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EVALUATION OF THE GRINDING ELEMENTS SERVICE LIFE

Summary. An attempt has been made to show the wear test procedure which simulates tribological conditions in the ball - race type coal mill, and which enable the laboratory results to be applied with a reasonable degree of certainty, in evaluating the service life of the grinding elements. The tribological conditions in the ball - race system, namely pressure distribution, sliding velocity gradient and temperature inside the grinding zone, were identified. The design of the laboratory rig and the outline of the operating procedure were based on principles of similarity. A comparison between industrial data and simulative tribotesting results shows a very good correlation. This proved that the results from a relatively simple rig may be used in predicting the service life of the machine elements. The presented simulative tribo-testing procedure and rig can be used to evaluate the abrasiveness of any granular material and for testing the wear - resistance of any material in any two - body abrasive action.

1. INTRODUCTION

In all tribological investigations model tests are frequently used in the development of new materials for certain applications as original, industrial elements involve high expenditure as regards both duration and energy. However, with model tests of tribological processes the problem often arises, to what extent the results obtained in laboratory conditions are applicable to the industrial conditions. This problem arises since tribological processes are usualy very complicated and influenced by many factors. As the operating costs of a coal pulverizing plant comprise mainly grinding element replacement due to wear, the importance lies firstly in the correct wear - resistance materials choice, which will result in minimum wear of the elements, and secondly in the accurate estimation of their service life. In this paper, an attempt has been made to show the wear test procedure which simulats tribological conditions in ball - race type of coal pulverizer and which allows the results of the test experiments to be applied with a reasonable degree of certainty.

2. IDENTIFICATION OF TRIBOLOGICAL CONDITIONS IN BALL - RACE COAL PULVERIZERS

In ball - race mills, which at present comprise a significant number of pulverizers used for coal grinding, the predominant mechanisms of comminution are crushing and attrition. In the ball - race system shown in figure 1, the tribological conditions are described by pressure distribution, gradient of sliding velocity and temperature inside the grinding zone of the coal as well as on the surface between the coal and the grinding elements. The geometry of the ball - race system is constantly changing since progressive wear process is taking place. To identify the pressure condition on the interface between the ball and the bed of fine coal model shown in figure 1 was applied. Loading and geometrical data were taken from the Babcock 12,9 E type mill, as follows: load per ball $L = 120$ kN, $2r = d = 0{,}98$ m, $b = 0{,}32$ m, $\beta = 16^{o}$, $d_1 = 0{,}742$ m. Since $s = r \sin\beta$ and $s_1 = r_1 \sin\beta$ then $s = 0{,}135$ m and $s_1 = 102$ m. The area of contact was calculated from equation 1:

$$A = bs_1 + r\,s\,\sin^{-1}\left(\frac{b}{r}\right) = 0{,}08\ \mathrm{m}^2 \qquad (1)$$

Then the average pressure on the interface between the ball and the coal layer $\bar{p} = \frac{L}{A} = 1{,}5$ MPa was obtained. Assuming certain pressure distribution inside the contact zone maximum nominal pressure was calculated. The value of maximum pressure, p_{max}, was taken as the representative for the given mill. Similar pressure conditions were created in the laboratory test rig [3, 4] by normal force $N = 2000$ N which results in maximum nominal pressure, $p_{max} = 2{,}83$ MPa.

It has been assumed that the stress distribution between the ball and the upper race in a full - scale mill is Hertzian. A model of a cylinder on a plane (equation 2) [5], simplifying geometrical configuration in the pulverizer, was used to calculate the maximum contact pressure. This model is the most suitable when the radii of the balls and the race are identical.

$$p_{max} = \frac{L'}{\pi a b} = 145\ \mathrm{MPa} \qquad (2)$$

where:

$$a = \left(\frac{2L'r}{\pi bE'}\right)^{\frac{1}{2}} = 0{,}00065 \text{ m} \qquad (3)$$

$E' = 219 \cdot 10^9 \frac{N}{m^2}$

$L' = 95$ kN

The value of the maximum slip velocity between the ball and the race (or coal layer) was calculated based on the pattern shown in figure 1.

$$v_{s\ max} = v\left(\frac{h-l}{r-l} + \frac{b}{R}\right) = 1{,}55 \frac{m}{s} \qquad (4)$$

where:

