ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 1986
Seria: GÓRNICTWO z. 144 Nr kol. 884

1st International Conference - Reliability and Durability
of Machines and Machinery Systems in Mining
1986 JUNE 16-18 SZCZYRK, POLAND

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ABRASIVE WEAR IN CONTACT WITH PARTICULATE MATERIALS

Summary. A rig has been developed to study the abrasive wear of materials in friction contact with solid particles. The equipment hasa wide pressure and velocity range, and can be used to simulate the tribo - conditions inside pulverizers. Using the rig, a number of different materials have been tested and classified according to their resistance to abrasive wear in rubbing contact with the particulate coal. The investigation was divided into two parts, in each part the different shape of grinding blade (tested material) was used in order to focus attention onto the different wear phenomena. Tests with triangular blades can provide usefull information about wear properties of various materials. Apart from the maximum wear resistance, MWR, the initial drop of wear resistance, IDWR, can be determined. The value of IDWR gives information about the share of the brittle fracture of the sharp edges and asperities in the total wear of the blade.

1. INTRODUCTION

Abrasive wear is the major form of wear on components of a mills. This wear is usually caused by hard mineral particles with non-- metal interatomic bonds which produce no significant adhesion and seizure phenomena. For this reason, the physical processes resulting in abrasive wear are relatively simple. On the other hand a great variety of shapes and mechanical properties of abrasive particles (e.g. quartz and pyrite particles in coal) and diverse loading conditions give rise to variable stresses at the contact [1]. Wear debris are seperated from the main metal as a result of a single or, generally, multiple action of the abrasive agents, i.e. either microcutting or fatigue (low - cycle in the plastic region and multiple - cycle in the elastic region) takes place. This diversity of wear processes and conditions results in various combinations of the elementary processes involving disintegration and loosening of the surface layers. As a consequence of the great varieties of abrasive wear are distinguished in practice such as, gouging abrasion, grinding abrasion and erosion abrasion. Resistance to abrasive wear is improved by correct design, by reducing abrasive action, by selecting suitable materials, and by using methods to strengthen them. Using the new method [1] a number of different materials have been tested and classified according to their resistance to abrasive wear in contact with the particulate coal. The investigation was divided into two parts, in each part the different shape of grinding blade (tested material) was used for focusing attention onto different wear phenomenas.

2. EXPERIMENTAL DETAILS

A new method [1, 2] has been developed which allows for much closer simulation of stress conditions found in actual mills. It is faster and less expensive than the standard Hardgrove test [3] and any material combination (i.e. material of blade or particulate material) can be used under any operational condition (i.e. pressure, sliding velocity, temperature). Another advantage of this method over other methods is that the ground material (coal was used in these tests) is allowed to leave the grinding area as occurs in actual mills. The apparatus consists of a disc rotating in a cylindrical chamber under a normal force [1]. The coal sample is placed in the bottom of the chamber. The grinding blade (figure 1) is attached to the underside of the disc. The coal is ground by the rotating blade until just before it reaches the bottom of the chamber. Power input is measured during the grinding process. From the mass of blade material lost during grinding and the power input the wear resistance of a blade material can be determined. The following formulas are used:

Wear of blade

$$\Delta W = m_1 - m_2 \tag{1}$$

Energy input

$$EI = 2\pi T \cdot i \tag{2}$$

where:

T - is the average integral torque, Nm

i - is number of revolution.

Wear resistance of material

$$WR = \frac{EI}{\Delta W} 10^{-6}, \quad \frac{MI}{g} \tag{3}$$

Relative wear resistance of material

$$\varepsilon = \frac{WR(specimen)}{WR(standard)} \qquad (4)$$

The highly abrasive Camden coal [2] was used in all tests. The coal sumples were unwashed but had been crushed and sieved so its grain size was 600 - 1180 μm. The first group of materials tested consists of five hard cemented tungsten carbides, one standard carbon steel, and one high chrome cast iron, CI1 (table 1) carrently used for rings in ball - race pulverizers. The decision to select this set of materials was based on significant success achieved in a casting process that metallurgically bonds exceptionally hard cemented tungsten carbides to tough 4330 base steel. This casting process reduced excessive wear problems in some severe operating conditions and could be applied for the manufacture of the grinding elements. In the second part of the investigation, with triangular blade, the group of materials presented in table 1 was tested. The materials from this group are recomended for liners in tube mills, with the exception of standard carbon steel.

