Journal of Technology and Engineering
P-ISSN: XXXX, E-ISSN: 3025-4094
Volume 1, Nomor 2, 2023

Influence of Fixed Carbon Carburizer on the Hardness and Microstructure of Cast Iron FC 25

[1]Adi Ganda Putra, [2]Aurobindo Ghose, [3]Pawawoi, [4]Sony Sukmara

[1,2,3] Mechanical Engineering Study Program, Faculty of Manufacturing Technology, Jenderal Achmad Yani University, Cimahi, Indonesia

[4] Mechanical Engineering Study Program, Faculty of Technology and Informatics, Mathla ul Anwar University, Banten, Indonesia

Email: adi.ganda@lecture.unjani.ac.id, aurobindo@gmail.com, pawawoi@lecture.unjani.ac.id, sony_sukmana@yahoo.com

Kata Kunci:
Gray Cast Iron, FC 25, Carburizer, Hardness, Microstructure

Abstrak: Cast iron smelting is carried out with the main materials, namely steel scrap (C) 0.08% and recycled material FC 25 (C) 3.37% so that the mixture of the two raw materials results in the carbon content being less than the FC 25 target which has a content range (C) between 3.10% – 3.40% (JIS G 5501). In order for element (C) to meet the material standardization criteria, a carburizer is used as an addition to element (C) in the smelting process. This research uses an induction furnace with a capacity of 1500 kg for the melting process. Metallographic testing aims to see the comparison of the microstructure that occurs. Brinell hardness testing is carried out by providing 5 point indent traces on the surface. (α) and 2 points in the phase (α+Fe3C). The research results show that the addition of element (C) using a carburizer with a fixed carbon content of 91.57% and 96.7% in casting FC 25 material affects the value of material hardness, phase hardness and microstructure in FC 25 material. The use of carburizers with different contents This does not affect the graphite shape, graphite type and graphite size. The use of a 96.7% carburizer produces a Brinell hardness value of 205 HB, Vickers 259 HV and a pearlite phase percentage of 59% which is higher than a 91.67% carburizer which produces a Brinell hardness value of 184 HB, Vickers 238 HV and a pearlite phase percentage of 56%.

INTRODUCTION

PT. X uses some Fix Carbon Carburizer content in the process of smelting the material to raise elements (C) in the process of casting cast iron, one of which is the gray FC 25 iron for cylinder pipe line boring. Carburizer is a material used in the smelting process to increase the C (carbon) content in the liquid. Carburizers are classified as having a fixed carbon (FC) content of 80%, 85%, 90%, 96% and 99%. The basic ingredient for a carburizer is petroleum coke which comes from green coke resulting from the distillation (refining) process of crude oil. (Churiyanto, 2013).

The carburizer is used to add the element C (Carbon) to the material so that the element (C) meets the standardization criteria for the material to be used because the element (C) will decrease in the charging process because the steel scrap raw material which has a small amount of the element (C) is added with FC 25 recycled material, the element (C) in the smelting process will be reduced. One of the Carburizers used for melting is with a Carburizer content of 91.57% and 96.7% with the same casting target calculation but with a different total weight of added Carburizer because the contents of the two Carburizers also have different contents.

Carbon has an important role in cast iron materials because carbon influences the hardness and graphite values in the microstructure. Therefore, the author tries to compare the effect of the Carburizer content in adding the element C (Carbon) to the melting of the casting with comparative parameters, namely the comparison of hardness and microstructure of the two types of carburizer in the FC 25 material.

Based on the above background, research was carried out on the effect of using a carburizer with a content of 91.57% and 96.7% on material hardness and phase hardness as well as on the microstructure (graphite shape, graphite size, graphite type, percentage of cementite, ferrite, pearlite) on FC 25 material.

The aim of this research is to determine the effect of using a carburizer in adding element (C) in the smelting process with steel scrap raw materials and FC 25 recycled material with a fixed carbon content in the carburizer of 91.57% and 96.7% in making the material. FC 25 on material hardness, phase hardness and microstructure (graphite shape, graphite size, graphite type, percentage of cementite, ferrite and pearlite).

