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EFFECT OF SILICON CONTENT ON THE HOMOGENEITY OF HARDNESS AND WEAR RATE PROPERTIES OF GREY CAST IRON USED FOR CANDIDATE OF BRAKE SHOE OF TRAIN

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Abstract

Generally there is the the segregation of chemical composition in the brake shoe made of grey cast iron which it used for train. Silicon content of the outside and the inside of grey cast iron is differed, since it is mainly influenced by the different cooling rates between the outside and the inside parts of the castings. This condition results in the different hardness and wear rates of the brakes, caused by decreasing of the thickness of the brake after its operation time by time. The hardness and wear rate are directly affected by the amount of graphites and mechanical properties of the phases in gray cast iron. The purpose of this study was to obtain the data of the hardness and wear rate of the grey cast iron, for five variation of silicon content. The liquid of gray cast iron used in this study has composition of 3.34% C, 2.46% Si, 0.313% Mn, 0.0553% P, 0.106% S, 0.302% Cr, 0.0770% Mo, 0.0527% Ni, 0.0070% Al, 0.168% Cu, 0.020% Sn, 0.0207% Ti, 0.0100% V, and 0.0017% Mg. Ferro silicon (75% Si) is used to increase the silicon content in the liquid of gray cast iron, to obtain the five kinds of silicon content of gray cast irons. The results of the study showed that the best homogeneity of the hardness and wear rate are obtained in gray cast iron of containing of 3.51% C, 3.35% Si, 0.294% Mn, 0.148% P, 0.134% Cr, 0.0448% S, 0.0070% Al, 0.157% Cu, 0.022% Sn, 0.020% Ti, 0.0100% V, 0.0019% Mg.

Keywords: *Segregation, Homogenity, Hardness, and Wear rate*

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1. INTRODUCTION

Graphite structure is formed in grey cast iron if it contains both Si and C [1,2].Phosphor has effect on the formation of primary graphite if its content is low and the Si content is high[3].Graphite structure make the hardness of grey cast iron is low, particularly for grey cast iron that has coarse graphite, its if the Si and C content is high [4]. Ferrite structure has the lower wear resistance than pearlite structure so that the wear resistance of ferritic grey cast iron is lower than pearlitic grey cast iron [4]. Silicon is one of the elements which is dissolved in ferrite structure and make the hardness of ferritic grey cast iron is increased [5]. Microvolumes of supersaturated silicon make the formation of embryos of graphite in grey cas iron [6]. The graphite distribution is improved by the existence of Al, Ca, and Zr elements[7].Graphitization can also improved by the using of SiC that is not contain of aluminium and other elements [8].Some of the nonmetallic inclusions in the grey cast iron are (Mn, X) S, where X is Fe, Al, O, Ca, Si, Sr, Ti, etc. These inclusions are covered by silicate and act as the centers of the formation of lamellar graphite [9]. There are 3 stages of the formation of graphite. The first stage is the formation of small oxide (less than 2·0 μm),the second stage is the formation of complex compounds of (Mn,X)S (less than 5·0 μm) that is nucleated by stage 1, and the third stage is the nucleation of graphite on the sides of the compounds of (Mn,X)S[10]. Grey cast iron has the flake graphite which has the sharp edges and result in the notch effects so that reduces the strength of grey cast iron caused by the stress concentration contribution. The deterioration of strength of grey cast iron is caused by decreasing of the size of the efficient section. Graphite flake gives the effect of lubrication on the grey cast iron so that make the rise of the wear resistance of grey cast iron [11].

2. MATERIALS AND METHODS

2.1 Sand Mold Preparation

The sand molds were made from the mixture of silica sand, water, bentonit and dextrin based on the BS14 standard [12]. The wooden pattern which the dimension was the same as the dimension of the brake shoe of railway, was used to make five pair of cope and drag moulds. The dimension of the pattern is the same as for the brake shoe of type "C". The five moulds were labeled as Batch 1, 2, 3, 4, and 5 respectively.

