National University of Science and Tehcnology "POLITEHNICA" Bucharest
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SCIENTIFIC BULLETIN
AUTOMOTIVE series
year XXIX, no. 33

UNDERSTANDING CONSTRUCTION ALLOYS: PROPERTIES UNVEILED

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Article history
Received 20.07.2023
Accepted 20.10.2023

DOI https://doi.org/10.26825/bup.ar.2023.003

Abstract: This article presents an experimental study on the characterization of carbon steels, alloy steels, aluminum alloys, brass, and cast iron commonly used in the construction industry. The focus is on evaluating the mechanical properties of these materials through optical microscopy and Brinell hardness testing. A series of samples representing each material type were prepared and subjected to optical microscopy analysis to examine their microstructural characteristics. The images obtained were further analyzed using ImageJ software to measure the size of various microstructural constituents. Additionally, the Brinell hardness test was conducted on each sample to quantify their mechanical strength and resistance to indentation. The experimental results provide valuable insights into the microstructural characteristics and mechanical properties of these construction materials, aiding in the selection and design of appropriate alloys for specific construction applications. The findings also contribute to the broader understanding of carbon steels, alloy steels, Si-Al, brass and cast iron, offering potential improvements in construction material selection and performance.

Keywords: Carbon steels, alloy steels, characterization, construction material

INTRODUCTION

The construction industry heavily relies on a wide range of materials to meet the diverse demands of infrastructure development and structural integrity [1]. Among these materials, carbon steels, alloy steels, siluminates, brass, and cast-iron play crucial roles due to their favorable mechanical properties. Understanding the microstructural features and mechanical behavior of these materials is essential for ensuring their optimal performance in construction projects [2].

In this study, we aim to investigate the microstructural characteristics and mechanical properties of carbon steels, alloy steels, siluminates, brass, and cast iron through experimental testing. Optical microscopy, a widely used technique for examining material microstructures, will be employed to visualize and analyze the internal structures of the samples. By utilizing ImageJ software, we will measure the size of various microstructural constituents, providing quantitative data on the microstructural features of these materials.

In addition to microstructural analysis, the Brinell hardness test will be conducted to assess the mechanical strength and resistance to indentation of the samples. The Brinell hardness value is a widely accepted measure of a material's ability to withstand external forces and is crucial in determining its suitability for construction applications.

The findings of this study will contribute to a comprehensive understanding of the microstructural features and mechanical properties of carbon steels, alloy steels, siluminates, brass, and cast iron. This knowledge will aid in the selection and design of materials for specific construction applications, ensuring optimal performance and durability. Moreover, the results will provide insights into potential improvements in construction material selection, leading to enhanced structural integrity and overall project success.

OPTICAL MICROSCOPY TO CHARACTERIZE THE SAMPLES

Preparation of samples

The phase of sample preparation is a crucial step before commencing optical microscopy analysis for different materials. For C25 steel, C35, C40, 18MoCN13 alloy steel, Al-Si, and 45CuZn alloy, the samples need to undergo a series of preparation procedures. These include cutting the samples into desired shapes and sizes, followed by grinding and polishing to obtain a smooth surface. Next, the samples are etched with specific etchants, in our study we used Nital 2%, to reveal the microstructure and highlight any structural features.
On the other hand, for cast iron spheroidal graphite and cast-iron lamellar graphite, the preparation process involves cutting the samples, followed by mounting and polishing to achieve a flat surface. Subsequently, the samples are etched using suitable etchants to distinguish between spheroidal and lamellar graphite structures.
Proper sample preparation ensures accurate and reliable optical microscopy analysis, allowing for detailed examination of the microstructural characteristics and properties of these materials.

Optical microscopy

Optical microscopy is a powerful technique used for the analysis of various materials: C25, C35, C40, 18MoCN13, and 45CuZn alloys. With optical microscopy, the samples can be examined at high magnification levels to observe their microstructural features. This technique utilizes visible light to illuminate the samples, which then interact with the material’s structure, providing valuable information about grain boundaries, phase distribution, and defects. By using different objectives and lenses, optical microscopy allows for the visualization of fine details and the characterization of the material’s composition. The size, shape, and distribution of grains can affect the strength, ductility, and toughness of the alloy.
The microstructure of carbon steel is mainly composed of ferrite and cementite, with the relative proportions of these phases depending on the carbon content, as shown in figure 1-3. While stainless steel can vary depending on the specific type, but it often includes ferrite, austenite (another iron-based crystal structure), and chromium carbide precipitates. A brittle iron-carbon alloy with a high carbon content is dominated by graphite (the stable form of carbon at cast iron's solidification temperatures) and ferrite or cementite, as presented in figure 5 and 6. The microstructure of brass can consist of alpha (a face-centered cubic solid solution) and beta (a body-centered cubic solid solution) phases, depending on the zinc content, as seen in figure 4. In the case of bronze can consist of alpha (a solid solution of tin in copper) and delta (an intermetallic compound of copper and tin) phases.

