

THE COMPARATIVE ANALYSIS OF HARDNESS IN FC250 CAST IRON BASED ON LITERATURE STUDIES

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Article Info	ABSTRACT
Article history: Received October 7th, 2025 Revised January 12th, 2026 Accepted January 28th, 2026 *Corresponding Email: muharulyk1976@gmail.com	Gray cast iron (FC250) is a material widely used in engine components, such as cylinder sleeves and brake shoes, due to its good mechanical properties and economical production process. This study aims to analyze the comparative hardness value of FC250 cast iron based on literature studies and laboratory test results. The methods used include chemical composition testing using an Optical Emission Spectrometer (OES) and hardness testing using a Vickers Matsuzawa VMT-7 on four cylinder sleeve samples. The test results show that the chemical content of FC250 is relatively in accordance with standards, although there are small variations in C, Si, and S elements when compared to the literature. The average hardness value of the tested cylinder sleeves is 192.3 HB, lower than the reference FC250 hardness value of ± 220 HB. This difference indicates the influence of chemical composition, microstructural phase distribution, and casting process factors on the mechanical properties of the material. Thus, this study emphasizes the importance of composition control and casting parameters to obtain material quality according to application standards. Keyword: Ammonia Level, Environment Quality, Fenat Method, Well water

Introduction

Grey cast iron is one of several types of cast iron that is relatively inexpensive and readily available. Generally, Grey cast iron is used for machining applications, primarily for piston rings and cylinder liners, because of its excellent characteristics, resistance to friction and wear, and its relatively low manufacturing cost (Riahi and Alpas, 2003). According to the Japanese standard (JIS (Japanese Industrial Standard)) G5501, gray cast iron is classified into six types based on its mechanical properties. The naming convention begins with the prefix "FC," which stands for "Flake Graphite Cast Iron." One such grade is FC250, which has a tensile strength of 250 MPa and a hardness of approximately 241 HB. This material is frequently used in the manufacture of cylinder sleeves and brake shoes, both of which play a crucial role in engine and vehicle systems. The various grades are listed in Table 1 (Al Hassany et al., 2024).

One product made from gray cast iron is the cylinder sleeve, which is often referred to as a cylinder liner, a critical component in internal combustion engines. It is used to protect the cylinder walls from wear and damage caused by friction between the piston and the cylinder walls. The cylinder sleeve also aids in dissipating the heat generated during the combustion process, thereby maintaining a stable engine temperature. With a cylinder sleeve in place, the engine can operate more reliably and have a longer service life. Additionally, cylinder sleeves allow for more cost-effective repairs because only this component needs to be replaced when wear occurs, rather than the entire engine block (Heywood, 1988).

The cylinder sleeve casting process is typically carried out using sand casting or permanent mold casting methods. In the sand-casting method, sand is used as a mold material that is easy to shape and can be removed after the casting is complete. Meanwhile, in permanent mold casting method, the used molds can be reused multiple times, making them more efficient for mass production. This casting

process requires strict control over temperature and cooling rates to ensure optimal material quality and mechanical strength (Fakarudin *et al.*, 2012; Zhang and Li, 2024). The manufacturing of cylinder sleeves involves several stages, ranging from mold making and casting the raw material to final processes such as machining. After the casting process, cylinder sleeves typically undergo heat treatment to enhance their strength and durability. Machining is the final stage in cylinder sleeve manufacturing, which includes grinding, turning, and surface finishing. Machining is performed with high precision to ensure the sleeve's inner and outer diameters meet design specifications and that its surface is smooth to minimize friction with the piston (Huston and Hornik, 2008).

In addition to cylinder sleeves, another product that uses FC250 cast iron as its raw material is the brake shoe. A brake shoe is a component designed to press against the disc or the inner wall of a drum brake, generating friction to slow down and stop the rotation of a vehicle's wheels (Prasetyo *et al.*, 2024). This study aims to analyze the hardness values of FC250 cast iron based on a literature review, comparing FC250 cylinder sleeves with FC250 brake shoes.

