

Failure Analysis on Hammer Crusher in Clinker Cooler

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Abstract - Hammer crusher is one of the main components in the clinker cooler. A hammer crusher is a tool for crushing clinker that has cooled to reduce the size of the slag. The Hammer crusher wears out which causes its service life not to match its ideal use. The purpose of this study is to determine the cause of the failure of the hammer crusher, to know the mechanism of the failure of the hammer crusher, and to find the solution for the failure of the hammer crusher. The methodology used to solve the problem is by conducting tests where the tests carried out to analyze the hammer crusher material is composition testing carried out with the OES tool, hardness testing using the Vickers method, impact testing using the Charpy method, and metallography observed under an optical microscope. Based on testing the material composition of the hammer crusher is not up to standard. Then from the hardness test, the average value is 569.8 HVN on the hammer worn part and 481.2 HVN on the part far from worn. From the impact test, the average impact energy value in the wear section is 1.917 Joules with an average impact strength of 0.023 Joule/mm², in areas far from wear the average impact value is 1.733 Joules with an average impact strength of 0.021 Joules./mm². Factors that cause the failure of the hammer crusher in the clinker cooler are the incompatibility of the material composition and the low toughness value compared to the standard, then the hammer crusher failure mechanism occurs due to wear and tear caused by differences in hardness values and changes in the mechanical properties of the material and to overcome the failure, namely by replace material according to ASTM A532 standard composition.

Keywords: hammer crusher, clinker cooler, hardness, impact.

I. INTRODUCTION

In general, the process of making cement starts from taking and crushing raw materials, while taking raw materials starts with crushing, stockpiling, grinding raw materials, and loading them into silos. Followed by the process of making clinker, namely preheating, rotary kiln, and, cooling (cooling). Continue with the cement grinding process, namely mixing with additives, grinding and powdering, and the last is the cement packing process, which is putting cement into packaging and storing it in the warehouse [1].

In the cement manufacturing process, after the burning process is carried out, the next step is the material cooling process which is carried out in the clinker cooler. Figure 1 shows the main components of the clinker cooler. The cooling process starts when (b) the clinker comes out of (a) the rotary kiln and is continued by (c) the crossbar to (e) the hammer crusher who reduces the initial size of the clinker. During the journey to the hammer crusher, the clinker is cooled by the (f) fan under the crossbar and the hot air in the clinker cooler exits through the (d) exhaust duct, then the clinker is crushed by the hammer crusher into a larger size. small [2].

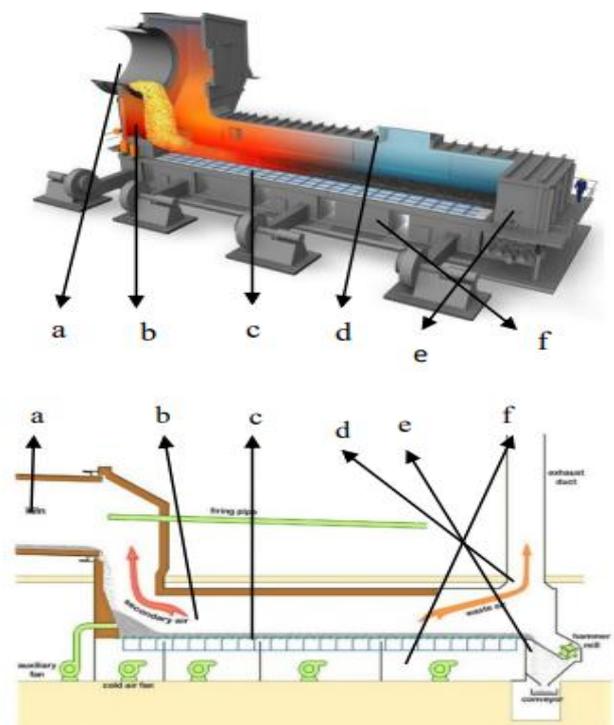


Figure 1: Clinker cooler components [2]

A hammer crusher is a grinding tool that has a rotating rotor and a hammer-shaped breaker where the hammers are hung on a rotor that can rotate quickly. Figure 2 shows the hammer crusher components, including feeders that function as flow regulators and separators of materials and raw material receivers. Hammer is a component that functions to break down and reduce the size of the material, and a screen (sieve) is a component in stone crushing equipment that functions to filter, form gradations, and indirectly control the distribution of material to the crusher unit [3].

