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BUILDING ASSESSMENT OF MECHANICAL AND CHEMICAL PROPERTIES OF HIGH MANGANESE STEEL IN TALL BUILDING CONSTRUCTION

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Abstract- This article presents a relevant case study that holds significant importance in the field of materials technology and construction engineering. It centers on the examination of high manganese steel; a material widely employed in the construction of tall buildings and focuses on its mechanical and chemical properties. The study's value lies in its empirical approach, involving a series of experimental tests with regards to tensile and bending assessments, along with meticulous chemical analysis. The research outcomes are noteworthy, revealing a high level of mechanical robustness in 22 mm diameter high manganese steel, with a yield strength of 220 MPa and an ultimate tensile strength of 554 MPa. The absence of cracks observed during bending tests underscores the material's ductility and resilience, making it a reasonable choice for structural applications. Moreover, the chemical analysis results affirm that the steel composition complies with industry standards, ensuring its reliability and safety. This study contributes insights into the effective utilization of high manganese steel for critical roles in the construction industry, particularly in the context of tall building construction, which not only increase rapidly in number but also in density in urban areas. Furthermore, it explores the role of manganese in steel production, emphasizing its multifaceted impact on steel properties. By drawing upon previous research related to Tirana's seismic concerns and construction materials, this study builds upon existing knowledge, providing a solid foundation for further exploration. The case study's practical implications extend to addressing material sourcing, specialized fabrication techniques, structural design considerations, and construction methodologies, offering valuable guidance for architects, engineers, and builders seeking to harness the unique attributes of high manganese steel to enhance structural performance and safety in the face of Tirana's seismic and wind challenges. This research bridges gaps in understanding the effects of manganese content and casting methods on high manganese steel, contributing complementary information to the broader scientific discourse. In conclusion, the study emphasizes the high potential of high manganese steel for tall building construction in a high-density building of an urban area, because of its strength, ductility, and compliance with industry standards, and paves the way for further investigation and applications to elucidate its long-term performance and cost-effectiveness in future construction projects.

Keywords: High Manganese Steel, Tall Building Construction, Mechanical Properties, Chemical Analysis, Structural Performance.

1. INTRODUCTION

High manganese steel is an alloy known for its unique mechanical properties. This study includes tensile and bending tests, as well as chemical analysis. The experiments aimed to assess the steel's suitability for structural applications, such as in the construction of high-rise buildings. The results reveal valuable insights into the mechanical behavior and chemical composition of steel, contributing to its effective utilization in the construction industry. Manganese (Mn) is a common alloying element in periodic steel and plays a crucial role in its properties (Callister 2010). The works of various researchers have contributed valuable insights into materials and construction practices relevant to Tirana's unique context. Oztiirk and Ormeni (2021) provided a comprehensive evaluation of earthquake activity in the Frakull Durres fault zone, aligning with Tirana's seismic concerns. Gulerce, et al. (2017) produced seismic hazard maps tailored to the Western Balkans, including Tirana, a key reference for structural planning. Muco, et al. (2002) established seismic zonation in Albania, offering foundational data for seismic-resistant designs.

In their study of materials, scientist working on seismic hazard harmonization in Europe [15], shared seismic hazard harmonization insights applicable to Tirana, addressing structural robustness. Markusic et al. (2016) offered an updated earthquake catalog for the Western Balkans, aiding in assessing seismic risks. These cited studies collectively inform and enhance the understanding of construction materials and practices suitable for Tirana's infrastructure projects, serving as a vital knowledge base for further research endeavors. These prior studies collectively provide valuable insights into the mechanical and chemical properties of construction materials within regions that share geological similarities with Tirana. This body of research informs the suitability and durability of such materials for infrastructure projects in Tirana, Albania. In the following sections, we follow this existing knowledge base and present experimental evaluation of high manganese steel for rapid and dense construction applications.

2. MANGANESE PROPERTIES IN STEEL

One of the valuable roles of manganese in steel production, as described by Hadfield (1888) in his pioneering work on Hadfield's Manganese Steel, is its function as a deoxidizer and desulfurizer. During the manufacturing process, manganese engages in chemical reactions with the oxygen and sulfur present in molten steel. This results in a substantial reduction of oxygen and sulfur levels, thereby enhancing the purity of the steel. Consequently, this contributes to improved ductility and overall steel stability and qualities of paramount importance in ensuring the quality and reliability of steel materials for diverse applications. Further research by Sebastian Wesselmecking, et al. (2021) underscores manganese's significant role in strengthening steel. Manganese readily forms solid solutions with iron, significantly fortifying the steel's structural integrity. This interaction effectively increases both its tensile and yield strength, rendering steel suitable for high-stress applications where structural integrity is crucial. Additionally, manganese's presence augments the steel's strain-hardening capacity - a pivotal characteristic that bolsters its performance in demanding conditions.

