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HOT STAMPING SIMULATION ON GLEEBLE THROUGH THERMOMECHANICAL CYCLES: A BIBLIOGRAPHIC REVIEW

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ABSTRACT

Steel sheet hot stamping technology is based on the simultaneous mechanisms of plastic forming and quenching heat treatment. The blank in the austenitized condition is shaped and, simultaneously, quenched, due to the contact with the cooled die. The aim of this process is to induce the complete martensitic transformation of the stamped steel. Currently, simulations of the thermomechanical cycles achieved in hot stamping can be performed using the Gleeble testing machine. However, the Faculty of Mechanical Engineering at UNICAMP does not have this equipment to carry out these tests. In this context, the researchers of the FME intend to develop a cooling module to be coupled to the universal testing machine MTS 810 available at the Mechanical Testing Laboratory at FME, in order to simulate the quenching during hot stamping. For the testing and validation of the prototype to be developed, the following work aims to present a bibliographic review that analyzes research carried out in the area, having as a final result a set of experimental parameters that will be applied to the newly designed cooling module, such as heating and cooling rates, holding times and temperatures, strain rates and Gleeble gas pressure to achieve the required thermomechanical conditions of hot stamping.

Keywords: *Gleeble, hot stamping, controlled cooling, quenching, tensile test.*

INTRODUCTION

Given the growing concern about environmental issues, factors such as limitations on greenhouse gas emissions, energy efficiency, vehicle safety and weight reduction of automotive vehicles are increasingly in the spotlight of the automotive sector. With this in mind, the use of advanced materials with properties that meet this demand is an increasingly requested and urgent reality(1). In this scenario, the application of automotive parts produced by hot stamping of sheets is a growing trend. This technology is based on plastic forming and quenching the sheet, resulting in a martensitic microstructure of the stamped steel. The direct hot stamping process begins with heating the blank to a temperature above its austenitizing temperature and remaining in the furnace until complete transformation. Then, the blank must be transferred as quickly as possible to the die in which the plate is formed and cooled until complete martensitic transformation of the part.

As the die for automotive parts is large, being cooled by internal cooling channels(2) and the sheet under deformation often does not have uniform thickness (as in regions with two welded sheets and/or with heterogeneous stretching during the process), the cooling is not the same throughout the part. Thus, in order to better study the cooling rates and their impacts on the steel structure, in addition to the analysis of critical efforts, it was necessary to replicate this thermal cycle at the laboratory level. The structure available at the Faculty of Mechanical Engineering at UNICAMP does not include a device that allows this simulation to be carried out. For this reason, the researchers of the FME are developing a cooling module, adapted from the work of Omer et al. 2017[3], to be coupled to the universal testing machine, making possible the controlled cooling of the heated sample simultaneously with the tensile test. In a first step, for project validation, a bibliographic review was carried out to support the determination of some input parameters of the experimental phase and to compare the final results. This review is the focus of the present work.

MATERIALS AND METHODS

The literature review presented here is a simplified application of the methodology developed by Tranfield, Denyer, and Smart, 2003[4]. The initial phase of the review consisted of research on the "Web of Science" platform, chosen due to its comprehensive number of articles available for access. The research was carried out between August 8 to 10, 2022. The results were obtained by combining the following search keywords: "Gleeble"+"hot stamping"+"microstructure". These words were searched as "topic" on the platform, to cover the largest number of results, from the title to the scope of the articles searched.

The keywords were chosen in order to effectively cover the information of interest. "Gleeble" was chosen because the equipment aims to simulate the applications of this machine. "Hot Stamping", since this process contains the steps that determine the final microstructure of the sample. "Microstructure" because it is intended to obtain a certain result whose evaluation criterion is the final microstructure of the material. A total of 25 articles[5-30] were found with the chosen search keys. Due to the small amount of articles found, all of them were included in the data analysis.

