International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume 36 العدد
Part 1 المجلد

http://www.doi.org/10.62341/eaam0759

Received	2025/01/11	تم استلام الورقة العلمية في
Accepted	2025/01/30	تم قبول الورقة العلمية في
Published	2025/02/04	تم نشر الورقة العلمية في

The Effect of Cold Deformation and Heat Treatment on the Hardness and Microstructure of Structural Steel

Enas Fessatwi[1], Ali Ahmad Musbah[2],Abdulhakim A. Hameda[3], Mohammed A Samba[4]

[1] The libyan center of Advanced Technology, Tripoli, Libya.
[2] Department of Mechanical Engineering, Bani waleed University, Libya.
[3] Materials and Metallurgical Engineering Department, University of Tripoli, Tripoli, Libya.
[4] Petroleum Engineering Department, Sebha University, Libya.
[4] Medfezzan Research Center.

E-mail: E.Fessatwi@yahoo.com

Abstract.
Heat treatment processes are widely used to achieve high mechanical properties in materials. Additionally, the combination of cold deformation and heat treatment is one of the oldest methods employed to alter the mechanical properties of materials. In this research, a combination of cold deformation and heat treatment was applied to structural steel samples (ASTM A615) to investigate the effect of prior deformation on subsequent heat treatment, specifically focusing on the microstructure and hardness of this steel type. Samples were deformed to different extents (20%, 30%, 40%, and 50%) before being austenitized at 850°C. Following austenitization, some samples were quenched in water, while others were allowed to cool in air. Hardness measurements and microstructural investigations were conducted. The results indicate that the hardness of water-quenched samples exhibited a significant increase compared to that of the as-received samples. This increase was attributed to the transformation of the microstructure from ferrite-pearlite to a bainitic structure. Cold deformation was found to accelerate the transformation processes due to the introduction of structural defects, which acted as

http://www.doi.org/10.62341/eaam0759

preferred sites for precipitation. Both the amount and morphology of the transformation products were influenced by the extent of deformation.
Keywords: Steel bars, Hardness, Heat treatment, Microstructure, ASTM.

تاثير المعالجة الحرارية والتشكيل علىٰ البارد على الصلادة والتركيب المجهري للفولاذ الانشائي

[1]ايناس فساطوي، [2]علي أحمد مصباح، [3]عبدالحكيم احميدا، [4]محمد الشريف صمبة

[1] المركز الليبي للتقنيات المتقدمة ، طرابلس، ليبيا
[2]قسم الهندسة الميكانيكية، جامعة بني وليد، بني وليد، ليبيا
[3] قسم هندسة المواد والمعادن، جامعة طرابلس، طرابلس، ليبيا
[4]قسم هندسة النفط، جامعة سبها، سبها، ليبيا
[4] مركز مد فزان للبحوث
البريد الالكتروني: E.Fessatwi@yahoo.com

الملخص:

تُستخدم عمليات المعالجة الحرارية على نطاق واسع لتحقيق خصائص ميكانيكية عالية في المواد. بالإضافة إلى ذلك، يُعد الجمع بين التشوه على البارد والمعالجة الحرارية من أقدم الأساليب المستخدمة لتعديل الخواص الميكانيكية للمواد. في هذه الدراسة، تم تطبيق مزيج من التشوه على البارد والمعالجة الحرارية على عينات من الفولاذ الإنشائي (**ASTM A615**) لدراسة تأثير التشوه المسبق على المعالجة الحرارية اللاحقة، مع التركيز بشكل خاص على البنية المجهرية والصلادة لهذا النوع من الفولاذ. تم تشويه العينات بنسب مختلفة (20%، 30%، 40%، و50%) قبل إخضاعها لعملية الأوستنيتة عند درجة حرارة 850°**C**. بعد ذلك، تم تبريد بعض العينات سريعًا في الماء، بينما تُركت عينات أخرى لتبرد في الهواء. تم إجراء قياسات الصلادة وفحوصات البنية المجهرية. أظهرت النتائج أن العينات التي خضعت للتبريد السريع في الماء شهدت زيادة كبيرة في الصلادة مقارنةً بالعينات الأصلية. وقد عُزيَت هذه الزيادة إلى تحول

http://www.doi.org/10.62341/eaam0759

البنية المجهرية من طور الفريت–البيرلايت إلى بنية بينيتية. وُجد أن التشوه على البارد يُسرّع عمليات التحول نظرًا لإدخاله لعيوب بنيوية، والتي عملت كمواقع مفضلة للترسيب. كما تأثرت كل من كمية ومورفولوجيا نواتج التحول بدرجة التشوه المسبق.

