Research on Wear Rate and Mechanical Properties of Brake Sabots (Shoes) Used in Railway Rolling Stocks

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Abstract

In this work, wear resistances, wear rates, friction forces and coefficients of pig-iron, composite and sintered sabots (brake shoes) used in self-propelled or pulled transportation equipment as well as their hardness-density, fracturing energies and chemical compositions, have been studied experimentally. Based on the assessment of the wear rates and manufacturing costs, composite sabot has been determined as the most feasible sabot material.

Keywords: Sabot (Brake Shoe), Pig, Sintered, Composite Sabot Wearing

1. Introduction

Railway transportation tries to keep up with the requirements of our age through a continuous change and progress. A more efficient transportation is ensured by means of building new roads or repairing the current ones. Manufacturing more contemporary wagons incerases the speed of the current trains by increasing in braking force and efficiency, as well. Studies hev been carried out for the new brake systems for improving of mechanical properties of brake shoes such as friction coefficient at higher speeds, wear resistance, reduction of noise, corrosion resistance and prolonging the use life of its materials [1].

Railroad brake sabots are supposed to be light, corrosion-resistant, in line with performance characteristics, as well as having to have a stable friction coefficient, a low wear rate, a low noise, a long use life, and a reasonable cost [2]. Brake systems used in railroad industry consist of dynamic brakes, hydrodynamic brakes, magnetic brakes, hand brakes (auxiliary brake units) and compressed air (master cylinder) brakes [3]. The type of the brake system being used varies depending on the type of railroad vehicle and whether it is self-propelled or pulled. In this work, wear resistances, wear rates, friction forces and coefficients, hardness-density, fracturing energies and chemical compositions of pig-iron, composite and sintered sabots (brake shoes) have been studied in the test stands of mechanical laboratories.

2. Material, Method and Experimental Studies

Experimental studies have started with the preparation of the samples taken from dry friction UIC 2501 [4] type of brake sabots being used in the brake systems of railroad vehicles. To begin with, two samples for each of the new manufactured pig-iron, composite and sintered sabots have been provided. They have been processed separatelyin the sharper so that their concave and convex surfaces have been turned into the flat shape. At the same time, they have been changed into the required dimensions and sizes through the machining techniques to be in line with the standards for the purpose of using in the test assembly and stands.

2.1 Spectrometric Analysis (Chemical Components)

The chemical compositions of pig-iron, composite and sintered sabot samples, each having the dimension of 30x30x10 mm are given Tables 1, 2 and 3. The chemical compositions have been determined by an instrument with the Spektrolab branded with 19 elements, shown in Figure 1.

Figure1: Spektrolab Instrument With19 Elements

Table 1: Chemical Components of Pig-iron Sabot

% C	%Si	%Mn	% P	% S	%Cr	%Ni	%Mo	%Al	%Co
3,22	1,55	0,795	0,970	0,0416	0,514	0,030	0,0041	0,055	0,067
%Cu	%Nb	%Ti	% V	% W	%Pb	%Sn	%Mg	%Fe	
0,450	0,0035	0,0253	0,011	0,0047	0,0002	0,069	0,0002	92,29	

Table 2: Chemical Components of Sintered Sabot

% C	%Si	%Mn	% P	% S	%Cr	%Ni	%Mo	%Al	%Co
3,16	0,643	0,293	0,0624	0,154	1,88	0,060	0,137	0,0906	0,046
%Cu	%Nb	%Ti	% V	% W	%Pb	%Sn	%Mg	%Fe	
5,88	0,102	0,0852	0,131	0,039	0,0191	0,171	0,108	87,03	

Table 3: Chemical Components of Composite Sabot

Aramid Fibre	Phenolic Resin	Graphite	Barium Sulphate ($BaSO_4$)	Rubber Dust	Iron Dust	Alumina (Al_2O_3)
5%	20%	12%	30%	20%	10%	3%

2.2 Hardness Tests

Hardness values for the materials of pig-iron, composite and sintered sabot samples having the dimension of 50x30x10 mm, have been determined by means of a Schaffhausen-Schweiz 8875 branded loading instrument and a Schaffhausen-Suisse branded optical measurement having a precision of 0,001mm. Three tests conducted for each sample have been averaged. As a conclusion of the tests, with an average value of 233 HB, pig-iron sabot has been found to have the highest hardness value. It has been observed that sintered sabot, having an average hardness value of 123,6 HB, had a lower hardness than that of pig-iron sabot, while it was harder than composite sabot, having the lowest hardness value with an average of 102 HB.