1. EXPERIMENTAL PROCEDURES

This research was conducted through a series of experimental stages to investigate the effect of Carburizer content on the mechanical properties and microstructure of cast materials. It began with a literature review to understand the fundamentals of metal casting, the role of Carburizer, and the testing methods employed. Subsequently, the preparation of equipment and materials was carried out, including a melting furnace, sand molds, and composition and hardness testing instruments. The experiment involved two different melting compositions with Carburizer contents of 91.57% and 96.7%, which were melted in the furnace until the casting temperature was reached. A composition test (Chill Test) was then performed to ensure the appropriate Carburizer content in the molten metal. If the composition did not meet the desired specifications, adjustments were made before proceeding with casting. The molten metal was then poured into a ladle and subsequently into sand molds, followed by mold disassembly after cooling to obtain test specimens. These specimens were then evaluated through Vickers hardness testing, metallographic examination, and Brinell hardness testing to assess the mechanical properties and microstructure of the material. The obtained data were analyzed to compare the influence of different Carburizer contents on the casting results. Finally, conclusions were drawn based on the findings, along with recommendations for future research to enhance casting quality.

In this research, preparations were made for the manufacture of FC 25 casting material with the provisions of the JIS G 5501 standard. The equipment used for smelting was an induction furnace with a capacity of 1600 kg with a capacity of 1500 kg to minimize the occurrence of additional material if there was a shortage of alloying elements or materials. recycling such as defective castings and unused FC 25 channel systems is 70% and steel scrap is 30% of the induction furnace capacity. At this stage, alloy materials such as recycled materials and steel scrap will be tested for composition first to determine the addition of elements needed during melting. Table. 1 and table. 2 shows the requirements for FC 25 material with the JIS G 5501 standard. Table. 3 shows tools and materials for making materials and tables. 4 shows the composition of the C (carbon) content in the alloy material, table. 5 shows the specifications of the two types of carburizers.

Table 1. Chemical composition of FC 25 (JIS G 5501)

GRADE JIS 5501	CHEMICAL COMPOSITION (%)				
	C	Si	Mn	P	S
FC 25	3.10-3.40	1.80 – 2.00	0.9 – 0.95	0.25	0.15

Table 2. Mechanical properties of FC 25 (JIS G 5501)

JIS 5501	liquid temperature (^{0}C)	Hardness (HB)	Tensile Strength (N/mm^2)
FC 25	1160-1225 (1202)	180-240	250

Table 3. Smelting tools and materials

Tools and Materials	Persentase (%)	Capacity/Weight
induction furnace	100	1500
recycled material	70	1050
steel scrap	3	450

Table 4. Content (C) of alloy materials.

Material Content	Steel Scrap (%)	BDU/Return (%)
C	0,08	3,37

Table 5. Carburizer specifications.

GRADE	*Size* (mm)	*Spesifications of analysis (%)*				
		FC	*S*	*Volatile*	*ASH/Abu*	*Moisture*
Carburizer	0,5 - 3	91,57	0,14	2,61	7,8	5,9
Carburizer	1 - 8	96,7	0,46	2,3	0,7	0,56

The casting process is carried out with predetermined calculations and conditions. When the liquid is full in the furnace, a composition test will be carried out first before the liquid is poured or what is usually called a chill test. Figure. 1 shows a specimen from a chill test.

Figure 1. Chill test.

After the chemical composition of the liquid reaches the FC 25 target, the liquid will be poured into the prepared mold. If the composition contains missing elements, a recalculation will be carried out and elements will be added.

The formation of test specimens is based on the casting process existing in the industry. Test specimens are formed for hardness testing and microstructure testing. The test sample was divided into two test specimens with 91.57% carburizer test samples and 96.7% carburizer test samples. The initial form of the test specimen is cylinder pipe liner boring, then the sample is formed according to the test. Table. 6 shows an image of the specimen.

