WEAR ANALYSIS OF VERTICAL COAL MILL PLATE

By Diah Kusuma Pratiwi

WEAR ANALYSIS OF VERTICAL COAL MILL PLATE

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ABSTRACT: Vertical Coal Mill (VCM) is equipment for grinding and pulverizing coal into micron size. Rotary kilns then use the powders as fuel burners. The VCM has a housing section equipped with a lining plate as a wear and tear protector. The housing comprises segments with similar thicknesses and materials that are severe to wear due to gas-carrying solid particles hitting the surface. The specific material resilient to abrasion is required to extend operating services. This study aims to determine the wear properties of Hardlite and Everhard C500LE on the lining plate. Characterization of the samples, including composition, microstructure, hardness, and wear test. Microstructure observation shows that the more extensive and profound the wear marks formed, the higher the volume of exfoliated material. The test results show that the Fe-Cr-C hard-facing alloy significantly affects the hardness value of a material and its wear resistance. The hardness test results showed an average Hardlite overlay layer hardness value of 703 BHN (N/mm^2), almost double that of Everhard C500LE.

KEY WORDS: Vertical coal mill, lining plate, wear plate, Hardlite, Everhard C500LE

1. INTRODUCTION

Cement has main ingredients of limestone, clay, silica sand, and iron sand, as well as corrective raw materials such as gypsum, trass, and high-grade limestone. The cement production process comprises five main stages: raw material supply, raw material milling, burning, final milling, and packaging or packaging. The combustion process uses coal as fuel with 200-300 messes pulverization using a Vertical Coal Mill as rotary kiln fuel to produce clinker.

Industrial development demands innovation and efficiency in the operating process. Innovation is needed to improve product quality and appropriate materials. The cement factory production process always carries out regular and corrective maintenance intending to maximize the performance of all machines. Maintenance at the factory is often faced by companies or decision makers related to maintenance, such as the replacement of spare parts, lubrication, and overhaul. Maintenance is needed to overcome problems that often occur in factories and are frequently encountered at uncertain times. With planned maintenance, the factory can produce optimally without experiencing breakdowns.

Some VCM components are prone to wear, such as hammer crushers, grate plates, and lining plates. It is caused by friction between the material being produced, those passing through it, and other accompanying elements. In the cement industry, materials with high wear resistance is beneficial for company operations because this can reduce maintenance costs, both service, and spare parts. Lining plates on the verVCM are installed with several segments and sizes for time effectiveness and ease of installation. Based on the above-mentioned, the research concerns determining the extent of the wear of the lining plate. It is expected to get differences in physical and mechanical properties between wear plates and alternative plates made of composite plates so that it becomes a consideration in choosing the type of material with a longer service life.

2. RESEARCH DESCRIPTION

The implementation of this research followed the flowchart shown in Fig. 1. This research was started by knowing the material specifications and study literature by looking at the Vertical Coal Mill Housing design, functions, and work systematics of the Vertical Coal Mill supported by a site survey first.

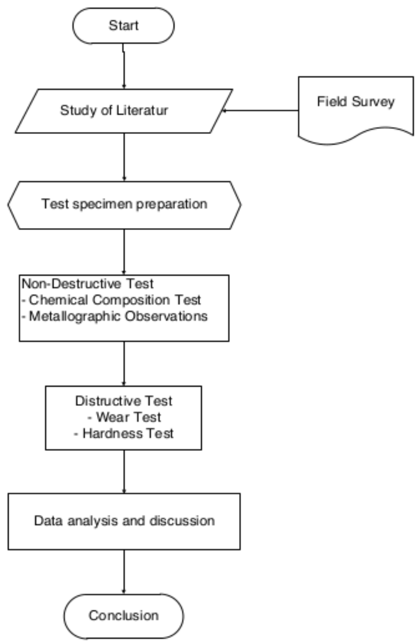


Fig. 1. Research flow chart.