$v = \frac{n}{30}$ $R = 4{,}67 \frac{m}{s}$, $h = 0{,}12$ m, $l = 0{,}06$ m

$R = 1{,}65$ m and $n = 27 \frac{1}{min}$

Determined thermal conditions inside the coal mills are maintained as all the moisture contained in coal must be evaporated before ignition can take place. The drying capability of a given pulverizer design depends on the extent of circulating load within the mill, the ability to mix the dry classifier returns rapidly with incoming raw, wet, coal feed, and the air weight and air temperature which the design will tolerate. Some pulverizers are designed to operate statisfactorily with an inlet air temperature up to 700 K. Within the shear zone of crushed coal the temperature is usually 100 K to 200 K lower than the inlet air temperature. The calculated value of velocity, $v_{s\ max} = 1{,}55 \frac{m}{s}$ applied in the recommended laboratory rig [3, 4] was generating too high an equilibrium temperature, which exceeded the temperature inside industrial mills. The temperature inside the grinding zone of the coal was taken as more important similarity criterion than velocity. By means of preliminary experiments [3], the velocity was fixed at a level which guaranteed the same temperature in the laboratory rig as in industrial mills. This was important since for at temperatures above the critical point, coals start to burn and fundamentaly changed their properties. Finely a slip velocity of $v_{s\ max} = 0{,}157 \frac{m}{s}$ ($n = 100 \frac{1}{min}$) was chosen for the proposed tester [3, 4]. The procedure for adjusting the operating variables in simulative tribo - testing is shown in figure 2.

3. LABORATORY TRIBO - TESTING

The simulative tribo - testing of the phenomenas inside the coal pulverizer was divided into two parts, dealing first with the interactions between the ball and the upper race, and secondly concerning the ball - coal layer interface. A schematic diagram of procedure for the simulative tribo - testing is shown in figure 2. Only this part of the investigation which simulates the ball - coal layer system, is presented in this paper.

3.1. Basic mechanical properties of selected coals

In order to attain the greatest efficiency in processing coal, it is essential to obtain a thorough knowledge of the fundamental behaviour of coal when subjected to various kinds of forces such as those occuring during compressive strength tests, impact strength tests [6], or hardness tests. Once these properties of the coals have been determined, an attempt to establish a correlation with other properties such as grindability can be made, and a way of predicting coal behaviour inside a pulverizer can be found. Coal has to be broken down to sizes appropriate to combustion. Due to the ever-increasing mechanisation of coal processing, it has become important to have more knowledge about the strength of coal and an insight into the mode of breakage of these under stress. Coals vary widely both in chemical constitution and physical structure. The breakage of coal is produced as a result of applied stresses on weaknesses due to cracks, ranging in size from sub - microscopic to macroscopic, that run through the coal. Five coals namely: Camden, Duvha, Grootvlei, Hendrina and Kriel were selected for tests. All results are summarised in table 1. The relation between the various properties of selected coals in the form of the regression equation may be presented as follow:

$$ISI = 60{,}4 + 0{,}236\,(\sigma_{c\perp}), \qquad r = 0{,}870$$

$$\sigma_{c\perp} = 3\,(VH_{5\perp}) - 729, \qquad r = 0{,}463 \qquad (5)$$

$$ISI = 46 + 1{,}32\,(VH_{5\perp}), \qquad r = 0{,}770$$

where: r is the coefficient of correlation.

3.2. Simulation of conditions at the ball - coal layer system

The analysis of comminution processes in ball - race mills showed that the relative redistribution of fine coal layers in front of the rotating balls is the main agent in the grinding process. Pulverization takes place on the planes of shear between loose particles of coal under stress and in the sector of semi - Hertzian contact (if the stress in this sector is higher than the compressive strength of coal). Wear on both grainding elements (i.e., the balls and the race) originates mainly from the sliding interaction between herd coal components and the grinding elements. The relative displacement of quartz and pyrite particles produces abrasion - like grooves by cutting and ploughing. Assuming that the predominant wear phenomena result from the relative rubbing between the layers of coal and the grinding elements, and that the grinding processes take place mainly in the shear zone of fine coal, the pulverizer's ball - race configuration could be simplified and replaced by a simulated test such as that shown in figure 3. In this apparatus, various wear and grinding conditions may be simulated (figure 2) by adjusting the operating variables (Load (L) and rotation speed (n)) and the constant quantities such as: diameter of disc (d_1), diameter of cylinder (d_2), height of blade (h). The proposed test method described below was chosen to simulate, as closely as passible, the grinding) wearing action in a full size ball - race pulverizer.