Table. 6. Specimen formation.

Nama sampel	Bentuk awal	Sampel pengujian struktur mikro	Sampel pengujian kekerasan *brinell*	Sampel pengujian kekerasan *Vickers*
Carburizer 91,57 %				
Carburizer 96,7 %				

METHOD

This study employs a qualitative approach using a literature review method to analyze the influence of fixed carbon content in carburizers on the hardness and microstructure of FC 25 cast iron. The literature review method was chosen as it allows for the evaluation of findings from various relevant sources and the identification of trends and conclusions related to the research topic.

Type of Research

This research is a qualitative descriptive study, focusing on analyzing prior research findings on the effects of fixed carbon content in carburizers on the mechanical properties and microstructure of FC 25 cast iron. The study emphasizes conceptual analysis by synthesizing information from multiple sources to provide a comprehensive understanding of the subject matter.

Data Sources

The data used in this study are secondary data, gathered from scientific journals, books, conference papers, and research reports relevant to the carburization process in cast iron, specifically regarding fixed carbon content, hardness, and microstructure of FC 25 cast iron. The sources are drawn from academic databases such as Google Scholar, ScienceDirect, SpringerLink, and IEEE Xplore.

Data Collection Techniques

The data collection technique involves a systematic literature review. The process includes searching for relevant literature using keywords such as "fixed carbon," "carburizer," "FC 25 cast iron," "hardness," and "microstructure." Literature that meets the inclusion criteria—such as being published within the last 10 years, relevance to the topic, and validity of the findings—was selected for further analysis. The selected articles were then thoroughly reviewed to identify relevant information related to the research focus.

Data Analysis Method

The data analysis method applied in this study is content analysis. Data collected from various literature sources are analyzed to identify themes or patterns related to the effect of fixed carbon content on the hardness and microstructure of FC 25 cast iron. The analysis begins with reading and understanding each article comprehensively, followed by categorizing and coding relevant information. Key themes, such as changes in material hardness and the influence of fixed carbon on the microstructure (pearlite, ferrite, and graphite), are identified and compared across studies to draw comprehensive conclusions.

Through this approach, the study aims to provide a deeper understanding of how variations in fixed carbon content in carburizers influence the mechanical properties and microstructure of FC 25 cast iron.

RESULT AND DISCUSSION

3.1. Chemical Composition

The results of chemical composition testing on carburizer specimens were 91.57% with the FC 25 JIS G 5501 standard which can be seen in tables 2.2 and 2.3. The following results were presented in the table. 7.

Table 7. Results of testing the chemical composition of carburizer specimens 91.57%.

Specimen	Chemical Composition						Pouring temperature (^{0}C)
	C	Si	Mn	P	S	Cu	
Carburizer 91,57%	3.360	2.050	0.590	0.025	0.039	0.253	1372
	Cr	Ti	Ni	Mo	V	Mg	
	0.075	0.012	0.068	0.009	0.002	-	

The test results above show that the composition meets the standards of JIS G 5501 for FC 25.

The results of chemical composition testing on carburizer specimens were 96.7% with the FC 25 JIS G 5501 standard which can be seen in tables 2.2 and 2.3. The following results were presented in the table. 8.

Table 8. Test results for the chemical composition of the 96.7% carburizer specimen

Specimen	CHEMICAL COMPOSITION (%)						Casting temperature (^{0}C)
Carburizer 96,7%	**C**	**Si**	**Mn**	**P**	**S**	**Cu**	1381
	3.200	1.550	0.650	0.003	0.022	0.389	
	Cr	**Ti**	**Ni**	**Mo**	**V**	**Mg**	
	0.046	0.007	0.030	0.008	-	-	

The test results above show that the composition meets the standards of JIS G 5501 for FC 25.