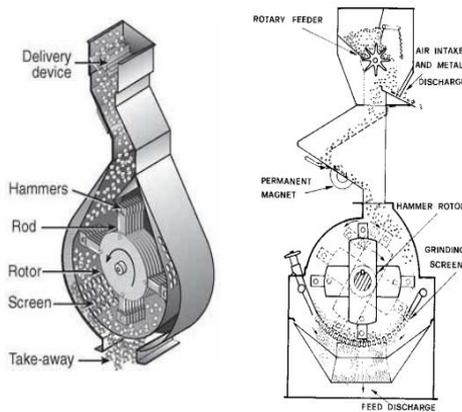


Figure 2: Hammer crusher components [3]

The hammer crusher material that should be by existing standards is white cast iron by ASTM A532. White cast iron is suitable for grinding, milling, earth handling, and manufacturing industries [4]. Then ASTM A681 Steel is an alloy steel with high carbon content and has a high chromium alloy. Mechanical properties of ASTM A681 Type D2 also vary, one of which is hardness, toughness, and modulus of elasticity [5].

Steel is an alloy of iron and carbon which may contain other alloying elements. The mechanical properties are strongly influenced by the carbon content, which is usually less than 1.0 wt%. In general, steel is classified according to carbon concentration, namely low, medium, and high carbon. It can also be grouped based on the content of the alloying elements. Ordinary carbon steel (plain carbon steel) contains only a concentration of carbon and steel in addition to having few impurities and a small amount of manganese alloy [6].

In general, cast iron is part of an iron (Fe) alloy with carbon (C) content above 2.14%. Most cast iron contains between 3.0-4.5% carbon, with the addition of some alloying elements [6]. Cast iron is grouped into 4 types, namely white cast iron, metalabel cast iron, gray cast iron, and nodular cast iron [7]. White cast iron is a hypoeutectic alloy where after pouring and solidification, carbon will mix with iron to form cementite [19]. The microstructure of high chromium white cast iron consists of Cr carbide, with an austenite or ferrite matrix (in as-cast condition). The high Cr content in this material causes the Fe₃C carbide in white cast iron to become unstable, and its presence is replaced by (Fe, Cr)₇C₃ (primary carbide) and M₂₃C₆ or (Fe, Cr)₂₃C₆ (secondary carbide) [8]. The hammer material that failed was included in the high chromium white cast iron group with a carbon content of 1.73% and Cr as much as 17%, so it was included in the hypoeutectic alloys group. Hypoeutectic alloy structure, carbon content is lower than the eutectic point. The solidification process begins with the formation of dendrites from the matrix (austenite) at a certain solidification temperature range until it reaches the eutectic temperature. Then the process continues with the formation of a eutectic structure [9]. Carbide in high chromium white cast iron is very hard, brittle, and has good wear resistance. In general, the wear resistance can be increased by increasing the amount of carbide (increasing the carbon composition), while the toughness can be increased by increasing the amount of metallic matrix (reducing the carbon composition) [10]. The mechanical properties of white cast iron are tensile strength and toughness. Table 1 shows the transverse strength, deflection and toughness of various types of white cast iron [11].