2.3 Fracture Tests

Tests have been carried out according to the standards of TS 269/75 EN10045 Charpy Impact Test on Metalic Materials [5]. Three samples, processed in the dimensions as shown in Figure 2 and notched in the middle, have been manufactured for each sabot. Tests have conducted with three samples for each sabot and average values obtained have been entered to Table 4.

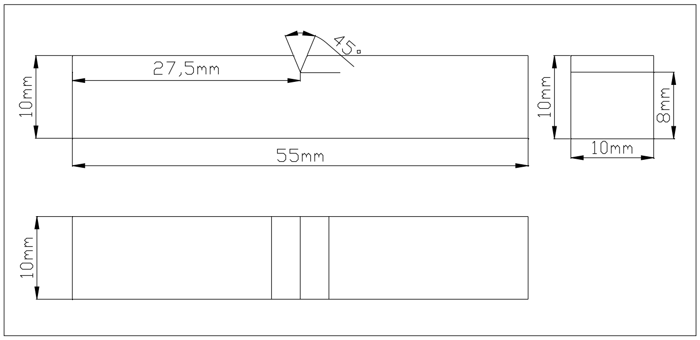


Figure 2: Charpy Impact Test - SabotSample Dimensions

Table 4. NotchImpact Fracturing Energies (Joule)

	1.Run	2. Run	3. Run	Average
Pig-iron	6	4	4	4,66
Composite	1	1,5	1	1,15
Sintered	4	3	4	3,66

Notch impact strengths,calculated by the division of the energy absorbed to the cross-sectional area of the sample, have been put in Table 5.

Cross-sectional Area of the Sample = 8mm*10mm = 80mm² = 0,8cm²(1)

Notch Impact Strength = Fracturing Energy / Cross-sectional Area (2)

Table 5. Impact Strengths (Joule/cm²)

	1.Run	2.Run	3.Run	Average
Pig-iron	7,5	5	5	5,83
Composite	1,25	1,88	1,25	1,46
Sintered	5	3,75	5	4,58

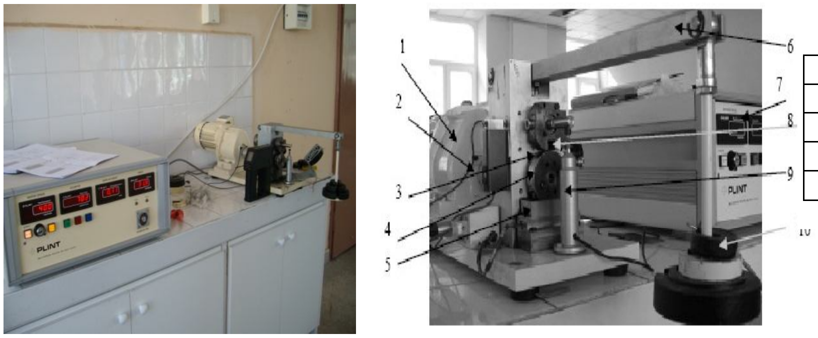
Based on the results, pig-iron sabots seem to have the best impact strength with 5,83 joule/cm², while composite sabots have the worst impact strength with 1,46 joule/cm².

2.4 Density Measurements

Densities of five samples prepared for each sabot have been determined separately according to the standards [6] and their arithmetic averages have been measured as 7,232 g/cm³ for pig-iron, 6,250 g/cm³ for sinter and 1,814 g/cm³ for composite. In the meantime , weights of brake sabots in their actual dimensions have been weighed as 9,6 kg for pig-iron, 8 kg for sinter and 2,8 kg for composite. They seem to be consistent with their densities. Additionally, the weight of the pig-iron sabot is about 3,4 times that of composite sabot; while the weight of the sintered sabot is about 2,85 times of it.

