Mechanical Properties of Powdered Coal and Their Influence to Technological Processes

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Summary

In recent years, growing human population is more and more dependent on production of various wares which are dependent on the functionality of manufacturing technologies. The Laboratory of bulk materials solves many problems of flow failure in different technologies and processes with particulate materials. A perfect understanding of powder behaviour is very important for optimization processes. Due different mechanical and physical properties of a wide scale of particulate materials it is very hard to design appropriate technologies. Goal of this paper is to subscribe some samples of powdered coal by the measurement of its mechanical and physical properties important for storage of the bulk solids. Experimental work was performed by the Freeman Technology FT4 Powder Rheometer and Cilas 1190 Particle Size Analyser. The device allows obtaining a considerable amount of information about powder behaviour from basic bulk density until friction or mechanical interlocking. It was found that dominant parameter in storage process is compressibility. Dependence between compressibility and the ratio of the microparticles and nanoparticles was observed. Depending on the granulometry of samples different compressibility and angle of internal friction was observed. The measured properties of powdered coal have been used for determine cohesion and easy-flowing to free flowing regime. The aim of this article is bulk solid behaviour prediction based on specific properties like compressibility, angle of internal friction, wall friction, angle of repose, humidity, cohesion and others. We need to find a way how to completely describe powders and bulk solids by a few parameters. The problem is bulk solids are very complex and wide field of specialization. Laboratory of Bulk Materials at Technical University of Ostrava is focused on measurement of mechanical and physical properties of the bulk solids and powders and simultaneously it deals with virtual DEM (Discrete Element Method) simulations of particulate matters. Nowadays we are able to predict behavior of bulk materials based on verified models in DEM simulations and flow properties measurement. These simulations are used in innovative way of designing storage and process devices in all kinds of industry.

Keywords: measurement, flow properties, bulk solid, powder, powdered coal

Introduction

A particulate or bulk solid, powder, granulates. A several designation of one specific state of matter. Knowledge of mechanical and physical properties of powders and bulk solids is necessary when designing a new silo/bin/hopper, stockpile, feeder, chute, conveyor or other material handling equipment to improve functionality which we require. There are a lot of problems which we meet on the way to ensure no flow problems flow failures (arches, chimneys, etc.), segregation, powder caking, irregular flow, flooding, etc. Key bulk material flow properties that should be measured for troubleshooting problems, assessing powder flowability, or designing a bulk material handling system are: [1]

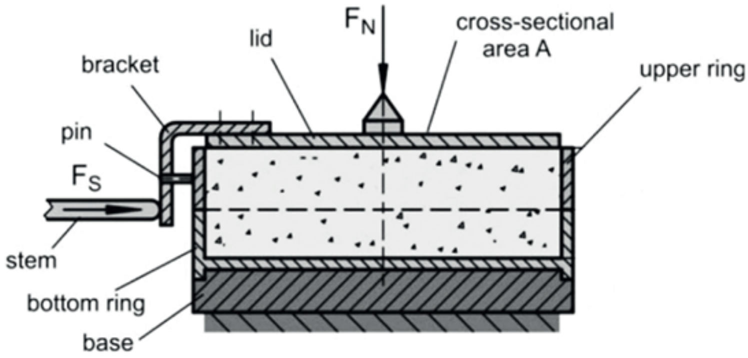
- Cohesive strength: powder flowability through hoppers
- Wall friction: hopper angles to achieve mass flow
- Internal friction: static and kinematic angles of internal friction
- Compressibility: bulk density as a function of major consolidation pressure
- Permeability: gas/solids interactions, limiting discharge rates from hoppers
- Angle of repose: angle of slope of material at rest
- Bulk/tap density: bulk density measured before and after vibration
- Aeration/De-Aeration: behavior bulk solid during interaction with gas

The flow properties mentioned above depend on many parameters (e.g. particle size, shape and distribution, chemical composition of the particles, moisture, temperature, etc.). It is not possible to theoretically determine the flow behavior of powders in dependence of all of these parameters.

