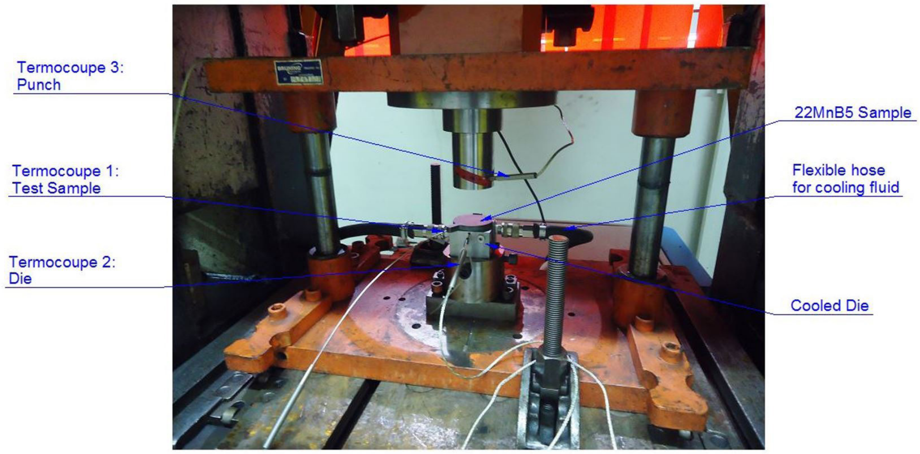

Figure 3. Picture showing the experimental tool and the termocouples.

Figure 4. Pictures showing the experimental setup and the equipment used. A) Front view showing hydraulic press with test tool, data acquisition system and furnace. B) Rear view showing the cooling unit.

Table 2. Tested process parameters

Specimen	Surface preparation	Soaking temperature	Soaking time	Specimen transfer time	Cooling fluid flow rate	Contact pressure	Coolant temperature
[#]	[-]	[°C]	[min.]	[s]	[l/min.]	[Mpa]	[°C]
1	Natural	1000	5	<7	12.6	100	5
2							
3							
4	Ground						
5							
6							
7	Polished						
8							
9							

The roughness parameters Ra and Rz were used for characterizing the surface of the test pieces. Ra and Rz were measured at three different locations in each face of the specimens, in longitudinal and transverse directions, using a surface profile measuring gauge with cut-off length = 0,8x5. Figure 5 shows the average roughness of the three measured locations, for both faces and the two measuring directions for each specimen surface preparation.

In the test procedure, specimens were austenitized at 1000°C for 5 minutes, allowing for a complete and

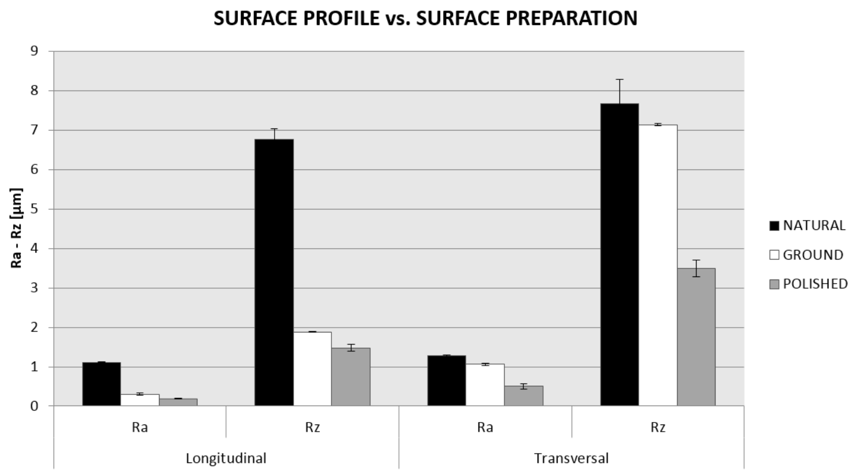

Figure 5. Average specimens surface roughness.

Table 3. Test results in the calculation of the cooling rate

Specimen	Surface preparation	Soaking temperature	Forming start temperature	Coolin time down to 430°C	Mean cooling
[#]	[-]	[°C]	[°C]	[s]	[°C/s]
1	Natural	971	951	19	29
2		961	941	20	26
3		951	916	18	29
4	Ground	935	895	17	30
5		977	924	16	35
6		970	944	19	28
7	Polished	978	967	14	39
8		982	948	16	35
9		960	929	17	31

homogeneous transformation to austenite, and then rapidly transferred to the tool (transfer time was less than 7 seconds). The transfer was carried out manually. A specific clamp was used for the task, guaranteeing stability during the transfer and providing safety for the operator.