The apparatus (figure 3) consists of a drive shaft and disc rotating in closed cylindrical chamber. Normal pressure can be applied to the disc through the drive shaft. The wear element consists of a rectangular blade fixed to the underside of the disc. The space in the bottom of the cylinder is filled with a given mass of coal sample. The disc is then rotated for a given number of revolutions, and the mass loss of the blade is determined. During the grinding/wear process the power input is measured. The use of the proposed method enable a number of parameters of interest in tribology and comminution to be determined. These are expressed mathematically as follows:

Wear of blade

$$\Delta W = m_1 - m_2 \tag{6}$$

Energy input

$$EI = 2\pi T_1 \quad \text{where:} \quad T = \frac{1}{t_d}\int_0^{t_d} T(t)dt \tag{7}$$

Abrasion factor of coal

$$AF = \frac{\Delta W}{FC} 10^6 \tag{8}$$

Intensity of abrasion

$$IA = \frac{\Delta W}{St_d} \tag{9}$$

Work index

$$W_i = W \left(\frac{F}{F-P}\right)^{0,5} \left(\frac{P}{75}\right)^{0,5} \tag{10}$$

Index of comminution of coal

$$IC = \frac{PC}{EJ} 10^3 \tag{11}$$

Wear resistance of material

$$WR = \frac{EI}{\Delta W} 10^{-6} \tag{12}$$

Relative wear resistance of material

$$\varepsilon = \frac{WR\ (specimen)}{WR\ (standard)} \tag{13}$$

Peak value of shear strength of crushed coal

$$\tau_p = \frac{3T_p}{2\pi R^3} 10^{-6} \tag{14}$$

Residual value of shear strength of crushed coal

$$\tau_r = \frac{3T_r}{2\pi R^3} 10^{-6} \tag{15}$$

Apparent cohesion of interlocked coal particles

$$C = \frac{3}{2\pi R^3} (T_p - T_r)\ 10^{-6} \tag{16}$$

Ultimate friction angle of internal resistance

$$\phi = \arctan \frac{\tau_r}{\sigma_n} = \arctan \frac{3T_r}{2RN} \tag{17}$$

A series of tests have been performed on five selected coals for determination of their grindability and abrasiveness. The results of the tests are summarised an table 1. As only these results from tests which completely simulate operational and materiel conditions in the industrial pulverisers can be directly applied to design calculations, the same grade of cast iron for blades was used as it is currently used on the races.

4. CORRELATION BETWEEN THE MILL GRINDING COMPONENT LIFE AND THE ABRASIVENESS OF COALS DETERMINED IN LABORATORY CONDITIONS

A comparison has been made between industrial date collected by ESCOM Power Station Performace Monitoring Services and the laboratory results for five coals: Camden, Duvha, Grootvlei, Handrina and Kriel (table 2). A very good correlation has been found between simulative tribo-testing results and full - scale industrial mills data (figure 4). In the form of the regression equations the correlations may be presented as follows:

$$\begin{aligned} MSL &= 27287 - 95{,}6\ (AF_c) \quad (r = -0{,}834) \\ MSL &= 27064 - 137\ (IA_c) \quad (r = -0{,}923) \\ ASL &= 20725 - 105\ (AF_c) \quad (r = -0{,}960) \\ ASL &= 19976 - 140\ (IA_c) \quad (r = -0{,}988) \end{aligned} \qquad (18)$$

where: r is the coefficient of correlation.

5. CONCLUSION

A comparison between industrial data and the laboratory results indicates a very good correlation between factors discribing the abrasiveness of coal according to the new proposed method of testing and the maximum and average service life for the bottom ring in Babcock vertical mills. Abrasive Factor and Intensity of Abrasion can be applied for calculation the maximum and average service life of the rings. In this case, the results from relatively simple laboratory apparatus, designed and operated according to principles of similarity, may by used to predict the service life for the machine elements in industry. The presented simulative tribo-testing procedure and rig can be used to evaluate the abrasiveness of any granular material and for testing the wear-resistance of any material in any two - body abrasive action.