الكلمات المفتاحية: قضبان الفولاذ، الصلادة، المعالجة الحرارية، البنية المجهرية، **ASTM**

1. Introduction

Steel is an iron-based material containing low amounts of carbon and various alloying elements, which allows for the creation of thousands of compositions with specific properties to meet diverse needs. Approximately 26 different elements are used in various proportions and combinations in the production of both carbon and low-alloy structural steels (Motagi and Bhosle, n.d.). ASTM A615 is a high-strength structural steel commonly used in reinforced concrete to improve its properties. Cold deformation and heat treatment processes are frequently employed to enhance the mechanical properties of steels (Mangi and Soomro 2016). When combined, these processes are referred to as thermo-mechanical treatment (Saeidi et al. 2019; Zhu et al. 2015; Silverstein and Eliezer 2016; Yadav 1994). This treatment alters the microstructure by affecting phase transformation processes, which in turn influences the mechanical properties (Joshaghani et al. 2021). Thermo-mechanical treatment has been extensively utilized to improve the properties of many alloys (Odası, n.d.).

The need for such treatments arises from challenges encountered in various fields. For example, in petroleum engineering, issues with casing sections are well-documented. The casing is essential for preventing contamination of formation water and avoiding the collapse of the formation (Thorhallsson and Sveinbjornsson 2012; Shaughnessy, Romo, and Soza 2003). Exposure to both low and high temperatures can lead to deformation of the casing (Elsharafi 2018).

The aim of this research is to investigate the effects of thermo-mechanical treatment on the microstructure and hardness of structural steel (ASTM A615). This study will focus on examining how thermo-mechanical treatment influences the microstructure and hardness of this type of steel.

http://www.doi.org/10.62341/eaam0759

2. Experimental Work

2.1 Chemical Composition

The chemical composition of the investigated steel was analyzed using a Foundry Master Pro instrument. The results of this analysis are shown in Table 1.

TABLE 1. Chemical composition of used steel

Element	Fe	C	Ni	Si	Cr	Al	W	others
Wt %	98.1	0.178	0.104	0.303	0.10	0.011	0.0106	……..

2.2 Cold Deformation and Heat Treatment Procedure

Heat treatment was conducted by heating the samples to the austenitization temperature of 850°C for 30 minutes. The samples were labeled as S1, S2, S3, S4, S5, S6, S7, and S8. Prior to heating, each sample underwent varying degrees of cold deformation. The details of the deformation levels and the cooling regimes (CR) applied to each sample are provided in Table

TABLE 2. Shows the amount of deformation and cooling regime

Sample No.	Deformation %	C.R regime	Sample No	Deformation %	C.R regime
S1	20 %	quenched	S2	20 %	air cooled
S5	30 %	quenched	S3	30 %	air cooled
S4	40 %	quenched	S6	40 %	air cooled
S7	50 %	quenched	S8	50 %	air cooled

2.3 Microstructure Examination

All samples were prepared for metallographic analysis using conventional methods, including grinding, polishing, and etching with a 2% nital solution. The microstructure of the samples was examined using an optical microscope. Selected micrographs are presented in Figs. 1 to 4. Fig. 1 shows the microstructure of the as-received steel, which primarily consists of ferrite and pearlite.

http://www.doi.org/10.62341/eaam0759

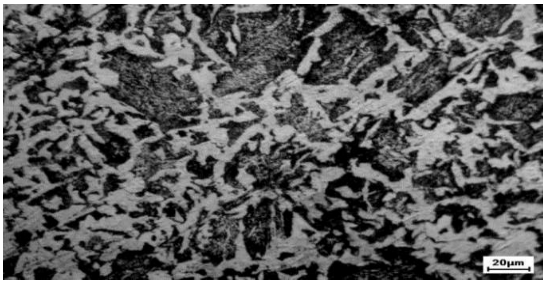


Fig. 1. Microstructure of as received steel

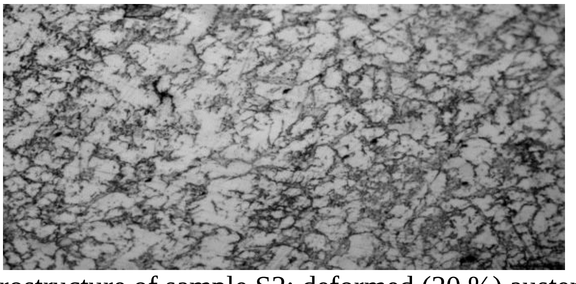


Fig. 2. Microstructure of sample S2; deformed (20 %) austenitized and then air cooled

