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Investigation and Comparison of Process Parameters for Advanced High Strength Steels for Next-Generation Vehicles

Ebru Barut[*1,2], **Aysegul Akdogan Eker**[1], **M. Emre Kaymak**[2]

[*1] Institute of Science and Technology, Mechanical Engineering, Yildiz Technical University, Istanbul
[2]Research and Development Center, Toyotetsu Automotive Parts Industry and Trade Inc., Kocaeli

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Austenitizing temperature,
Soaking time,
22MnB5,
Mechanical properties,
Microstructure.

Abstract: Innovations are now required in the automotive industry, as well as in many other industries, due to environmental concerns and initiatives to minimize greenhouse gas emissions. The use of lightweight materials has grown for this purpose and specifically created new generation high-strength steels have begun to be used. In this work, the hot stamping method was used to examine the impact of process variables on the mechanical characteristics and microstructures of materials from two different steel manufacturers. The outcomes of varying the soaking time and austenitizing temperature were examined in order to analyze the process conditions. The analyses led to the selection of 890°C as the ideal austenitizing temperature and 240s as the ideal soaking time in the furnace. It was found that as the soaking time in the furnace decreased, it improved the microstructure and indirectly the mechanical characteristics. At 890° 240s parameters, the tensile strength of MAT1 material increased by 14.52% compared to MAT2 material. MAT1 material showed a high tensile strength of 1.34% for 240s at the same temperature at different times. This study has the feature of guiding the determination of the optimum parameters for the materials of different manufacturers starting from the manufacturing stage and then in the material selection stage.

Yeni Nesil Araçlar İçin Gelişmiş Yüksek Mukavemetli Çeliklerin Proses Parametrelerinin İncelenmesi ve Karşılaştırılması

Anahtar Kelimeler
Östenitleşme Sıcaklığı,
Bekletme Süresi,
22MnB5,
Mekanik Özellikler,
Mikroyapı.

Öz: Çevresel kaygılar ve sera gazı emisyonlarını en aza indirmeye yönelik girişimler nedeniyle artık birçok sektörde olduğu gibi otomotiv endüstrisinde de yeniliklere ihtiyaç duyulmaktadır. Bu amaçla hafif malzemelerin kullanımı artmış ve özel olarak oluşturulan yeni nesil yüksek dayanımlı çelikler kullanılmaya başlanmıştır. Bu çalışmada, iki farklı çelik üreticisinden alınan malzemelerin mekanik özellikleri ve mikro yapıları üzerindeki proseste kullanılan parametrelerin etkisini incelemek için sıcak şekillendirme yöntemi kullanılmıştır. Proses koşullarını analiz etmek için bekletme süresi ve östenitleşme sıcaklığının değiştirilmesinin sonuçları incelenmiştir. Analizler sonucunda ideal östenitleşme sıcaklığı olarak 890°C ve ideal fırın bekletme süresi olarak 240 s seçilmiştir. Fırında bekletme süresinin azalmasının mikroyapıyı ve dolaylı olarak mekanik özellikleri iyileştirdiği gözlenmiştir. 890° 240s parametrelerinde MAT1 malzeme çekme mukavemeti MAT2 malzemeye göre %14,52 artmıştır. Aynı sıcaklıkta farklı sürelerde MAT1 malzemesi 240s için %1,34 yüksek çekme mukavemeti göstermiştir. Bu çalışma, farklı üreticilere ait malzemeler için imalat aşamasından başlayarak malzeme seçimi aşamasında optimum parametrelerin belirlenmesinde yol gösterici niteliktedir.

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*Corresponding Author, email: barutebru@gmail.com

1. Introduction

Environmental regulations, fuel economy standards and expectations for high performance standards are all growing for the automotive industry [1]. Researchers are looking for ways to employ clean energy and lower gas emissions due to factors including rising costs of gasoline globally and environmental damage brought on by fuel consumption. The usage of lightweight materials in the automobile industry is seen as an environmentally sound, widely used method of lowering gas emissions [2].

