GOSPODARKA SUROWCAMI MINERALNYMI – MINERAL RESOURCES MANAGEMENT

2020 Volume 36 Issue 3 Pages 185–202

DOI: 10.24425/gsm.2020.133939

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Characteristics of hard coal and its mixtures with water subjected to friction

Introduction

Friction occurs in the area of contact of two moving bodies, which is accompanied by resistance to motion. It is one of the most common physical phenomena occurring in nature and simultaneously one of the main reasons for the degradation of working machine components. Friction processes occurring in tribological systems cause energy losses and surface damage. A tribological system is defined as a system composed of elements of a kinematic pair forming a friction pair in contact with close and distant surroundings (Fig. 1) (Płaza et al. 2005).

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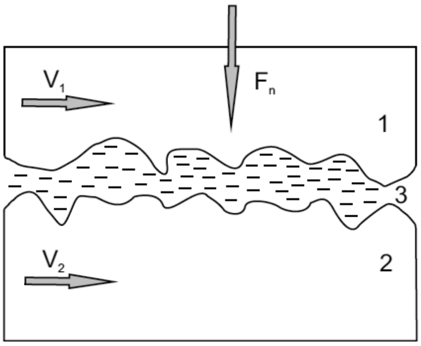

Fig. 1. Diagram of the tribological system
1 – an element exciting relative motion, 2 – an element taking over the kinematic excitation,
3 – intermediating layer, Fn – load, V1, V2 – velocities of the elements of the tribological pair

Rys. 1. Schemat układu tribologicznego

Under dry friction conditions, most of the mechanical energy (80–95%) is dissipated as heat and the rest is used for the formation and migration of defects, cracking and increased electrification of surfaces, abrasion of materials, plastic deformation, emission of photons, electrons, ions, and neutral particles, phonon vibration and other effects. It is reported that around 30–50% of the energy produced annually is absorbed by friction resistance. This considerable amount of energy expended to overcome the friction force during a machine's operation when performing a specific job and taking into account wear processes is called a direct tribological loss. In specific processes, wear losses can be more than five times greater than losses caused by friction alone (Scott 1983; Tylczak 1992; Hawk and Wilson 2001).

One of the most common types of tribological wear is abrasive wear, which can be defined as the process of destruction and removal of material from the solid's friction surface, which is accompanied by a change in mass, dimensions, and shape as well as the structure and physical properties of friction elements (Płaza et al. 2005).

Abrasive wear applies in particular to mining, road, or construction machine components and occurs largely due to the impact of fragmented rock material transported from the environment to the mating zone of the tribological system elements.

The most common abrasive wear mechanisms are micro-cutting and micro-ploughing (Fig. 2). The occurrence of a given mechanism depends on the hardness of the surface being worn. For soft rocks, other wear mechanisms, such as surface fatigue, may also occur.

Depending on the lithological structure of the rock mass where, for example, the excavation is being carried out, it may consist of fragments of clastic rock: sandstone, silt and clay, as well as coal. Most often it is a mixture of rock fragments and coal, so the wear effect and the wear mechanism itself depend on the properties of the constituent minerals (Labaš et al. 2012). The specific wear mechanisms as well as the interactions between wear processes that occur during machine operation are complex and depend on the type of friction pair materi-

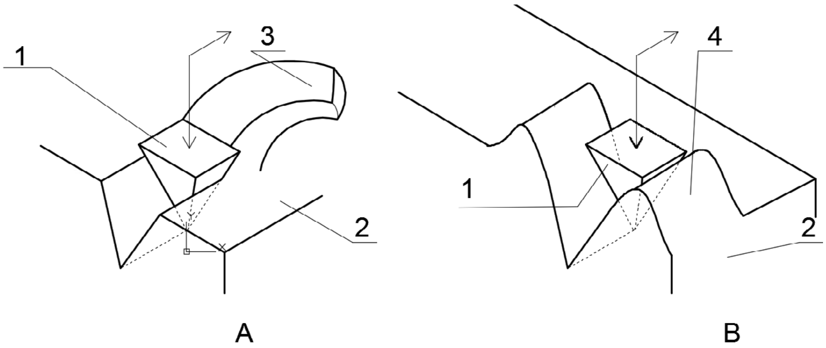

Fig. 2. Schematic representation of elementary mechanisms of abrasive wear
A – micro-cutting, B – micro- ploughing; 1 – abrasive particle, 2 – surface being worn,
3 – separated cut, 4 – ridge (Zum Gahr 1987)

Rys. 2. Schematyczne przedstawienie elementarnych mechanizmów zużycia ściernego

al, the nature of the abrasive material (Shao and Chen 1983; Mutton 1988; Hawk and Wilson 2001; Petrica et al. 2014), and environmental factors (Wieczorek 2018a).

