University of Belgrade
Technical Faculty in Bor
Mining and Metallurgy
Institute Bor

56th International October Conference on Mining and Metallurgy

PROCEEDINGS

Editors:
Ljubiša Balanović
Dejan Tanikić

IOC 2025
International October Conference

22-25 October 2025,
Bor Lake, Serbia

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PREFACE

On behalf of the Organizing Committee, it is a great honor and pleasure to welcome all esteemed participants of the **56th International October Conference on Mining and Metallurgy (IOC 2025)**, scheduled to take place at **Bor Lake, Serbia**, from **October 22nd to 25th, 2025**.

The collaborative efforts of the University of Belgrade – Technical Faculty in Bor and the Mining and Metallurgy Institute Bor have once again brought together academia, industry, and research institutions to organize this year's IOC. Our focus remains firmly set on presenting the latest research achievements and technological advancements in geology, mining, metallurgy, materials science, technology, environmental protection, and other engineering disciplines.

This year's conference program is rich and diverse, featuring **4 plenary lectures, 4 invited lectures, 158 full papers, and 6 abstracts**. The proceedings reflect the contributions of authors from **19 countries**: Austria, Bosnia and Herzegovina, Bulgaria, Canada, China, Croatia, Germany, Hungary, India, Mexico, Montenegro, Poland, Romania, Russia, Serbia, Slovakia, Slovenia, Turkey, and the United Kingdom. Among the submitted papers, eight young researchers under the age of 35 have qualified to participate in the "**MDPI Young Researcher Award**" competition, further emphasizing the conference's commitment to supporting and recognizing excellence among the new generation of scientists and engineers.

We are also delighted to host the **9th International Student Conference on Technical Sciences (ISC 2025)**, running in parallel with IOC 2025. The student conference brings together young researchers from Serbia and the wider region, with **one plenary** and **50 student papers** presented, offering an invaluable opportunity for the next generation of scientists and engineers to share their ideas and discuss the future of their disciplines with experts. The "**Professor Dragana Živković Best Student Paper Award**" will be presented to the most outstanding student contribution based on originality, research quality, and presentation.

The Organizing Committee expresses its deepest gratitude to all who have supported this event. Our General Sponsor is the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia. We are especially grateful to our Platinum Donors, HBIS Serbia and Serbia Zijin Mining, as well as our Gold Sponsor, DPM Metals Inc., and our Gold Donors, Copper Mill Sevojno and Serbia Zijin Copper Bor. This year, the conference is also supported by the Silver Donor, "MC LABOR" d.o.o. Beograd.

We proudly host a diverse exhibition, featuring Indemak, Labtim SE d.o.o., MERIS d.o.o., Krug International LTD, Altium International d.o.o., Metalurg Foundry Ltd., Fugro Germany Land GmbH, Analysis d.o.o., Lola institut, Tescan and Mikrolux d.o.o., Trokuttest Serbia, Novos d.o.o., Changsha Rui Rui Technology Co., Ltd., MDPI and the Winery of Bukovo Monastery. The official opening of the conference has been supported by Epiroc Srbija a.d.. Finally, we warmly acknowledge our Friends of the Conference: Messer Tehnogas AD Belgrade, the China-Serbia Joint Laboratory on Green Steel Manufacturing, and the Foundation B.Sc. Boško Injac.

We sincerely thank all authors, committees, reviewers, speakers, and chairpersons for their invaluable contributions to shaping IOC 2025. We are confident that the conference will once again serve as a alive platform for scientific exchange, professional networking, and the promotion of sustainable development in mining, metallurgy, and related fields.