Table 1. Classification of *gray cast iron* based on JIS standards

Type	Tensile Strength (MPa)	Hardness (HB)
FC100	100	201
FC150	150	212
FC200	200	223
FC250	250	241
FC300	300	262
FC350	350	277

Methods

In this experiment, the primary material to be used is a cylinder sleeve from the Batur Jaya Industrial Cooperative, manufactured using steel/iron meeting the FC250 standard. This material will be used for chemical composition testing and hardness testing. One sample will be used for the chemical composition test, and four samples will be used for the hardness test. For the chemical composition test, the sample used is a specially shaped sample taken during the smelting process, with the aim of determining the chemical composition of the molten metal so that any deficiencies or excesses in the material can be detected. Sample preparation involves grinding to smooth the sample surface, after which the samples are taken to a special room for chemical composition testing using an OES (Optical Emission Spectrometer).

For hardness testing, the samples used are sections from the center of the cylinder sleeve obtained from rejected or defective material so as not to compromise the finished product. The four samples to be used are first smoothed using coarse-grit sandpaper until the sample surface is flat and stable. Sanding is performed on one side or both sides if necessary. After coarse sanding, the samples are smoothed again using fine-grit sandpaper to remove the lines formed during the coarse sanding process. Next, the now-smooth surface is polished using Autosol.

Next, the four polished samples are taken to a special room for hardness testing. The instrument used for this hardness test is the Matsuzawa VMT-7, a Vickers-type hardness tester that uses a diamond as the indenter. The results obtained will then be compared with existing literature to identify other possibilities that could be utilized to further improve the cylinder sleeve.

Results and Discussion

Chemical Composition Testing

The cylinder sleeve and brake shoe were cast using standardized gray cast iron (FC250). These composition tests were conducted to determine whether the two products comply with existing

standards (Table 2). The following are the results of the cylinder sleeve composition test using Optical Emission Spectroscopy (OES). The composition of the brake shoe is listed in Table 3.

Table 2. Composition of the FC250 cylinder sleeve

Element	% Content
Carbon (C)	3.3459
Silicon (Si)	2.0960
Manganese (Mn)	0.6622
Phosphorus (P)	0.2612
Sulfur (S)	0.8766
Copper (Cu)	0.3802
Tin (Sn)	0.0429
Manganese (Mn)	0.0075
Chromium (Cr)	0.0873
Nickel (Ni)	0.0109
Aluminum (Al)	0.0079
Molybdenum (Mo)	0.0086
Zinc (Zn)	0.0191
Vanadium (V)	0.1018
Antimony (Sb)	0.0021
Titanium (Ti)	0.0837
Iron (Fe)	92.006

Table 3. Composition of FC250 brake shoes

Element	% Content
Carbon (C)	3.36
Silicon (Si)	1.89
Manganese (Mn)	0.92
Phosphorus (P)	0.14
Sulfur (S)	0.08
Iron (Fe)	93.61

As demonstrated in the metallurgical evaluations conducted by [Al Hassany et al. \(2024\)](#), the averaged baseline values from multiple structural tests provide a baseline to contrast customized procurement criteria. The composition standards for FC250 have been met; for example, FC250 typically has a carbon content of 3–3.5%, but PT Toyota requires a carbon content of 3.5% in its products. [Antara News \(2019\)](#) reported the integration of the Batur Jaya Cooperative into PT Toyota Motor Manufacturing Indonesia's local ecosystem required rigorous structural alignment and multi-year quality training to meet high-precision cylinder sleeve casting expectations. Based on these results, there are slight differences in the main elements present in the FC250 composition of the two products, specifically 0.02% for C, 0.2% for Si, 0.26% for Mn, 0.12% for P, 0.79% for S, and approximately 1.61% for Fe.