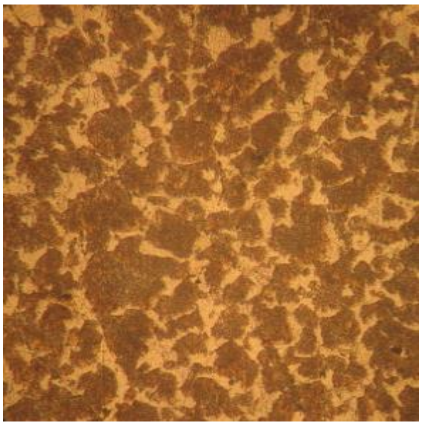


Figure 1. C25 steel microstructure (scale x200)

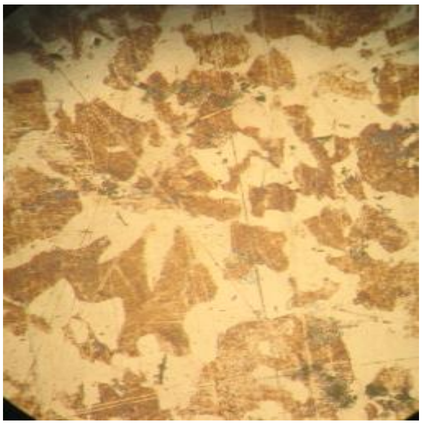


Figure 2. C35 steel microstructure (scale x500)

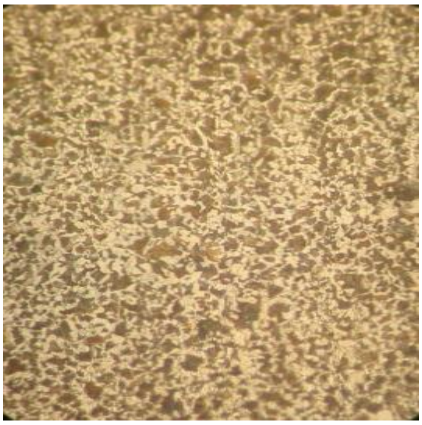


Figure 3. C40 steel microstructure (scale x200)

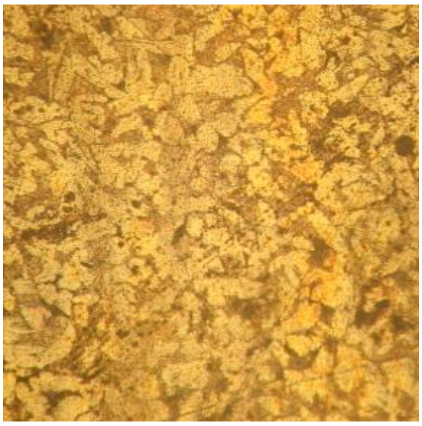


Figure 4. 45CuZn alloy "Brass" microstructure (scale x200)

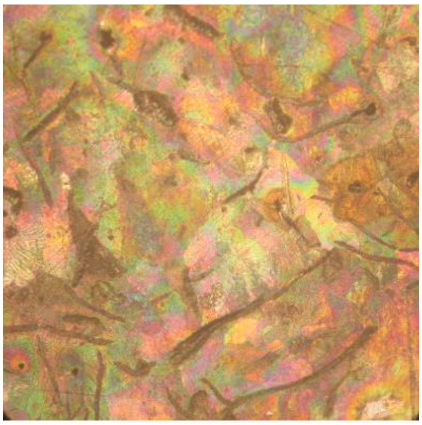


Figure 5. Cast Iron lamellar graphite microstructure (scale x200)

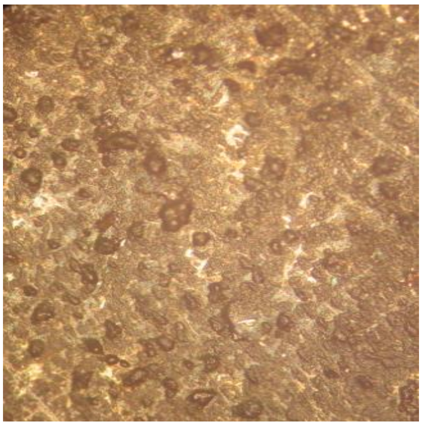


Figure 6. Cast Iron spheroidal graphite microstructure (scale x200)

After completing the optical microscopy process, ImageJ is commonly utilized for further analysis and processing of the acquired images.