The damage trend to Lining Plate can be known from the data obtained from plate replacement and other supporting data. Then the specimen is taken to prepare for testing. The first investigation is carried out by non-destructive tests such as chemical composition testing and metallographic observations. The chemical composition test uses the Niton XL2 material composition test kit by first cleaning the tested surface using a brushing machine until the surface is shiny. Metallographic testing is carried out after grinding, polishing and etching the plate material as a test specimen to obtain a microstructural pattern with a magnification of 1000x. The next test is a destructive test: wear testing and Hardness Testing. Wear testing uses the Ogoshi High-Speed Universal Wear Testing Machine (OATU Type), where the test object obtains a friction load from the revolving disc resulting in repeated inter-surface friction loading so that it takes some material on the surface of the test object. It is known the level of wear of the test object surface against friction or scratches. The hardness test was carried out using the Brinell Hardness Tester Torsen type BH-3CF on a flat surface. The test results are compared so that each test specimen's type of material, mechanical properties and wear resistance are known. The results of the several tests were then analyzed and discussed to determine the cause of the damage and obtain suggestions for minimizing the wear and tear in the Housing Vertical Coal Mill.

3. RESULTS AND DISCUSSION

3.1. Vertical Mill Housing

Vertical Coal Mill Housing is equipped with a special seal to prevent false water from entering. Doors that open easily for inspection purposes, facilitating maintenance and installation. The contour design of the housing ensures optimal material distribution, rapid collection of ground material and reliable conveyance of finished material to the separator. Parts of the housing prone to wear are equipped with replaceable wear guards. Lining Housing is a wear-resistant material. The fact that it always occurs in the field whenever maintenance is carried out on a coal mill, the Lining Coal Mill always experiences wear and tear-this causes the performance of the coal mill to be not optimal. Before modifications, the Lining Housing used wear-resistant material BS EN 10029. Because it was assessed using wear-resistant material BS EN 10029, it often experienced wear and tear. The material was replaced with composite material while paying attention to the same size and thickness. This modification can indeed increase the wear resistance of the Lining housing, with the hope that it will last longer than what was installed from the start.

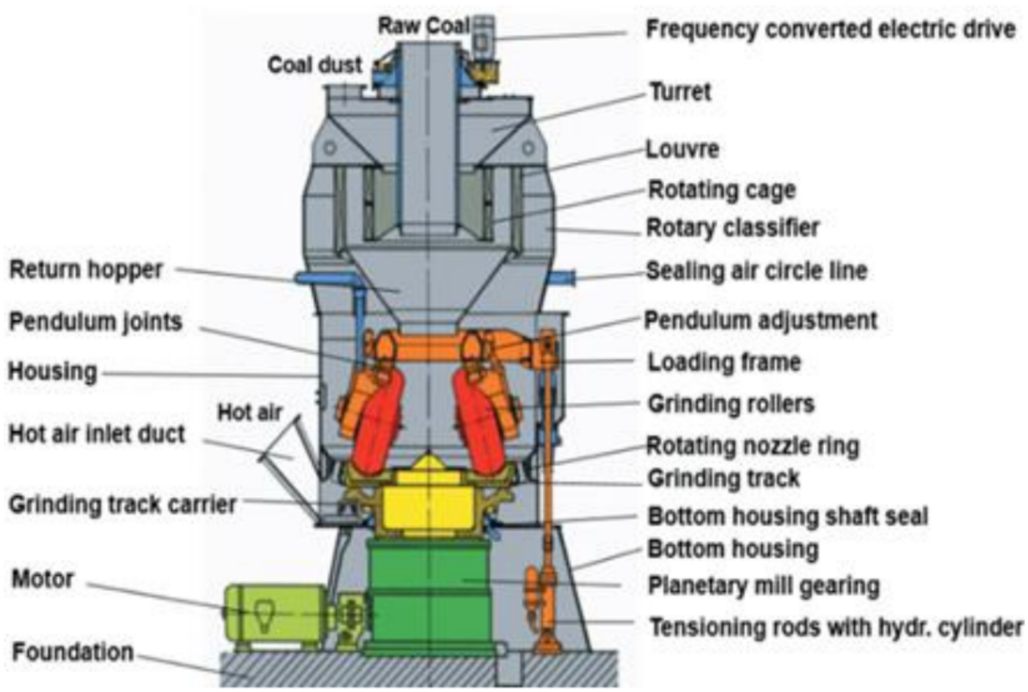


Fig. 2. Layout of vertical coal mill [1].