On behalf of the 56th IOC Organizing Committee,
Prof. dr Ljubiša Balanović

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Abstracts

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THERMOMECHANICAL TREATMENT OF S275JR STEEL: IMPACT ON MICROSTRUCTURE, HARDNESS, AND IMPACT TOUGHNESS

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Abstract

This study investigates how different thermomechanical treatment procedures affect the hardness, microhardness, impact toughness, and microstructure of S275JR structural steel. For the experiment, an as-received rectangular bar of structural steel was normalized at 900 °C for 60 minutes. Following normalization, the samples were pre-strained (cold deformed) by 8% at room temperature using a rolling mill. After deformation, the samples were aged for 30 minutes at temperatures of 100 °C, 150 °C, 200 °C, and 250 °C. The hardness, microhardness, impact toughness, and microstructure were analyzed for both the as-received sample and treated samples. The results indicated that normalization improved both hardness and impact toughness due to grain refinement. The straining conducted after normalization led to an increase in hardness but a decrease in impact toughness as a result of work hardening. The subsequent aging further strengthened the material, likely due to the interaction between dislocations and secondary phase particles, such as Fe_3C *and other alloying elements.*

***Keywords**: S275JR steel, normalization, strain aging, impact toughness, hardness*

1. INTRODUCTION

Steel ranks as the most widely utilized material in the 21st century. Its affordability and ease of processing make it a desirable option for various industries [1]. General structural mild steels, classified within a broader category of steels, are valued in various industries for their strength, ductility, and good weldability [2, 3]. Structural steels are classified as carbon-manganese steels, and their microstructure can be altered through heat treatment. This ability enables a straightforward enhancement of their mechanical properties. As a result, the automotive industry considers these steels highly desirable for applications in body panels, chassis parts, and other structural components [4-6]. S275JR structural steel, classified as low- to medium-carbon steel with approximately 0.2% carbon content, has limited options for heat treatment. These steels are rarely used in a quenched state because the martensitic transformation can lead to brittleness. The heat treatment process for this type of steel generally involves heating it above the eutectoid temperature and then cooling it in a controlled manner. This approach aims to achieve a balanced microstructure consisting of a mixture of ferrite, pearlite, and/or bainite, which helps promote optimal hardness and toughness [7-9]. Strain aging is a specific heat treatment technique commonly used for low-carbon and low-alloy steels. Strain aging in steels involves plastic deformation at room temperature, typically following a normalizing or annealing treatment. The material is then aged at room or slightly elevated temperature (~200 °C). This heat treatment allows dislocations created during the plastic deformation to become pinned by diffusing atoms, such as nitrogen, carbon, or manganese. As a result, the steel's strength is increased; however, this comes at the cost of reduced ductility and toughness [2]. The aim of this paper was to investigate the influence of strain aging on hardness, microhardness, impact toughness, and microstructure. Various properties were examined after normalizing heat treatment at 900 °C for 60 minutes, followed by air cooling. Once normalized, the samples were subjected to an 8% strain (cold deformation) and then aged for 30 minutes at 100 °C, 150 °C, 200 °C, and 250 °C.

2. EXPERIMENTAL

The hot rolled 12×12×1000 mm rectangular S275JR steel bar was used in this study. Before the thermomechanical treatment, the as-received (*AR*) samples were cut and prepared for hardness, microhardness and impact toughness measurements. One of them was left for further testing and all other samples were normalized at 900 °C for 60 minutes, followed by air cooling. This was done in order to remove the as-received structure and further refine the microstructure. After cooling, two normalized (N) samples were separated for analysis: one was used for impact toughness testing, and the other for all remaining tests. Other normalized samples were then subjected to 8% strain (cold deformation) on Joliot Paris rolling mill. These samples were labeled as *N+D* (normalized and deformed). After deformation, four samples were strain aged for 30 minutes at 100 °C (*NDA100*), 150 °C (*NDA150*), 200 °C (*NDA200*), and 250 °C (*NDA250*). After aging the samples were separated for individual analyses.

During the thermomechanical treatment hardness was measured on VEB Leipzig hardness tester with a 15 kg load and a 15 s dwelling time following the ASTM E92-17 [10]. Also, microhardness values were measured using a PMT-3 Vickers microhardness tester using 150 gf loads with load duration of 15 s, according to ASTM E384-22 [11]. The impact toughness was determined using the VEB Leipzig Charpy pendulum, following the EN ISO 148-1:2016 [12]. The samples were machined to dimensions of 10×10×55 mm with a V-notch that is 2 mm deep. The mass of the pendulum hammer was 18.65 kg.

For microstructural analysis, the specimens were sanded using emery paper ranging from Grit 3 to Grit 0000, and then polished with an alumina slurry with particle size of 0.3 and 0.05 microns. To reveal the microstructure, the specimens were etched with a 2% Nital solution (2 ml of HNO_3 mixed with 98 ml of C_2H_5OH) for 15 seconds. The microstructures were examined using Carl Zeiss Jena Epytip 2 optical microscope.