Abrasive wear caused by the presence of an additional body – the abrasive – is a complex process and there are many variables that should be taken into account when considering its effects. It has been shown that a change in one variable can significantly affect the results of wear tests (Stachowiak and Stachowiak 2001; Terva et al. 2009; Ratia et al. 2014).

An additional factor influencing the intensity of the surface wear of machine components is the presence of water from excavations or precipitation, often containing dissolved salts. In such a case, a hydrated dust mixture is formed that can synergistically affect wear processes (Wieczorek 2018a).

The impact of the abrasive type has been put under scrutiny in the context of the problem of excessive wear of the surface of scraper conveyors caused by the impact of the mined material generated during the driving of development or exploitation galleries. For hard abrasives, such as quartz, the main mechanism of damage caused by friction is micro-scratching, which causes significant degradation of the surface. A completely different behaviour was observed in soft materials exhibiting plastic properties, e.g. for hard coal. In the tests carried out for an abrasive based on hard coal, the effects of wear processes were manifested by damage typical for fatigue processes. The surface wear caused by the impact of carbon abrasives, despite the presence of quartz and alumina in them, was significantly lower compared to the wear caused by the impact of quartz grains.

According to Płaza (2005), the friction resistance in a carbon joint depends upon: the degree of comminution, the type of surface of mating materials, the surface finish, the sliding speed, the load, and the atmosphere of the friction joint. In the presence of coal, at very high loads, there is no adhesion between the mating surfaces, but due to oxidation occurring from 260°C, its use as a lubricant is limited. In the literature on the problem of abrasive wear, i.a. concerning scraper conveyors, the abrasive grain size, the slip speed, and the load size are usually the main factors under consideration (Gåhlin and Jacobson 1999; Shi and Zhu 2017; Wang and Wand 2017). Factors such as the type of coal and barren rock, the presence of water, and the relative quantity ratio of these components are rarely taken into account (Xia et al. 2019).

The behaviour of the hard coal contained in the abrasive can be associated with its plastic properties. Coals exhibit properties characteristic of polydisperse colloidal systems, which is manifested by a large development of the inner surface, swelling capacity, ability to turn into sol under the influence of a solvent, plastic deformation under the influence of forces tangential to the surface, as well as turning to a plastic state due to the influence of temperature. The plastic state of coals in the aspect of colloid chemistry is a system composed of a dispersion medium and a dispersed medium. The dispersion medium are the lighter components of the carbon isogel called border lubricants, while the dispersed medium are the heavy components – carbon micelles (Jasieńko 1995). According to Berkowitz (Berkowitz 1994, 1995), the ability to go into a plastic state is conditioned by the formation of a layer made up of a part of the components of the carbon substance on the surface of carbon micelles. The formation of this boundary layer, acting similarly to a solid lubricant and a thermal weakening of the existing bonds between micelles, allow the carbon micelles to move relative to each other.

It has been proven that during heating, hard coal decomposes, turning first into a plastic state, and then it solidifies into a product with a changed structure, free of gaseous and liquid parts. Semi-coke or coke is formed depending on the thermal conditions applied (Kułakowski i in. 1981).

According to the van Krevelen (van Krevelen 1950) diagram, the coal reaches its plastic state at a temperature from 350 to 500°C. At temperatures up to 350°C, constitutional water as well as CO_2 and H_2S are released initially in the coal subjected to the temperature, and finally small amounts of flammable gases and tar are released. This stage has been called the “state before softening”.

The relevant literature provides information on the potential for using the unique features of carbon nanostructures to modify the performance properties of plastic greases. For example, it is stated that the addition of carbon nanotubes and fullerenes, in addition to tribological properties, improves thermal conductivity and allows for the stabilization of electrical conductivity of lubricating media during operation. Apart from nanotubes, graphene is introduced into the lubricants. The Nanotec patent describes a lubricating composition with improved lubricating properties containing dispersed graphene nanoslabs (NGP – Nano graphene platelets) in a lubricating liquid (Krasodomski i in. 2014; Patent US 2011046027).