Part design, method and material are recognized as the major issues that guide the literature and R&D research in the automotive industry. The fundamental needs in this area are the utilization of modern production processes, material selection, and structural optimization, which includes size, form, and topology optimization. It is expected that the energy absorbing capabilities of the parts will be good in accordance with the safety standards in order to ensure passenger and occupant safety, even though lightness is an important criterion in the design, material selection, and manufacturing phase of the components to be used in the automotive. To verify their level of safety and energy absorption, crash tests are performed [3, 4].

According to both simulation activities and real-world research, high strength steels, aluminum and magnesium alloys and composite materials have recently been selected for weight reduction in part lightening studies [3]. The best category to choose from when selecting materials is advanced high strength steels (AHSS), which exhibit high strength values as well as their elongation qualities [5]. As structural and safety elements, the AHSS steel group is utilized in the vehicle chassis and body parts such as the A-pillar, center pillar (B-pillar), in-door safety bars, bumper, roof, and seat arches. When compared to mild steels, AHSS offers about 50% more lightness. With the use of 40–50% of the most sophisticated high strength steels, gas emissions are reduced by 5% [6].

The most popular process for creating modern, high-strength steels is hot stamping. The processes of hot forming, cooling, and phase transformation make up the hot stamping process. Due to the martensite microstructure of the finished product, 22MnB5 is the most desired steel in the automobile industry due to its excellent mechanical qualities, weldability, and cost factors. The yield and tensile strengths of the press-hardening steel group 22MnB5 can, respectively, reach 1000 MPa and 1500 MPa levels after stamping. It is feasible to differentiate the material's microstructure and its physical, chemical, and mechanical properties by altering the hot stamping process parameters [7–10]. By adjusting the process settings, certain papers in the literature analyze the mechanical and microstructural features.

Using 22MnB5 steel, Chang, Z. et al. heated the steels to 900°C to complete the austenite phase transition. Once austenitization was complete, the steels were chilled under various cooling conditions, including water, oil, and pressure. Additional heat treatment included tensile and V-notch impact tests, as well as an examination of the microstructures of the steels that had been heated to 170 °C for 20 minutes. The temperature at which martensite crystallizes, or Ms, was lowered by nano-sized ε-carbide formation while the values for ductility and toughness rose by 0.36%C [11].

The microstructures created under various air cooling and quenching circumstances were evaluated by Mandal, G. et al., and the mechanisms that improve the strength in the internal structure were investigated, in order to examine the structure-property relationship for 2 GPa microalloyed ultra-high strength materials. Dislocations and carbide/ carbonitride precipitates have been shown to produce strength-increasing processes in microstructure. The ensuing bainite and martensite structures were studied, and under various conditions, the steel's elongation values improved to values of 8–9% with a strength of 1841–1928 MPa. The steel originally had a strength of approximately 1991–2032 MPa with an elongation of 5-7% [12].

In order to optimize the process parameters during hot forming, the 22MnB5 material used in automotive components was shaped and subjected to a quenching procedure in the study by Aqida, S. The samples were heated to 950°C to generate austenite. The study's control parameters, including cooling water temperature, press (holding) time, and water flow rate, were established. The obtained samples were evaluated mechanically by taking tensile and hardness measurements, as well as metallurgically under an optical microscope. The study's findings indicated that shortening the chilling period was the best option, and as a result, the yield and shrinkage values—which raised the hardness value—were determined to be 1546 and 1923 MPa, respectively [13].

The variation in the microstructural features and mechanical properties of hot-formed 22MnB5 steels under various heating settings was investigated by Cavusoglu, O., et al. Within the parameters of the investigation, air cooling, quenching, and quenching+ tempering operations were applied to the steel samples heated in the furnace at 700°C, 800°C, and 900°C. Tensile testing and hardness measurements were used to understand their mechanical characteristics while an optical microscope was used to examine their microstructures. The finest mechanical qualities were obtained by cooling in water at a temperature just around 800 °C. Additionally, it was found that the tempering procedure, which was followed by water chilling, marginally raised the overall elongation value, with elongation values ranging from 2 to 4 percent [14].