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2.2 Casting Process and Inoculation Process of Silicon

The melted grey cast iron was prepared by melting the grey cast iron foundry returns of 100 kg in an induction furnace of 500 kg crucible capacity.The melted grey cast iron was poured at 1300°C into moulds. The first batch which represents the control sample was poured into the mould labeled batch 1 without any alloy addition. Thereafter, a known quantity of 75% ferrosilicon granules were added to the remaining molten bath and heated up to 1300°C, stirred manually with a dry wooden stick to facilitate a homogeneous bath and poured into the second mould labeled batch 2. The same process was repeated for the remaining batches of moulds with increasing 75% ferrosilicon granule additions. After pouring, the casting were allowed to solidify and cooled in the mould to room temperature before they were knock out and cleaned up. The cast bars (brake shoe) were labeled to ensure traceability. Fig -1 shows the brake shoe that is made of grey cast iron, with the thickness is of 50 mm and length is of 300 mm.

Fig -1: Brake Shoe of Train, 50 mm thick, 85 width, and 500 mm length

2.3 Composition of Cast Iron

Composition of cast iron of each batch was determined using composition tester which the model was of metalscan 2500 series. Table-1shows the composition of cast iron of each batch.

Table -1: Elemental Composition of Cast Iron

SAMPLES	Elemental Composition (wt %)														
	Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Sn	Ti	V	Mg
Batch 1	93.06	3.34	2.46	0.313	0.0553	0.106	0.302	0.0770	0.0527	<.0070	0.168	<0.020	0.0207	<.0100	0.0017
Batch 2	92.72	3.47	2.92	0.291	0.0344	0.0615	0.163	<0.070	0.0476	<.0070	0.159	0.0214	0.0192	<.0100	0.0020
Batch 3	92.20	3.51	3.35	0.294	0.148	0.0448	0.134	<.0.070	0.0432	<.0070	0.157	<0.020	0.0206	<.0100	0.0019
Batch 4	91.79	3.62	3.64	0.289	0.0855	0.0770	0.164	0.0742	0.0494	<.0070	0.155	<0.020	0.0186	<.0100	0.0020
Batch 5	91.83	3.26	4.01	0.293	0.0701	0.0614	0.144	0.0680	0.0502	<.0070	0.161	<0.020	0.0178	<.0100	0.0019

2.4 Specimen Preparation for Hardness and Wear Test

From the cast bars, sample representatives from each bar were cut and machined at the middle part of the brake shoe, for example it is as shown in Fig -2. Brake shoe was cutted with a thickness of 10 mm. Hardness test was performed at the position of 2 mm, 12 mm, 22 mm, and 32 mm from the surface of the brake shoe, whereas for wear test was performed at the posisition of 2 mm, 17 mm, and 32 mm from the surface of the brake shoe. Schematic figure showing both the position of hardness and wear test are shown in Fig-3 and Fig-4.

