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Charpy Impact Testing and Hardness Evaluation of S355MC High-Strength Steel After Gleeble Modeling with Varied Cooling Times

Absztrakt: Magas szilárdságú acélötvözetek, mint például az S355MC, széles körben alkalmazottak szerkezeti és autóipari alkalmazásokban, ami alapos megértést igényel viselkedésükről különböző feldolgozási feltételek mellett. E tanulmány azt vizsgálja, hogy a Gleeble modellezés által létrehozott S355MC acélminták ütközési keménységét és keménységét hogyan befolyásolja a hűtési idő, egy kritikus tényező a mikroszerkezet kialakulásában.

Az anyag mechanikai tulajdonságainak vizsgálatához Charpy ütési tesztek és Vickers keménységmérések voltak elvégezve az acél különböző hűtési feltételeire [1]. A kutatás során egy sor S355MC acél mintát vizsgáltak, mindegyiket különböző hűtési idők mellett Gleeble modellezésnek vetve alá. A Charpy ütközési tesztek, az ASTM szabványok szerint, feltárják az acél képességét az hirtelen terhelés elviselésére és az energiaelnyelő képességére.

Az eredmények azt mutatják, hogy a rövidebb hűtési idővel a acél ütési energiaelnyelő képessége csökken. A Vickers keménységi tesztek információt szolgáltatnak a anyag helyi műanyag deformáció elleni ellenállásáról és alkalmazhatóságáról. Az eredmények azt mutatják, hogy az S355MC keménysége csökkenő hűtési idővel növekszik, ami összefüggést mutat a mikroszerkezet és a keménység között [2].

E tanulmány rámutat a hűtési idő szabályozásának jelentőségére az S355MC acél hőkezelési folyamatában. A ütközési és keménységi tesztek által nyert információk nélkülözhetetlenek a feldolgozási feltételek optimalizálásához, biztosítva az acél megbízhatóságát azokban az alkalmazásokban, ahol az ütésállóság és a keménység létfontosságú.

Kulcsszavak: S355MC magas szilárdságú acél, Gleeble modellezés, Charpy ütközési tesztelés, Vickers keménységmérés, hűtési idő, mikroszerkezet, mechanikai tulajdonságok.

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[1] Hutchinson, B.–Ghosh, A. K. (2006): Microstructure and Impact Properties of HSLA-100 Steel Subjected to Controlled Rolling and Cooling. *Metallurgical and Materials Transactions A,* 37., (7.), pp. 2127–2137.

[2] Callister, W. D.–Rethwisch, D. G. (2014): *Materials Science and Engineering: An Introduction. New York:* John Wiley & Sons.

Abstract: High-strength steel alloys, like S355MC, are widely employed in structural and automotive applications, demanding a deep understanding of their behavior under different processing conditions. This study investigates the impact toughness and hardness of S355MC steel samples after Gleeble modeling, a thermomechanical simulation technique. The cooling time, a critical factor in microstructural development, is varied to explore its influence on mechanical properties. Charpy impact testing and Vickers hardness measurements were performed to assess the steel's response to different cooling conditions [1].

The research includes a series of S355MC steel specimens, each subjected to Gleeble modeling under distinct cooling times. Charpy impact tests, following ASTM standards, reveal the steel's ability to withstand sudden loading and its energy absorption capacity. The results show that with shorter cooling times, the impact energy absorption capacity of the steel decreases. Vickers hardness tests provide information on the material's resistance to localized plastic deformation and its suitability for specific applications. The findings reveal that the hardness of S355MC increases with reduced cooling times, indicating a relationship between microstructure and hardness [2].

This study highlights the significance of cooling time control in the heat treatment process for S355MC steel. The insights obtained from the impact and hardness testing are essential for optimizing processing conditions, ensuring the steel's reliability in applications where impact resistance and hardness are vital.

Keywords: S355MC high-strength steel, Gleeble modeling, Charpy impact testing, Vickers hardness, cooling time, microstructure, mechanical properties.