The impact of austenitization parameters on the mechanical characteristics and microstructure of Al-Si coated PHS (press hardening steel) steels was examined by Golem, L., et al. in their study. The austenitization temperature and soaking time effects on the 22MnB5 material were explored in the study. The primary austenite grains were found to be more evenly dispersed as the waiting period and furnace temperature increased, and the diffusion between the substrate material and coating layer also grew. By using tensile, double notch, and bending tests, mechanical properties were examined. The mechanical properties were adversely impacted by the development of primary austenite grains, and a decline in the toughness value was noted [15].

The impact of heating and cooling process parameters on the microstructure and mechanical characteristics of 22MnB5 steels was studied by Jiakai, S. By analyzing the structure of high-strength steels used in automotive, the study aims to investigate the characteristics of customized (various strength levels on the same part) and its impact on vehicle weight reduction. The temperature value after heating in the furnace was lowered to 720°C for this reason. Tensile strengths were thus measured starting at 1500 MPa and decreasing to 570 MPa values. The study found that various temperature and cooling rates led to the development of sections on the center pillar of the vehicles that had varying strengths and hardness. This effect was produced on the same part by adjusting the process parameters rather than connecting various sections together by welding [16].

The phase transition effect on 22MnB5 high strength steel suited for hot forming was investigated by Venturato, G., et al. under various process conditions. In order to create the martensite phase, the sheet materials were heated to the austenitization temperature, formed in the die, and then chilled at the slowest possible rate which is about 27°C/s. The continuous cooling transformation curves, heated at 850°C, 900°C, and 950°C, were examined for this purpose. These curves led to the conclusion that the cooling rate and quenching in the die altered the flow stress dependent on the rate of the bainite transition and that 550°C was a key temperature for the phase change [17]. General analyses of the research in the literature have revealed that they are designed around structure-property relationships.

In this study; different austenitization conditions were chosen, specifically for 22MnB5 steel, which is most frequently used in hot forming, and changes in mechanical properties and microstructure were seen with the modification of process parameters. No study comparing the materials of various steel manufacturers for the same steel material has been found in the literature, and this study aims to fill that gap. In the current article, the materials from the same steel group from two different steel manufacturers were chosen in order to examine the microstructure and mechanical qualities produced as a result of various production circumstances.

2. Material and Method

2.1. Materials

Steels from two different steel manufacturers were used in the experimental experiments called MAT1 and MAT2. Company information has been kept confidential for ethical and commercial reasons. Table 1 displays the materials' chemical make-up as employed in the experimental tests. Only the manufacturers and production processes of the two steels utilized change; both are members of the new generation advanced high-strength steel family, also known as 22MnB5. The impact of this discrepancy on mechanical characteristics and microstructure was examined in the experimental study.

Tablo 1. Chemical Compositions of Steels

Steel Type	C%	%Mn	%Si	%Ti	%P	%S
MAT 1	0,183	1,280	0,184	0,039	0,009	0,002
MAT 2	0,275	1,310	0,225	0,031	0,011	0,002

2.2. Hot Stamping Process

The hot stamping method is a forming method in which the internal structure of the material changes greatly depending on the process conditions. Figure 1 is a schematic illustration of the hot stamping method employed in experimental research. To obtain the austenite microstructure, the steel sample is placed into an industrial furnace and heated around the A3 curve while taking into account the time-temperature-transformation diagram of pure iron.