2.5 Wear Tests

Wear tests of the test samples in terms of time, load and rotation speed have been performed. In these tests, the studies have been kept on with Weight Difference Method [7]. A disk functioning as an abrasive is fixed via two allen screws to a mill, being connected to an engine which is capable of adjusting the speed precisely through frequency control. Pressing force of the test sample anchored on the disc by means of a setscrew could be adjusted by the masses placed in a barrow, manually through a weight-arm. In additon that, the changes in the friction force and wear height during the abrasion are visible via a thumbwheel switch on the converter (Figure 3)



1-Engine	6-Weight-arm
2-Speed sensor	7-Control panels
3-Sample compartment	8-Sample
4-Abrasive disc	9-Altimeter
5-Lubricatorcompartment	10-Barrow

Figure 3: PLINT® Universal Frictionand Abrasion Equipment[8]

Test samples have been manufactured from pig-iron, composite and sintered sabots as five for each, each being ø12,7mm in diamater and length for the purpose of use in the abrasion test equipment (Figure 4). Another disc, to serve as a counter abrader in the test equipment, has been manufactured in the diameter and thickness of ø60mm and 20mm, respectively, from a monoblock cylinder bandage, also used in freight wagons (Figure 5).

Figure 4: Wear Test Samples

Figure 5: CounterAbrasive Disc

Preliminary tests have been carried out for the determination of the parameters to be used in the test schedule. Upon the specification of the parameters,based on these tests, 180-360-540-720 seconds as the sliding times, 300-400-500-600 rpm as the the abrasive disc speeds and 92-122-152-182 Newton as the forces to be exerted, actual tests have been switched to. Below-mentioned steps have been followed for each sample till all the test runs have been completed:

- Initial weighing of samples
- Fixation of sample to the pulley holder via screw and pin supporter so as to achieve a suitable surface for friction
- Adjustment of load and speed value in the test schedule and start
- Stopping the device and other equipment after the test and disassembling the sample
- Determination of wear rate by weighing the sample
- Cleaning of sample surface in case of any particle due to abrasion

Weights of the samples before and after the wear test have been measured by an electronic scale with a precision of 1/10000 (Figure 6) and the results have been recorded in the tables. Also, the graphs including weight loss vs time, weight loss vs load, weight loss vs speed, friction force and coefficient have been provided and evaluated.

Figure 6: Electronic Scale with a Precision of 1/10000

3. Wearing Results

Tests have been conducted with the previously prepared samples by using 4 different values for each parameter [i.e., sliding time (180sec, 360sec, 540sec, 720sec), forces exerted (92N, 122N, 152N, 182N) and speed (300, 400, 500, 600rpm)]. Weight losses, found by weighing the samples with the help of an electronic balance with the precision of 1/10000, are shown in Table 6. Wear rate and weight loss quantities from the studies with the sample of pig-iron sabot are seen to be significantly much more higher (around 6-7 times) compared to those of sintered and composite sabot samples. Although the tests are regarded as adhesive wear tests, occurences of abrasive and corrosive wear mechanisms have also been observed. Volumetric losses, calculated in the order of magnitude of ‰ by taking, the ratio of weight losses (wear rate) as a result of the tests to the weights initially measured, are given in Table 7. Lifetimes of sabots depend on volumetric wear. Although the differences between the wears in terms of weight are bigger, those difference for volumetric wears look to be smaller. Friction coefficients (µ) obtained depending on the changing parameters during the tests have been recorded in Table 8. The graphs for the findings obtained by changing the loads exerting on the sabots provided that sliding time of 360 sec and disc speed of 500 rpm are kept constant, are shown in Figures 7-8-9.