3. RESULTS

3.1. Tests with rectangular blades

The tribological conditions which are generated on the bottom surface of the rectangular blade simulates conditions on the ball - coal layer interface inside a ball - race mills [1, 2]. Hence wear and wear resistance results, from the tests,can be applied directly in order to predict material performance in the industrial pulverizers. The results are summarised in table 2. Most of the cemented tungsten carbides gave excellent wear resistance. With material grade K3109, wear resistance was increased by 658 times compared to the standard material and 26 times compared to high chrome cast iron presently used for casting race. Table 2 includes, additional parameters such as hardness, relative impact resistance and optianal parameter F. Parameter F is based on the assumption that the relative wear resistance and relative impact resistance are an equally important property when considering application of materials. Applying parameter F as a criterion, the grade K3109 was chosen and recommended as a filler for the composite cemented tungben carbide - 4330 base steel rings. The relationship between wear and the binder percentage is shown in figure 1. This indicates that the optimal percentage of binder for a given range of sintered carbides and triboconditions was about 12%.

Electron microscope studies of the wear phenomenas on the surface of various specimens after testing are shown in figure 3 end 4. The distinct abrasion cutting action of hard particles, originating in the coal (figure 3a) occured on the specimen surface. For the chemical identification of the particles (figure 3b) the energy dispersive X-ray analysis (KeVeX) was used.

In the case of cast iron the wear occured predominantly as the result of low cycle frictional fatigue in the form of cracks and material flow at the edges of the grooves. The sintered composites used in the experiments consisted of a tungsten carbide skeleton with the cobalt enclosed in pockets. All the tested cemented specimensts demonstrated the same pattern of wear during abrasion tests which appeared to take place through a combination of cobalt erosion and microfracture of the carbide skeleton (figure 4). In particular the formation of a crater close to edge of specimen (fig. 4a) and some scouring or grooving took place, which suggest plastic deformation of the carbide skeleton (fig. 4b,c). The remobal of small broken lumps of the composite due to brittle fracture of the tungsten carbide skeleton, rounding of the carbide grains corners exposed to abrasion and spalling of the most prominent part of the skeleton are shown in figure 4d and 4e. The preferential removal of the cobalt (or nickel) binder is clearly seen in figure 4e. The most intensive wear occured close to the edges with evidence that the carbide grains were broken into small fragments and loosened by cobalt erosion due to the quartz particle action, occasionally embedded between carbide fragments (figure 4f).

The presented mechanism of wear may be summerized and divided into four modes (figure 5):

1. remove of exposed binder from between carbide grains,
2. rounding and spalling of the oardide grains. corners,
3. break-up and fragmentation of the carbide grains,
4. pullont of carbide particles after sufficient binder has been removed.

The intensity of wear of some grades, such as K3109 is extremely low, and this type of material is seen as an alternative to high chrome cast iron if cost calculation could justify this choice.

3.2. Tests with triangular blades

Investigations with rectangular blades showed that the most intensive wear occured on the leading edges. The shape of the blades was changed to triangular (fig. 1b), to focus attention on the high stress tribo-phenomena which take place on the edge. The results from this part of investigation were computed using equations (1) to (4), and are shown in fig. 6a. The graphs show how the wear resistance varies with the number of uses of the blade, or with state of the grinding edge. As can be seen from fig. 6a the wear resistance of nearly all blades varied widely with each use of the blade. Only on two of the blades (carbon steel, CS and alloy steel, AS2) the wear resistance did not vary greatly with each use. This diversity in wear resistance is assumed to be a result of the blade's geometrical change. When the blade is initialy sharp, the edge suffers a great deal from brittle fragmentation of the carbides which tends to act as a flaw, and this reduction in wear resistance can only improve once the blade becomes blunt enough for cutting and gouging mechanisms to dominate. Because the initial geometry of the blades and coal samples are identical only the resultant of the certain mechanical properties of the materials tested such as fracture toughness, impact resistance and brittelness can influence the value of the initial drop of wear resistance, IDWR (fig. 6b). Hence it appears that IDWR is a measure of material property, namely the resistance of material to brittle fragmentation in microcontact zones.