3.2. Microstructure

The microstructure test results of the 91.57% FC 25 carburizer gray cast iron specimen can be seen in the picture. 3.

Figure 3. Microstructure of carburizer 91.57% (100X, Nital 3%).

The results of microstructure testing of 91.57% carburizer specimens produced lamellar or VII-shaped graphite, producing graphite A distribution, namely graphite flakes that were evenly distributed and in arbitrary orientation and produced graphite size 5. The pearlite phase area had a brown color and the ferrite had white, while cementite is black or shows graphite in the microstructure (Fig. 3). Using chemical composition test data (Table 7), it is known that the carbon (C) content is 3.360%. The pearlite phase (α+Fe3C) formed was 56% and the graphite phase obtained was 44%. The results of microstructure testing of FC 25 carburizer 96.7% gray cast iron specimens can be seen in the picture. 4

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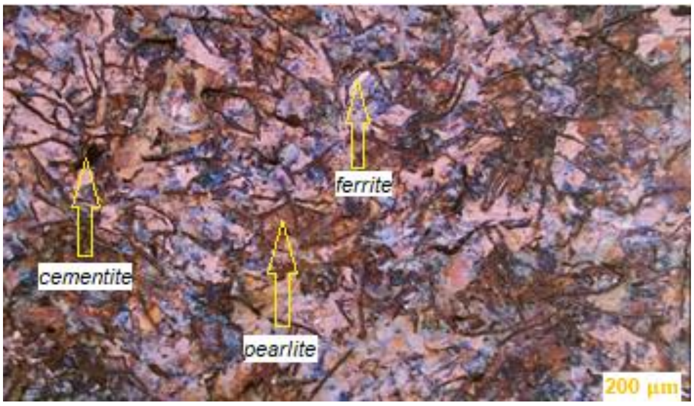

Figure 4. Microstructure of 96.7% carburizer (100X, Nital 3%).

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The test results from both specimens show the results that will be displayed in the table. 9 As follows:

Table 9. FC 25 graphite material

Specimen	**Graphite**		
	Shape	**Type**	**Size**
Carburizer 91,57%	Lamelar (VII)	A	5
Carburizer 96,7%	Lamelar (VII)	A	5

Table. 9 shows that 91.57% of the carburizer specimens obtained VII A 5 graphite results and 96.7% of the carburizer specimens obtained VII A 5 graphite results. These results show that the graphite has the same shape, type and size. According to (Surdia and Chijiwa, 1986) type A graphite has graphite flakes that are evenly distributed and the orientation is arbitrary. This graphite is a high class cast iron that has a pearlite matrix and suitable graphite size. Twisted graphite pieces provide ultimate strength to cast iron.

There is a slight difference in the results of the two specimens, namely the precipitate in the graphite crystallization process, namely the carbon material with the highest density (carburizer 96.7%) dissolves the slowest because it has a carbon grain size of 1-8 mm (table. 5) especially visible in fast conditions. movement and deposition of gaphite crystals. This is different from the carbon grain size of the carburizer of 91.57%, which has a grain size of 0.5-3 mm (table. 5) so it has good graphite crystallization results because it dissolves more quickly but has a high level of evaporation (volatile) or losses. it's higher.

One way to maximize the dissolution process is to increase the reaction surface between the carburizer and the liquid by reducing the grain size in the carburizer to 96.7% while increasing the amount. (Bartocha and Janerka, 2010). The shape, size and distribution of graphite will affect the mechanical properties of cast iron (Setyana, 2015).

With these results it can be concluded that the use of 91.57% and 96.7% carburizers is good for use in making FC 25 material regarding the shape, size and distribution of graphite.