The purpose of this paper is to assess the impact of friction conditions and presence of water in the context of properties of a hard coal-based abrasive. It is a continuation of the work (Wieczorek 2018b) in which a significant reduction in the abrasive wear of hard-wearing steels in the presence of ground hard coal as compared to other abrasives was exhibited.

1. Research methods

The research included:

- the analysis of the chemical and phase composition of the initial hard coal sample using the X-ray fluorescence method and phase analysis using X-ray powder diffraction;
- wear tests for three abrasive variants:
  - variant I: dry carbon abrasive,
  - variant II: hydrated mixture with 76% hard coal,
  - variant III: hydrated mixture with 58% hard coal;
- microscopic observations using scanning electron microscopy of steel ring surfaces after wear tests;
- the determination of the content of the C element in the initial hard coal sample and in the abrasive transformed under the influence of friction.

The chemical composition analysis of coal was performed on samples ground to a particle size below 63 μm using a grinder with a tungsten carbide lining and dried at the temperature of 105°C to constant weight. In order to determine the chemical composition by means of the X-ray fluorescence method according to PN-EN ISO 12677:2011, the loss of roasted (L.O.R.) at the temperature of 815°C was determined. The sample heated to constant mass was fused with a mixture of lithium tetraborate, lithium metaborate, and lithium bromide XRF flux grade. The weight ratio of sample to flux was 1:9. Chemical composition analysis was performed using a PANalytical MagiX PW2424 spectrometer.

The ash content was determined in accordance with the PN-80/G-04512 standard at 815°C. The content of the C element was determined using a Leco SC 144 DR analyser. The test sample was burned at 1350°C in an oxygen stream. The CO_2 content in the forming gas was determined by measuring the absorption of infrared radiation.

The characteristics of the phase composition based on the analysis using X-ray diffraction (XRD) was conducted using a PANalytical XPERT PRO MPD powder diffractometer with a X-ray tube with a Cu anode, graphite monochromator at the diffracted beam side, X'Celerator counter, and a spinner. X-ray diffractograms were made for the range of angles of 5–80° 2Θ at lamp operational parameters of 30 mA and 40 kV. HighScore software from PANanalytical and the ICDD PDF-4 + database were used to identify the phase composition.

The observations of sample surfaces were carried out using a SEM scanning electron microscope with the use of SE secondary electron detection at an accelerating voltage of 20 kV and magnification in the range of 60–1000 x. The qualitative analysis of the chemical composition in the micro-areas of the tested material was carried out by means of the characteristic X-ray energy spectroscopy at an accelerating voltage of 20 kV. Prior to testing, the samples were sprayed with a thin layer of gold to ensure that electrical charge was evacuated during the test.

The wear tests were carried out for hard coal samples which were initially crushed and then sieved through a 50 mm sieve. The fraction with the dimensions <50 mm was used for the testing.

2. Results

2.1. Mineral and chemical tests

Before starting the wear tests, the following was determined for the initial hard coal sample: chemical composition using XRF analysis, content of the C element, and ash content (Table 1).

Table 1. Results of analyses of the initial hard coal sample

Tabela 1. Wyniki analiz wyjściowej próbki węgla kamiennego

Component	Content (% wt.)
L.O.R.	74.11 ± 7.41
SiO_2	14.82 ± 0.74
Al_2O_3	7.15 ± 0.36
Fe_{total} converted to Fe_2O_3	1.38 ± 0.14
TiO_2	0.35 ± 0.18
MnO	0.02 ± 0.01
CaO	0.58 ± 0.29
MgO	0.41 ± 0.21
Na_2O	0.14 ± 0.07
K_2O	0.59 ± 0.30
P_2O_5	0.10 ± 0.05
Cr_2O_3	0.01 ± 0.05
Σ	99.66
C	58.23 ± 2.33
Ash	25.89 ± 2.59

It was observed that in the studied coal, silica SiO_2 is present in quite significant amounts, the content of which reaches up to 14.82%. The silica is accompanied by 7.15% alumina Al_2O_3 and iron oxide Fe_2O_3, with content reaching 1.38%. Other ingredients are present in smaller quantities, their content does not exceed 1%. The presence of silica is associated with impurities of quartz and clay minerals, while alumina and iron are associated with impurities of clay minerals.

The loss of roasted in the studied coal reached the value of 74.11%, which, according to Stolecki (Stolecki 1988), is characteristic for coal shale, where the content of roasted losses is about 70%. Loss of roasted consists primarily of burning coal, however, due to the fact that the sample content of carbon is lower than the loss of roasting (58.23%), it can be concluded that other ingredients are released from the sample during roasting. These can be the products of organic combustion, chemically bound water, or carbon dioxide from the decomposition of carbonates.