3. RESULTS AND DISCUSSION

Figure 1 illustrates the results of hardness and microhardness measurements taken after each step of the thermomechanical treatment. From the figure, it can be concluded that both hardness and microhardness increased following the normalization treatment (sample N). The structure of the as-received (AR) sample was refined after heat treatment, which contributed to the increase in hardness and microhardness values. Further analysis revealed that the introduction of cold deformation resulted in a significant increase in both hardness and microhardness due to work hardening. When an 8% strain was applied gradually through rolling, the dislocation density increased, which hindered further dislocation movement and resulted in the hardening of the material. Following strain aging, the hardness and microhardness of the deformed samples exhibited notable variations. Aging at 100 °C for 30 minutes resulted in a slight increase in both properties compared to the N+D sample. In contrast, subsequent aging at more elevated temperatures (150 °C and 200 °C) led to a modest reduction in hardness and microhardness values. The highest measurements were observed after strain aging at 250 °C for 30 minutes. The increase in both hardness and microhardness can be attributed to diffusion of interstitial atoms such as C and N. At elevated temperatures, interstitial atoms become mobile and diffuse through the lattice, where they interact with dislocations to form Cottrell atmospheres, effectively impeding further dislocation motion [2, 13-16]. An addition to this mechanism, strengthening can also arise from interactions between dislocations and secondary particles, such as Fe_3C (cementite) or other precipitates formed from alloying elements [17]. Moreover, cold deformation lowers the activation energy required for diffusion, thereby facilitating these strengthening mechanisms [2].

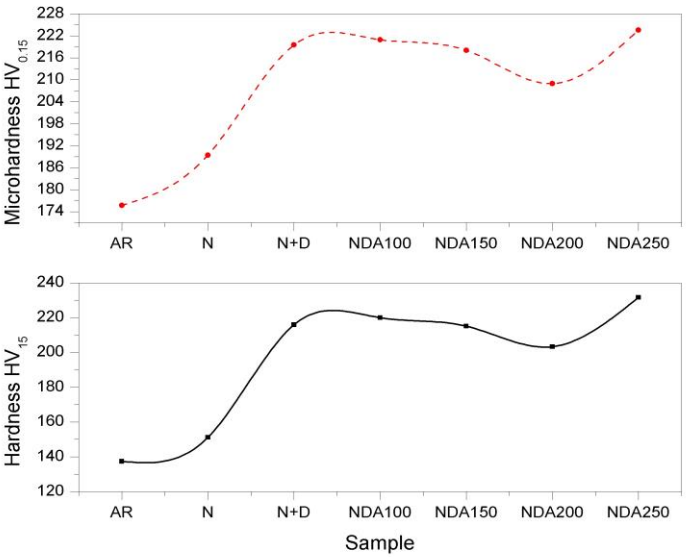

Figure 1 – The change in hardness and microhardness values as a function of thermomechanical treatment

Table 2 – The results of the Charpy V-notch impact test of the selected samples

Sample	Impact toughness (J)
AR	175.31
N	196.42
N+D	88.3
NDA100	120.2
NDA250	83.38