All the blades showed the same wear pattern on the grinding edge, the degree of blunting increases from the centre to the outer edges of the blade. This is understandable as the outer extremities of the blade move faster, end this has a marked effect on the race of wear of the material. The standard carbon steel, CS showed relatively uniform wear resistance (fig. 6a) for all five repeated tests. The blade had 3 to 5 times the wear resistance of the rectangular blades (table 2) of the same material. There was also a large degree of plastic deformation at the trailing edge of the grinding face. The increase in wear resistance over the rectangular blades is attributed to a lower surface area exposed to abrasive action. It is expected that the wear will significantly increase if the surface area increases, due to severe blunting. Alloy steel, AS2 showed similar characteristics to the plain carbon steel, but showed a lesser degree of plastic deformation on the grinding face. Some of the deeper gouges showed brittle fracturing of the chip at the trailing edge of the face.

The weld hard facing sample, WS and cast irons, CI1 and CI2 samples showed comparable wear characteristics. Rising uniformly to their maximum wear resistance, MWR, the three blades showed good overall tribo - properties. The high wear resistance of CI2 is attributed to its high chrome content (28,06%) and to its martensitic matrix. It had a high carbide volume fraction (34,04%) and relatively small carbide size (8,75μm), which give good wear resistance, since the hardness of the carbides is greater then that of the coal impurities. The 22% chrome cast iron, CI1 showed the highest MWR of all the blades. The high values of the initial drop in wear resistanee, IDWR, as a consequence of brittle fragmentation and chipping of the edge, suggest low toughess of these tree materials.

The wear resistance of alloy steel, AS1 was initially constant and then it rose 40% to a maximum, and slowly began to decline again with further use. Abrasion was a result of severe cutting and gouging actions accompanied by a large degree of a plastic deformation. It had relatively high IWR for an austenitic matrix but this is attributed to work-hardening of the grinding face of the blade. The jump from the IWR to MWR can probably be explained by the fact that, althongh the grinding face was work-hardened, it still suffered (structural failure), in two first runs due to the sharpness of the edge. The graphs (fig. 6) revealed that the number of tests with the triangular blade can provide more useful information about wear properties of the materials than tests done with the rectangular blade. Apart from the maximum wear resistance, MWR, the initial drop of wear resistance, IDWR, can be determined. The value of the, IDWR gives information about the share of the brittle fragmentation and the fracturing of the sharp edges and asperities in the total wear of the blade.

4. CONCLUSIONS

An apparatus has been developed to study the abrasive wear of materials in friction contact with solid particles. The equipment has a wide pressure and velocity range and can be used to simulate tribo-condition inside pulverizers. The rig was used to study the abrasive wear resistance of various materials.

The abrasive wear mechanism of the sintered carbides consists of removal of exposed binder from between the carbide grains, rounding and spalling of the carbide grains corners, break up and fragmentation of the carbide grains and pullout of carbide particles after sufficient binder has benn removed. Intensity of wear of some grades, such as K3109 (with optimal 12% of binder) is extremely low and this type of material is seen as an alternative to high chrome cast iron if cost calculation could justify this choise.

It is possible that the initial drop in wear resistance, IDWR is an accurate measure of the materials property, namely the resistance of a material to brittle fragmentation and chipping of the edgess during tribo-contact with solid particles. Further study should be carried out to determine the relation between IDWR and other properties of materials such as fracture toughness and impact resistance. In any further tests the blades should have the same surface characteristic i.e. all surfaces should be ground and polished. The same operational conditions and the same particulate material should be used in all tests.

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[2] Ścieszka S.F.: New Concept for Determining Pulverizing Properties of Coal, Fuel, vol. 64, August 1985, pp. 1132 - 1142.