3 RESULTS AND DISCUSSIONS

3.1 Cooling Rate

The cooling rate for each condition tested was obtained from the temperature values acquired and stored by the data acquisition system. Calculation of the cooling rate was performed by subtracting the temperature values between the moment the specimen was placed on the matrix and the martensite formation start temperature (T = 430°C) [20]. Then, the result was divided by the cooling time between these temperatures. Table 3 shows the results obtained.

The average cooling rates for the three specimens of each surface condition evaluated are shown in Figure 6.

It can be seen in Figure 6 that in all tests the cooling rate lies above 27°C/s. For 22MnB5 steel, cooling rates greater than 27°C/s form a microstructure composed of 100% martensite [12,13]. In the natural crude surface condition, the values of the cooling rate are very close to 27°C/s. An increase of this rate is observed in the ground and polished surface conditions, the latter being the highest cooling rate. This fact can be justified by the effect of the lower surface roughness in this condition, showing an increase of near 20% in the contact area.

3.2 Metallographic Analysis

A scanning electron microscope (SEM) model Tescan Veja 3LM was used for the metallographic analyzes of the specimens. The specimens were properly prepared and etched with Nital 4%. Figure 7 shows the microstructure of sample 3, with the natural surface condition.

The sample shown in Figure 7 presents a microstructure composed basically of martensite. This was expected since the sample was cooled at cooling rate above 27°C/s and a

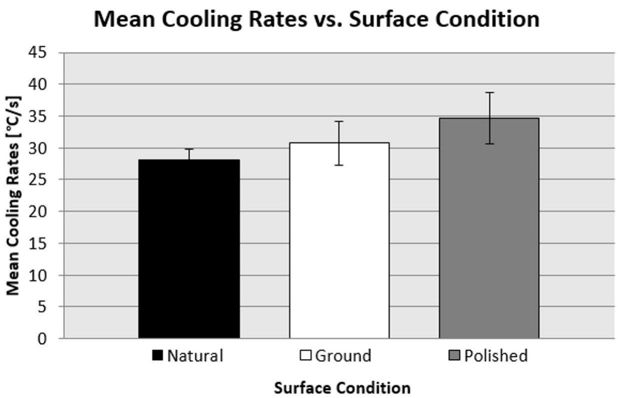

Figure 6. Mean values of the cooling rates for the tested surfaces.

quenching temperature above 780°C. The microstructure is basically constituted by martensite laths (characteristic for low carbon steel), presenting a certain amount of finely dispersed carbides in the martensitic matrix. In addition, coalesced martensite plates are observed.

Figure 8 shows the microstructure of sample 5, with ground surface condition. The cooling rate for this sample was 35°C/s and the quenching temperature was 924°C.

In Figure 8, the microstructure is basically composed of martensite. Similarly to the previous sample, the microstructure is basically constituted by martensite laths (characteristic for low carbon steels), presenting a certain amount of finely dispersed carbides in the martensitic matrix.

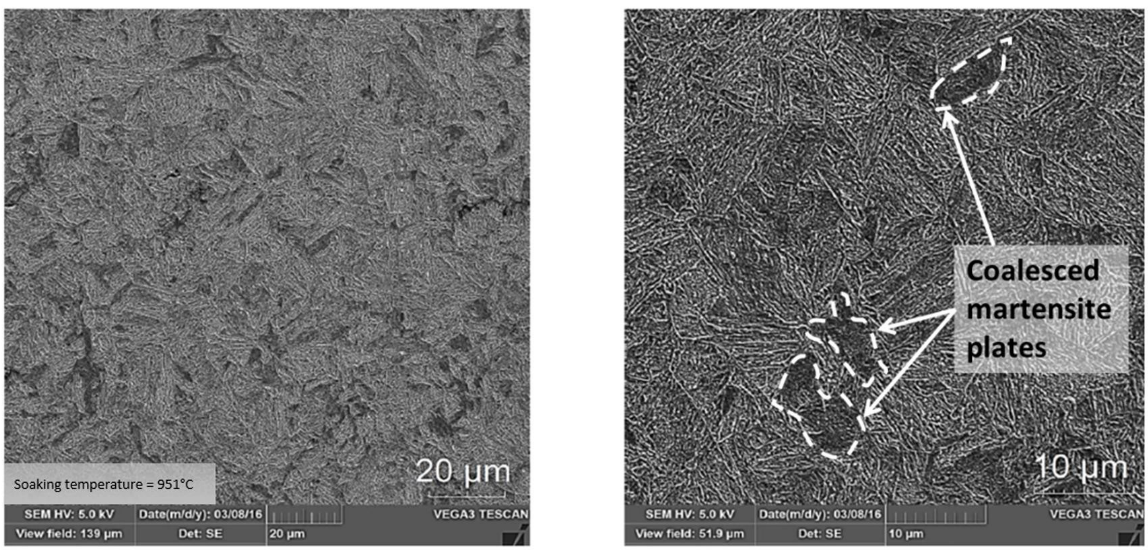

Figure 7. Microstructure of the sample processed with natural surface condition.