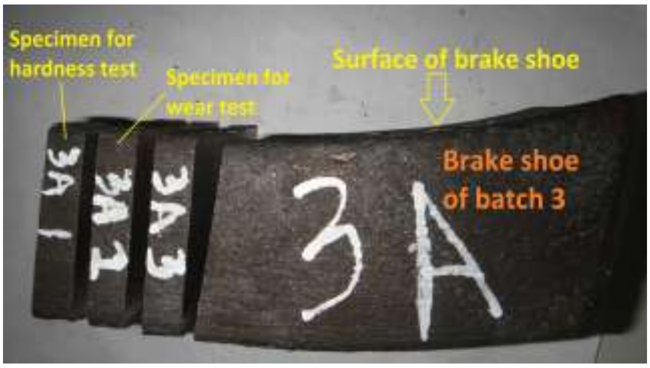

Fig -2: Pieces of Brake Shoe Used for Specimen of Hardness and Wear Test

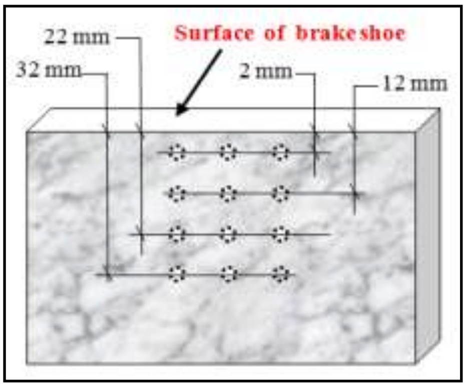

Fig -3: Schematic Figure showing The Position of Hardness Test

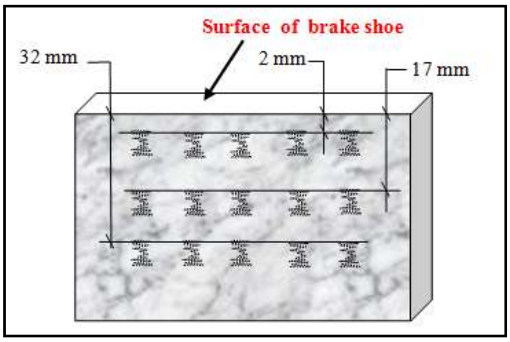

Fig -4: Schematic Figure showing The Position of Wear Test

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3. TEST RESULT AND DISCUSSION

3.1 Hardness Test Result

The hardness of the samples was determined using Brinell hardness tester which the model was of HMV-Controlab. Hardness test was carried out under a load of 60 kg and a dwell time of 10 seconds. The results of hardness test are shown in Table-2 through Table-6. These data were arranged in the form of charts as shown in Fig-5 through Fig-9.

3.2 Wear Test Result

Wear test was carried out using wear tester which the model was of Riken Ogoshi's Universal Wear. Type: OAT-U. Equation (1) was used to calculate the wear rate [11].

$$\text{wear rate} = \frac{\text{wear volume loss}}{(\text{sliding distance}) \times (\text{applied load})} \qquad (1)$$

Table -2: Hardness of Cast Iron of Batch 1

Hardness of Grey Cast Iron with the Silicon Content of 2.46% (BHN)				
Position of Hardness Test	2 mm from the surface	12 mm from the surface	22 mm from the surface	32 mm from the surface
	92.602	89.767	84.469	92.602
	87.059	92.602	95.570	92.602
	92.602	87.059	89.767	84.469
Average	90.754	89.809	89.935	89.891
Stand.dev	3.200	2.771	5.552	4.695

Table -3: Hardness of Cast Iron of Batch 2

Hardness of Grey Cast Iron with the Silicon Content of 2.92% (BHN)				
Position of Hardness Test	2 mm from the surface	12 mm from the surface	22 mm from the surface	32 mm from the surface
	89.767	89.767	89.767	89.767
	89.767	92.602	89.767	89.767
	89.767	89.767	89.767	89.767
Average	89.767	90.712	89.767	89.767
Stand.dev	0	1.636	0	0

Table -4: Hardness of Cast Iron of Batch 3

Hardness of Grey Cast Iron with the Silicon Content of 3.35% (BHN)				
Position of Hardness Test	2 mm from the surface	12 mm from the surface	22 mm from the surface	32 mm from the surface
	101.943	101.943	89.767	95.570
	89.7679	105.367	105.367	89.767
	92.6027	92.602	89.767	92.602
Average	94.771	99.971	94.967	92.646
Stand.dev	6.371	6.607	9.006	2.901

Table -5: Hardness of Cast Iron of Batch 4

Hardness of Grey Cast Iron with the Silicon Content of 3.64% (BHN)				
Position of Hardness Test	2 mm from the surface	12 mm from the surface	22 mm from the surface	32 mm from the surface
	92.602	101.943	101.943	101.943
	95.570	95.570	95.570	95.570
	101.943	95.570	101.943	98.681
Average	96.705	97.694	99.819	98.731
Stand.dev	4.773	3.679	3.679	3.186

Table -6: Hardness of Cast Iron of Batch 5

Hardness of Grey Cast Iron with the Silicon Content of 4.01% (BHN)				
Position of Hardness Test	2 mm from the surface	12 mm from the surface	22 mm from the surface	32 mm from the surface
	108.964	101.943	98.681	95.570
	92.602	108.964	92.602	101.943
	108.964	105.367	95.570	92.602
Average	103.510	105.425	95.617	96.705
Stand.dev	9.446	3.5107	3.039	4.773