The test results from both specimens show the results that will be displayed in the Table. 10 As follows:

Table 10. FC 25 material phase

Phase area	**Phase (%)**	
	Carburizer 91,57%	**Carburizer 96,7%**
Ferrite (a)	50	52
Cementite (Fe3C)	50	48
Total	**100 %**	**100 %**
Pearlite (a+Fe3C)	56	59
Graphite	44	41
Total	**100 %**	**100 %**

The results of phase analysis show that the 91.57% carburizer specimen produces 50% ferrite (α), 50% cementite (Fe3C) and 56% pearlite (α+Fe3C), 44% graphite phases. The result of the carburizer specimen was 96.7%, producing a ferrite (α) phase of 52%, cementite (Fe3C) 48% and pearlite (α+Fe3C) phase of 59%, graphite 41%. The 91.57% carburizer specimen forms balanced ferrite and cementite phases and has a lower percentage of pearlite phase than the 96.7% carburizer specimen. These results show that the carbon in the carburizer specimen is 91.57% more likely to form graphite than to form the Fe3C/cementite compound in pearlite (α+Fe3C). The carbon obtained from the 96.7% carburizer specimen shows that carbon tends to form α+Fe3C pearlite compounds so that the percentage of pearlite produced is higher. The pearlite phase is hard so that the use of a 96.7% carburizer produces higher hardness compared to carbon obtained from a 91.57% carburizer..

3.3. Hardness

The results of Brinell hardness testing with 5x tracking with an indenter ball diameter of 2.5 mm and a load of 187.5 Kgf on carburizer specimens of 91.57% and 96.7% can be seen in the table. 11.

Table 11. Brinell hardness test results

Specimen	Diamterindentor (mm)	Burden (kgf)	Footprint diameter (mm)	HB	HB Average (kgf/mm^2)
Carburizer 91,57 %	2,5	187,5	1,11	184	184
			1,10	187	
			1,10	187	
			1,11	184	
			1,12	180	
Carburizer 96,7 %			1,06	202	205
			1,09	191	

			1,05	207	
			1,02	219	
			1,05	207	

The average hardness value obtained for the 91.57% carburizer specimen was 184 HB and the 96.7% carburizer specimen had an average hardness of 205 HB. To see more specific results, the difference in hardness of the two specimens can be seen in the graph in the image. 5.

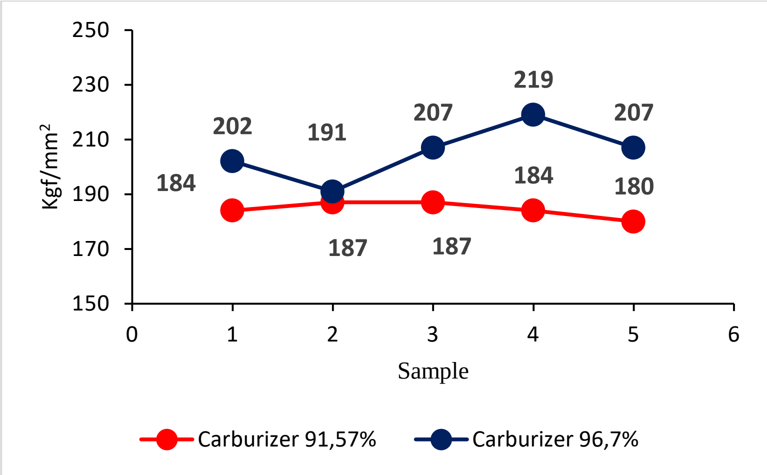

Figure 5. Brinell hardness graph.

The results of the Brinell and Vickers hardness tests for the two specimens show the results that will be displayed in the Table. 12 As follows:

Table 12. Hardness analysis

Specimen	**HV**		**HB**
	Pearlite	Ferrite	
Carburizer 91,57%	276	200	184
Average	238		
Carburizer 96,7%	255	262	205
Average	259		

The Brinell hardness values of the two specimens are in the FC 25 JIS G 5501 range with a range of 180 – 240 HB. The choice of carburizer type can be used according to the hardness number that will be determined. When comparing the average hardness of cast irons made on the basis of different carburizers in laboratory and industrial conditions it can be observed that the results are not very different. This shows that the cast iron produced based on the low content carburizer has a hardness close to that of the high content carburizer. (K. Janerka, et al., 2010).