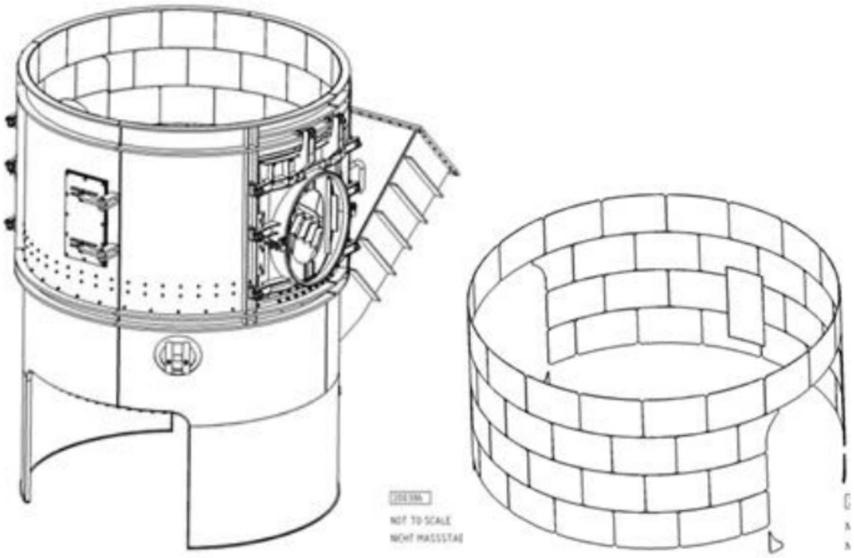
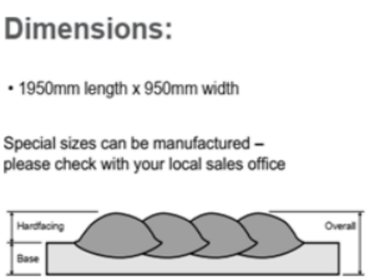


Fig. 3. Vertical coal mill housing and lining plate [2].

3.2. Specimen preparation

The lining plate is installed around the wall of the VCM, as shown in Fig. 3, with the number of segments and sizes of lining plate thickness is 6 mm. The test specimens used are Hardlite and Everhard C500LE. The Hardlite material is a composite plate with 2 (two) parts, as shown in Fig. 4.



Thickess (mm)

Base	Hardfacing	Overall
2	2	4
2	3	5
3	2	5
3	3	6

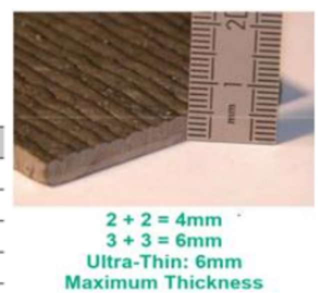


Fig. 4. The Hardlite dimensions [3].

3.3. Material Analysis

The data obtained from the test results are used to analyze and ascertain the possible causes of wear and tear on the Lining Housing Vertical Coal Mill by comparing two different materials. These data are also used to analyze the differences in mechanical and metallurgical properties. Analysis of physical properties in the form of microstructure appearance obtained from the results of macro metallographic. Mechanical properties is characterized via hardness. The wear properties of each specimen were obtained via the Ogoshi test. The data obtained will facilitate the analysis and discussion of the relationship between these tests and the wear changes that occur in the two different materials.

3.3.1. Chemical Composition Testing (XRF)

The chemical composition of the specimen material is shown in table 1. It can be seen that the most dominant difference between the Hardlite and the Everhard C500LE is the content of Fe and Cr. As discussed earlier, Hardlite is a composite plate with a total thickness of 6 mm as a base, a mild steel plate with hardfacing on its surface, while Everhard C500LE is a wear plate without hardfacing.

Table 1: Comparison of chemical composition (%) of the Hardlite and the Everhard C500LE

Material	Material composition (%)													
	Al	**Si**	**S**	**Ti**	**Mn**	**Fe**	**Ni**	**Cu**	**Pb**	**Zn**	**Zr**	**P**	**Cr**	**LEC**
Hardlite	-	0 to 0.69	-	-	0.79 to 0.91	73.46 to 76.39	0.18 to 0.2	0.39 to 0.74	0 to 0.01	0.04 to 0.07	0.23 to 0.29	0 to 1.42	21 to 22.3	-
Everhard 500	0 to 0.97	0.7 to 0.87	0.07 to 0.11	0.06 to 0.07	1.14 to 1.26	96.73 to 98.62	-	-	-	-	-	0.04 to 0.05	-	0.17