Possibilities of measuring flow properties of powders

The best known principles that are used to measure an angle of internal friction and wall friction are Jenike (translational) and Schultze (rotational) methods. They are based on movement of a shear cell with a sample of material and measurement of force that is needed to overcome friction resistance of the material. The goal of the shear test is to measure the yield limit of a consolidated bulk solid. The yield limit is called yield locus in bulk solids technology. For the shear test, a bulk solid specimen is loaded vertically at normal stress. Then a shear deformation is applied on the specimen by moving the top platen with a constant velocity. This results in a horizontal shear stress. With increasing shear stress the resultant force, affecting the bulk solid specimen, increases.

The shear cell of Jenike shear tester consists of a



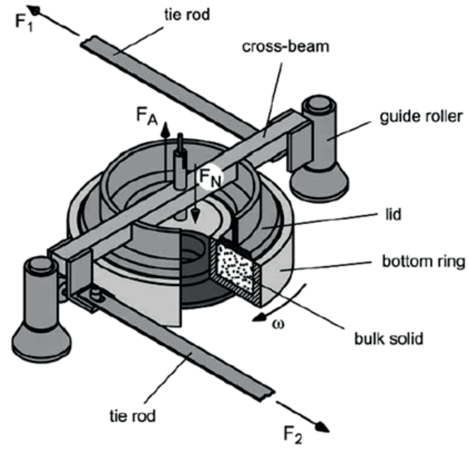


Fig. 1 Shear cells of Jenike shear tester and Schulze ring shear tester, [1, 2]
Rys. 1 Ścięte komórki w testerze ścinania Jenikego i tester ścinania w pierścieniu Schulzego [1, 2]

$$FF=\frac{\sigma_1}{\sigma_c}=\frac{MPS}{UYS}=ff_c \quad (1)$$

Free – flowing	10 < *FF*
Easy – flowing	4 < *FF* < 10
Cohesive	2 < *FF* < 4
Very cohesive	1 < *FF* < 2
Non – flowing	*FF* < 1

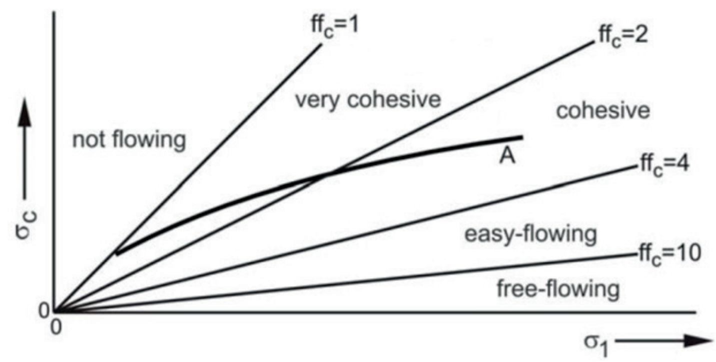


Fig. 2 Flow function and lines of flowability
Rys.2 Funkcja zasilania i linie płynięcia