Table 6: Wear Quantities in Terms of Weight (mg) (Weight Losses)

		Pig-iron Sabot	Composite Sabot	Sintered Sabot
SlidingTime (sec)	180	15,10	2,80	3,20
	360	24,30	3,10	4,40
	540	34,00	3,80	5,20
	720	47,30	4,70	7,10
Exerted Force (N)	92	16,60	1,00	2,30
	122	24,30	3,10	3,40
	152	32,60	4,20	4,80
	182	43,30	4,80	5,70
Speed (rpm)	300	13,10	2,00	2,30
	400	17,20	3,00	3,00
	500	24,30	3,10	3,40
	600	35,20	3,90	4,50

Table 7: (‰) Volumetric WearLoss Ratios

		Pig-iron Sabot	Composite Sabot	Sintered Sabot
SlidingTime (sec)	180	1,31	0,98	0,32
	360	2,11	1,05	0,44
	540	2,96	1,34	0,52
	720	4,03	1,69	0,70
Exerted Force (N)	92	1,44	0,35	0,23
	122	2,11	1,05	0,34
	152	2,84	1,42	0,47
	182	3,70	1,73	0,56
Speed (rpm)	300	1,11	0,72	0,23
	400	1,51	1,01	0,30
	500	2,11	1,05	0,34
	600	3,09	1,32	0,45

Table 8: Friction Coefficients (µ)

		Pig-iron Sabot	Composite Sabot	Sintered Sabot
SlidingTime (sec)	**180**	0,45	0,26	0,37
	360	0,44	0,25	0,37
	540	0,47	0,27	0,37
	720	0,48	0,24	0,38
Exerted Force (N)	**92**	0,43	0,23	0,36
	122	0,44	0,25	0,37
	152	0,44	0,25	0,37
	182	0,43	0,26	0,37
Speed (rpm)	**300**	0,45	0,28	0,43
	400	0,42	0,26	0,40
	500	0,44	0,25	0,37
	600	0,46	0,23	0,35

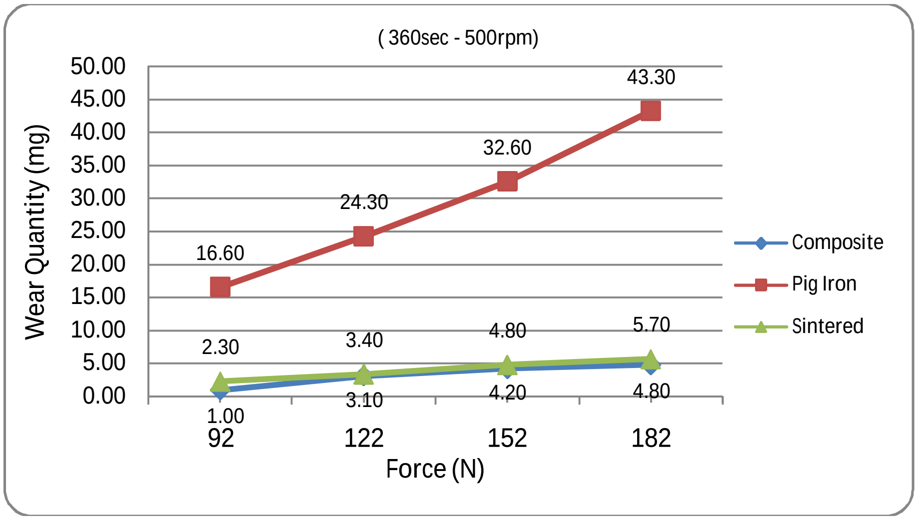


Figure 7: Change of Wear Quantities Depending on the Exerted Forces at 360sec-500rpm