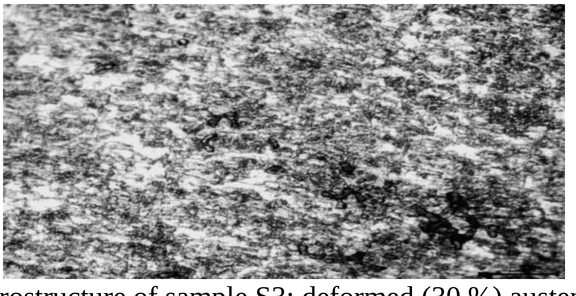


Fig. 3. Microstructure of sample S3; deformed (30 %) austenitized and then air cooled

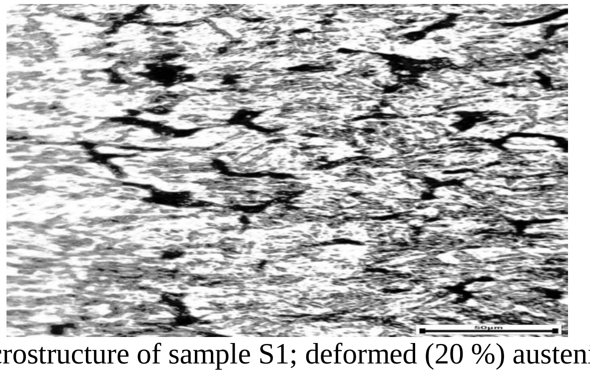


Fig. 4. Microstructure of sample S1; deformed (20 %) austenitized and then water quenched

http://www.doi.org/10.62341/eaam0759

2.4 Hardness Test

A Vickers hardness test was performed on all samples, with the results shown in Fig. 5. The hardness value for the as-received sample was measured at 273 HV.

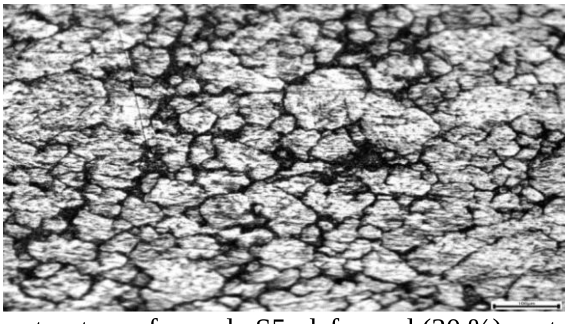
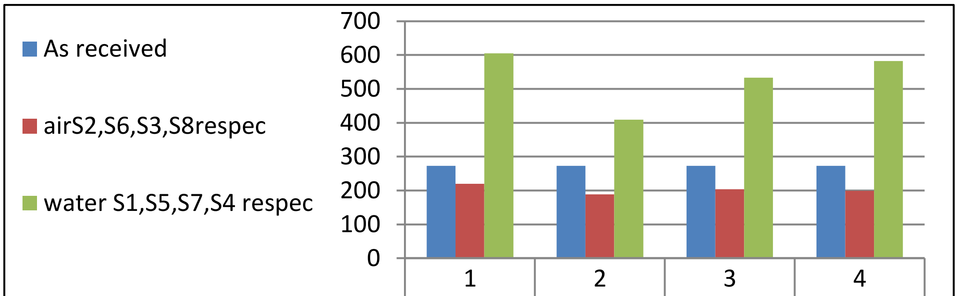


Fig. 5. Microstructure of sample S5; deformed (30 %) austenitized and then water quenched



	1	2	3	4
As received	273	273	273	273
airS2,S6,S3,S8respec	220	189	204	199
water S1,S5,S7,S4 respec	605	409	533	582

Fig. 6 . Illustration of hardness values for all samples

3. Results and Discussion

To study the effects of deformation and cooling rate on the microstructure and hardness of structural steel. As mentioned above, eight samples were subjected to varying degrees of deformation before heating to the austenitization range and then cooled either in air or by water quenching. The results showed that the hardness of air-cooled samples, as illustrated in Fig. 6, did not significantly change with varying amounts of deformation. The average hardness values of these samples were lower than that of the as-received sample. This reduction in hardness can be attributed to changes in the morphology of the microstructure

http://www.doi.org/10.62341/eaam0759

constituents, as seen by comparing the microstructure of the as-received sample (Fig. 1) with that of the deformed samples (Figs. 2 and 3).