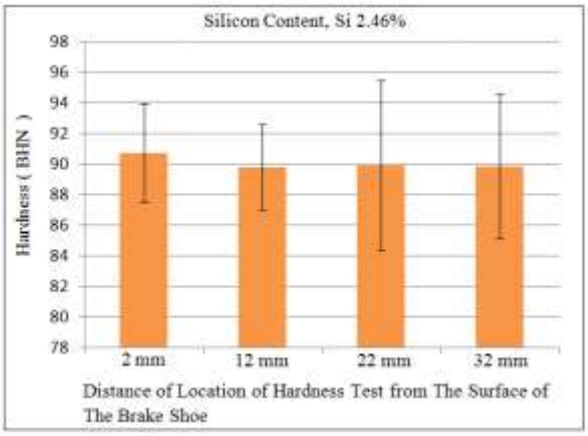

Fig -5: Hardness of Cast Iron of Batch 1

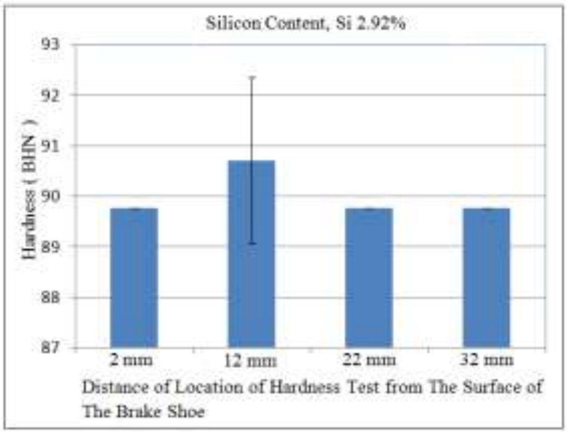

Fig -6: Hardness of Cast Iron of Batch 2

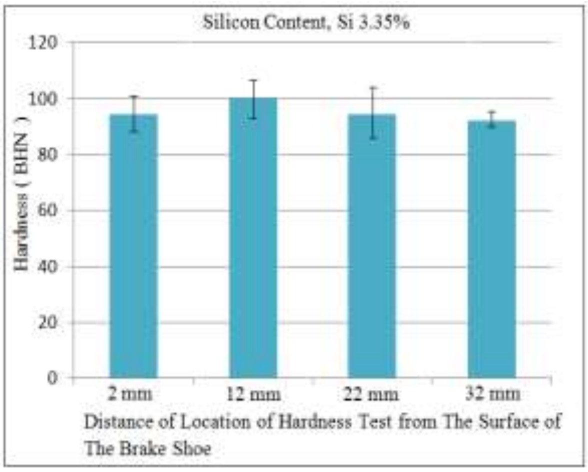

Fig -7: Hardness of Cast Iron of Batch 3

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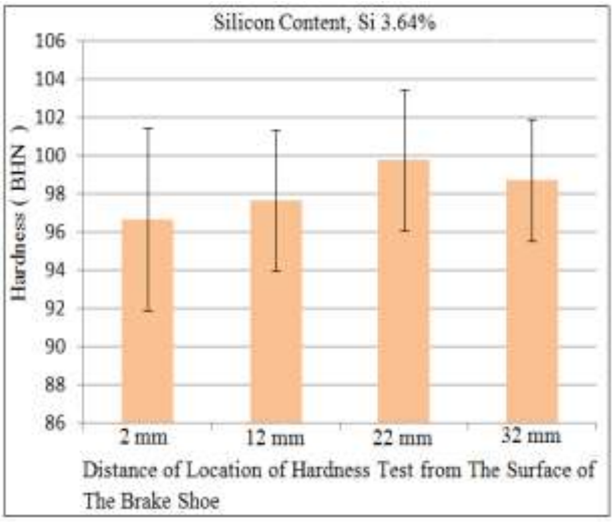