ImageJ Analysis

ImageJ is a widely used image processing and analysis software that provides researchers with a powerful set of tools for working with digital images.

With ImageJ, we can perform a multitude of tasks such as image enhancement, filtering, segmentation, and measurement, the magnification scale used in our study is x200.

PRESENTATION OF RESULTS

The tables (1 and 2) below present the results of size measurements conducted on various samples. For C25, C35, C40, 18MoCN13, and 45CuZn alloys, we measured the size by examining two diagonals, for each component of the structure, namely pearlite and ferrite. For cast iron with spheroidal graphite and cast iron with lamellar graphite we measured consecutively the diameter, and the length.
We were unable to measure the size of Al-Si due to the complex shape of its microstructure. It is important to note that a scale of (x200) was used and a conversion of 43.1 pixels corresponding to 0.002 mm was used for all the samples. Finally, we calculated the average grain size for all the samples in micrometers.

Table 1. Average grain size measurement of the samples in micrometers (scale x200)

Sample	Composition	Size of diagonals(pixel)	Average of two diagonals (pixel)	Average grain size (pixel)	Average grain size (µm)
C25	pearlite	20.10	24.35	18.94	0.878
		28.60			
		21.10	20.99		
		20.88			
		24.00	20.06		
		16.12			
		10.77	13.04		
		15.30			
		14.04	16.24		
		18.44			
	ferrite	18.11	15.08	11.31	0.525
		12.04			
		11.18	9.59		
		8			
		11	10.11		
		9.22			
		11.4	12.81		
		14.21			
		6.32	8.99		
		11.66			
C35	pearlite	16.03	24.64	21.21	0.984
		33.24			
		14.04	16.52		
		19.00			
		14.14	17.07		
		20.00			
		16.12	14.47		
		12.81			
		32.00	33.35		
		34.70			
	ferrite	11.66	15.76	16.93	0.785
		19.85			
		19.24	20.17		
		21.1			
		14.87	17.26		
		19.65			
		17.8	14.73		
		11.66			
		10.3	16.75		
		23.19			
C40	pearlite	9.22	14.92	12.48	0.578

		20.62			
		9.49	11.96		
		14.42			
		5.10	8.25		
		11.40			
		10.77	12.33		
		13.89			
		18.44	14.92		
		11.40			
	ferrite	7.62	8.84	10.47	0.485
		10.05			
		13	14,15		
		15.3			
		9.06	8.17		
		7.28			
		10	12.44		
		14.87			
		8.06	8.75		
		9.43			
18MoCN13	pearlite	26.25	38.29	26.46	1.228
		50.33			
		13.04	20.06		
		27.07			
		12.00	20.87		
		29.73			
		16.00	15.91		
		15.81			
		28.02	37.21		
		46.39			
	alloyed-ferrite	15.52	16.49	16.98	0.787
		17.46			
		8	20.50		
		33			
		13.04	14.77		
		16.49			
		15.52	16.49		
		17.46			
		17.49	16.65		
		15.81			
45CuZn Alloy	α	38.60	30.00	22.90	1.062
		21.40			
		31.30	24.14		
		16.97			
		19.24	22.37		
		25.50			
		27.60	19.91		
		12.21			
		19.42	18.11		
		16.80			
	β	18.12	27.12	30.13	1.398
		36.12			
		39.56	26.34		
		13.12			
		24.62	18.33		
		12.04			
		62.1	41.36		
		20.62			
		27.17	37.51		
		47.85			

Table 2. Average grain size measurement of spheroidal and lamellar graphite in micrometers (scale x200)

Sample	Parameter	Grain size (pixel)	Grain size (μm)	Average grain size (μm)
spheroidal graphite	diameter	14.76	0.68	0.84
		19.72	0.91	
		13.42	0.62	
		18.44	0.85	
		24.84	1.15	
lamelar graphite	lenght	98.18	4.55	5.36
		65.86	3.05	
		70.23	3.25	
		182.78	8.48	
		161.53	7.49	