Table 1: Toughness value of white cast iron [11]

Type of Iron	Basic Composition	Transverse Strength		Deflection		Toughness					
		kg	lb	mm	in	kg.m	lb.in				
Sand cast pearlitic	3.2-3.5 C, 1-2 Cr	635	1400-	2.0-2.3	0.0080-	1.29-	112-162				
		815	1800								
Sand cast martensitic	2.8-3.6 C, 1.4-4 Cr, 3.3-5 Ni	1810-	4000-	2.0-3.0	0.80-0.12	3.68-	320-600				
		2490	5500								
		2270-	5000-					2.0-2.8	0.08-0.11	4.6-7.60	400-660
		2720	6000								
		1015-	2235-								
1370	3015										
800-	1760-	2.0-2.8	0.08-	1.60-	140-240						
1000	2200										
Chill cast martensitic	2.8-3.6 C, 1.4-4 Cr, 3.3-5 Ni	2040-	4500-	2.0-3.0	0.08-0.12	4.15-	360-840				
		3180	7000								
		2500-	5500-					2.5-3.8	0.10-0.15	6.34-	550-
		3180	7000								
1980-	4360-	5.1-6.5	0.202-	10-15.2	870-						
2295	5060										
1270-	2800-	3.6-3.8	0.140-	4.52-6.0	392-520						
1575	3470										

Failure analysis can be defined as the inspection/testing of damaged components or structures along with the conditions that cause failure intending to find out the cause of the failure. The main purpose of failure analysis is to find out the mechanism of failure and provide solutions that can be implemented to overcome the failure problem. Some of the factors that cause failures that often occur in the industrial world are material selection errors, poor component maintenance, and errors in component design [12].

Wear is generally defined as the progressive loss of material due to friction between solid surfaces or the displacement of a certain amount of material from one surface as a result of relative movement between that surface and another. Wear is common in any material that experiences friction with other materials. Wear is not a basic property of the material, but the response of the material to the external system (surface contact) [13].

Chemical composition testing is a test to determine the content of chemical elements contained in a metal test object. A Spectrometer is a tool that can analyze the elements of the parent metal and its alloys accurately, quickly, and easy to operate. The basic principle of knowing the elemental content and composition in this tool is that when a metal is subjected to electrical or heat energy, the atomic condition becomes unstable [14].

In general, hardness expresses resistance to deformation and is a measure of a metal's resistance to plastic deformation or permanent deformation. In hardness testing, there are three

types of hardness measurements, this depends on the method of testing, namely scratch hardness, indentation hardness, and rebound hardness. In addition, there are various kinds of indentation hardness tests, including the Brinell, Vickers, Rockwell, and Knoop hardness tests. The Vickers hardness test uses a diamond pyramid pouncer with a square base. The measure of the angle between the faces of the pyramid that are opposite each other is 136° . This angle was chosen because this value is close to most of the desired comparison values between the indentation diameter and the diameter of the ball mash [15].

Impact testing is used to determine the tendency of a material to become brittle or ductile based on its toughness. Several impact tests of notched test rods of various designs have been carried out to determine the brittle fracture of metals. Two methods have become the standard for this impact test, namely the Charpy method and the Izod method. The Charpy method is widely used in the United States, while the Izod method is used more often in most of Europe. In impact testing, the amount of energy absorbed by material for fracture is a measure of the impact resistance or toughness of the material [15].

II. MATERIALS AND METHODOLOGY

The hammer crusher material used is high chromium white cast iron steel which has a chemical composition as shown in Table 2. The hammer crusher in the clinker cooler experiences wears as shown in Figure 3. Figure 4 and Table 3 are the design and specifications of the hammer crusher material.

Table 2: Chemical composition of hammer crusher [17]

Element	C	Mn	P	Si	Cr	W	Ni	Nb	S	Mo
%	1.73	0.674	0.030	0.745	17.5	1.22	0.418	0.90	0.0089	0.89



Figure 3: (a) Hammer crusher that is worn out, (b) hammer crusher that is still intact [16]