[3] ASTM D 409-71. Standard Test Method for Grindability of Coal by the Hardgrove Machine Method. American Sociaty for Testing Materials.

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Wpłynęło do Redakcji: styczeń 1986 r.

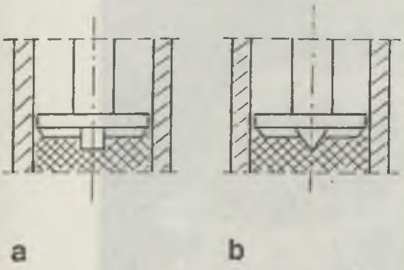

Fig. 1. Disc - blade assembly with two different shapes of blade,

a) rectangular, b) triangular

Rys. 1. Układ dysk-próbka z dwoma różnymi kształtami próbek,

a) prostokątny, b) trójkątny

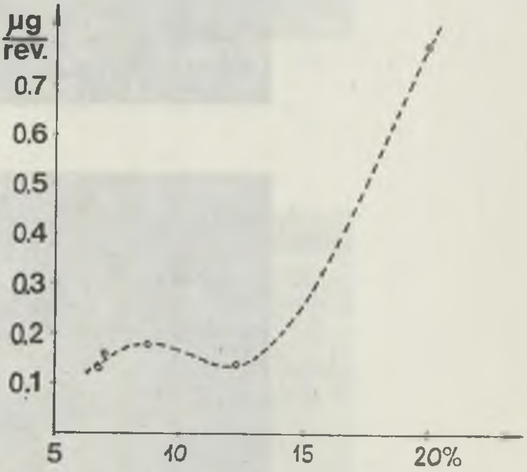

Fig. 2. Diagram of the relation between the wear and weight percentage of the binder of the grades tested

Rys. 2. Wykres zależności pomiędzy zużyciem a wagowym udziałem lepiszcza w badanych kompozytach

Fig. 3. SEM micrographs of the standard carbon steel specimen's surface showing individual grooves formed by the cutting action of trapped and broken quartz particles (a), KeVeXe technique was used to determine the chemical composition of the particle (b)

Rys. 3. Obraz mikroskopowy, SEM, powierzchni próbki ze stali węglowej pokazujący pojedyncze bruzdy wykonane przez cząsteczki kwarcu (a). Metoda Kevex została zastosowana dla wyznaczenia chemicznego składu cząsteczki (b)

Fig. 4a

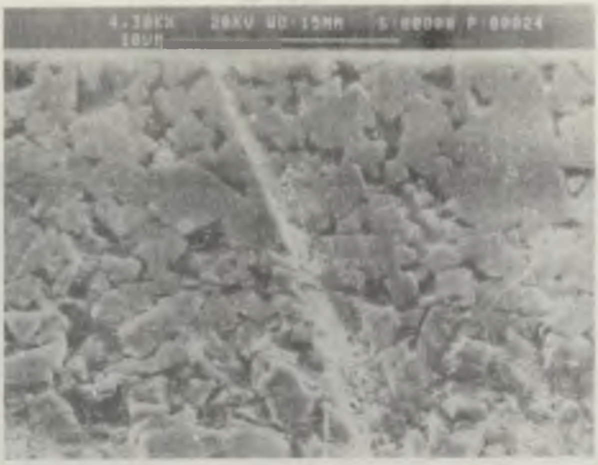

Fig. 4b

Fig. 4. SEM micrographs of the tungst carbide grade K3109 surface after abrasion test showing mechanisms of wear of polycrystalline ceramic material

Rys. 4. Obraz mikroskopowy, SEM, powierzchni próbki z węglika wolframu o symbolu K3109 po próbie zużycia pokazujący mechanizm zużycia polikrystalicznego materiału ceramicznego