RESULTS AND DISCUSSION

A priori, an analysis of the results obtained by the collected data was performed. In the graph of Figure 1 it is possible to verify that all the works obtained in the research were published within the last 13 years. The oldest article on the subject is from 2009 and the years that presented the larger number of published works were 2014 and 2016. Therefore, it can be concluded that hot stamping is a recent research topic with few studies carried out, with growing interest. Figure 2 presents an analysis of publications by homeland. The country in which the most papers on the topic of interest were published was China, with 17 studies. In second place, England appears, with 6 studies. The difference between first and second place is quite large (11 publications). This difference shows China's interest in this line of research, as the country is one of the largest steel producers in the world and the world's largest producer of vehicles.

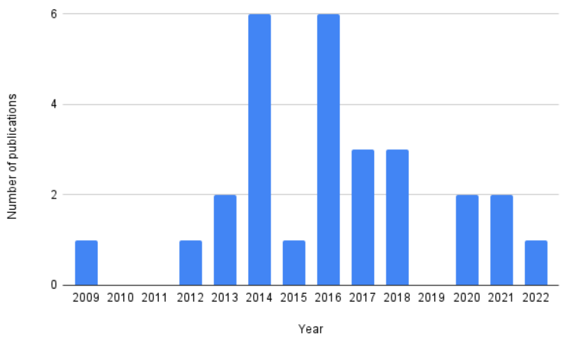
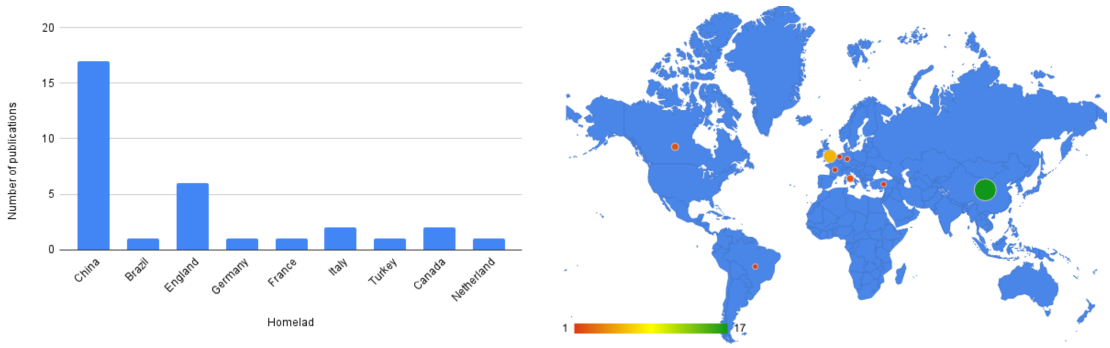


Figure 1. Number of publications per year.



(a) (b)

Figure 2. Number of publications per homeland: (a) graphic; (b) map.

With regard to the content of the published works, in general, the aim is to obtain microstructures and, consequently, optimized mechanical properties (plasticity, hardness, resistance, etc.), studying the phase transformations acting during hot stamping and mechanisms of action on these transformations, such as process parameters (especially thermal cycles). Two works presented particular topics: In one of them[16], a device for thermomechanical tests was developed, simulating with greater precision the stresses and thermal cycles acting in hot stamping. In another[26], a time-dependent springback prediction (with stress relief effect) observed in hot stamped sheets was performed.

Regarding the materials studied in the hot stamping research, it was observed that most of the works address boron steels[11, 16, 18, 23, 27], especially the 22MnB5 steel[5-7, 12,, 20, 24, 25], since both boron and manganese act to improve the hardenability of steels, and boron also helps to obtain hardness levels necessary for the required performance of automotive components. In addition, there are studies with ultra-strength steels and with transformation-induced plasticity (TRIP) steels, both types are manganese-rich[8, 9, 14, 15, 19, 21, 29], Ti alloys[26, 28] and Al alloys[22]. Studies focusing on the coating of sheets subjected to hot stamping are also noteworthy, such as the work by Gui et al., 2014[10], which studies the interaction between the elements present in the coating of the sheets (in this case, Al-Si) with the core material (ferrous alloy), in the transformation of an Al-Fe intermetallic; and the work by Liang et al., 2017[17], in which the influence of heating parameters on the properties of the Al-Si coating applied to sheets for hot stamping is analyzed.