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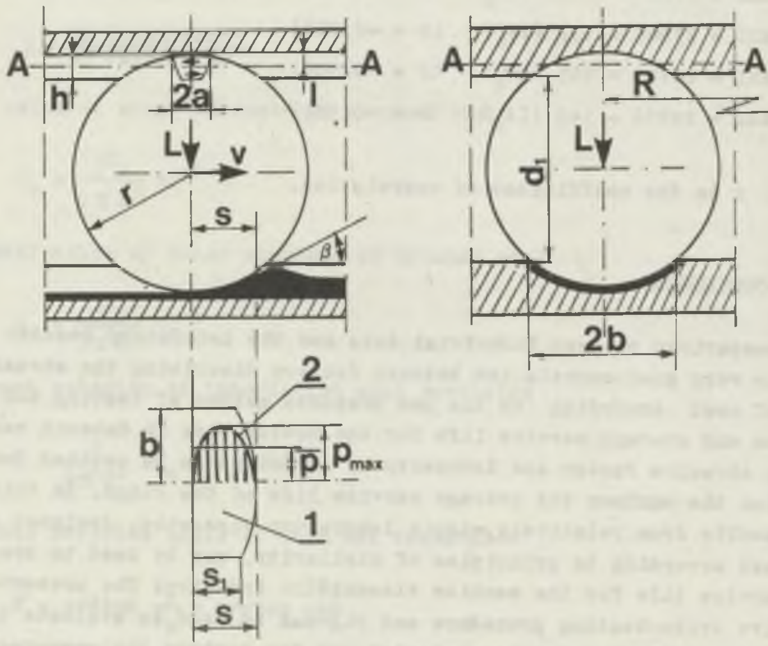

Fig. 1. Simplified contact pattern between the ball and the upper race and the ball and the coal layer, where: A-A is the instantaneous axis of rotation, 1 is area of contact and 2 is pressure distribution on the interface between the ball and the bed of coal

Rys. 1. Uproszczony model styku pomiędzy kulą a górną bieżnią oraz pomiędzy kulą i warstwą węgla, gdzie: A-A jest chwilową osią obrotu, 1 jest powierzchnią styku, a 2 jest rozkładem ciśnień na powierzchni styku między kulą i warstwą węgla

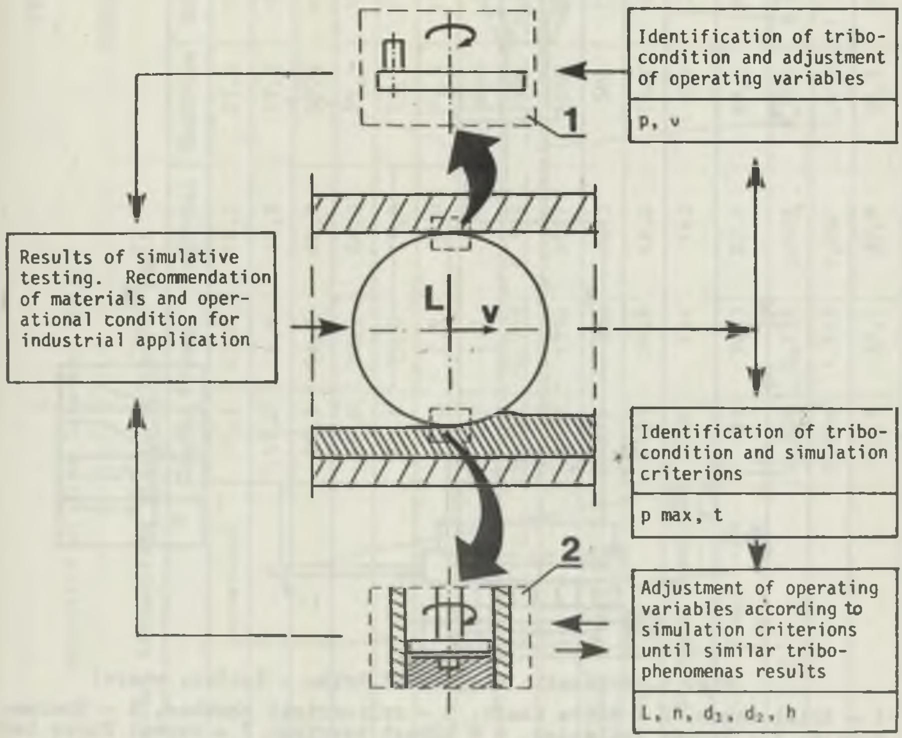

Fig. 2. Simulative tribo - testing of phenomenas inside the coal pulverizer, where: 1 is simulation of the conditions on the ball-- upper race interface, 2 is simulation of tribo - condition in the ball - coal layer system