Microvickers hardness testing was also carried out on FC 25 material, indentation load 50-100 gf, pressing time 15 seconds, and 3-4 times tracking in the ferrite and pearlite phase areas (Tables 13 and 14).

Table 13. Microvickers carburizer test results 91.57%

Area	Test results					
	Point	d1 (um)	d2 (um)	d Avg (um)	HV	Avg
Ferrite	1	27,9	30,2	29,1	220	200
	2	32,3	31,9	32,1	180	
Pearlite	3	26,8	26,3	26,6	263	276
	4	24,8	25,9	25,4	289	
Average (HV)					238	

The microvickers test results obtained a total average phase hardness value of 238 HV which was divided between ferrite hardness of 200 HV and pearlite hardness of 276 HV.

Table 14. Microvickers carburizer test results 96.7%

Area	Test Result					
	Point	d1 (um)	d2 (um)	d Avg (um)	HV	Avg
Ferrite	1	18,6	19,5	19,1	255	255
Pearlite	2	26,5	27,5	27,0	254	262
	3	25,9	26,5	26,2	270	
Average (HV)					259	

The microvickers test results obtained a total average phase hardness value of 259 HV which was divided between ferrite hardness of 255 HV and pearlite hardness of 262 HV.

The phase hardness value tested by the Vickers method shows that the 96.7% carburizer specimen has an average hardness value of 259 HV, which shows a higher value than the 91.57% carburizer specimen, namely 238 HV. The 91.57% carburizer specimen has an average phase hardness value at the ferrite point of 200 HV and the pearlite point is 276 HV while the 96.7% carburizer specimen has an average phase hardness value at the pearlite point of 262 HV and the ferrite point is 255 H.V. This value shows that the 96.7% carburizer specimen produces balanced ferrite and pearlite phase hardness because the ferrite contained in the 96.7% carburizer specimen is located in the pearlitic area, resulting in high ferrite phase hardness.

The analysis results of the entire test can be seen in the table. 15 below.

Table 15. Overall test results

Specimen	C (%)	Violence (HB)	Violence (HV)	Graphite shape	Phase volume (%)			
					a	Fe3C	a+Fe3C	Graphite
Carburizer 91,57%	3,360	184	238	VII A5	50	50	56	44
Carburizer 96,7 %	3,200	205	260	VII A5	52	48	59	41

From the tests that have been carried out, the results obtained show that the use of a carburizer affects the percentage of the phase produced, simultaneously with increasing the percentage of the phase it also affects the hardness of the material and the hardness of the phase. The use of carburizer types that have different contents does not affect the graphite shape, graphite type and graphite size, but affects the amount of graphite formed in the microstructure.

The use of a 91.57% carburizer in making FC 25 material helps the formation of lamellar graphite but the dominance of the pearlite phase is not too dominant so the hardness value is not optimal. The low hardness in the 91.57% carburizer is because carbon tends to form graphite more than forming pearlite compounds. Thus, the dominance of pearlite becomes less and the resulting hardness value becomes lower and more graphite is produced.

The use of a 96.7% carburizer inhibits the carbon diffusion process during the eutectoid reaction, thus reducing the formation of graphite in the eutectoid transformation and facilitating the formation of cementite in the pearlite phase which results in an increase in the pearlite phase in the 96.7% carburizer specimen. Therefore, the 96.7% carburizer specimen has a higher hardness value where the hardness value is influenced by the pearlite phase content. According to (K. Janerka, et al., 2010) a good carburizer must have a high carbon content (>95%), low sulfur content (<0.3%) volatile parts (<1%) and does not contain more than 0.9% water content (moisture). High ash content in the carburizer reduces the rate of carbon assimilation, increases the volume of slag and causes a decrease in the quality of the resulting alloy. The process rate and mass transfer coefficient also decrease. The carburizer content can be seen in the table. 5.