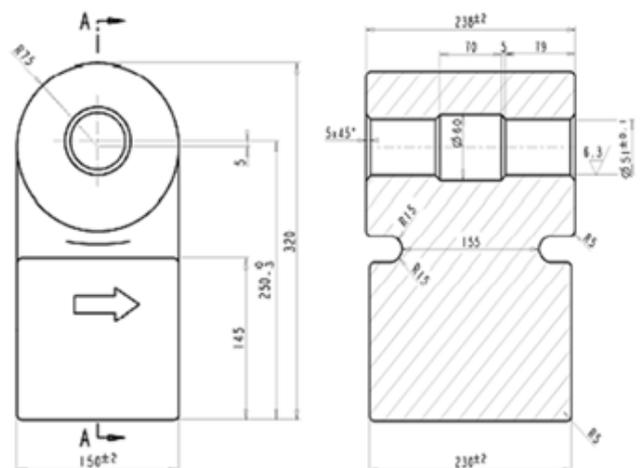


Figure 4: Hammer crusher design [17]

Table 3: Hammer crusher specifications [17]

Hammer Crusher Data	
Rotation Speed	349.598 rpm
Working Temperature	130°C
Linear speed	2073.66 mm/s
Lifetime	12 bulan
Product clinker	335 ton/hrs

The problem-solving process carried out will be explained using a flow chart to make it easier to understand. The flow chart can be seen in Figure 5.



Figure 6: Hammer crusher (a) before wear (b) after wear [16]

After calculating the volume of wear, the material experienced a material loss of $3,616,764.71 \text{ mm}^3$ or $3,616,765 \text{ cm}^3$.

3.2 Hammer Crusher Chemical Composition Test Results

The results of testing the chemical composition of the hammer crusher that are subjected to wear and the standard composition are shown in Table 4. The hammer crusher component in the clinker cooler based on existing standards usually uses white cast iron according to the ASTM A532 standard.

Table 4: Test results of hammer crusher chemical composition [16]

Element (%)	Material Uji	ASTM A532 IIA	ASTM A532 IIB	ASTM A532 IID
C	1.73	2.00 – 3.00	2.00 – 3.30	2.00 – 3.30
Mn	0.674	2.00 max	2.00 max	2.00 max
P	0.030	0.10 max	0.10 max	0.10 max
Si	0.745	1.50 max	1.50 max	1.50 max
Cr	17.5	11.0 – 14.0	14.0 – 18.0	18.0 – 23.0
W	1.22	-	-	-
Nb	0.900	-	-	-
Ni	0.418	2.5 max	2.5 max	2.5 max
S	0.0089	0.06 max	0.06 max	0.06 max
Mo	0.893	3.00 max	3.00 max	3.00 max
Fe	Balance	Balance	Balance	Balance

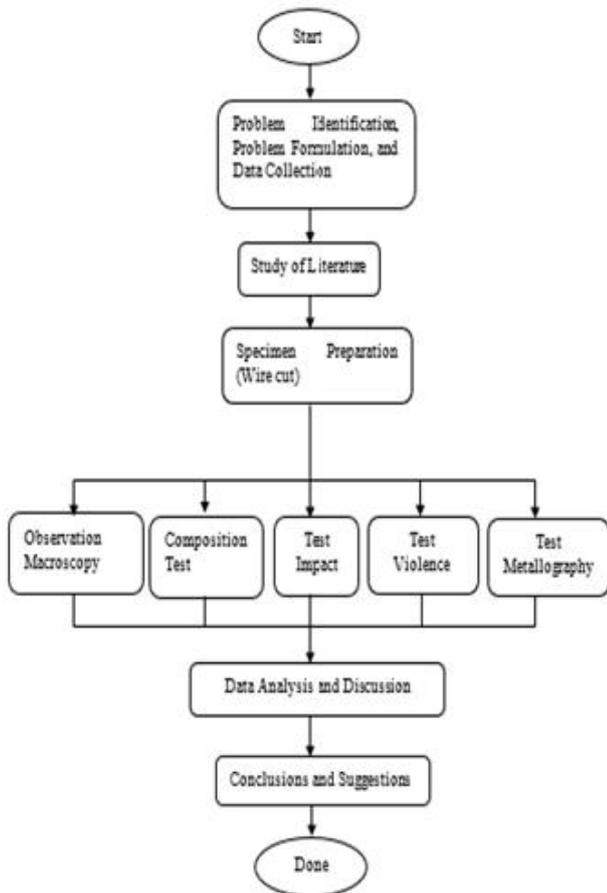


Figure 5: Flow chart

III. RESULTS AND DISCUSSION

3.1 Hammer Crusher Macro Observations That Failed

Based on the results of macro visual observations on the hammer crusher components that are experiencing wear and tear in Figure 6, it can be seen that the hammer crusher material wears out and there is a reduction in the dimensions of the hammer crusher which initially had a length of 320 mm, to 277 mm.