In the initial coal sample, the ash content was also determined, which is a residue consisting of a mineral substance obtained after complete combustion of coal at a specified temperature. The result of ash determination is 25.89%, which allows the tested coal to be classified as characterized by a high ash content. It is stated that the average ash content in hard coal ranges from 11 to 16%. It should be noted that the composition and amount of ash are not associated with the coalification process, and depend primarily on sedimentation conditions and the type of organic matter (Wells et al. 2004; Wells et al. 2005; Jelonek et al. 2018). In order to identify the phase composition of the mineral substance, tests were performed using XRD analysis (Fig. 3).

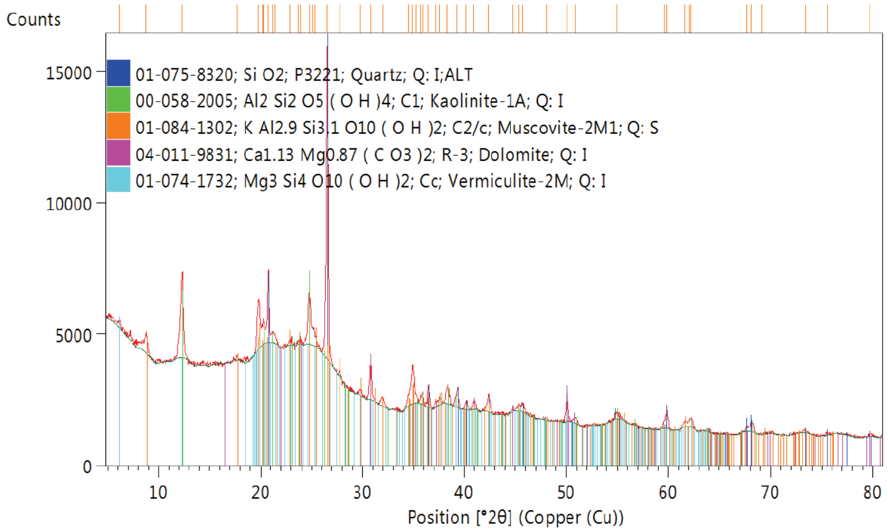

Fig. 3. X-ray diffraction pattern of coal sample with the identification of crystalline phases

Rys. 3. Dyfraktogram rentgenowski próbki wyjściowej węgla wraz z identyfikacją faz krystalicznych

It has been demonstrated that one of the main minerals forming the mineral substance in the studied coal is quartz. Its presence on the diffractogram is marked in the form of characteristic peaks, among which the peak with the highest intensity corresponds to a d_{hkl} value of 3.34. The quartz present in hard coal is most often of terrigenous origin and occurs in the form of small, coated grains. Autogenic quartz, precipitated from solutions, is less common.

Apart from quartz, clay minerals were found, with kaolinite as the dominant type $Al_4[Si_4O_{10}](OH)_8$. This mineral is one of the most widespread representatives of this group.

It can form various morphological forms in coal: fine dispersions, single grains of up to 100 mm; occur in the form of impregnation of cell cavities in plant tissues. Kaolinite is usually formed syngenetically in a peat bog (Gabzdyl 1987; Hasemi 2010). In addition to kaolinite, among the clay minerals an impurity of vermiculite was found, belonging to the group of three-layer clay minerals; it is hydrated magnesium aluminosilicate with a variable and complicated chemical composition: $(Mg,Fe,Al)_3(Al,Si)_4O_{10}(OH)_2 \cdot 4H_2O$. Vermiculite is a product of weathering or hydrothermal decomposition of biotite.

Peaks from dolomite $[Ca,Mg](CO_3)_2$ (which belongs to carbonates) also appear on the diffractogram. Minerals from this group are widely distributed as an impurity found in hard coal. They are formed during the processes of diagenesis as well as epigenetically. In addition, an impurity of muscovite $KAl_2(OH,F)_2AlSi_3O_{10}$ was found in the mineral substance.

2.2. Wear tests

To analyse the impact of friction conditions on the tested hard coal, a ring-on-ring stand was used (Fig. 4a). The conditions that have been simulated at the test stand correspond to the conditions of the actual wear of machine components in the presence of hard coal.

The basic friction pair used during the tests consists of two ring samples made of Hardox 400 wear resistant steel, with a surface hardness in the range of 380–405 HB, which were made by turning and grinding.