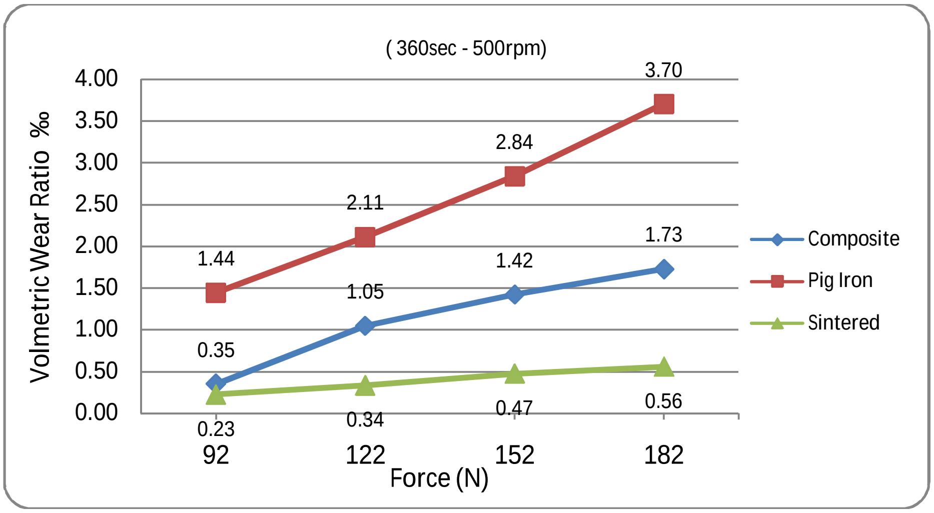


Figure 8: Change of Volumetric (‰) Wear Ratios Depending on the Exerted Forces at 360sec-500rpm8

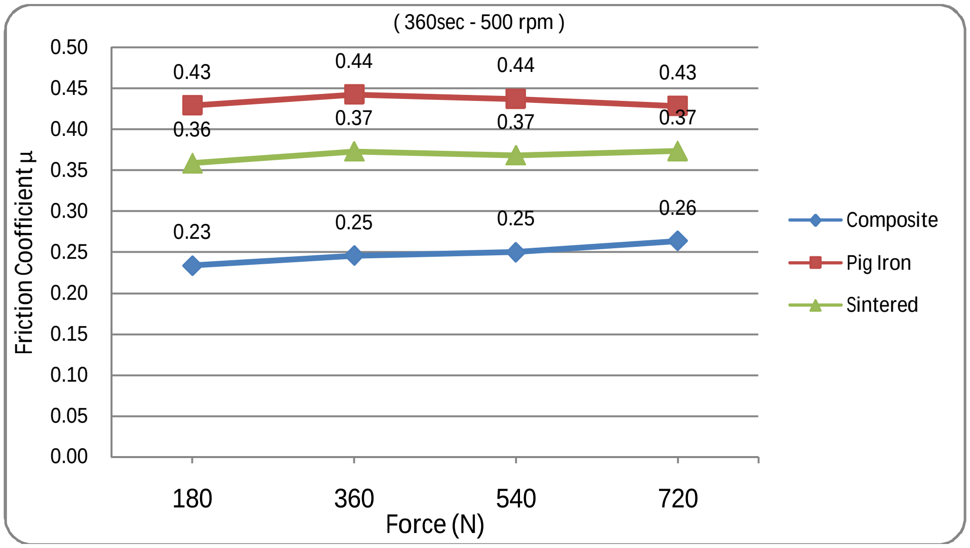


Figure 9: Change of Friction Coefficients (µ) Depending on the Exerted Forces at 360sec-500rpm

While an increase in weight losses are seen with the increasing loads under every condition in Figure 8, the slopes of the graphs in the upward direction for the composite and sintered samples are significantly lower compared to the pig-iron sample. Due to the fact that for the sintered and composite samples, increases in the weight losses are lower in comparison to the increase of the forces exerted on them, it could be said that adhesive wear, rather than abrasive wear, is more dominant in those systems.

It has also been proved by the researchers that higher copper (Cu)ratio in the chemical composition of sintered sabot and some alloy elements such as Cr, Mo, V, Sn and P caused the perlit ratio in the structure to increase, leading to a higher surface hardness and higher adhesive wear resistance. In some other researches, it has been asserted that graphite in the structure played a significant part in wear resistance. Based on the experimental studies performed, it has been clearly revealed that the graphite, functioning like a solid lubricator, protected the surface [9]. High wear resistances in composite sabots arise from high content of graphite in their structures.

In the test runs conducted with each of the three samples, it is seen that friction forces increases in proportion to the increasing loads. Looking at the graphs for friction coefficients, no a slope, as a distinct line, either in upward or downward direction, are seen. The situation that the coefficient of friction remains constant while the friction force increases is consistent with the theory that the friction force is a function of the exerted force.

4. SEM Pictures

Pictures for the worn surfaces of pig-iron, sintered and composite test samples obtained under the paramaters 360sec-122N-500rpm via LEO 440 computer-controlleddigital scanning electron microscobe with the magnification capacity of 5x-300.000x, are shown in Figure 10. It is evaluated that abrasive wear are more dominant for the worn surfaces of pig-iron sabots. Abrasive and adhesive wear have equal impacts in sintered and composite sabots,. It is seen that counter abrasive surface, with the press on the surface of the main component, moves the material in a remolding way in the scratching regions. There are arepartly breakaways from the materials and particles broken away accumulate at the exit of abrasion region.