The hammer crusher material used after being tested for composition (OES), had results that did not match the composition of ASTM A532 class IIA, IIB, and IID. When viewed in terms of different compositions, such as the element carbon, which has a lower value of 1.73%, while the standard carbon value of ASTM A532 is 2.00-3.30%. This causes the hammer crusher material to have a lower hardness and strength value than standard materials. The Cr element has the advantage of having a high composition of 17.6% when compared to ASTM A532 class IIA but is suitable when

matched with ATM A532 class IIB and IID. The presence of the Cr element causes the formation of carbides which provide high hardness and good wear resistance. The content of elements of W and Nb is higher than the standard material. The content of W and Nb can increase the harden ability of the hammer crusher material. This difference in composition resulted in the hammer crusher material quickly wearing out from its supposed life of 1 year, it only lasts less than 6 months [4].

3.3 Vickers Hardness Test Results

Table 5 shows the hardness value from the hardness test results on the hammer crusher that is experiencing wear and tear. Then Table 6 shows the hardness value according to the hammer crusher material, which is white cast iron which has a hardness of 485 HVN.

Table 5: Hardness test result data [16]

Material	Hardness Value (HVN)					Average (HVN)	Average (HVN)
	T1	T2	T3	T4	T5		
A	515	559	574	479	490	523.4	569.8
B	580	559	571	489	483	536.4	
C	839	686	609	595	519	649.6	
G	476	504	327	422	504	446.6	481.2
H	515	473	511	504	535	507.6	
I	515	493	489	493	448	489.4	

Table 6: Hammer crusher hardness value according to ASTM A532 standard [4]

Class	Type	Designation	As cat or as cast and stress relieved		
			HB	HRC	HVN
II	A	12% Cr	550	53	600
II	B	15% Cr-Mo	450	46	485
II	D	20% Cr-Mo	450	46	485

In terms of hardness, the material that is far from the hammer crusher wear has a slightly lower hardness than the standard, which is 481.2 HVN, and the hammer crusher wear area has a hardness that exceeds the standard of 569.8 HVN. While the standard of hardness seen from ASTM A532 is 485 HVN. The difference in hardness in the hammer wear area increased in hardness compared to areas far from hammer wear due to the high stress acting on the hammer wear area hitting the clinker [4].

3.4 Impact Test Results on Hammer Crusher

Impact testing is carried out to determine the resistance of a material to impact loads or shock loads, expressed by the amount of energy required to break the test specimen. The impact energy values of the test specimens are shown in Table 7.

Table 7: Impact energy values on test specimens [16]

Material	Impact Energy (Joule)	Average (Joule)	Impact Strength (Joule / mm ²)	Average (Joule/mm ²)
Hammer wear area	2	1.917	0.024	0.023
	2		0.024	
	1.75		0.022	
Area away from hammer wear	1.6	1.733	0.02	0.021
	1.6		0.019	
	2		0.024	

The results of the impact test using the Charpy V-notch (CVN) method found that the hammer wear material has an average impact energy of 1.917 Joules, average impact strength of 0.023 Joule/mm², and has all the brittle fracture pattern. This shows that in this area the material has a high hardness so its toughness is of small value. In areas far from hammer wear, the average impact energy value is 1.733 Joules, the average impact strength is 0.021 Joule/mm², and has a mixed fracture pattern but is still brittle. Judging from the fracture pattern, the material far from hammer wear has slight differences because it has an uneven surface, is slightly fibrous, and is slightly opaque, so it is said to have a mixed fault pattern. Compared to the standard toughness of martensitic white cast iron, which has a value ranging from 3.21 – 4.93 Kg-m (31,458 – 48,314 Joule), the toughness value of this hammer crusher material is very brittle. The hardness of a material can affects the toughness of the material, the harder the material, the tougher it will decrease [18].