Fig -8: Hardness of Cast Iron of Batch 4

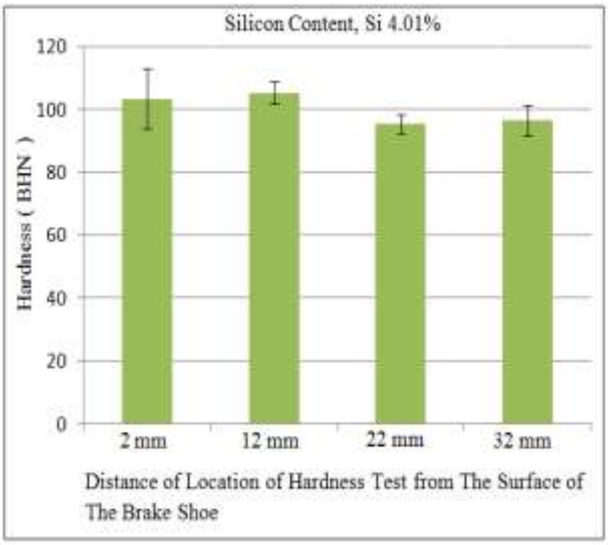

Fig -9: Hardness of Cast Iron of Batch 5

The results of the wear test are shown in Table-7 through Table-11. These data were arranged in the form of charts as shown in Fig-10 through Fig-14.

Table -7: Wear Rate of Cast Iron of Batch 1

Wear Rate of Grey Cast Iron with the Silicon Content of 2.46% (mm^3/kg.m)			
Position of Wear Test	2 mm from the surface	17 mm from the surface	32 mm from the surface
	7.17952E-05	9.13E-05	2.83E-05
	7.92167E-05	9.56E-05	5.53E-05
	0.000114008	3.45E-05	4.15E-05
	0.000140225	3.68E-05	3.24E-05
	5.23387E-05	5.53E-05	4.95E-05
Average	9.15168E-05	6.27E-05	4.14E-05
Stand.dev	3.51906E-05	2.92E-05	1.13E-05

Table -8: Wear Rate of Cast Iron of Batch 2

Wear Rate of Grey Cast Iron with the Silicon Content of 2.92% (mm^3/kg.m)			
Position of Wear Test	2 mm from the surface	17 mm from the surface	32 mm from the surface
	4.6736E-05	5.53E-05	4.95E-05
	3.91048E-05	7.18E-05	8.31E-05
	4.94845E-05	2.83E-05	4.15E-05
	2.46258E-05	5.23E-05	9.13E-05
	4.15482E-05	2.64E-05	5.53E-05
Average	4.02999E-05	4.68E-05	6.41E-05
Stand.dev	9.67531E-06	1.93E-05	2.18E-05

Table -9: Wear Rate of Cast Iron of Batch 3

Wear Rate of Grey Cast Iron with the Silicon Content of 3.35% (mm^3/kg.m)			
Position of Wear Test	2 mm from the surface	17 mm from the surface	32 mm from the surface
	0.000140225	0.000105	9.56E-05
	0.000118964	0.000119	0.00014
	9.55594E-05	0.000124	7.18E-05
	7.92167E-05	7.18E-05	0.000183
	7.17952E-05	0.000114	0.00014
Average	0.000101152	0.000107	0.000126
Stand.dev	2.83648E-05	2.08E-05	4.34E-05

Table -10: Wear Rate of Cast Iron of Batch 4

Wear Rate of Grey Cast Iron with the Silicon Content of 3.64% (mm^3/kg.m)			
Position of Wear Test	2 mm from the surface	17 mm from the surface	32 mm from the surface
	9.12813E-05	4.15E-05	7.18E-05
	0.000151745	4.95E-05	3.91E-05
	4.15482E-05	4.15E-05	0.000114
	8.3112E-05	5.53E-05	7.18E-05
	7.17952E-05	4.95E-05	4.95E-05
Average	8.78963E-05	4.75E-05	6.92E-05
Stand.dev	4.03682E-05	5.91E-06	2.88E-05