Recent research by Jacob et al. (2020) further emphasizes manganese's importance in refining steel's microstructure. During the cooling and solidification process of steel, manganese plays a crucial role in refining the structure by aiding in the formation of fine grains. This refinement significantly contributes to the steel's overall strength, stability, and resistance. In comparison to coarse-grained steel, the fine-grained variant exhibits superior qualities, making it an attractive choice for various industrial applications. Moreover, manganese serves as an austenite stabilizer, as evidenced by Shivkumar Khaple, et al. (2023) in their research on Fe-Al based ferritic lightweight steel. This property is particularly valuable in preserving the austenitic phase of steel at room temperature or during cooling. Austenitic steels are renowned for their exceptional formability, corrosion resistance, and stability. This characteristic makes manganese an essential element in steel alloys designed for applications requiring these properties.

Lastly, manganese plays an important role in enhancing steel hardenability, allowing for controlled heat treatment processes like quenching and tempering. U. Bohnenkamp and R. Sandstrom (2000) in their work on the evaluation of the density of steels and ASTM International (2012) highlight the formation of various carbides within the steel matrix, enabling the steel to attain desired levels of strength and toughness. Such control over hardenability is a critical factor in tailoring steel materials for specific applications. In summary, manganese's multifaceted impact on steel properties underscores its significance in the realm of material science and engineering. Its contributions to deoxidation, strengthening, grain refinement, austenite stabilization, and hardenability collectively make it an indispensable element in the formulation of steel alloys tailored to meet a wide array of industrial and construction needs.

3. EXPERIMENTAL DETAILS AND TEST SPECIMEN CHARACTERISTICS

During the experimental procedure, accredited tensile and bending tests were conducted on periodic steel samples with varying diameters from 10 mm to 22 mm as show in in Table 1. The selection of samples was from one of the highest new buildings in the center of the city. These tests included the determination of yield strength, ultimate tensile strength, elongation, and reduction in area.

Figure 1. Universal testing machine DLY-30 and rebar sample photo selected randomly during measurements

Several tests were carried out periodically using a DLY-30 hydraulic universal testing machine, known for its precision and accuracy in measuring mechanical properties. This machine shown in Figure 1, is suitable for testing the tensile, compression, bending, and shearing characteristics of metallic and non-metallic materials.

Table 1. Details of test specimens

Dimensions			Mechanical Properties and chemical analysis
Section Diameter (mm)	Section Area S_0 (mm²)	Length L_0 (mm)	
22	379.1	110	Manganese Content (%) Yield Strength (Re) (MPa) Ultimate Strength (Rm)(MPa) Elongation (A) (%) Reduction in Area (Z) (%) C (%); Mn (%); Si (%); S (%); P (%); Cu (%); N (%); Ceq
20.4	326.2	100	
18.4	268.2	90	
16.4	212.3	80	
10.7	91	50	

The chemical analysis of the steel's composition, including follows the guidelines established in [17] SSH EN ISO 4829-1:2018, titled "Title of the Standard.". The international standard, published on 22 Jan 2019, provides a comprehensive methodology for precise chemical analysis of steel materials. It specifies the techniques, equipment, and procedures required to determine the concentrations of various alloying elements and impurities in the steel.

4. RESULTS AND DISCUSSIONS

The chemical analysis results show that the steel composition, including carbon (C), manganese (Mn), silicon (Si), sulfur (S), and phosphorus (P), falls within acceptable limits. This follows to industry standards and ensures the steel's reliability and safety. Figure 2 present results of the chemical composition of the high manganese steel samples so we can gain deeper insights into the influence of these compositions on various factors, including diameter variations and suitability for tall building construction. The statistical analysis we conducted in this study was generated using a software named PAST (Statistics Software Package for Education and Data Analysis) [18].

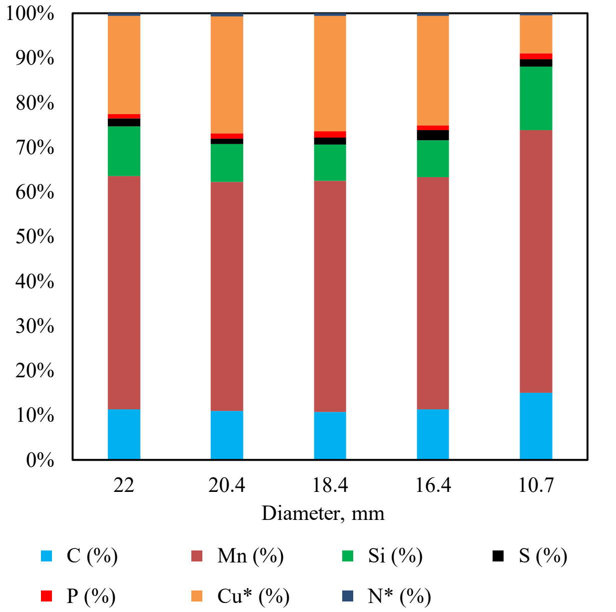

Figure 2. Chemical element analysis of different samples with different diameters left to right: 22 mm, 20.4 mm, 18.4 mm, 16.4 mm, 10.7 mm