3.5 Metallographic Test Results

Metallographic or microstructure testing is carried out to determine the initial structure formed on the hammer crusher material that is experiencing wear and tear. Observations were made using an optical microscope at a magnification of 100x to 500x.

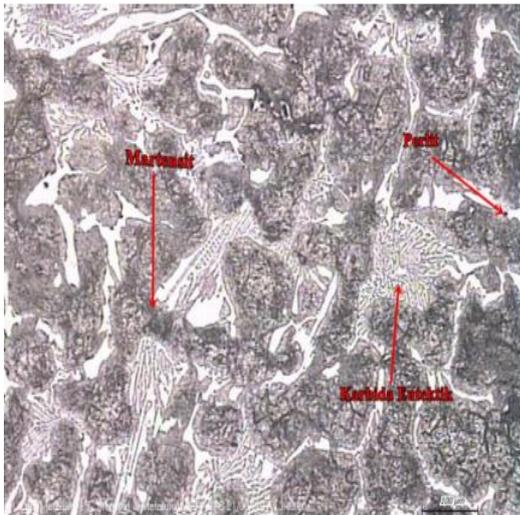


Figure 7: Microstructure of the material away from worn hammer crusher at 100x magnification [16]

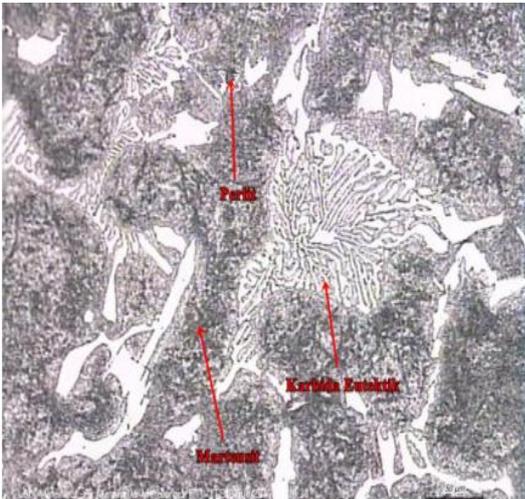


Figure 8: Microstructure of the material away from worn hammer crusher 200x magnification [16]

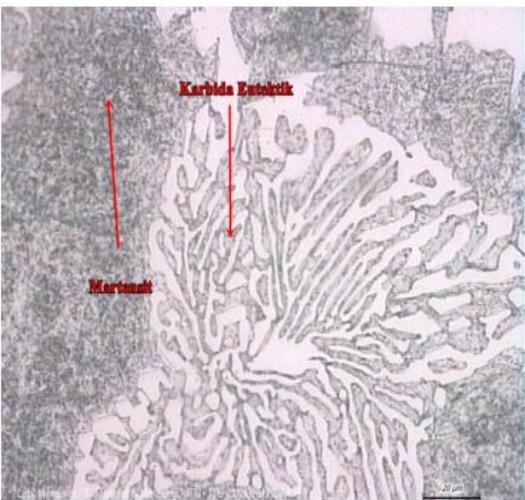


Figure 9: Microstructure of material away from wear hammer crusher 500x magnification [16]

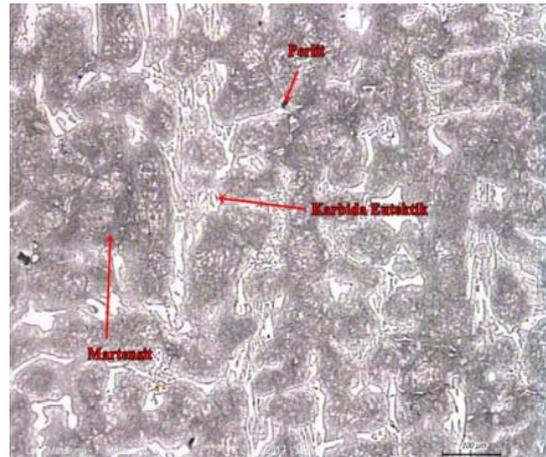


Figure 10: Microstructure of hammer crusher wear material at 100x magnification [16]