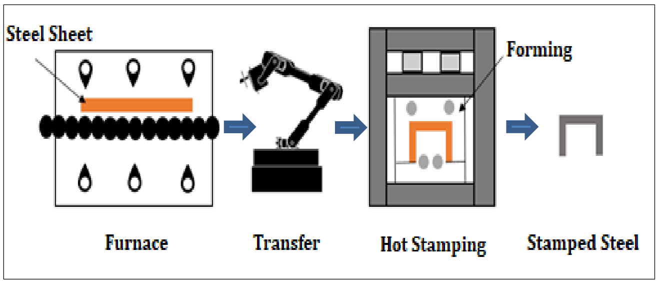

Figure 1. Schematic of Hot Stamping Process

To analyze the final microstructure of the austenitizing temperature, three different austenitizing temperatures—870, 890, and 910 °C—were chosen for this investigation. Three alternative periods, 240, 480, and 720 seconds, were chosen to study the impact of the steel sample's soaking time in the furnace on the final microstructure. The rate of cooling is 30 °C/min. The steel samples were heated to various temperatures up to the austenite transformation area, as shown in Figure 2, then cooled by holding them in the furnace for various lengths of time. The material was plastically deformed up to the martensite starting temperature (Ms) in the microstructure during the cooling process, which took the form of cooling in water. After 8 seconds, the samples were taken out of the die and allowed to cool in the air until the temperature (Mf) at which the martensite transition was complete. The collected samples were set up for the tests to be performed in accordance with the test requirements.

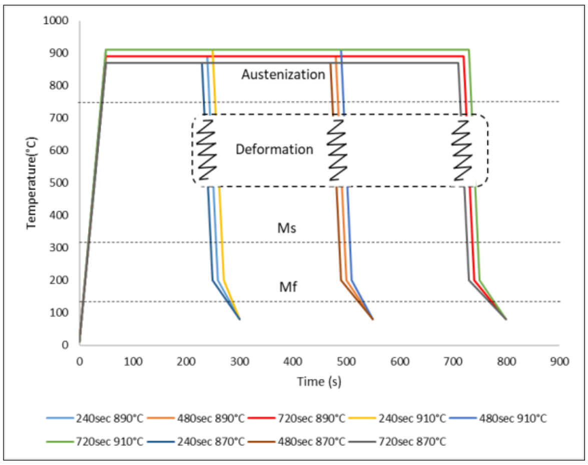

Figure 2. Thermal Cycle of Experimental Hot Stamped Steels

2.3. Test Methods and Sample Preparation

The steel sheet material that is produced by the hot stamping technique has the following measurements: 988x225x1.4 mm. By using the laser technology to cut the steel sheet material in line with the necessary criteria, test samples were created.

2.3.1. Tensile Test

According to TS EN ISO 6892-1 test standards, uni-axial tensile tests on test samples were conducted [18]. As seen in item a) in Figure 3, the test samples were made by cutting at 0°, 45°, and 90° in accordance with the rolling direction. They were then examined as described in item b). The test was conducted using an Instron floor-type biaxial extensiometer tensile-compression tester with a 250kN capacity.

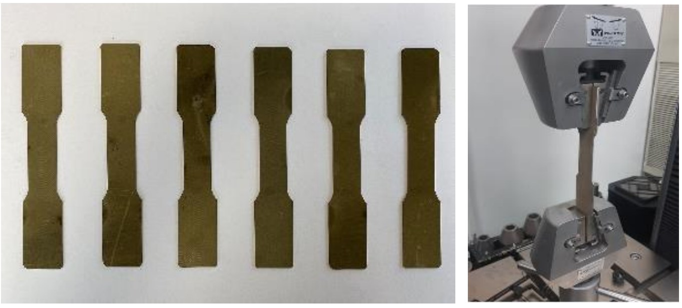

Figure 3. Tensile Test a) Samples b) Real Conditions Test

2.3.2. Hardness Measurements

According to TS EN ISO 6507-1 regulations, the test samples' hardness was evaluated using a Mitutoyo HV-100 A type Vickers hardness measurement apparatus [21].

2.3.3. Hole Expansion Ratio

In plastically deformed parts, areas with cut edges and fractured regions may vary depending on the sheet material's ductility and formability characteristics. High-strength automobile steels that have recently been created make these distinctions even more obvious. It is an experimental metal forming process simulation known as the "Hole Expansion (HE) - hole expansion" experiment that compares the production of cracks that take place during shaping of cut edges. The test is conducted using the guidelines established in the ISO 16330-2009 and TSG2309G standards [19, 20]. As shown in Figure 4, a conical punch is used to widen the hole that was drilled in the centre of the 10x10 mm2 square-cut samples until a crack forms that travels along the section. A measure of formability is the rise in the percent expansion ratio in the hole diameters produced as a result of this application.