The Cr material is used in stainless steel, heat-resistant alloy, and high-strength steel; this metal is very hard. Three types of Fe-Cr-Ni alloys are Superalloy (nickel base), stainless steel (Cr at least 10% wt) and high chromium white cast iron. Transition metal elements such as Cr are also used as wear and corrosion protection agents [4]. This addition of chromium gives steel unique corrosion resistance properties, denoted as stainless steel, by increasing the chromium content, usually well above 12 wt.% Cr. Therefore, the chromium content is usually 15 wt.%, 18 wt.%, 20 wt.%, and even up to 27 wt.% Cr in certain levels. In addition, further addition of alloys (e.g., Mo, Ti, S, Cu) can be made to adjust the chemical composition to meet the needs of different corrosion conditions, operating temperature range, and improve hardenability or to improve weldability, engine capability, and resistance to wear. Using Nickel combined with other alloying elements, such as chromium, increases the toughness of fractures and, to some extent, the wear resistance of tool steel [5]. Cu element, a common alloying element, is used to increase strength, hardness and resistance to corrosion. And it is often used as an infiltrate to fill porous parts and increase density. Other alloying elements in the Hardlite are Pb elements, although very few are useful, including high density, low melting point, ease of forging and corrosion resistance. Si (silicon) usually, only a small amount (0.2%, for example) is present in rolled steel when silicone is used as a deoxidizer. However, in steel casting, 0.35-1.0% is common. Silicon is soluble in iron and tends to strengthen it. Welded metals typically contain about 0.5% silicon as a deoxidizer. Some filler metals can contain up to 1.0% to improve cleaning and deoxidation for welding on contaminated surfaces. When this filler metal is used for clean welding surfaces, the strength of the resulting welding metal increases markedly. The resulting decrease in ductility can give rise to cracking problems in some situations. [3]. Cu element as an alloying element is usually used to increase strength, hardness and resistance to corrosion; it is often used as an infiltrate to fill porous parts and increase density. Other alloying elements found in the hardlite are Pb elements, although very few useful Pb elements include high density, low melting point, ease of forging and corrosion resistance.

3.3.2. Metallographic observation

Metallography is a testing method for viewing metal structures on a micro scale-this is done using an optical microscope and an electron microscope. Metal structures or images that are visible through observation with a microscope are called microstructures. If the surface of a metal specimen is carefully prepared, and its microstructure is observed using a microscope, it is noticeable that the sample has a different structure. In Fig. 4, you can see the area of the micro-size of the metal structure that is generally observed with a microscope. Micro-testing on test specimens was performed using 1000x magnification optical lenses. The metallurgical structure of the hardlite overlay based on the datasheet consists of a high chromium cast iron alloy, consisting of primary chromium carbide and eutectic type M_7C_3[5] as shown in Fig. 4. The use of M_7C_3 carbide ($(Cr, Fe)_7C_3$) results in a very hard and wear-resistant hyper eutectic Fe-Cr-C hard-facing alloy coating [6, 7]. The superior abrasive and erosive wear resistance of Fe–Cr–C alloys results from many hard carbides with excellent corrosion resistance [7].

Alloys with a high Cr content are iron alloys containing chromium between 12% and 30%. The microstructure of all alloys with hypoeutectic high Cr consists of an M_7C_3 eutectic carbide network in the austenite dendrite matrix or its transformation products. These eutectic carbides' type, quantity, and morphology control wear resistance and toughness [8]. The abundance of chrome in the alloy increases its hardness of the alloy. Chrome increases hardness because chrome atoms infiltrate substitutionally on the crystal structure of carbon steel, causing dislocations in the crystal structure. The more chrome dissolved in the alloy, the higher the hardness value of the alloy. This kind of chrome hardening mechanism is also called solid solution hardening. High chromium alloy iron containing 12wt% to 30wt%Cr and 0 to 3wt%Mo is used as a worn share in the slurry, mining, mineral and cement transportation industries. Hypo-eutectic iron is widely used, which solidifies as the primary austenite dendrite, followed by a eutectic mixture of austenite and carbide M7C3. Molybdenum is added to high chromium alloys to improve hardenability but also leads to the formation of other hard carbides apart from typical M_7C_3, including M_2C and M_6C depending on the Cr/C ratio of iron [9].