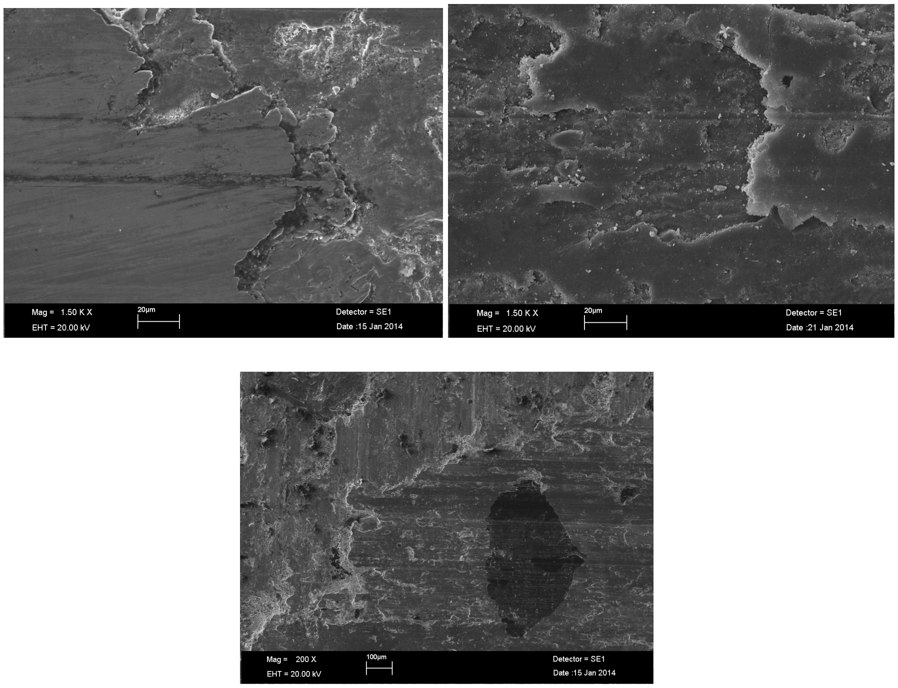


Figure 10: SEM Pictures for the Worn Surfaces of Pig-iron /Composite/Sintered Sample

5. Results

It has been seen that changing sliding times had no significant impact on friction force and coefficient. Wear quantities are seen to increase in parallel to the increases in sliding time, exerted force and speed.

Changes in sliding speeds are not desired to have any impact on friction force and coefficient. But, it is not so possible in practice. It is observed that in pig-iron sabots, friction coefficient, initially tended to reduce as sliding speed increases and inclined to increase after 400rpm is exceeded. In composite and sintered sabot samples, as the speed (sliding speed) increases, friction coefficients have a tendency towards the decrease.

Average coefficients of friction for pig-iron, sintered, composite sabots are obtained as 0.44, 0.37, 0.25, respectively.

As a result of the findings obtained by observing the different sliding times and sliding speeds (rotation speeds) of sabots, it is seen that pig-iron sabot wears significantly faster compared to composite and sintered sabot. The pig – iron sabot of lifetime is 3 times shorter than that of composite sabot and 6 times shorter than that of sintered sabot.

The best result for wear resistance has been obtained with sintered sabot samples. However, considering the factors in railroad operations, alteration and labor times in maintenance and repairement for sintered and pig-iron sabots extend as they are significantly heavier (about 4 times) than composite sabot. Moreover, initial costs of sintered sabots are also significantly higher. Not hardening the surface of the wheel bandage increases the attachment of wheels to the rails (i.e., increase in adherence strength). Sintered sabots, due to their higher costs, are determined to be more efficient for self-propelled vehicles (locomotives) during road testing. For the pulled vehicles (wagons), composite sabot are considered to be optimum choice because of their lightness, long lifetimes, low costs and extended service periods owing to their easy replacement.

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