Rys. 2. Symulacyjne badania tribologiczne zjawisk wewnątrz młyna węglowego, gdzie: 1 jest to odwzorowanie warunków w układzie kula - górna bieżnia, 2 jest to odwzorowanie warunków tribologicznych w systemie kule - warstwa węgla

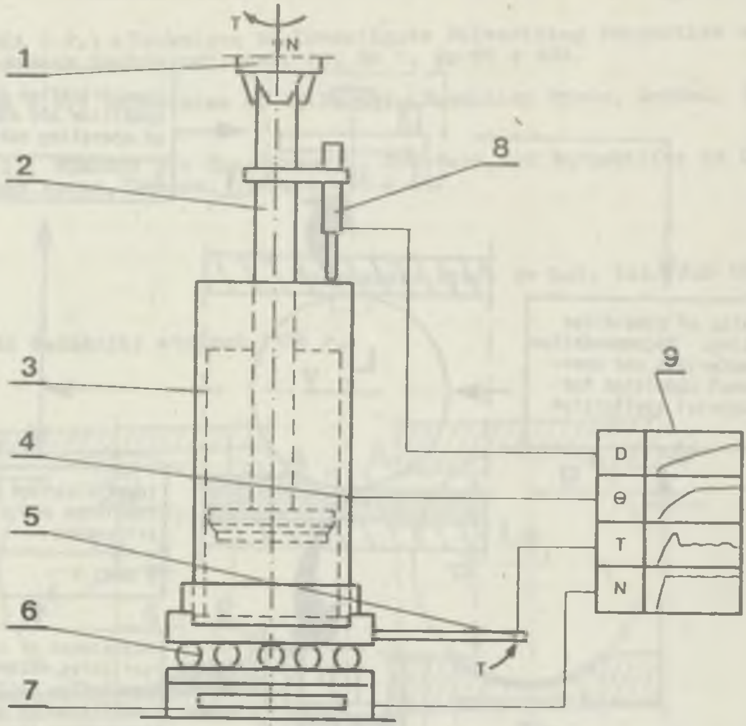

Fig. 3. Schematic diagram of tribo - tester, where:

1 - drill chuck, 2 - drive shaft, 3 - cylindrical chamber, 4 - thermocouple, 5 - torque indicator, 6 - thrust bearing, 7 - normal force indicator, 8 - displacement indicator, 9 - recorder

Rys. 3. Schemat przyrządu pomiarowego, gdzie:

1 - uchwyt, 2 - wałek napędowy, 3 - cylindryczny pojemnik, 4 - termopara, 5 - momentomierz, 6 - łożysko oporowe, 7 - wskaźnik obciążenia normalnego, 8 - wskaźnik przemieszczenia, 9 - rejestrator

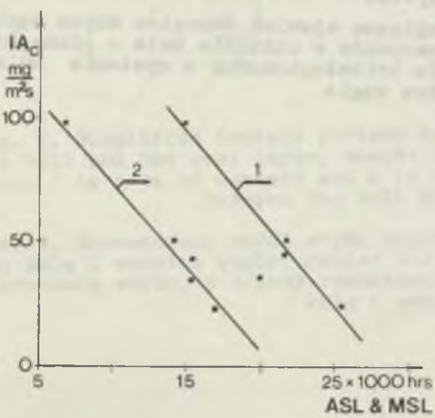

Fig. 4. Correlation between Intensity of Abrasion, IA_c, maximum and average service life for bottom ring, MSL & ASL, where 1 and 2 are regression lines of the equations MSL = 27064-137(IA_c) and ASL = 19976-140(IA_c)

Rys. 4. Korelacja między intensywnością ścierania, IA_c, a maksymalną i średnią trwałością dolnej bieżni, MSL i ASL, gdzie 1 i 2 to linie regresji równań MSL = 27064-137(IA_c) oraz ASL = 19976-140(IA_c)