1 cm^3 of hard coal – based abrasive was added between the samples thus prepared. A characteristic feature of the test is the continuous presence of carbon grains between the samples (Fig. 4b). The view of the samples and the carbon abrasive after the test is shown in Figure 5.

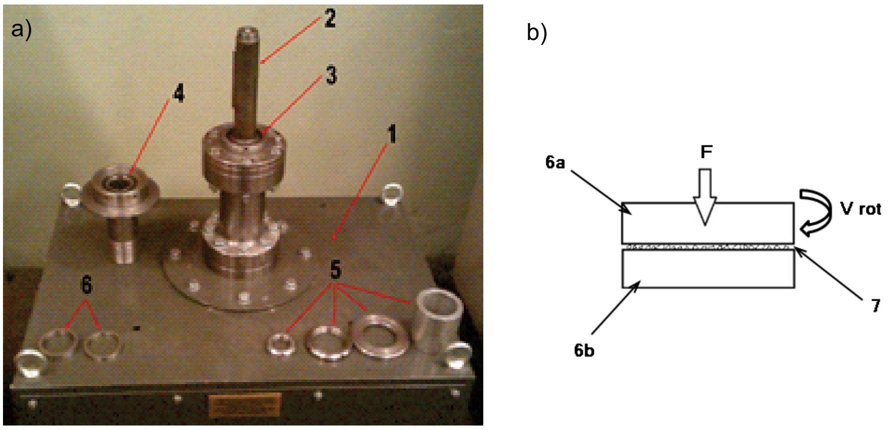

Fig. 4. Test stand: a – site view, b – carbon abrasive load model
1 – station body with engine, 2 – drive shaft, 3 – upper sample holder, 4 – lower sample holder,
5 – mounting elements, 6 – test samples (6a – upper sample, 6b – lower sample), 7 – hard coal

Rys. 4. Stanowisko badawcze: a – widok stanowiska, b – model obciążenia ścierniwa węglowego

Fig. 5. Steel ring sample after wear test

Rys. 5. Stalowa próbka pierścieniowa po badaniu zużyciowym

Table 2 summarises the values of basic parameters of the test carried out under friction conditions.

Table 2. Basic parameters of wear tests

Tabela 2. Podstawowe parametry badań zużyciowych

Parameter	Value
Compressive stress (MPa)	0.094
Rotation speed (RPM)	149.1
Test duration (minutes)	8×10
Friction path (m)	190

After the completion of the wear tests, the next stage of the study was to assess the effects of the action of carbon abrasive on the surface of the steel samples tested. To this end, microscopic observations of sample surfaces were performed using scanning electron microscopy.

For the first variant of wear – in the presence of dry coal abrasive, single scratches caused by the abrasive grains were observed on the surface of the samples (Fig. 6a, b). The main reason for this type of damage could be the aggregation of quartz, which is one of the basic components of the mineral substance found in the tested hard coal.

In test variants II and III, when the effect of hydrated carbon mixtures was investigated, scratches characteristic of the impact of aggregated quartz were also formed on the surface of the samples. A small part of the carbon abrasive was pressed into these scratches (Fig. 6a, b). Under the influence of wear caused by friction, small depressions were also formed, where coal penetrated.

The remaining, non-pressed part of carbon (variant I) or its hydrated mixture (variants II and III of the test) was subjected to the friction effect caused by the load pressure of the tester

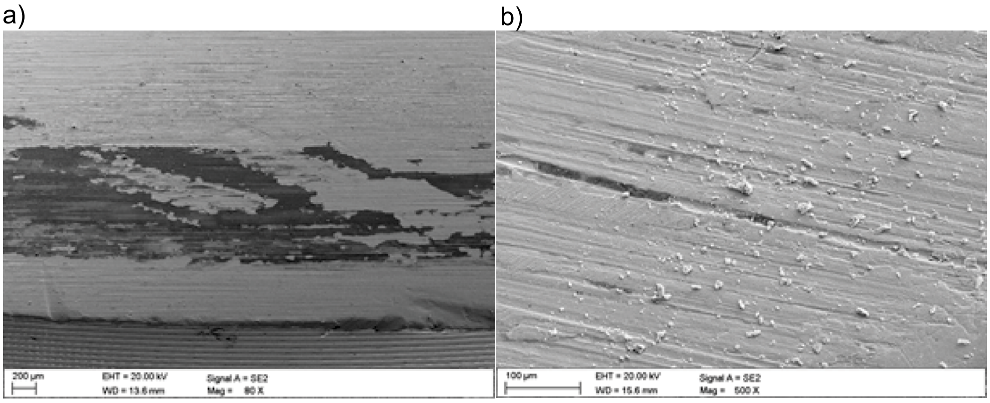

Fig. 6a, b. SEM micrographs of the surface of the steel sample after wear tests using hard coal