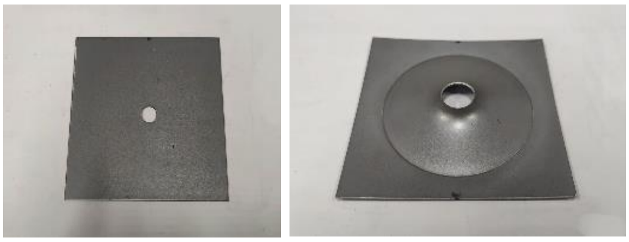

Figure 4. Hole Expansion Ratio a) Sample Before Test b) Sample After Test

2.3.4. Microstructure Analyses

On a Phenom XL model instrument of the Phenom-World brand, SEM analyses of the test samples were carried out. The test samples were initially mounted in bakelite and subjected to surface grinding before SEM examination. The prepared surfaces were made ready for imaging by polishing and etching procedures, respectively.

$$\begin{aligned}\mathrm{Ac3} = 910 - 203\mathrm{C} - 15.2\mathrm{Ni} + 44.7\mathrm{Si} + 104\mathrm{V} + 31.5\mathrm{Mo} + 13.1\mathrm{W} - (30\mathrm{Mn} + 11\mathrm{Cr} + 20\mathrm{Cu} - 700\mathrm{P} \\ - 400\mathrm{Al} - 120\mathrm{As} - 400\mathrm{Ti})\end{aligned} \tag{1}$$

$$\mathrm{Ac1} = 723 - 10.7\mathrm{Mn} - 6.9\mathrm{Ni} + 29.1\mathrm{Si} + 16.9\mathrm{Cr} + 290\mathrm{As} + 6.38\mathrm{W} \tag{2}$$

3. Results

The Ac1 temperatures for the MAT1 and MAT2 samples utilized in the experiment are 718.52°C and 717.67°C, respectively, based on the formulas mentioned above formula (1) and (2). Ac3 is 879.66 and 857.62 degrees Celsius, respectively. In Tables 1 and 2, it is shown how heating the materials to temperatures around and above the Ac3 temperature alters their tensile strength, yield strength, unit deformation, and hardness properties.

Tablo 2. Experimental Samples Conditions and Test Results of MAT1

Conditions	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Hardness (HV)
240sec, 870°C	1801,56	1312,71	4,33	489,9
480sec, 870°C	1804,06	1320,36	4,3	502,1
720sec, 870°C	1781,67	1222,82	4,39	459,4
240sec, 890°C	1831,3	1283,68	4,29	504,1
480sec, 890°C	1825,91	1278,29	4,34	492,0
720sec, 890°C	1807,06	1268,04	4,34	550,1
240sec, 910°C	1813,55	1216,88	4,38	502,0
480sec, 910°C	1811,32	1296,04	4,37	507,8
720sec, 910°C	1809,55	1283,74	4,41	471,1

Tablo 3. Experimental Samples Conditions and Test Results of MAT2

Conditions	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Hardness (HV)
240sec, 870°C	1583,23	1157,24	4,37	490,7
480sec, 870°C	1559,36	1108,49	4,32	472,5
720sec, 870°C	1535,71	1094,01	4,34	520,2
240sec, 890°C	1598,98	1138,96	4,33	482,7
480sec, 890°C	1568,17	1063,44	4,34	488,2
720sec, 890°C	1577,98	1097,36	4,33	544,2
240sec, 910°C	1510,84	965,43	4,37	482,4
480sec, 910°C	1508,58	1058,30	4,29	498,9
720sec, 910°C	1563,89	1151,59	4,33	465,9

The tensile and yield strength values of 22MnB5 material are reported to increase as the austenitization temperature increases but drop once the turning point is beyond 900°C in the literature [23, 24]. The tensile and yield strengths of the test samples grew and reached their maximum values when the temperature increased from 870°C to 890°C, according to the results shown in Tables 1 and 2. As the temperature increased further, the strength values declined. The values obtained were thought to be compatible and consistent with the literature, and this holds true for both of the materials utilized in the experiment.