The characterization techniques used in the studies range from microstructural analysis by light optical microscopy[5-7, 9, 12, 14, 15, 19, 21, 23, 26-29] and scanning electron microscopy[10, 11, 15 , 17, 28-29), EBSD[15], X-ray diffraction[11, 15, 17], 3D surface topography[10, 17], mechanical tests such as hardness[5, 6, 14, 15, 23, 29], tensile tests[6-9, 11, 12, 14-16, 18-29], creep tests[20], formability tests[22-24], fractography[10, 11, 21, 29], dilatometry[13, 15, 18, 28], to modeling and computer simulations[6-8, 12, 14, 19-20, 22-26, 29]. One of the studies stands out by using the non-destructive technique of Barkhausen's magnetic noise[27] to detect mixed microstructures (bainite/martensite) in hot-stamped sheets.

Since the thermal cycles applied in hot stamping are dependent on the materials of the stamped sheets, the 22MnB5 steel was chosen (same material to be tested in the device that will be built in the future at FME-UNICAMP) for analysis of the parameters applied at Gleeble. The thermomechanical cycle model for simulating hot stamping is shown in Figure 4 and the respective parameters are shown below in Table 1, with A being the pre-strain applied to the blank (%), B the heating rate (K/s), C the austenitization temperature (K), D the austenitization holding time (min), E the initial cooling rate (K/s), F the holding temperature during cooling (K), G the strain rate applied during stamping (s^{-1}), H is the holding time on cooling (s), I is the rapid cooling rate at the end of the process (K/s) and J is the Gleeble air pressure (10^5 MPa): except when not applicable (NA) to the experimental setup, such as, for example, the non-relevance of the secondary cooling rate when analyzing the creep behavior of the material, or when not informed (NI) in the papers.

Table 1. Parameters of the thermomechanical cycle used in experiments with Gleeble to simulate the hot stamping process.

Reference	A	B	C	D	E	F	G	H	I	J
5	0 - 17	NA	1223	4	18 - 25	873 - 1073	0	1 - 2	3,6 - 100	1 - 8
6	0	15	1173	5	30	693 - 1173	0.1 - 0.5	NA	30 - 90	NI
7	0	NA	1562 - 1742	2 - 10	NA	1202 - 1562	0.1 - 1.0	NA	NA	NI
12	0	15 & 5	1697	3	50	1292 - 1652	0.01 - 10	10	air cooling	NI
20	0	10	1652	3	50	1202 - 1562	0.01 - 1.0	NA	NA	NI
24	0	10	1292 - 1652	4	30	1202 - 1562	0.1 - 10	10	50	NI
25	0	10 & 5	1223	1	60	973 - 1223	0.02 - 0.2	NA	NA	NI

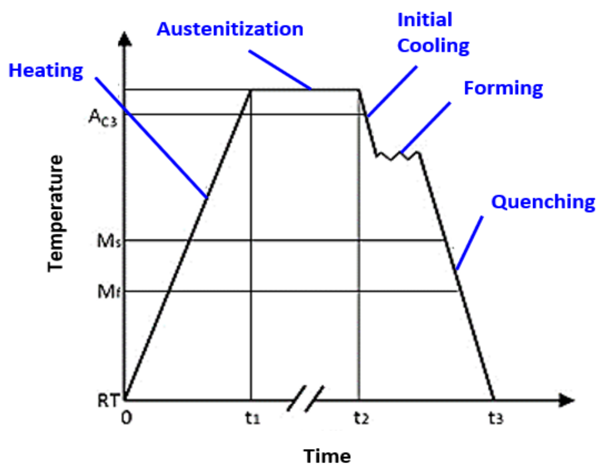


Figure 4. Thermomechanical model cycle for hot stamping simulation.

CONCLUSIONS

The literature review using the search terms “hot stamping” + “gleeble” + “microstructure” in the Web of Science database enable the achievement of an overview of the thematic research approaches, the publication trends, the homeland of the published articles, the most studied metallic alloys, the most applied characterization techniques and the usual parameters of the thermomechanical cycles that simulate the hot stamping operation in terms of heating and cooling rates, holding times and temperatures, strain rates and gas pressure of the cooling device. Then, a wide range of relevant information was obtained for carrying out the tests and validation of the cooling module to be coupled to the universal testing machine (MTS) under development at FME-UNICAMP.

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