Rys. 6a, b. Mikrofotografia SEM powierzchni próbki stalowej po wykonaniu testów zużyciowych z użyciem węgla

seat and the relative movement of the surfaces of both steel rings. Real contact took place at the vertices of the irregularities and the actual contact surface was smaller than the nominal value. Therefore, the pressure affecting individual coal grains or its hydrated mixture during testing was significantly greater than that resulting from nominal values (Table 2). The carbon abrasive and its mixture after friction tests took the form of flat aggregates located on the surfaces of the samples.

The content of the C element was determined in abrasive samples that were subjected to wear tests in order to compare whether there were any changes in relation to the content of the C element in the initial sample of hard coal (Table 3).

In the initial coal sample, the content of the C element was 58.23%, while in the sample subjected to dry abrasion the amount of the C element increased by about 1% and reached the value of 59.20%. In the hydrated mixture in variant II, a minimal increase in the content of the C element by 0.15% was observed, while in variant III a clear decrease in the content of the C element was noted – by 4.56% in relation to the initial sample.

Table 3. Content of C element in carbon abrasive samples

Tabela 3. Zawartość pierwiastka C w próbkach ścierniwa węglowego

Sample	Content (% wt.)
Output sample	58.23 ± 2.33
Variant I: dry carbon abrasive,	59.20 ± 2.37
Variant II: hydrated mixture with 76% hard coal	58.38 ± 2.15
Variant III: hydrated mixture with 58% hard coal	53.67 ± 2.34

3. Discussion

During the analysis of the results of the wear tests carried out with the use of ground hard coal-based abrasive, particular attention was paid to two aspects: plastic properties of hard coal and changes in the content of the C element in the carbon abrasive.

Microscopic observations of the surface of the steel ring samples showed that the quartz present in the abrasive caused the formation of numerous scratches on the surface of the analysed samples, where hard coal was pressed into. In their works, Yarali et al. (Yarali et al. 2008) also point out this type of wear effect of steel tool components in the presence of carbon abrasive – and specifically the impact of quartz contained in the abrasive, indicating that the size of quartz grains also has a direct impact on the wear.

As already mentioned, during the tests carbon was pressed into the micro-scratches. The mechanism of such behaviour of carbon is also described by Xia et al. (Xia et al. 2019), who described a wear mechanism in the form of micro-fatigue. When the soft carbon particles in the loose abrasive are not sharp enough or the steel surface is characterised by a high strength and plasticity, the slip between them leads to the pressing of carbon into the irregularities and crevices occurring on the surface of the steel component. A convex is formed at the carbon pressing site. Under the influence of further load with subsequent carbon particles, it causes the formation of plastic deformations on the surface. Cracks may also form in the surroundings of the accumulated abrasive (Xia et al. 2019). Research conducted by Pertica et al. (Pertica et al. 2014) indicate that replacing dry abrasive with a suspension containing carbon reduces wear, indicating that carbon acts as a solid lubricant.

Coal, similarly to minerals of low hardness, may be relatively less invasive in processing due to their low abrasiveness. They do not cause significant damage to the surface as long as there is no significant chipping of the surface as a result of surface fatigue processes. However, the abrasive is never monomineral and, in addition to particles of low hardness, may contain grains characterised by a higher hardness. This applies especially to coals containing larger grains of harder minerals, such as quartz (Norman 1980; Hawk and Wilson 2001; Ngoy and Mulaba-Bafunbiandi 2013).

With reference to the second considered area of the analysis of the products of friction impact on the carbon abrasive, it should be stated that the tests of the carbon abrasive used to carry out wear tests showed that the content of the C element in the abrasive changes in relation to the content of the C element in the initial sample. In coal subjected to dry abrasion, a slight increase in the content of the C element (by about 1%) in relation to its amount determined in the initial sample was noted. However, in the case of the hydrated carbon mixture, the tendency to a reduction of the content of the C element was observed.

Rubbing materials are subject to heating, which does not lead to noticeable changes on a macroscopic scale. However, when viewed locally, a significant increase in temperature may occur in the surface layer, which may affect the abrasive properties of hard coal. The temperature field in the areas of contact of metals during friction determines the course of the wear process. In particular, the maximum temperature values determine the rate of chemical reactions and affect the intensity of wear (Maciąg 2009).