Table 1

Basic Mechanical Properties of Five Selected Coals

Tablica 1

Podstawowe własności mechaniczne pięciu wybranych węgli

No	Coal Properties	Camden	Huvha	Grootvlei	Hendrina	Kriel
1	Vicker's Hardness (Load 5 kg)⊥, HV_5	21,4	23,8	18,5	21,5	18,2
2	Vicker's Hardness (Load 5 kg)∥, HV_5	17,2	19,9	17,8	17,2	16,2
3	Compresive Strength⊥, σ_c [MPa]	80,3	54,0	46,0	51,6	41,5
4	Compresive Strength ∥, σ_c [MPa]	59,0	50,3	44,0	25,3	37,6
5	Impact Strength Index, IS⊥	78,4	75,6	71,3	73,7	67,9
6	Approximate percentage of quartz, %	14,2	2,5	2,0	21,5	15,5
7	Approximate percentage of pyrite, %	4,7	2,7	2,0	2,0	2,5
8	Index of Comminution IC, $\frac{mg}{J}$	0,734	0,755	0,575	0,673	0,645
9	Work Index, W_i, $\frac{J}{g}$	1533	1532	2057	1888	1974
10	Abrasion Factor, AF_s (Blade of Standard Steel) $\frac{mg}{kg}$	1547	340	283	586	395
11	Abrasion Factor, AF_c (Blade of Cast Iron) $\frac{mg}{kg}$	135	38,6	43,2	79,7	56,5
12	Intensity of Abrasion, IA_s (Blade of Standard Steel) $\frac{mg}{m^2 s}$	1300	284	163	391	251
13	Intensity of Abrasion, IA_c (Blade of Cast Iron) $\frac{mg}{m^2 s}$	99	32,3	22,6	49,1	34,4
14	Residual Shear Strength, τ_r [MPa]	2,304	2,176	1,689	2,096	1,978
15	Apperent Cohesion, C [MPa]	0,958	1,115	1,287	1,073	1,224
16	Ultimate Friction Angle,	39,1	37,5	30,8	36,4	34,8

Table 2

Comparison Between Mill Grinding Component Life and Abrasiveness of Selected Coals

Tablica 2

Porównanie pomiędzy trwałością elementów młyna i ściernością wybranych węgli

No	Coal	Max. Service life of bottom ring MSL hrs	Avg. Service life of bottom ring ASL hrs	AF_c $\frac{mg}{kg}$	IA_c $\frac{mg}{m^2 s}$
1	Camden	13260	5700	135,0	99,0
2	Duvha	20000	15300	38,6	32,3
3	Grootvlei	25435	16009	43,2	22,6
4	Hendrina	22000	14000	79,7	49,1
5	Kriel	22000	15500	56,5	34,4

OCENA TRWAŁOŚCI ELEMENTÓW KRUSZĄCYCH W MŁYNACH

S t r e s z c z e n i e

Przedstawiono metodę badań symulującą tribologiczne warunki w węglowych młynach kulowych. Metoda pozwala na zostosowanie z zadowalającą ufnością wyników badań laboratoryjnych do szacowania trwałości elementów kruszących w młynach. Opisano tribologiczne warunki w układzie kula - - bieżnia, a w szczególności rozkład ciśnień, gradient prędkości względnego poślizgu oraz temperaturę w strefie kruszenia. Konstrukcja przyrządu badawczego i procedura badań oparte zostały na zasadach teorii podobieństwa. Porównanie między danymi eksploatacyjnymi i wynikami badań symulacyjnych wykazało bardzo dobrą korelację. To potwierdziło, że wyniki badań przy użyciu względnie prostego przyrządu badawczego mogą być stosowane do oceny trwałości elementów maszyn. Przedstawiona metoda i stanowisko badawcze mogą być stosowane do wyznaczania ścierności dowolnego materiału sypkiego oraz do oceny odporności na zużycie dowolnych materiałów konstrukcyjnych w warunkach zużycia ściernego.

ОЦЕНКА ПРОЧНОСТИ ДРОБИЛЬНЫХ ЭЛЕМЕНТОВ В МЕЛЬНИЦАХ

Р е з ю м е

Представлен метод исследований, иммитирующий трибологические условия в угольных шаровых мельницах и позволяющий применять результаты лабораторных исследований для оценки прочности дробильных элементов в мельницах. Описываются трибологические условия системы шар - дорожка, в особенности распределение давлений, градиент скорости относительного скольжения, а также температура в зоне дробления. Конструкция опытного прибора и процедура испытаний основывались на принципах теории подобия. Сравнение эксплуатационных данных с результатами исследований обнаружено очень хорошую корреляцию. Это подтверждает, что результаты исследований, полученные при использовании относительно простого опытного прибора, могут быть применимы для оценки прочности элементов машин. Представленные метод и испытательный стенд могут применяться для определения абразивности любого сыпучего материала, а также для оценки сопротивления износу произвольных конструкционных материалов в условиях абразивного износа.