The highest tensile strength and the highest yield strength of the MAT1 test samples were determined to be 1831.30 MPa and 1283.68 MPa, respectively, under the test circumstances of 240 seconds of soaking time and 890°C austenitization temperature. Again, under 240 seconds of soaking time and 890°C austenitization temperature test circumstances, the maximum tensile strength and yield strength values for the MAT2 test specimen were attained.

The obtained results indicate that when the materials' microstructure is heated in the ferrite phase at ambient temperature and the austenitization temperature is exceeded, the austenite transformation is optimal in these conditions. The statistics in the table indicate that 240 seconds is largely adequate for completing the transformation, and the strength values fall when the time that produces the maximum result is increased further.

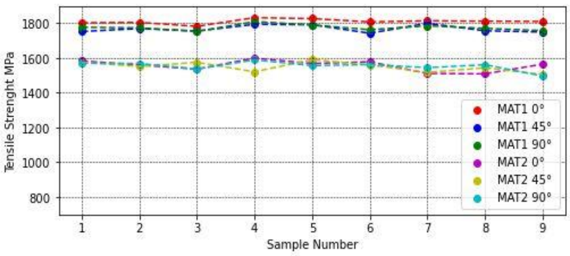

Figure 5. Tensile Strength Test Results of Samples

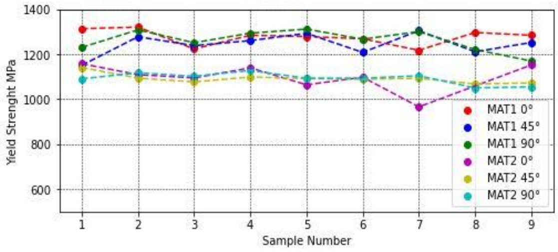

Figure 6. Yield Strength Test Results of Samples

The test results for the tensile and yield strengths of 0, 45 and 90° according to the rolling direction of 9 test specimens for MAT1 and MAT2 materials are presented in Figure 5 and Figure 6. According to Figure 2, tests conducted in the same direction as the 0° rolling direction had the maximum tensile strengths. The results of the testing for 0, 45, and 90° between yield strengths are represented in Figure 6 as Rp0,2 yield values. Since the materials of the AHSS group and high-strength steels do not have a significant yield point and exhibit brittle fracture, theoretically, 0.2% yield stress values are estimated. The resultant values are so distinct from one another.

Prior to the martensitic transformation, the 22MnB5 hardness value was 150HV; however, if a full martensite structure is achieved after the transformation, the hardness value should be above 450HV [23].

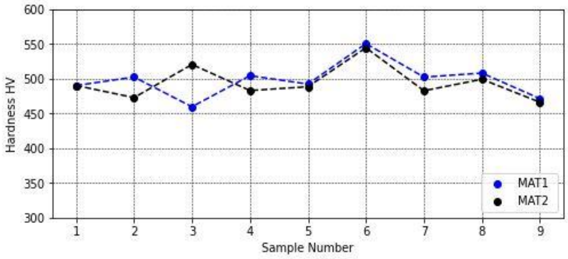

Figure 7. Vickers Hardness Values of Samples

The experimentally measured hardness values indicate that the structure undergoes martensite transition at a high rate (often above 95%). The variations in hardness values show that martensite is forming in the structure, along with an accumulation of leftover austenite grains at the grain boundaries and other phases like bainite. For MAT1 and MAT2, the greatest Vickers hardness values were measured to be 550.1 HV and 544.2 HV, respectively.

For both materials, the greatest value was attained at 890°C and 720 seconds of soaking time. These process variables lead to the conclusion that the austenite structure has undergone martensite transformation. Figure 7 displays a graphic representation of the experimental samples' hardness values.