The carbon content ranges from 0.197% to 0.23%, with a mean of 0.2118%. While carbon's influence on diameter variations is not explicitly evident, its controlled levels contribute to the steel's overall strength and performance. In tall buildings, consistent carbon content ensures uniform structural integrity. Manganese content varies from 0.83% to 1.06%, with a mean of 0.96%. Higher manganese levels enhance the steel's strength and ductility. The steel's reliability across different diameters suggests its adaptability for various structural components in tall buildings. Silicon content ranges from 0.15% to 0.215%, with a mean of 0.18%.

The wider Si% range implies variations in silicon levels, which may affect the steel's behavior. Ensuring controlled silicon levels is crucial for consistent performance in tall building construction. Both sulfur and phosphorus have relatively low mean values, indicating compliance with industry standards. Lower sulfur levels contribute to improved ductility, a vital property for tall buildings. Controlling phosphorus content is essential for steel's reliability. Both copper and nitrogen show significant variability, with Cu% ranging from 0.12% to 0.5% and N% from 0.007% to 0.012%. These variations may affect steel behavior, necessitating careful quality control. Ensuring consistent compositions is critical for reliable tall building construction. The mean Ceq is 0.466, which falls within acceptable limits. Ceq accounts for various alloying elements influence on steel behavior. A controlled Ceq ensures that the steel meets safety standards.

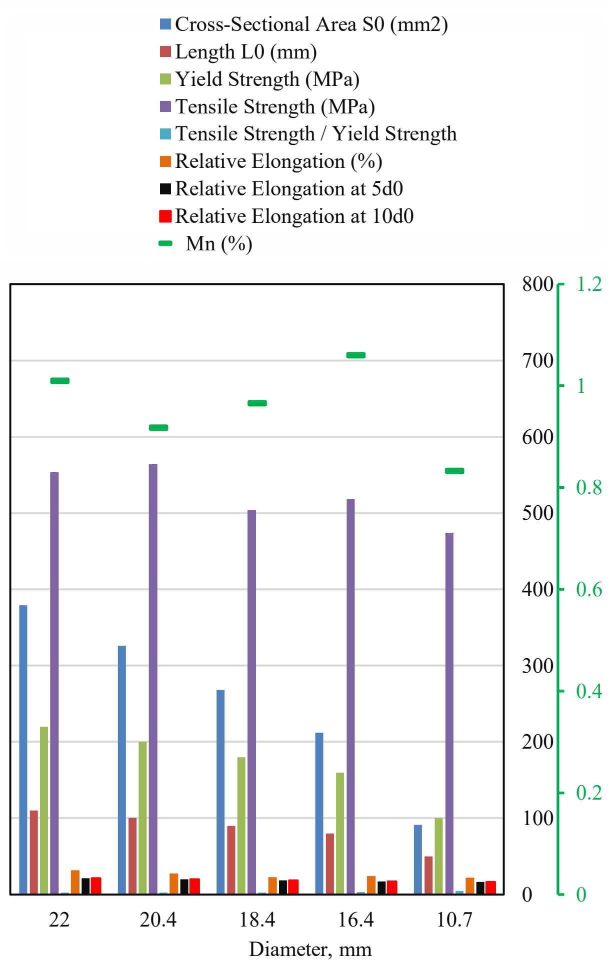

Figure 3. Mechanical properties of different samples with different diameters left to right: 22 mm; 20.4 mm; 18.4 mm; 16.4 mm; 10.7 mm

To investigate the impact of cyclic loads on high-strength steel structures, it is crucial to examine the mechanical characteristics of high-strength steels following fatigue-induced damage. Current research conducted by state institutions predominantly focuses on the mechanical attributes of steel post-corrosion, elevated temperatures [9], and steel fatigue properties.

Limited attention has been given to the residual mechanical properties of steel following fatigue-induced damage, and there remains a notable absence of relevant data in this regard.

The experimental analysis of high manganese steel used in the construction of one of the highest buildings reveals promising results. The tensile and bending tests on the 22 mm diameter steel sample show satisfactory mechanical properties, presented in figure 3, with a yield strength of 220 MPa and an ultimate tensile strength of 554 MPa. The presence of cracks was not observed during the bending test, indicating good ductility and resistance. The fact that these strengths remain consistent across varying diameters (20.4 mm, 18.4 mm, 16.4 mm, and 10.7 mm) suggests the reliability of high manganese steel across different structural components in tall buildings. The absence of cracks during bending tests, combined with elongation percentages ranging from 22% to 32%, demonstrates the material's ductility and ability to absorb energy before fracture. Ductility is essential for tall buildings in Tirana as it allows the steel to deform under loads, such as wind and seismic forces, without sudden failure. The steady increase in elongation values with decreasing diameter indicates that even thinner sections of high manganese steel maintain good ductility, which is crucial for various structural elements in tall buildings.