The microstructure of the deformed samples, while still containing ferrite and pearlite, exhibited variations in the morphology and quantities of these phases. Specifically, the amount of ferrite appeared to increase, suggesting that prior deformation may have accelerated ferrite nucleation. This increased ferrite content likely contributes to the observed decrease in hardness compared to the as-received sample. Additionally, the effect of deformation is evident in the microstructures shown in Figs. 2 and 3, where the ferrite grains are notably finer with increased deformation. This finer grain structure results from the increased nucleation rate of ferrite induced by the deformation process. The increased nucleation rate observed is attributed to the structural defects introduced during deformation, which act as preferential sites for nucleation, resulting in a finer-grained microstructure. In contrast, as shown in Fig. 6, the hardness of water-quenched samples increased significantly compared to the as-received sample. The microstructure of these quenched samples is predominantly bainitic, as expected, due to the accelerated formation of bainite induced by deformation. This bainitic structure contributes to the observed increase in hardness.

However, it is noted that the hardness values of samples S5 and S7 are relatively lower. This reduction in hardness is associated with the presence of cracks, which are clearly visible in the micrographs of these samples (Figs. 4 and 5).

4. Conclusions

Based on the findings from the present research, the following conclusions can be drawn:

1. **Acceleration of Phase Transformation:** Prior deformation has generally accelerated the phase transformation processes in structural steel. This effect is observed through changes in microstructure and mechanical properties resulting from deformation.
2. **Improvement in Hardness:** The hardness of the structural steel has been enhanced by pre-deformation. This improvement is attributed to the refined microstructure and phase transformations induced by the deformation process.

http://www.doi.org/10.62341/eaam0759

3. **Effectiveness of Deformation on Cooling Rates:** The amount of deformation has been found to significantly affect the hardness of quenched samples, resulting in a notable increase in hardness. In contrast, deformation did not show a pronounced effect on the hardness of air-cooled samples. This suggests that the benefits of pre-deformation are more evident in samples subjected to rapid cooling processes such as water quenching.

5.References

[1]. Elsharafi, Mahmoud Omran. 2018. "Literature Review of Water Alternation Gas Injection." Journal Of Earth Energy Engineering 7 (2): 33–45. https://doi.org/10.25299/jeee.2018.vol7(2).2117.

[2]. Joshaghani, Hosein, Mohammad Morovati, Saeed Moshiri, and Nima Rafizadeh. 2021. "Fuel Subsidies, Smuggling, and Regional Inequality." Smuggling, and Regional Inequality (September 6, 2021).

[3]. Mangi, Sajjad Ali, and F A Soomro. 2016. "Experimental Evaluation of Mechanical Properties of Locally Available Deformed Steel Bars." In 8th International Civil Engineering Congress (ICEC-2016),"Ensuring Technological Advancement through Innovation Based Knowledge Corridor.

[4]. Motagi, B S, and Ramesh Bhosle. n.d. "Effect of Heat Treatment on Microstructure and Mechanical Properties of Medium Carbon Steel."

[5]. Odası, TMMOB Metalurji Mühendisleri. n.d. "IMMC 2010."

[7]. Saeidi, Kamran, Sajid Alvi, Frantisek Lofaj, Valeri Ivanov Petkov, and Farid Akhtar. 2019. "Advanced Mechanical Strength in Post Heat Treated SLM 2507 at Room and High Temperature Promoted by Hard/Ductile Sigma Precipitates." Metals 9 (2): 199.

[8]. Shaughnessy, John M, Louis A Romo, and Robert L Soza. 2003. "Problems of Ultra-Deep High-Temperature, High-Pressure Drilling." In SPE Annual Technical Conference and Exhibition. OnePetro.

[9]. Silverstein, R, and D Eliezer. 2016. "Influences of Hydrogen and Textural Anisotropy on the Microstructure and Mechanical Properties of Duplex Stainless Steel at High Strain Rate (~ 10 5 S− 1)." Journal of Materials Science 51: 10442–51.

http://www.doi.org/10.62341/eaam0759

[10]. Thorhallsson, Sverrir, and Bjorn Mar Sveinbjornsson. 2012. "Geothermal Drilling Cost and Drilling Effectiveness." Short Course on Geothermal Development and Geothermal Wells. Santana Tecla, El Salvador.

[11]. Yadav, Pravesh Kumar. 1994. "Of Master's Thesis." Heat Treatment 85: 78.

[12]. Zhu, Qin-tian, Jing Li, Cheng-bin Shi, and Wen-tao Yu. 2015. "Effect of Quenching Process on the Microstructure and Hardness of High-Carbon Martensitic Stainless Steel." Journal of Materials Engineering and Performance 24: 4313–21.