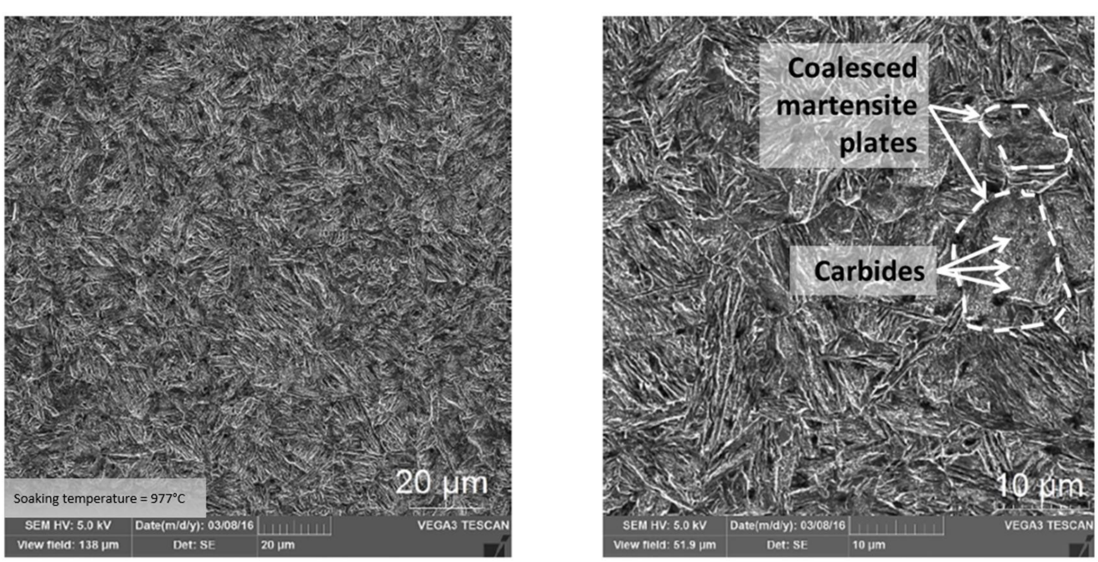

Figure 8. Microstructure of the sample processed with ground surface condition.

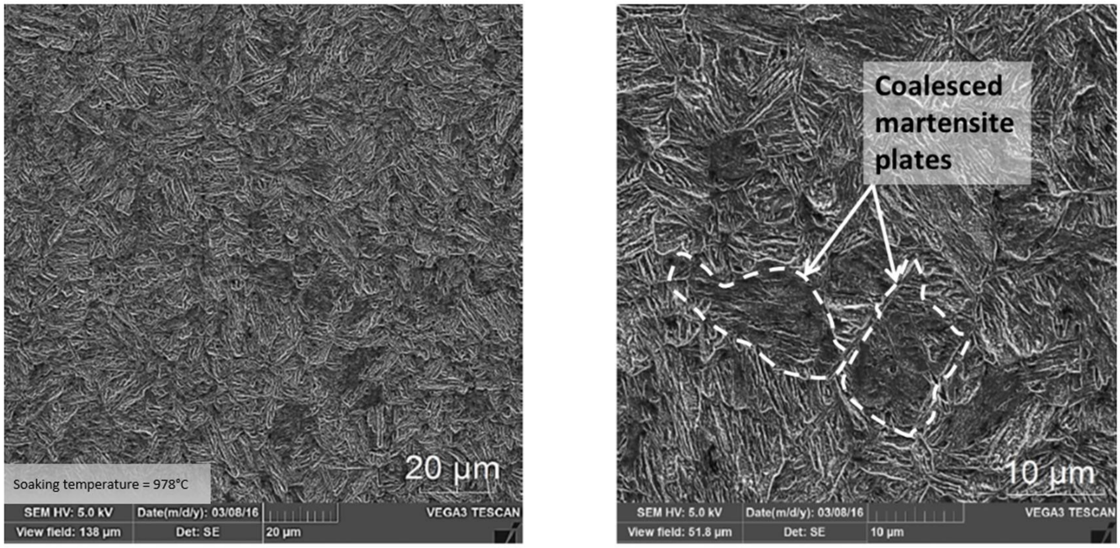

Figure 9. Microstructure of the sample processed with polished surface condition.