In the presence of an abrasive, the local increase in temperature and pressure caused by friction processes also affects the components of the abrasive. Depending on their physicochemical properties, they may undergo metamorphoses. Such conditions, created artificially in the laboratory or occurring on an industrial scale with the direct operation of machines, can be referred to natural conditions. In nature, the effect of high pressure and temperature on older rocks is associated with the metamorphism process. In relation to coal, metamorphism, or rather its effects, can in turn be identified with the carbonisation process, which includes a series of chemical and physical changes occurring in organic matter.

Hard coal, due to its physicochemical properties, is characterized by a complex structure that results from the presence of a complicated structure of hydrocarbons and the oxygen groups located on its periphery. The properties of hard coal change with the degree of metamorphism of the coal, because in this process the ratio of aromatic to aliphatic carbon changes while simultaneously changing the oxygen element content. The classic model of the chemical structure of hard coal is the model given by Krevelen, in which the author proposes structural units built of aromatic systems differing in the degree of aromatic condensation.

They are connected by means of aliphatic, alicyclic, hydrogen, and oxygen bridges. For coals with a lower degree of carbonisation, almost half of the carbon skeleton occurs as non-aromatic coal. As the coalification process progresses, the dimensions of the aromatic system increase, while the amount of carbon contained in non-aromatic structures forming bridges between aromatic systems decreases rapidly. Thus, according to Krevelen, the mentioned differences between individual types of carbon are inherent in the character of the monomer unit and its peripheral groups, in the bridges between the monomer units and in the degree of polymerization (Kreiner and Żyła 2006).

The coalification process is manifested by an increase in the content of the C element and a loss of volatiles in the organic sediment. The factors affecting the coalification process are pressure, temperature, and time. Under natural conditions, organic matter can be subjected to pressure caused by pressure from adjacent layers. Originally this was considered to be the most important factor in the process of coalification, since, according to Hilt's law, the degree of coalification increases with depth. Currently it is believed that this type of pressure is only relevant at the initial stage of the transformation of organic matter, which corresponds to the formation of brown coal. What is more important is the pressure which, under natural conditions, is caused e.g. by rapid tectonic movements, especially during the formation of highly coalified ortho- and methanatracytes and graphite.

The most important factor in the coalification process is the temperature, associated primarily with the paleogradient, meaning the increase in temperature for every 100 m depth. The organic sludge may also be affected by contact temperature, caused i.a. by the presence of an igneous intrusion. Time is the least significant coalition factor. Its effect is only visible when the sediment is deepened, although in this case the higher the paleotemperature, the greater the effect of time (Kruszewska and Dybova-Jachowicz 1997).

Parameters for assessing the degree of coalification can be divided into chemical and physical parameters – this paper pays particular attention to the content of the C element in coal. This parameter is considered one of the most accurate and useful determinations characterising the coalification process of organic sediment (Kruszewska and Dybova-Jachowicz 1997). The carbon content properly expresses the degree of coalification; along with the degree of coalification, the content of the C element increases. For example, for brown coal it is 58–77%, and 76–93% for hard coal. This parameter behaves inversely in proportion to the volatiles content (Gabzdyl 1987; Jelonek et al. 2018).

The natural process of coal transformation occurring under the influence of the above-mentioned factors (mainly temperature and pressure) on organic matter can be to some extent related to the conditions prevailing during the wear tests carried out in the presence of hard coal-based abrasive. During the tests, as a result of friction processes, the temperature could locally reach over 100°C.

However, a different situation was observed when using a hydrated coal mixture as an abrasive. In Variant II, taking into account the uncertainty coefficients, it can be stated that the content of the C element remained at the same level in relation to the content of the C element in the initial sample. However, a clear difference was noted in the case of Variant III, where a hydrated mixture containing 58% of carbon was used. In this case, after abrasive tests, the content of the C element has decreased by about 4.5%.

The discussed problem of changes taking place in the hard coal-based abrasive under the influence of the conditions in which the wear tests were conducted is undoubtedly an interesting topic. The test results presented in the paper should be treated as preliminary. The authors are aware of the need to perform further tests.