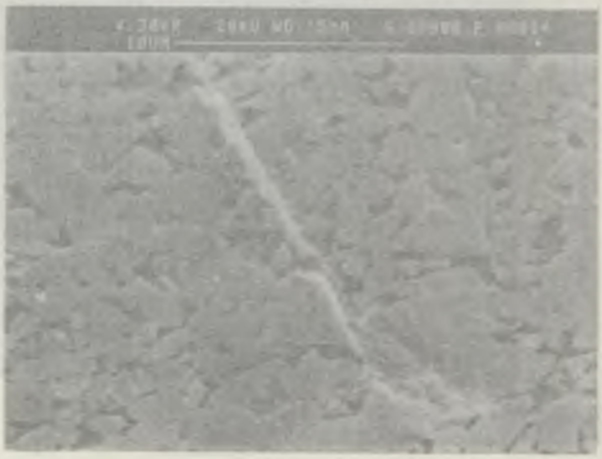
4.30KX 20KV WD:15MM S:00000 P:00014
10UM

Fig. 4c


37.3KX 20KV WD:15MM S:00000 P:00013
2UM

Fig. 4d

Fig. 4e

Fig. 4f

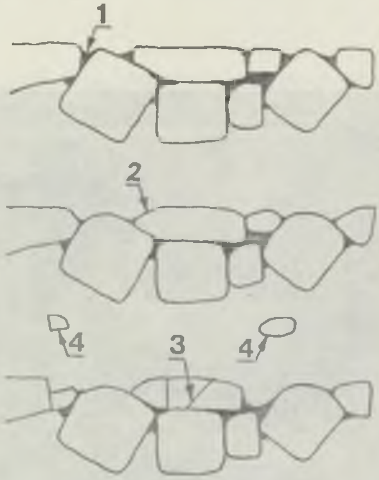

Fig. 5. Simplified pattern of abrasion wear of the tungsten carbides
Rys. 5. Uproszczony model zużycia ściernego węglika tytanu

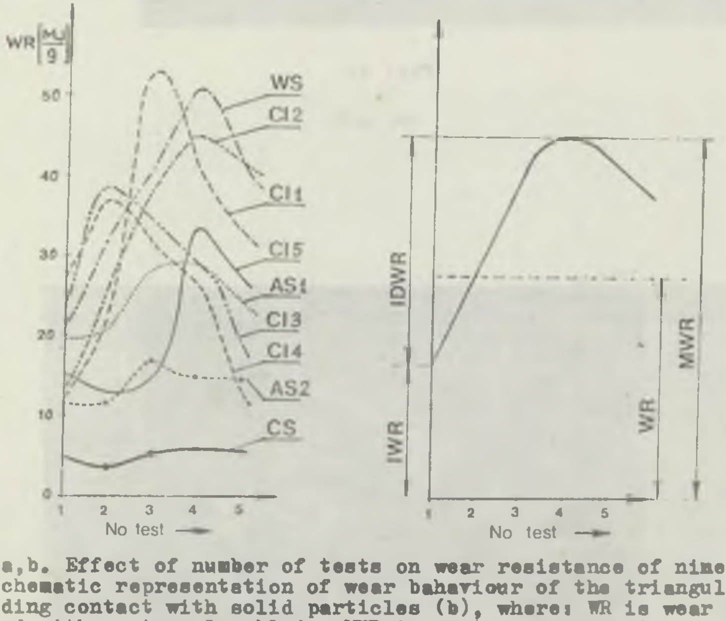

Fig. 6a,b. Effect of number of tests on wear resistance of nine materials (a), schematic representation of wear bahaviour of the triangular blade in sliding contact with solid particles (b), where: WR is wear resistance obtained with rectangalar blade, MWR is maximum wear resistance, IWR is initial wear resistance and IDWR is initial drop of wear resistance

Rys. 6. Wpływ ilości kolejnych badań na wyniki odporności na zużycie dziewięciu materiałów (a), schematyczne przedstawienie zmian zużycia próbki trójkątnej w ciernym kontakcie z cząsteczkami ciał stałych (b), gdzie WR jest odpornością na zużycie, uzyskana przy pomocy prostokątnych próbek, MWR jest to maksymalna odporność na zużycie, IWR to wstępna odporność na zużycie i IDWR to wstępny spadek odporności na zużycie