Table -11: Wear Rate of Cast Iron of Batch 5

Wear Rate of Grey Cast Iron with the Silicon Content of 4.01% (mm^3/kg.m)			
Position of Wear Test	2 mm from the surface	17 mm from the surface	32 mm from the surface
	9.12813E-05	6.49E-05	2.13E-05
	7.17952E-05	3.03E-05	5.23E-05
	9.55594E-05	3.45E-05	3.03E-05
	9.55594E-05	9.56E-05	7.18E-05
	8.3112E-05	6.16E-05	4.67E-05
Average	8.74615E-05	5.74E-05	4.45E-05
Stand.dev	1.01254E-05	2.64E-05	1.97E-05

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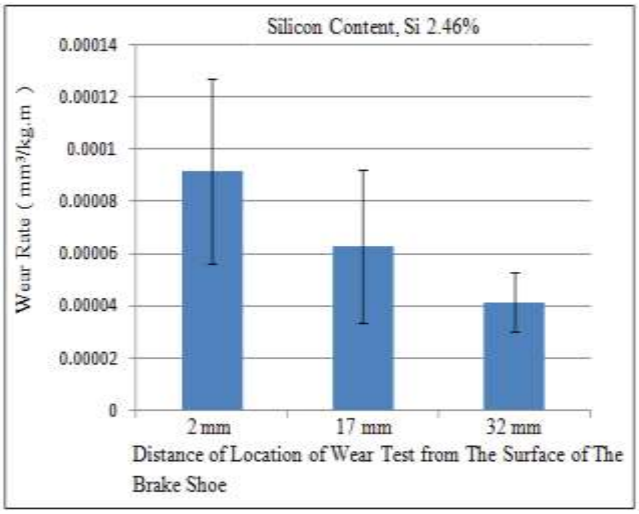