Values for hole expansion ratios are one way to compare the formability capabilities, particularly for high strength steel sheets. By using a conical punch to expand the hole on the sheet material, the hole expansion ratio value is computed using formula (3) in accordance with the relationship between the diameter after the first fracture in the hole and the first diameter. The diameter measured after the creation of a crack in the hole made by the punch in the sheet metal is represented by the Dh value in the equation, whereas D0 represents the initial diameter value [25].

$$\lambda = \frac{Dh - D0}{D0} x100 \qquad (3)$$

Experimental items; Table 4 provides the hole sizes and hole expansion heights following crack formation. Figure 8 illustrates the first crack that appeared during the test. Comparing the hole expansion values reveals that the MAT2 material, which is seen to have a 51.36% value, can be deformed more easily than the MAT1 material, which recorded a 30% value.

Tablo 4. Experimental Samples Hole Expansion Test Results

Material	Average hole diameter (mm)	Hole expansion ratio λ (%)
MAT1	13,37	33,71
MAT2	15,13	51,36

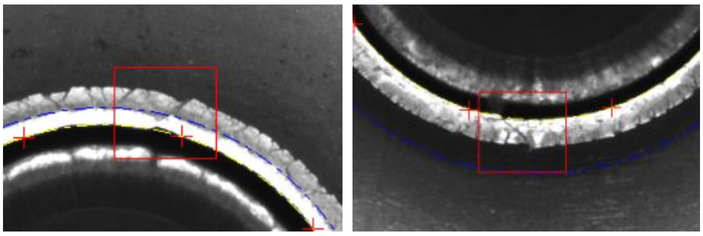

Figure 8. Hole Expansion Test Results of Samples a) MAT1 b) MAT2

After analyzing the samples' mechanical characteristics, SEM analysis was used to look at their microstructures. Each sample underwent SEM analysis at four distinct magnifications, including 500x, 2000x, 5000x, and 10000x. SEM images obtained at 5000x and 10000x for 240 second soaking time and 890°C austenitization temperature, which are the parameters of the best results obtained as a result of mechanical analysis, are shown in Figure 9 and Figure 10.

In the hot stamping technique, which is used for experimental work, the material was austenitized to alter the microstructure before being quickly cooled. It was anticipated that martensite would make up the majority of the material microstructure after the study's chosen cooling rate of 30°C/min. When the pictures in Figures 9 and 10 were analyzed, it was discovered that the microstructure had developed an acicular martensite phase as well as a bainite phase.

The residual austenite in the figures is also present, but it is enclosed by the acicular martensite phase and cannot undergo martensitic transformation.

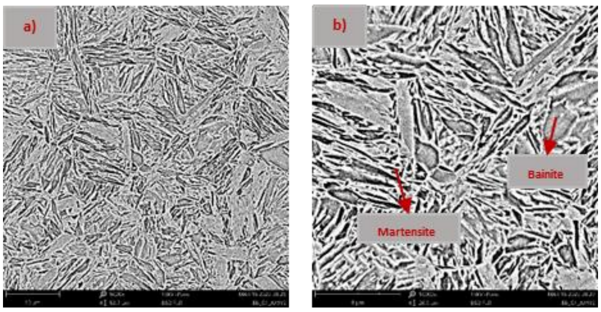

Figure 9. SEM Images of MAT1 at 240sec 890°C a) 5000x b) 10000x

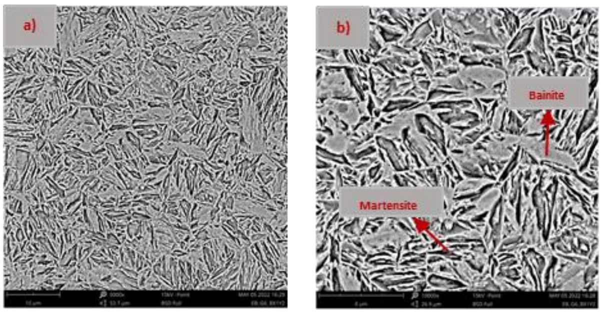

Figure 10. SEM Images of MAT2 at 240sec 890°C a) 5000x b) 10000x

As the second-hardest phase after cementite, martensite plays a significant role in steels. The martensite phase produced by the phase transformation enhances the mechanical properties of the steels, particularly in high carbon steels. The MAT1 material has higher hardness and tensile strength values, according to the experimental results.