Table 1

Composition and Hardness of Materials Tested

Tablica 1

Skład chemiczny i twardość materiałów badanych

No	Material	Composition					Hardness Vickers
		C	C_r	M_o	M_n	Matrix	
1	Carbon Steel, CS	0,08					159
2	Cast Iron, CI1	2,70	22,00	2,0		Martensitic	752
3	Cast Iron, CI2	2,93	28,06	0,08	0,454	Martensitic	663
4	Cast Iron, CI3	2,30	14,35	2,45	0,727	Martensitic	747
5	Cast Iron, CI4	2,58	28,70	0,14	0,442	Martensitic	670
6	Cast Iron, CI5	2,74	27,30	0,07	0,727	Martensitic	679
7	Alloy Steel, AS1	1,30	1,45	0,23	1,347	Austenitic	248
8	Alloy Steel, AS2	0,78	2,19	0,29	0,917	Austenitic	372
9	Welded Hard Facing, WS						763

Table 2

Mechanical Properties of Blade Materials

Tablica 2

Własności mechaniczne materiałów próbek

No	Material	Binder %	Wear $\mu g/_{rev}$	Wear Resistance $\frac{MJ}{g}$	Relative Wear Resistance ε	Hardness Vickers HV_{30}	Relative Impact Resistance	P
1	Carbon Steel, CS		74	1,18	1	134	188	1,4
2	Cast Iron, CI1		3,1	29,1	24,7	746	125	4,1
3	K 3109	12,2	0,14	776	658	1210	100	54
4	K 9	8,8	0,18	623	528	1310	71	28
5	K 3520	20,0	0,78	128	108	897	100	12
6	K 801	6,0	0,13	808	685	1501	25	11
7	K 703	7,0	0,16	666	564	1717	12	3,9

ZUŻYCIE ŚCIERNE W KONTAKCIE Z MATERIAŁAMI ROZDROBNIONYMI

Streszczenie

Przedstawiono przyrząd do badania zużycia ściernego materiałów konstrukcyjnych w kontakcie ciernym z cząsteczkami ciał stałych. W przyrządzie tym jest możliwość zmiany nacisku i prędkości w szerokich granicach, przez co umożliwia on badanie symulacyjne procesów tribologicznych w młynach węglowych. Przy użyciu ww aparatu szereg różnych materiałów zostało zbadanych i sklasyfikowanych według ich odporności na zużycie ścierne w kontakcie z rozdrobnionym węglem. Badania zostały podzielone na dwie części, w każdej części używano inny kształt próbki materiału badanego w celu zwrócenia uwagi na różne zjawiska zużycia. Badania z próbką trójkątną dostarczają użytecznych informacji o własnościach zużyciowych badanych materiałów. Oprócz maksymalnej odporności na zużycie, MWR, wstępne zmniejszenie odporności na zużycie, IDWR może zostać określone na ww przyrządzie. Wartość IDWR daje informację o udziale kruchego pękania krawędzi i nierówności powierzchni o ogólnym zużyciu próbki.

АБРАЗИВНЫЙ ИЗНОС ПРИ КОНТАКТЕ С ДРОБЛЁНЫМ МАТЕРИАЛОМ

Резюме

Представляется прибор для исследования абразивного износа конструкционных материалов при фрикционном контакте с частицами твёрдых тел. Этот прибор даёт возможность широко изменять нажим и скорость, что позволяет проводить исследования трибологических процессов в угольных мельницах.
Вышеназванный прибор помог провести исследование и классификацию ряда различных материалов с точки зрения их сопротивления абразивному износу при контакте с дробленым углем. Процесс исследования был разделен на две части; в каждой из частей использовались различные формы образца опытного материала с целью обратить внимание на разные явления износа. Испытания, проведённые над треугольным образцом, дают полезную информацию о свойствах износа исследованных материалов.
Кроме максимального сопротивления износу, MWR, вышеназванным прибором может быть также определено и предварительное уменьшение сопротивления износу, IDMR. Значение IDMR даёт информацию о доле хрупкого растрескивания граней и неровности поверхности при общем износе образца.