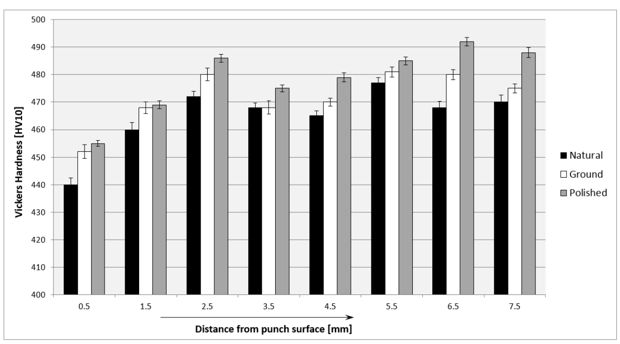

Figure 10. HV10 Hardness profile of the samples, starting on the punch side.

In this case, relatively higher coalescing martensite plates can be identified.

Figure 9 shows the microstructure of the third surface condition investigated in this work, namely the polished surface condition. This sample was annealed at cooling rate of 39°C/s and a quenching temperature of 967°C.

Again, the microstructure is basically constituted by martensite laths (characteristic for low carbon steels), presenting a certain amount of finely dispersed carbides in the martensitic matrix. The heat treatment parameters chosen in this case produced the largest coalesced martensite plates observed.

Comparing the micrographs obtained for the different cooling rates, no evidence was found that higher cooling rates could minimize the presence or decrease the size of these anomalous martensite plates. In contrast, the samples with higher cooling rates had the largest coalesced martensite plates. However, the size and quantity of these plates is not related to the cooling rate, but to the austenitization temperature. Romero and Bhadeshia [21] observed that when the austenitic grain size was reduced, the size of the coalesced martensite plates were considerably reduced. Higher austenitization temperatures promote austenite grain growth and, thus, favor the appearance of these anomalous martensite plates. The presence of these martensite plates is associated with a deleterious effect on the steel toughness, since these plates are crystallographically homogeneous and, therefore, offer little resistance to crack propagation by cleavage.

3.3 Hardness Profile

Eight indents along the thickness of each sample, in its central region, were performed, using a machine EmcoTest DuraScan. Vickers HV10 scale was used. The indents were equally distributed with 0.5 mm spacing between each point, starting 0.5 mm from the sample surface in contact with the punch (upper side) and ending near to the surface in contact with the die (lower side). It is important to mention that the cooling channels were present only on the die (lower side, see Figure 2). Figure 10 presents the average values of hardness of the samples.

From the results shown in Figure 10 it is evident that, for all the samples, the hardness increases with the proximity of the cooled die, where the cooling rate reaches its maximum value. Furthermore, the sample with polished surface shows a slight tendency of increase in hardness, confirming that the surface preparation of the samples has influence on the thermal contact resistance. Another important issue regarding press hardening of thick sheets is the hardness alongside the thickness. It was expected a stronger decrease in hardness in the middle-thickness region but, as Figure 10 shows, the hardness decreases only minimally from the die (cooled) surface until 2,5 mm from the punch surface, falling substantially thereafter.

4 CONCLUSIONS

In the present study three different surface conditions of 22MnB5 sheets with 8.00mm thickness were tested by hot stamping process simulations. Analysis and comparison of the thermal behavior and quality of the samples tested allowed the following conclusions:

- Despite of the high thickness of the samples, all tested conditions presented a cooling rate exceeding 27°C/s.
- The cooling rate is directly related to the surface roughness of the samples, where lower surface roughness results in higher cooling rates.
- The polished surface condition was the condition that produced the highest rate of cooling. With this, it is noticed that the martensite formed in this condition had the highest hardness value.
- In general, this study contributes for a better understanding of the thermal behavior in the press hardening process of high thickness sheets. Additionally, it shows the importance of the thermal contact resistance as a parameter for process optimization, showing that the die surface quality must be controlled in order to improve the overall process efficiency.
- The resulting microstructure of the samples suggests that there are room for improvements in press hardening steel formulations for the production of thick components. These improvements should be directed to the achievement of a more refined microstructure prior to quenching (smaller austenitic grain size), hence contributing to a better toughness of the part.

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Received: 28 Ago. 2017
Accepted: 13 Mar. 2018