Conclusions

On the basis of the conducted tests, the following was established:

- in the tests carried out for hard coal-based abrasive, the effects of wear processes were manifested by damage typical of wear mechanisms: micro-scratching and micro-fatigue,
- the effect of pressing of coal into micro-scratches, caused by the action of aggregated quartz, can be associated with the plastic properties of coal,
- tests of the abrasive conducted after the conclusion of wear tests have shown that under the influence of the local increase in temperature and pressure, the hard coal contained in the abrasive can undergo transformations,
- in the abrasive transformed under the influence of friction, small but measurable changes in the content of the C element in relation to the initial carbon sample were exhibited.

The publication was made as part of BK-267/RG-2/2019, 06/020/BK_19/0041: Tests of wear resistance of materials used for scraper conveyor components in the conditions of the combined impact of carbonaceous abrasives.

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CHARACTERISTICS OF HARD COAL AND ITS MIXTURES WITH WATER SUBJECTED TO FRICTION

Keywords

hard coal, friction, wear tests

Abstract

This paper deals with issues related to tribological processes occurring as a result of excessive wear of the surface of scraper conveyor components caused by the impact of the mined material created during drilling of development or exploitation galleries. One of the most common types of tribological wear is abrasive wear. Wear tests were carried out for hard coal – based abrasive using dry carbon abrasive and a hydrated mixture with 76 and 58% hard coal. Based on the conducted research, it was established that the effects of wear processes are associated with damage typical of wear mechanisms: micro-scratching and micro-fatigue. For the wear variant in the presence of dry coal abrasive, individual scratches caused by the abrasive grains were observed on the surface of the samples. The main reason for this type of damage was the aggregation of quartz, which is one of the basic components of the mineral substance present in the tested hard coal. When hydrated carbon mixtures were used as an abrasive, the surface of the samples also displayed scratches characteristic of the aggregate quartz. A small part of the carbon abrasive was pressed into the scratches. Under the influence of the wear caused by friction, small depressions were also formed, where coal penetrated. The effect of coal pressing into micro-scratches is related to its plastic properties. Tests of the abrasive conducted after the conclusion of wear tests have shown that under the influence of the local increase in temperature and pressure, the hard coal contained in the abrasive can undergo transformations. In the abrasive transformed under friction, small, but measurable changes in the content of the C element in relation to the initial hard coal sample were exhibited.

CHARAKTERYSTYKA WŁAŚCIWOŚCI WĘGLA KAMIENNEGO I JEGO MIESZANIN Z WODĄ PODDANYCH TARCIU

Słowa kluczowe

węgiel kamienny, tarcie, procesy zużyciowe

Streszczenie

W artykule poruszono problematykę związaną z procesami tribologicznymi zachodzącymi w wyniku nadmiernego zużycia powierzchni elementów przenośników zgrzebłowych wywołanych oddziaływaniem urobku powstającego w trakcie drążenia korytarzowych wyrobisk udostępniających lub eksploatacji węgla. Jednym z najczęściej spotykanych rodzajów zużycia tribologicznego jest zużycie ścierne. Testy zużyciowe przeprowadzono dla ścierniwa bazującego na węglu kamiennym, stosując suche ścierniwo węglowe oraz uwodnioną mieszaninę z udziałem 76 oraz 58% węgla.

Stwierdzono, że efekty procesów zużyciowych związane są z uszkodzeniami typowymi dla mechanizmów zużycia: mikrorysowania i mikrozmęczenia. Dla wariantu zużycia w obecności suchego ścierniwa węglowego na powierzchni próbek zaobserwowano pojedyncze rysy wywołane działaniem ziaren ścierniwa. Główną przyczyną tego typu uszkodzeń była agregacja kwarcu, stanowiącego jeden z podstawowych składników substancji mineralnej występującej w badanym węglu kamiennym. W przypadku zastosowania jako ścierniwa uwodnionych mieszanin węgla, na powierzchni próbek również wytworzyły się charakterystyczne dla oddziaływania zagregowanego kwarcu rysy, w które wprasowywała się niewielka część ścierniwa węglowego. Pod wpływem zużycia wywołanego tarciem powstały również niewielkie wgłębienia, w które przedostał się węgiel. Efekt wprasowywania się węgla w mikrorysy związany jest z jego własnościami plastycznymi. Badania ścierniwa po zakończeniu testów zużyciowych wykazały, że pod wpływem lokalnego wzrostu temperatury i ciśnienia zawarty w ścierniwie węgiel kamienny może ulec przeobrażeniom. W ścierniwie przeobrażonym pod wpływem tarcia wykazano niewielkie, ale mierzalne zmiany zawartości pierwiastka C w stosunku do próbki wyjściowej węgla.