CONCLUSION

1. The addition of element (C) using a carburizer with a fixed carbon content of 91.57% and 96.7% in the casting process of FC 25 material (JIS G 5501) affects the value of material hardness, phase hardness and microstructure in making FC 25 material.
2. The 96.7% carburizer specimen produced a higher average hardness value, namely 205 HB, 21 HB higher than the 91.57% carburizer which had a hardness value of 184 HB. The 96.7% carburizer has a higher phase hardness with a phase hardness value of 259 HV, 21 HV higher than the 91.57% carburizer which produces a hardness value of 238 HV.
3. The use of 91.57% and 96.7% carburizers in making FC 25 does not affect the graphite shape, graphite distribution and graphite size. Both types of carburizer have the same graphite, namely VII A 5, namely graphite in the form of VII (lamellar), having a distribution of graphite A and graphite size 5.
4. The 91.57% carburizer specimen produces 50% cementite and 50% ferrite phases. The 96.7% carburizer specimen produces a cementite phase of 48% and 52% ferrite, which means that the 91.57% carburizer specimen produces a higher cementite phase and a lower ferrite phase compared to the 96.7% carburizer.
5. The volume of the pearlite phase in the 96.7% carburizer produces a pearlite phase of 59% and the 91.57% carburizer produces a pearlite phase of 56%. Carburizer 96.7% produces a higher pearlite phase so that the hardness increases.

REFERENCES

Ari, Siswanto; R, Widodo; Egy, Ardiansyah. (2020). *Pengaruh Interlamellar Spacing Terhadap Nilai Kekerasan Besi Cor Kelabu Dengan Variasi Tembaga. Vol 22 No 1.* Bandung: Polman Bandung..

ASM Handbook Committee. (1988). *ASM Handbook vol. 15.* States of America: ASM International.

ASM Metal Handbook. (2004). *Metallography and microstructures Vol. 9.* States of America: ASM International.

ASTM 40. (n.d.). *Jurnal Penelitian Saintek.* Vol, 11. No 1.

ASTM A247-19. (2020). *Standard Test Method for Evaluating the Microstructure of Graphite in Iron Castings.* Amerika Serikat: ASTM International.
ASTM E384 Standard Test Method for Microindentation Hardness of Materials. (2017). Philadelphia: ASTM International.
Brown, J. (2000). *Foseco ferrous foundryman's handbook.* London: Butterworth Heinemann.
Callister, & Rethwisch. (2013). *Material Science And Engineering.* United States of America: Wiley.
Chandra, H. (2004). *Kaji Eksperimental Pembuatan Besi Cor Kelabu FC 250 Dengan Tanur Induksi Frekuensi Tinggi.* Palembang: Fakultas Teknik Universitas Brawijaya.
Churiyanto, M. (2013). Carbonriser Sebagai Bahan Penambah Kadar Karbon Dalam Peleburan Besi Baja, FC, Dan FCD.
D, Bartocha; K, Janerka. (2010). *Carburizer particle dissolution in liquid cast iron - computer simulation.* Poland: Foundry Commission of the Polish Academy of Sciences.
Janerka, Bartocha, D., Sjaznar, J., & Jezierski, J. (2010). The Carburizer Influence On The Crystallization Process And The Microstructure OF Synthetic Cast Iron. In D. o. Foundry, *Archive Of Metallurgy And Materials* (p. Volume 55). Poland: Silesian University Of Technology.
Setyana, L. D. (2015). Studi ukuran grafit besi cor kelabu terhadap laju keausan pada blok rem metalik kereta api. *Jurnal Material Teknologi Proses*, 16-21.
T, Surdia; L, Chijiwa. (1986). *Teknik Pengecoran Logam.* Jakarta: Balai Pustaka.
Widodo. (2012). *Komposisi Bes Cor Kelabu.* Bandung: HAPLI. Retrieved from https://hapli.wordpress.com/forum-ferro/komposisi-besi-cor-kelabu/