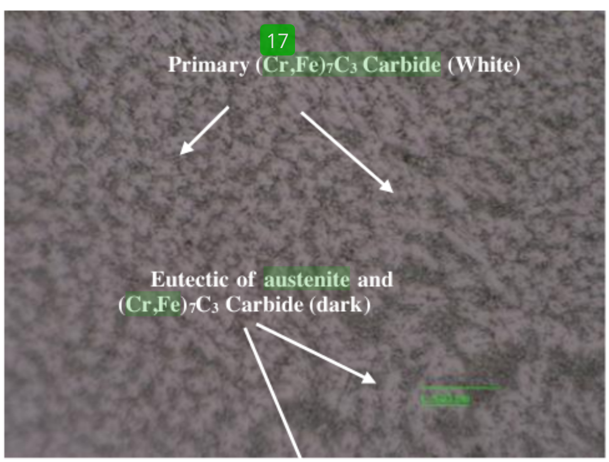


Fig. 5. Microstructure of 1000x magnification on Hardlite

The microstructure on the hardlite, consists of primary M_7C_3 carbides and eutectics of austenite and fine eutectic M_7C_3 carbides surrounding the primary carbides. The M_7C_3 eutectic carbide of the weld layer is much finer than the hypoeutectic carbide due to the faster cooling rate of the weld layer. Based on report elsewhere [10], the microstructure of Fe-Cr-C material is shown in Fig. 5.

Hardlite and Everhard C500LE test specimens have the same thickness, but the Everhard C500LE plate is not overlaid on the surface and is one plate layer. The metallurgical structure of the Everhard C500LE exhibits high homogeneity and post-martensitic orientation. This structure can be described as similar to tempered sorbitol (highly tempered martensite), like the shape of needles. Still, its hardness is significantly higher than sorbitol in pure steel [11]. In addition, microscopic observations of the Everhard C500LE showed that the Everhard C500LE had been hardened and then forged. As a result, it has a post-martensitic orientation (tempered martensit) structure with fine carbide precipitation coherently distributed inside the martensitic granules [11]. Martensite in specimen 3 Everhard C500LE has undergone greater forces from the outside so that the martensite structure is denser, and the carbide appears more above it.

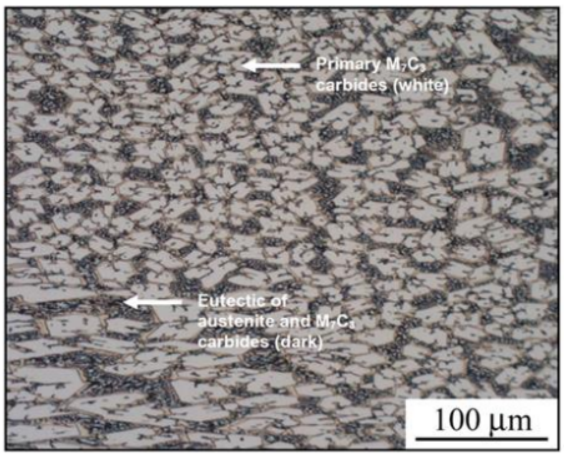


Fig. 6. Optical light micrograph of hypereutectical high chromium white iron welding layer, 200x, etched in ferric acid [10]

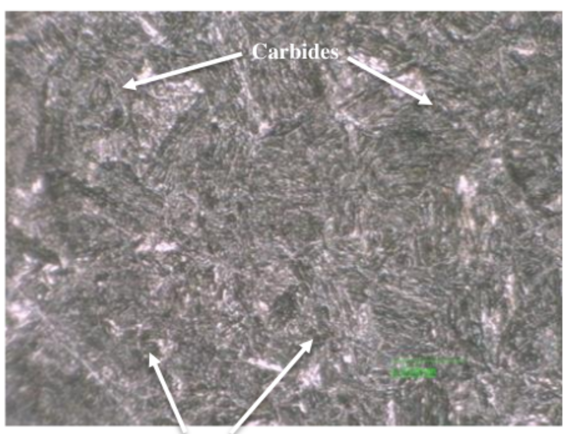


Fig. 7. Microstructure of 1000x magnification microstructure on specimen 2 Everhard C500LE