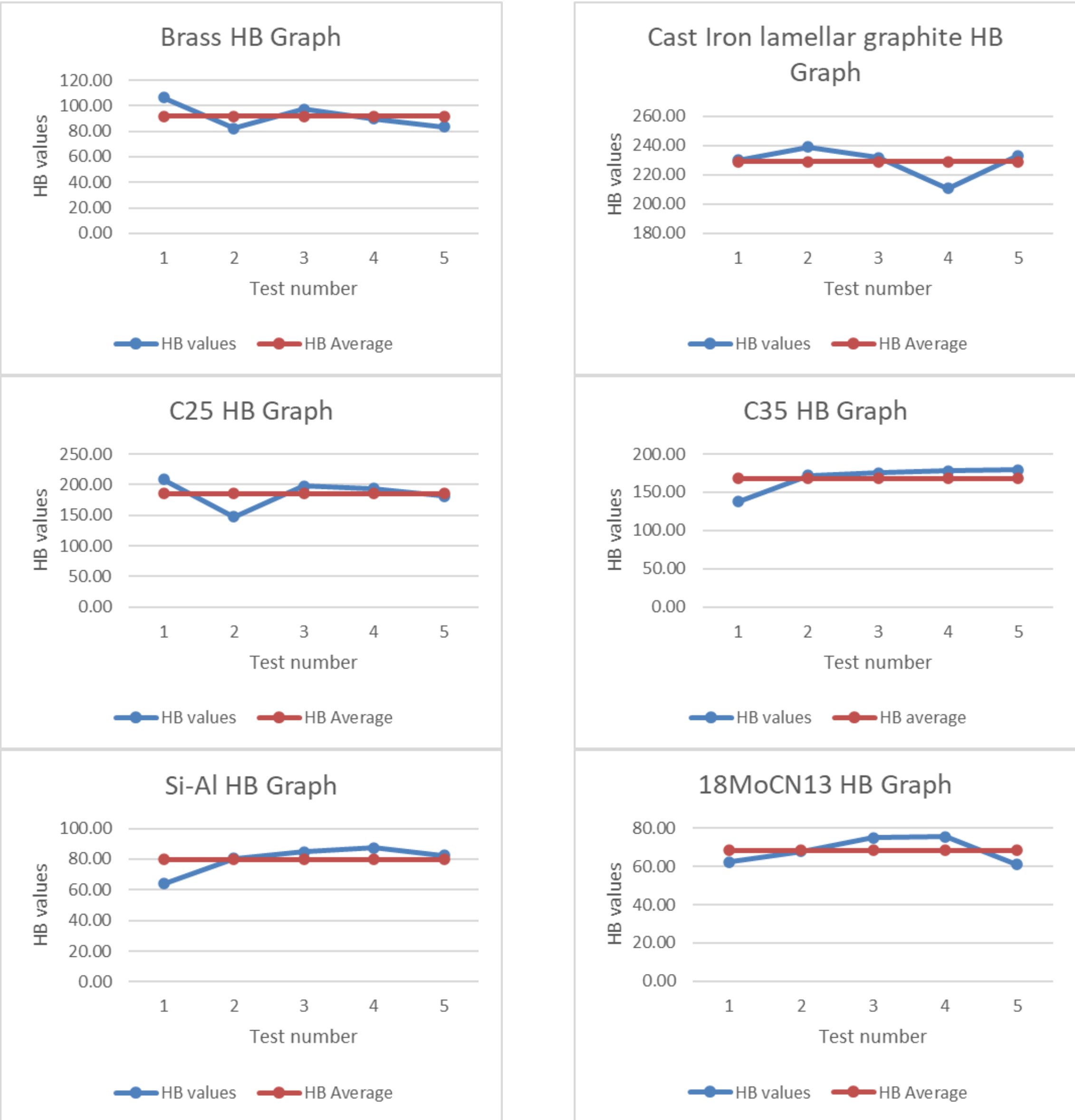
After measuring the grain size of the samples, the next step was to perform hardness tests to obtain the HB values. It is worth mentioning that, according to standards, we obtained a LD/HB ratio of 1.74.

Table 3. Average grain size measurement of spheroidal and lamellar graphite in micrometers

Sample	LD	HB	LD/HB	Average HB
C25	362	208.25	1.74	185.70
	257	147.85		
	343	197.32		
	337	193.87		
	315	181.21		
C35	239	137.49	1.74	168.33
	299	172.01		
	305	175.46		
	309	177.76		
	311	178.91		
C40	147	84.57	1.74	84.57
18MoCN13	108	62.13		68.23
	118	67.88		
	130	74.79		
	131	75.36		
	106	60.98		
Brass	185	106.43	1.74	91.81
	143	82.26		
	169	97.22		
	156	89.74		
	145	83.42		
Si-Al	111	63.86	1.74	79.73
	140	80.54		
	147	84.57		
	152	87.44		
	143	82.26		
	400	230.11	1.74	228.85
	415	238.74		

Cast Iron Lamelar Graphite	403	231.84
	366	210.55
	405	232.99

After calculating the average HB values for all the samples, we plotted a graph showing the HB values for each individual sample, as well as an average HB graph encompassing all the samples, as presented in figure.7.