The acicular martensite phase is shown to be more homogeneous in MAT1 samples when compared with SEM pictures. For MAT2 material, bainite and residual austenite are more typical. The MAT2 material's hardness values will rise as a result.

4. Discussion and Conclusion

In this investigation, material from two separate steel producers was created using the hot stamping method for 22MnB5 new generation high strength steel. The impact of process parameters on material properties was examined for the conventional hot stamping procedure using various austenitization temperatures and furnace soaking times. The findings of the present investigation are outlined as follows:

1) The average value for the tensile and yield strength values for the MAT1 material is 1809.55 MPa, while the average value for the MAT2 material is 1556.30 MPa. When the two materials' microstructures are compared, it can be shown that MAT1 has a larger ratio of martensite phase than MAT2. The %C ratio is larger in the MAT2 material when the chemical compositions of the materials are compared, and because C atoms cannot diffuse freely, this results in the creation of various phases at the grain boundaries. It has been noted that the tensile and yield strengths of the material are attained at lower levels as a result of the production of residual austenite and bainite. When the findings were reviewed in light of the process parameters, it was found that cutting down on the soaking time in the furnace improved the tensile and yield strengths, with the greatest results coming from 240s. The maximum values for the austenitization temperature are achievable at 890°C.

2) The tensile and yield strengths of the MAT1 material show greater values when the hardness measurements are evaluated; the hardness value rises as the soaking period at 890°C increases. At this temperature, the hardness value reached 550.1 HV. Even if high hardness values are expected results for new generation advanced high strength steels, easy formability should be at the forefront.

3) When the hole expansion values are compared, as 51.36%, it has been found that MAT2 material can be formed more readily than MAT1 material, which can be formed to a lesser extent when the ratios of C and alloying elements drop.

4) When the microstructure is analyzed, the greater rate of martensite phase found for MAT1 also contributes to the material's favorable mechanical characteristics. The most homogeneous martensite phase is produced when the austenitizing temperature of 890°C is reached, according to observations. It was found that as the residence time in the furnace increased, martensites began to develop other phases, like residual austenite.

The automotive industry is a vibrant, ever-evolving sector with a fierce rivalry that incorporates technology advancements. The hunt for novel materials that will suit the light and mechanical requirements in the automotive has boosted interest in advanced high-strength steels, along with the environmentalist strategies that have been the center of attention in recent years. There are several steel producers around the world, and much like in this study, materials with similar levels of quality but different attributes have found a market for themselves. The choice of material becomes one of the key concerns for the automotive sector with this method.

All automotive equipment sources meet the fuel economy target by weight according to Institutional Average Fuel Economy (CAFE) standards and international measurement regulations. The fuel economy target is challenging for most countries, in order to minimize the damage to the CO_2 emission transmissions spent on passenger services. In particular, the United States has set its 2025 target as 89 g/km of average CO2 emissions, reducing it by about 40% compared to 2015, thanks to the nature of lighter, stronger and greener cars. It is therefore essential to tap into new resources and design more efficiently for the cars of the future [26].

As seen in the study, the materials belonging to two different steel producers differ in terms of mechanical properties and thus their ability to be formed. When choosing the material if the vehicle part to be manufactured is safety parts that must have high strength values, MAT1 will be ideal for this choice. However, in some cases, in order to prevent problems such as tears and cracks in the part encountered during production, it may be necessary to choose a material with better formability but also provide the necessary mechanical properties. For certain parts, MAT2 would be the ideal choice in these situations. Considering the work done, it is important to understand the material properties to be used correctly and to evaluate the design and manufacturing processes as a whole before the material selection is made. Before choosing a material, it is crucial to understand its properties in order to use them appropriately and to assess the design and production processes as a whole.

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