Introduction

High-strength steels, such as S355MC, are widely utilized in the automotive and structural industries due to their exceptional strength-to-weight ratio and impact resistance. To ensure their reliable performance, understanding how different processing conditions, particularly cooling times after thermomechanical simulation, affect their mechanical properties is essential. In this study, we focus on S355MC steel and investigate its response to various cooling times following Gleeble modeling [3].

[1] Hutchinson, B.–Ghosh, A. K. (2006): Microstructure and Impact Properties of HSLA-100 Steel Subjected to Controlled Rolling and Cooling. *Metallurgical and Materials Transactions A,* 37., (7.), pp. 2127–2137.

[2] Callister, W. D.–Rethwisch, D. G. (2014): *Materials Science and Engineering: An Introduction.* John Wiley & Sons.

[3] Gao, J., Zhang, Y. –Liao, B. (2019): Effects of Cooling Rate on Microstructure and Mechanical Properties of a New High-Strength Steel. *Metals,* 9., (1.).

Methodology

- Sample Preparation: S355MC steel samples were prepared with known dimensions and subjected to Gleeble modeling in total 20 samples in four different cooling times (5, 10, 15, 20) five samples for each time. The modeling process involved heating the specimens to a specific temperature, followed by deformation and subsequent cooling. The critical variable examined in this study was the cooling time, which ranged from rapid cooling to slower cooling conditions. See *figure (1),(2) and (3).*

Figure 1. Preparation sample for the gleeble modelling

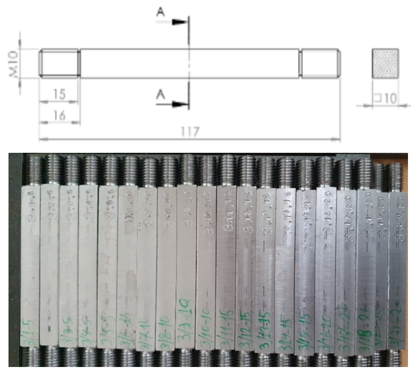
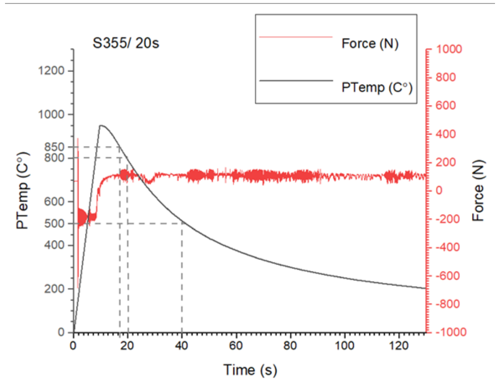


Figure 2. Some of the Samples after the modelling

[4] Lama Mkanna–Bela Palotas (2023): *Physical based determination of preheating temperature of High Strength Steels, Welding Managers XXIV. National Consultation.* (Visegrád, October 5–6. 2023)

[5] S355MC Steel Data Sheet. (*Manufacturer's Data*).

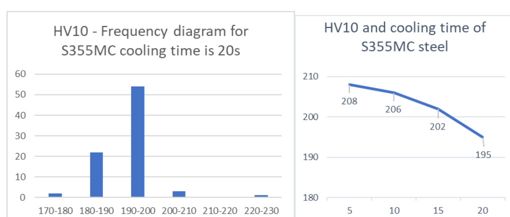
Figure 3. Example of the applied thermal cycles for 20sec [4]



– Hardness Measurements: Vickers hardness tests were performed to evaluate the material's resistance to localized plastic deformation. Hardness values are indicative of the steel's ability to withstand wear and indentation.

We carefully designed the test specimen's shape for our modeling, ensuring that we could conduct hardness measurements at the specimen's center on each plane. This setup also allowed us to measure impact energy. We manufactured five test specimens for each cooling time, resulting in a total of approximately 20 test specimens. This quantity provides a solid foundation for reliable evaluations. The results from the hardness measurements are presented in *Figure 4*. The data reveals that S355MC steel did not experience quenching in any instances, which aligns with the findings in a previous study [5].

Figure 4. Results of hardness measurements for S355CM steel [4]



The results further indicate that extended cooling times lead to a softer heat-affected zone, in line with theoretical predictions. We will evaluate these results against hardness criteria recommended in the literature, and this evaluation will be complemented with instrumented impact testing. The instrumented impact testing method offers a more precise analysis of fracture behavior [4].