Hardness Testing

The Brinell hardness test was conducted to determine whether the hardness of the FC250 cylinder sleeves at the Batur Jaya Cooperative was comparable to that of standard FC250 material, as indicated by the literature review ([Rosyid et al., 2026](#)). The load applied during this test was 10 kgf using a diamond indenter. The results of this hardness test are shown in the graph in Figure 1. Based on

hardness test using the Rockwell B (HRB) scale, the following hardness values vary for each test specimen. Specimen Sp-603 exhibited the highest hardness value, approximately 94 HRB, followed by Sp-598 with a value of 92 HRB. Specimen Sp-604 has a hardness of 91 HRB, while the lowest value was obtained for Sp-599 at 89 HRB. The average hardness value for all test specimens was 91.5 HRB. The lowest hardness value for FC250 was 215.9 HB, while the highest was 235.5 HB. This indicates that, in general, the tested material has a relatively high and uniform level of hardness despite differences between specimens.

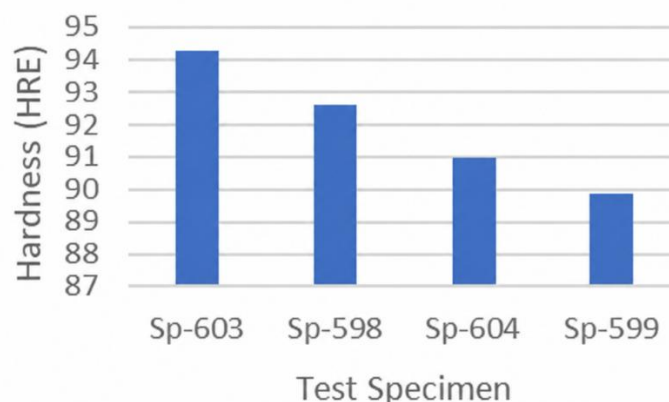


Figure 1. Hardness test results

The hardness test results for the four specimens, measured using the Rockwell B (HRB) scale, were then converted to the Brinell (HB) scale based on the ASTM E140 conversion table to facilitate comparison with the reference data for FC 250 material. Based on this conversion, the hardness values of the specimens ranged from 179 to 206 HB, with an average of approximately 192.3 HB. When compared to the reference hardness value for FC 250 of ± 220 HB, all specimens exhibited lower hardness. Specimen Sp-603 had the highest hardness value, approximately 206 HB, which is 14 HB ($\pm 6.4\%$) lower than FC 250, while specimen Sp-599 had the lowest hardness, approximately 179 HB, representing a difference of 41 HB ($\pm 18.6\%$) compared to FC 250. This difference indicates that, although Sp-603 approaches the mechanical properties of FC 250, the materials from all four specimens generally exhibit lower wear resistance.

These differences in hardness values may be due to several factors. One of them is variation in the material's chemical composition. The FC250 *cylinder sleeve* test specimen has a composition of 3.3459% C and 2.096% Si, while the reference FC250 has a composition of 3.36% C and 1.89% Si. This difference shows that the carbon content in both materials is relatively the same, but the silicon content in the test specimen is higher than that of FC 250. A higher silicon content can increase the amount of graphite formed during solidification, which tends to reduce hardness by decreasing the fraction of the hard metallic matrix. Conversely, a lower silicon content, as in FC 250, has the potential to increase the fraction of the pearlite matrix, which has higher hardness.

In addition to composition, other factors influencing hardness differences include heat treatment or the cooling rate during the casting process, which can alter the proportions and distribution of the pearlite and ferrite phases in the matrix (Stefanescu, 2105; Callister, 2018). The homogeneity of the microstructure is also a critical aspect, as inhomogeneity can lead to variations in mechanical properties across different parts of the specimen. surface conditions during testing, such as the degree of smoothness or the presence of microdefects, can also affect hardness readings (Zhang and Li, 2024).

Conclusion

Based on the tests conducted, it can be concluded that there are differences in mechanical properties between the FC250 from the cylinder sleeve and the FC250 from the drum brake shoe, although the differences are not very significant. The hardness test results for the FC250 *cylinder sleeve*

yielded an average value of 192.3. This value is lower compared to the reference value for FC250 in *the brake shoe*, which is approximately ± 220 HB. This difference in hardness values indicates that the cylinder sleeve has lower wear resistance compared to the brake shoe. The factors underlying the differences in the mechanical properties of the FC250 cylinder sleeve and the FC250 brake shoe are the chemical composition of the FC250 and the heat treatment applied to both samples.

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