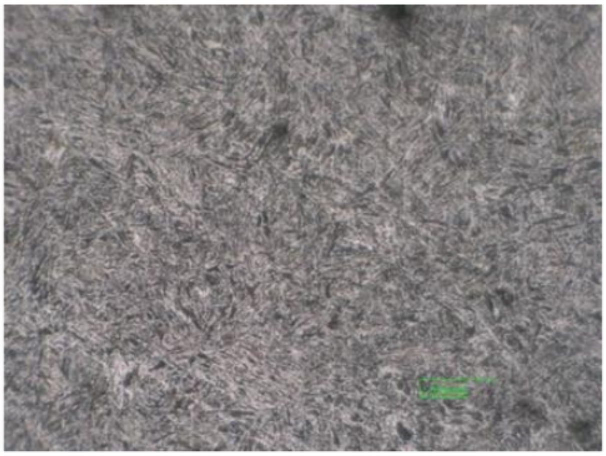


Fig. 8. Microstructure of 1000x magnification on specimen 3 Everhard C500LE

3.3.3. Hardness Testing

Hardness testing was carried out on the surface of the specimen from 3 different plates. The diameter of the indent obtained from the test results on the specimen is not always the same between one axis and another. This happens because there is difficulty in determining the edge of the indentation result in the test specimen. However, this diameter difference is still on a scale of 10-5 m, so it has little influence on the final result of the calculation. The value of the hardness test results is shown in Fig. 9.

The results of the hardness test value show that Harlite has the highest hardness, as in Fig. 9 and Table 2. The material used as the base plate of Hardlite is a mild steel material.

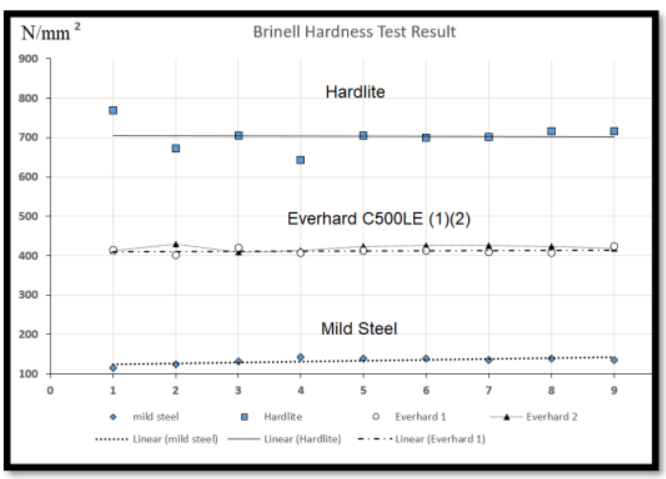


Fig. 9. Comparative graph of hardness values on Hardlite and Everhard C500LE specimens

Hardlite in Table 1 has a different material composition from Everhard C500LE material in Cr (Chromium) composition. The addition of Cr will increase the ability of this alloy to be given a stronger heat treatment than low-carbon steel [12], and used for high-strength components that require a combination of high strength, wear resistance and heat resistance.

Table 2: Brinell Hardness Result [13]

No	BHN (N/mm2)		
	Hardlite	Everhard 500 (1)	Everhard 500 (2)
1	770	415	412
2	672	401	429
3	705	421	409
4	644	406	412
5	705	412	423
6	699	412	426
7	702	409	426
8	717	406	423
9	717	423	418
Average	703	412	420

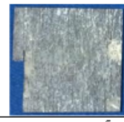
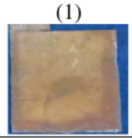
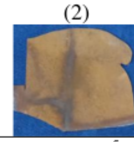
The addition of alloying elements, eutectic carbide (M_7C_3) chromium carbide, is a very hard phase. Eutectic carbides are harder than iron carbides in steel. The addition of abrasion resistance by alloy elements will increase wear life significantly [4].

3.3.4. Wear Testing

A wear test is a physical characteristic test used to determine how much the level of wear of an object (surface of an object) is against friction or scratches. The wear test is carried out by calculating the wear width of the sample; the test object obtains a friction load from the revolving disc. The loading will result in a contact that eventually picks up some of the material on the test object. The magnitude of the swiped material's surface footprint is used as the basis for determining the level of wear on the material [14].