In 2021, the housing area in the capital reached 1.43 million square meters, marking the highest historical level since at least 2005, as per the records provided by Albanian Institute of Statistics (INSTAT) detailing data by regions. The Gross Fixed Capital Formation (GFCF) indicator showed that construction constituted almost 87% of the total in 2006, setting a new record. Specifically, residential construction alone accounted for 62% of the total invested capital during that year. Following this, the sector underwent a phase of maturity, reflecting market saturation and a shift of businesses towards other industries. Post-2016, the construction sector experienced a resurgence, hitting 78.5% of the GFCF in 2020, the highest since 2010. Notably, residential construction alone represented over 47% of the total in 2020 with at least 12 towers under construction with an average height of around 20 stores [23].

In discussing the practical implementation of high manganese steel in tall buildings in Tirana, it is imperative to tackle the challenges and considerations encountered by engineers. These deal with securing a reliable supply of high manganese steel, given its relative scarcity compared to conventional construction materials, necessitating the establishment of dependable supply chains, possibly involving material importation, though local or regional suppliers can help mitigate procurement delays and costs. Specialized fabrication techniques are essential due to high manganese steel's elevated manganese content, with welding being a particular concern, demanding intricate processes to avert issues like cracking or compromised mechanical properties. Engineers and builders must ensure that welding procedures are tailored to high manganese steel, with welders obtaining the necessary training and certification.

The structural design must accommodate the steel's unique properties, including its robust strength, ductility, and deformation resistance, vital for preserving structural integrity amid Tirana's seismic and wind loads. Effective construction techniques, involving adjustments in assembly procedures, quality control measures, and specialized handling of thinner sections of high manganese steel, are key to the material's successful implementation in tall building projects.

The practical utilization of high manganese steel in Tirana's tall buildings entails addressing material sourcing, fabrication and welding, structural design, and construction techniques, necessitating collaborative efforts among engineers and builders to harness the material's distinctive attributes for bolstering structural performance and safety against Tirana's seismic and wind challenges. Several studies explored the influence of manganese content and casting methods on high manganese steel, provide valuable insights and complementary information that can enrich our discussion of results. In Torabi et al.'s study, the influence of increasing manganese content on high manganese austenitic steels was investigated [22]. They observed that higher manganese content led to an increase in hardness, ultimate tensile strength, and wear resistance. The results of their hardness tests, specifically the increase from 191 to 218 Vickers with increasing manganese content, align with our findings regarding the effect of manganese on steel properties. Amratav et al. delved into the steelmaking process and its impact on the composition of steel [21]. Their research emphasized the significance of removing impurities like sulfur and phosphorus and adding alloying elements like manganese to produce the exact steel required. They also discussed the continuous casting process, which is vital for steel production. Our findings are in alignment with Amratav et al.'s emphasis on steel composition control, particularly with regard to manganese.

4. CONCLUSONS

The analysis of high manganese steel in Tirana's tall building construction context indicates that this material exhibits highly favorable mechanical properties. Its strength, ductility, and adherence to industry standards make it a highly suitable choice for tall building construction, especially considering the seismic challenges the region faces, density of rapid constructions. Architects and engineers can confidently consider high manganese steel as a valuable material to enhance the structural performance and safety of tall buildings, contributing to against seismic and wind loads. Further research and real-world applications can provide additional insights into its long-term performance and cost-effectiveness.

Furthermore, this study serves as a foundational step towards theoretical and experimental discussion to review the full potential of high manganese steel in construction. While our findings demonstrate its promising mechanical and chemical properties, there is still room for further investigation and ongoing applications to provide additional information into its long-term performance and cost-effectiveness.

The practical implementation of high manganese steel necessitates addressing various challenges related to material sourcing, specialized fabrication techniques, structural design considerations, and construction methodologies. Collaboration among architects, engineers, builders and chemical engineers, with suppliers will be key in establishing the unique attributes of high manganese steel effectively to ensure the safety and resilience of tall buildings.

This research not only contributes to the growing body of knowledge regarding construction materials but also bridges gaps in understanding the effects of manganese content and casting methods on high manganese steel, adding valuable information to the broader scientific discourse. As the construction industry continues to evolve, high manganese steel stands as a promising option for sustainable, resilient, and cost-effective tall building construction, addressing the unique needs and challenges of urban areas.

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