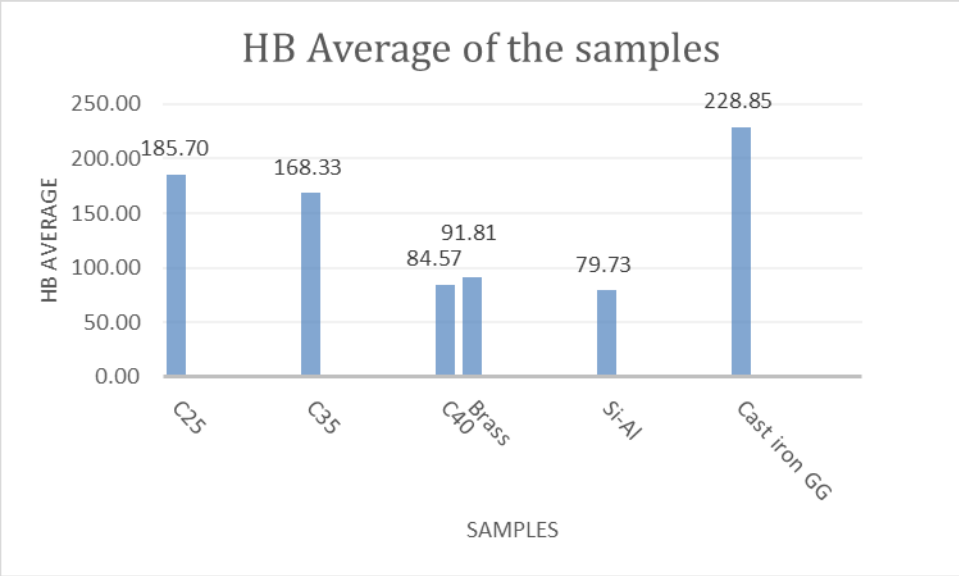


Figure 7. Average HB values of samples

Hardness directly translates to a material's ability to resist permanent shape changes from scratches, indentation, abrasion, and erosion. The average HB values of all the samples fell within the range specified by the standards [3],[4],[5],[6],[7]. However, we were unable to conduct the test for C40 and spheroidal graphite samples due to their small measurement surfaces. Harder alloys have a longer lifespan because they can better withstand everyday wear and tear. This is important for products that need to last a long time, such as car parts, tools, and building materials.

CONCLUSIONS

In this study, we conducted an experimental analysis to characterize the size and Brinell hardness of carbon steels, alloy steels, Si-Al alloys, and cast iron with spheroidal and lamellar graphite. Using optical microscopy, ImageJ software, and a hardness testing machine, we gained valuable insights into the microstructural features and mechanical properties of these materials.

Table 4. Average grain size measurement and HB average of the samples

Samples	Composition	Average grain size (μm)	Average Brinell hardness (HB)
C25	pearlite	0.878	185.70
	ferrite	0.525	
C35	pearlite	0.984	168.33
	ferrite	0.785	
C40	pearlite	0.578	84.57
	ferrite	0.485	
18MoCN13	pearlite	1.228	68.23
	alloyed-ferrite	0.787	
45 CuZn Alloy	α	1.062	91.81
	β	1.398	
Si-Al	-	-	79.73
Cast Iron Lamelar Graphite	-	5.36	228.85
spheroidal graphite	-	0.84	-

Based on the analysis of the results, it was observed that cast iron with lamellar graphite exhibited the highest hardness among the tested samples, indicating its superior resistance to deformation. On the other hand, Si-Al alloys displayed relatively lower hardness values, suggesting their lower mechanical strength compared to the other materials examined.

The importance of this study in the field of construction lies in its contribution to material selection and design. By characterizing the microstructural features and mechanical properties of carbon steels, alloy steels, Si-Al alloys, and cast iron, construction professionals can make informed decisions regarding the appropriate materials for specific applications. Understanding the relative hardness and strength of these materials enables engineers and designers to ensure the structural integrity and durability of construction projects.

Furthermore, this study provides a foundation for further research and development in the field of construction materials. Future investigations can focus on exploring methods to enhance the mechanical properties of Si-Al alloys, making them more suitable for construction applications. Additionally, the findings can inform the development of new alloys or the modification of existing ones to optimize their performance in construction projects.

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