Fig -10: Wear Rate of Cast Iron of Batch 1

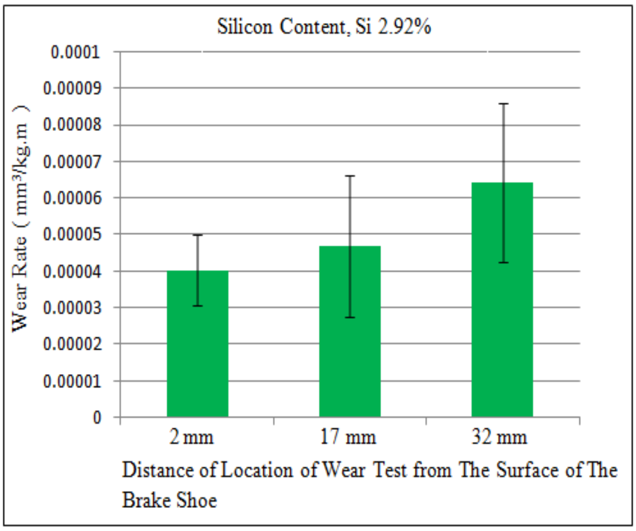

Fig -11: Wear Rate of Cast Iron of Batch 2

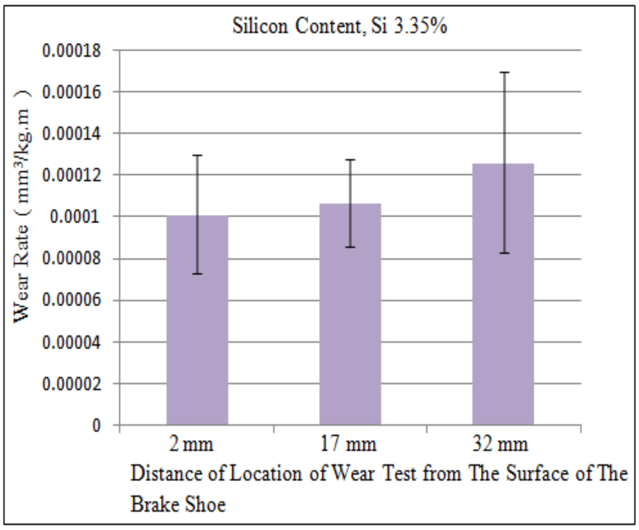

Fig -12: Wear Rate of Cast Iron of Batch 3

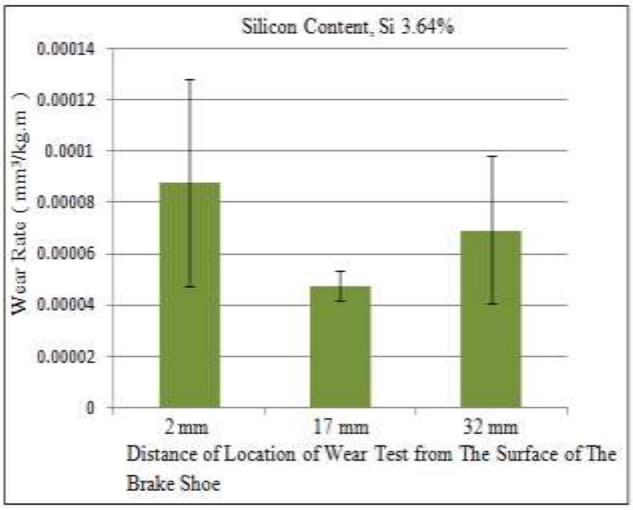

Fig -13: Wear Rate of Cast Iron of Batch 4

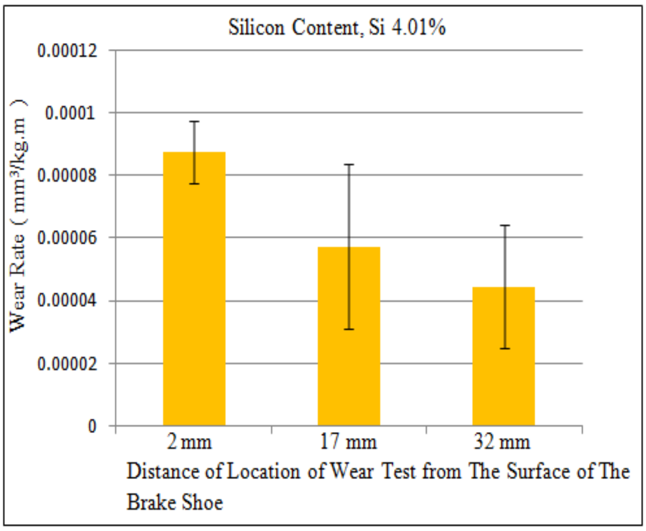

Fig -14: Wear Rate of Cast Iron of Batch 5

3.3 Discussion

Silicon make the hardness of cast iron is increased caused by the formation of more hard ferrite in cast iron [5], however the silicon result in the formation of coarse graphite and make the hardness of cast iron is decreased [4]. Wear resistance is decreased with the formation of more ferrite, but the formation of more graphite result in the wear rate is increased [11]. This condition is the counterbalancing each other of between the hardness due to the influence of ferrite and influence of graphite, and also counterbalancing each other of between the wear rate due to the influence of ferrite and the influence of graphite. Base on the Fig-5 through Fig-9 is shown that the small change of hardness inside the cross section of the cast iron is happened on the silicon content of 2.46% and 3.35%. The small change of wear rate inside the cross section of the cast iron is happened on the cast iron with the silicon content of 3.35% (Fig-12). Cast iron with the silicon content of 3.35% also has the higher wear rate than the other, it is 0.000126 mm^3/kg.m. High wear rate is needed for brake shoe to avoid the damage of wheel of train. The maximum hardness of

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cast iron with the silicon content of 3.35% is 99.97 BHN, its high enough and accordance with the requirement of mechanical properties of the brake shoe.

4. CONCLUSION

Five differences of silicon content of cast iron of brake shoe show the difference of homogeneity of hardness and wear rate inside cross section of brake shoe. Ideal silicon content of cast iron for brake shoe is of 3.35%. Complete elemental composition of this cast iron is of 3.51% C, 3.35% Si, 0.294% Mn, 0.148% P, 0.134% Cr, 0.0448% S, 0.0070% Al, 0.157% Cu, 0.022% Sn, 0.020% Ti, 0.0100% V, 0.0019% Mg. The hardness and wear rate of brake shoe is almost the same inside the cross section of brake shoe. During operation, the hardness and wear rate of the brake shoe is not change although the thickness of the brake shoe is decreased. The wear rate of the brake shoe is high enough, it is 0.000126 mm^3/kg.m, so the wheel of train is safe from damage.

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