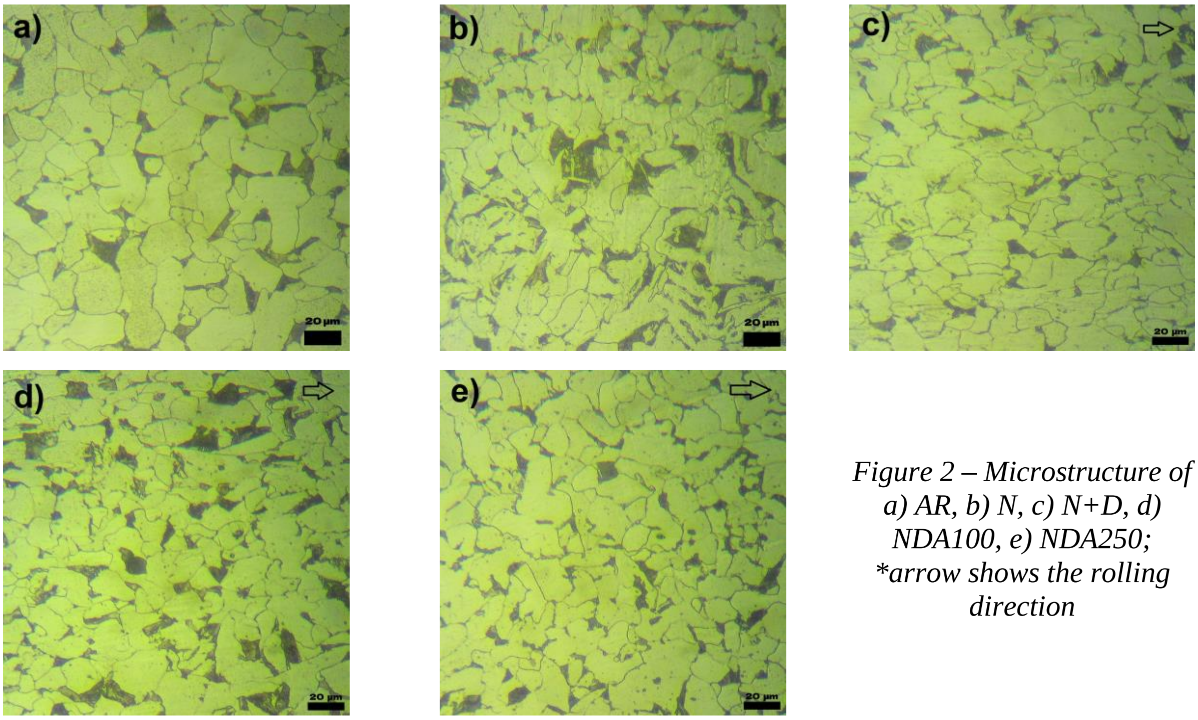

*Figure 2 – Microstructure of a) AR, b) N, c) N+D, d) NDA100, e) NDA250; *arrow shows the rolling direction*

Table 2 presents the results of the Charpy V-notch impact toughness test. The data indicate that normalization led to a slight increase in impact toughness, as evidenced by the comparison between the as-received (AR) and normalized (N) samples. J. Brnic et al. obtained somewhat similar results [18]. This improvement is attributed to grain refinement, which enhanced the material's ability to absorb energy during impact. In contrast, the introduction of plastic deformation resulted in a significant reduction in impact toughness, with values decreasing by more than 50%, from 196.42 J to 88.3 J. For the strain-aged samples (NDA), aging at 100 °C resulted in a considerable increase in impact toughness, whereas aging at 250 °C led to a decline in toughness values. Typically, strain aging promotes the formation of Cottrell atmospheres, which generally reduce impact toughness while increasing strength and hardness, as observed in the NDA250 sample. However, in some cases, mild strain aging (characterized by low deformation and short aging duration) can enhance toughness, as demonstrated by the NDA100 sample. In summary, the strengthening mechanisms responsible for the increased hardness and microhardness values generally correspond to a decrease in impact toughness, with the notable exception of the NDA100 sample, where strain aging improved both hardness and toughness.

Figure 2 presents the microstructure after each stage of the thermomechanical process. The microstructural analysis supports the previously discussed explanations for the changes in mechanical properties. A comparison of Figures 2a and 2b indicates that normalization resulted in grain refinement. Following rolling, the grains became elongated in the rolling direction, as observed in Figures 2c through 2e. The microstructure of all samples consists of a ferrite and pearlite. Similar microstructures were also observed by other authors [1, 2, 7].

4. CONCLUSIONS

This study investigates the effects of various thermomechanical treatment procedures on the hardness, microhardness, impact toughness, and microstructure of S275JR structural steel. Normalization resulted in microstructural refinement, leading to increased values across all tested properties. Cold plastic deformation introduced work hardening, which significantly increased hardness while reducing impact toughness. Subsequent strain aging at 100 °C and 250 °C further increased both hardness and microhardness. Notably, strain aging at 100 °C also led to an increase in impact toughness, which is atypical for steels. Microstructural analysis confirmed that normalization refined the microstructure of the as-received sample through grain size reduction.

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