– Charpy Impact Testing: Charpy impact testing was conducted in accordance with ASTM standards see *figure 6*, to assess the steel's ability to absorb energy when subjected to sudden loading. The impact tests provide insights into the material's toughness and its resistance to brittle fracture.

During the testing I lost some samples so in the end I got 11 samples with normal distribution. *See figure 5.*

Figure 5. Standard Charpy-V notch specimen

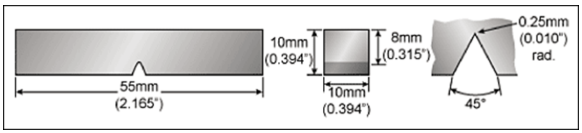


Figure 6. results for the impact test for S355MC

	Specimen id	Thickness [mm]	Width [mm]	Ligament length [mm]	Absorbed energy [J]
1	1	10.00	10.00	8.00	141.9
2	2	10.00	10.00	8.00	139.3
3	3	10.00	10.00	8.00	132.3
4	4	10.00	10.00	8.00	147.9
5	5	10.00	10.00	8.00	149.4
6	6	10.00	10.00	8.00	101.2
7	7	10.00	10.00	8.00	134.4
8	8	10.00	10.00	8.00	149.6
9	9	10.00	10.00	8.00	141.0
10	10	10.00	10.00	8.00	170.2
11	11	10.00	10.00	8.00	164.4
Average		10.00	10.00	8.00	142.9
Std dev		0.00	0.00	0.00	18.04
Coefficient of variation		0.00	0.00	0.00	12.63
Maximum		10.00	10.00	8.00	170.2
Minimum		10.00	10.00	8.00	101.2

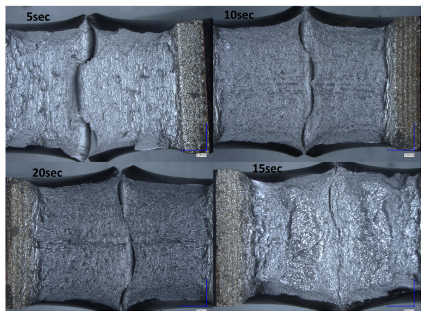
[4] Lama Mkanna–Bela Palotas (2023): *Physical based determination of preheating temperature of High Strength Steels, Welding Managers XXIV. National Consultation.* (Visegrád, October 5–6. 2023)

– 3D dimensional microscope

A 3D dimensional microscope is a powerful tool for studying microstructures and surfaces in three dimensions. This type of microscope utilizes various techniques, such as confocal microscopy or laser scanning, to create detailed 3D images of samples. For examining S355MC steel, a 3D dimensional microscope can be highly beneficial in analyzing its microstructure, grain boundaries, and surface characteristics. It allows for precise measurements and in-depth studies.

After the impact test I analyzed the fractured surfaces. See *figure 7.*

Figure 7. fracture surface for the samples in different cooling times



According to this photos in case of the 10 and 20 sec cooling time the fructure is ductile and for the rest of the samples is brittle.

Conclusion

Different cooling times in the Gleeble simulator will result in varying rates of cooling. Faster cooling times can lead to a finer microstructure, while slower cooling may produce coarser grains. These changes can influence the material's strength, toughness, and other mechanical properties. Varying cooling rates can affect the phase transformations that occur within the steel. For example, a faster cooling rate may suppress the formation of certain phases, while slower cooling can promote their development. This can have implications for the steel's hardness and ductility.

The cooling rate during modeling can significantly impact the hardness and strength of the S355MC steel. Rapid cooling may result in higher hardness and strength due to the formation of martensite, while slower cooling can produce a softer material.

The study demonstrates the importance of considering cooling times in the heat treatment of high-strength steel like S355MC. By controlling the cooling rate, it is possible to fine-tune the mechanical properties of the material to meet the requirements of various industries, ultimately enhancing its performance and reliability. This research serves as a foundation for further investigations into the optimization of high-strength steel for practical applications.