Based on Fig. 10, it can be seen that the wear of the 1st (hardlite) specimen is the lowest of specimens 2 and 3 (Everhard C500LE); this can be interpreted to mean that the resistance of the material is stronger against wear caused by material friction. In the process passed at the Vertical Coal Mill, there is an erosion process caused by gases carrying solid particles that hit the material's surface. The larger and deeper the wear imprint formed, the higher the volume of material chipped from Linner. In the process passed at the Vertical Coal Mill, there is an erosion process caused by gases carrying solid particles that hit the material's surface. The larger and deeper the wear imprint formed, the higher the volume of material chipped from Linner. If this wear is continuous, then there is a decrease in effectiveness, and this part of the liner runs out and touches the part of the mill wall. The desired liner is, of course, made of material with a low or small wear rate. Because if the wear rate of the material is large, the lining plate wears out quickly, which can cause damage to the elements of the equipment that intersect with the leaner in its construction. From the overall data of the wear test results, it was found that the smallest wear rate value was in specimen 1 (hardlite) testing with an average wear rate of 4.5×10^{-8} mm^2/kg; the data was contained in Table 3 and Fig. 10.

Table 3: Ogoshi wear testing value

No	**Wear result (Ws) (mm^2/kg)**		
	Hardlite	Everhard CC500LELE (1)	Everhard CC500LELE (2)
			
1	3.7×10^{-5}	9.3×10^{-5}	7.2×10^{-5}
2	7.1×10^{-5}	6.3×10^{-5}	2.3×10^{-5}
3	2.7×10^{-5}	1.3×10^{-4}	6.8×10^{-8}
Average	4.5×10^{-5}	9.4×10^{-5}	5.4×10^{-5}

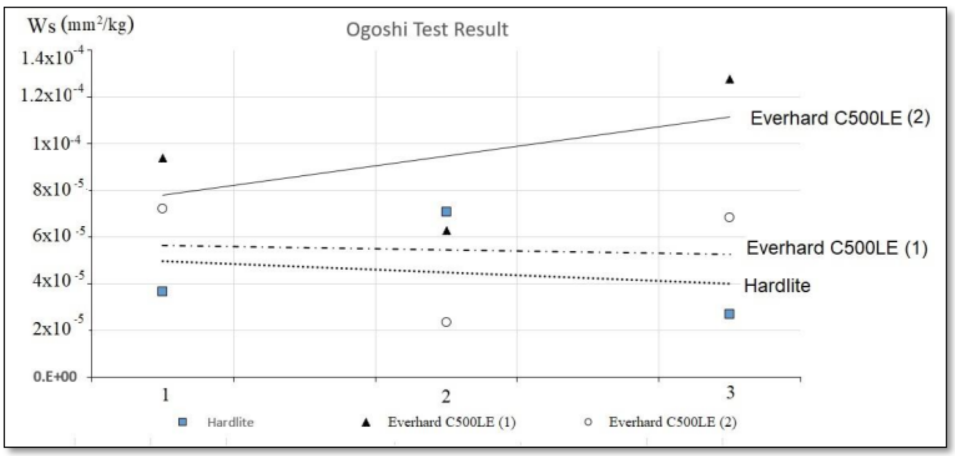


Fig. 10. Comparison of average wear values on the hardlite and the everhard C500LE specimens.

4. CONCLUSION

Based on the analysis of the results of the study of several test specimens from 3 specimens installed in the Vertical Mill, it can be concluded that:

1. Factors that affect the wear of lining plates are the composition and microstructure.
2. Failure of the liner on the Vertical Coal Mill is caused by fatigue wear because the liner material has poor toughness and is unsuitable. The plate material on the liner is not tough enough to accept repeated impact loads-this can be seen from the surface of the liner, which is more dominantly damaged.
3. The hardness test results showed an average Hardlite overlay layer hardness value of 703 BHN (N/mm^2), almost 2x higher than 2 (two) other sample materials, namely Everhard C500LE. With this hardness value, it is still damaged due to repeated impact loads from coal particle collisions, but the service life of the Hardlite exceeds that of the Everhard C500LE plate.
4. Hardlite material wears testing; it can be seen that the material's resistance is stronger against wear caused by material friction than other test specimen materials.

5. Adding Chromium elements protects the material against wear rates and gives it unique corrosion resistance properties.

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