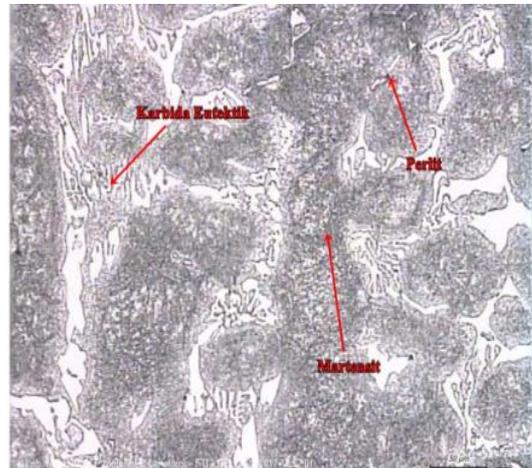


Figure 11: Microstructure of hammer crusher wear material 200x magnification [16]

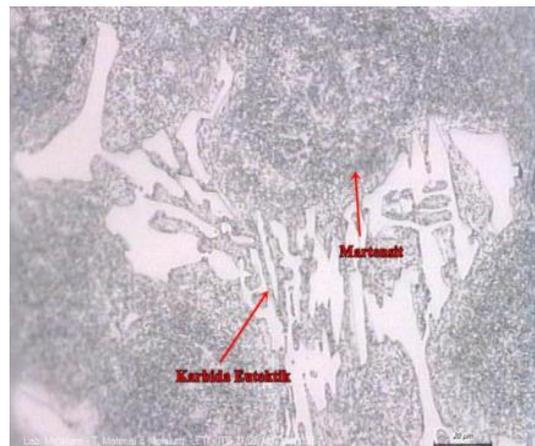


Figure 12: Microstructure of hammer crusher wear material 500x magnification [16]

Based on the observation of the hammer crusher microstructure above, obtained pearlite, martensite, and chromium carbide where pearlite is shown in gray with white spots, chromium carbide is shown in large white color, and martensite is shown in dark color. Pearlite is the result of a lamellar mixture of ferrite and cementite which is formed from

the decomposition of austenite through a eutectoid reaction in equilibrium. The pearlite matrix has low abrasive resistance but has good toughness so that the role of pearlite in cast iron is less needed [19]. Based on observations, the hammer crusher material located in an area far from hammer wear has a finer chromium carbide shape, compared to the hammer wear area, which affects the hardness properties in that area. In high chromium alloy white cast iron, the fine carbide structure in the matrix will provide an excellent combination of hardness and toughness when compared to the coarse carbide structure. The combination of hardness and toughness is the main factor of high chromium alloy white cast iron material [8].

The failure of the hammer crusher is due to wear and tear that occurs due to a mismatch in the main material elements, one of which is the lack of carbon content and changes in the mechanical properties of the material, where the hardness value of the hammer crusher material increases but decreases the ductility and the impact energy value of the material is far below the standard. This can be caused by operational processes that cause continuous friction so that the toughness of the material becomes lower and makes the hardness of the material increase due to strain hardening but makes the material more brittle.

VI. CONCLUSION

Based on the results of the discussion, there are several conclusions regarding the failure of the hammer crusher in the clinker cooler as follows:

1. The factors that cause failure of the hammer crusher in the clinker cooler are the inappropriate material composition and the low toughness value compared to the standard.
2. The hammer crusher failure mechanism in the clinker cooler occurs due to wear caused by differences in hardness values and changes in the mechanical properties of the material.
3. To overcome the failure is to replace the material according to the standard composition of ASTM A532.

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