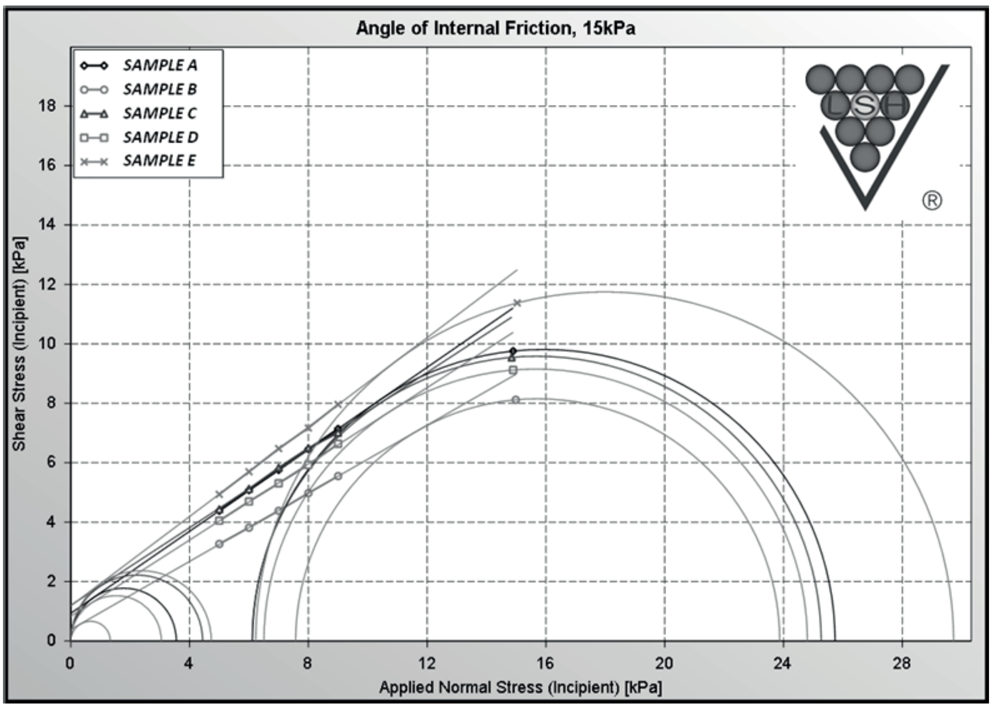
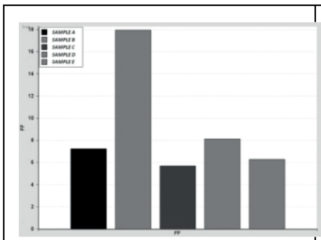
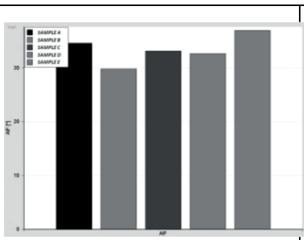
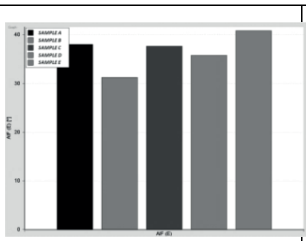
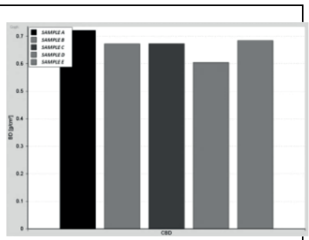
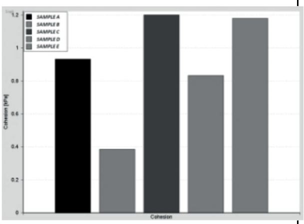
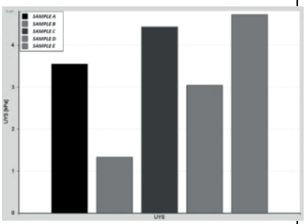
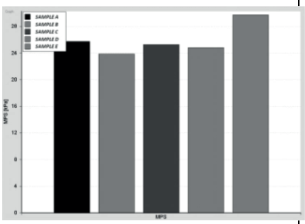
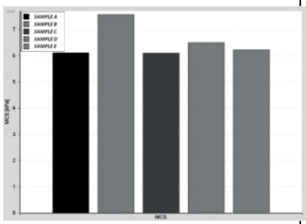


Fig. 3 Angle of Internal Friction
Rys. 3 Kąt tarcia wewnętrznego

Tab. 1 Comparing of different properties of powdered coal samples
Tab. 1 Porównanie właściwości próbek sproszkowanego węgla

			
Flow function	*Angle of Internal Friction*	*Angle of Internal Friction (Effective)*	*Conditioned Bulk Density*
			
Cohesion	*Unconfined Yield Strength*	*Major Principle Stress*	*Minor Consolidation Stress*

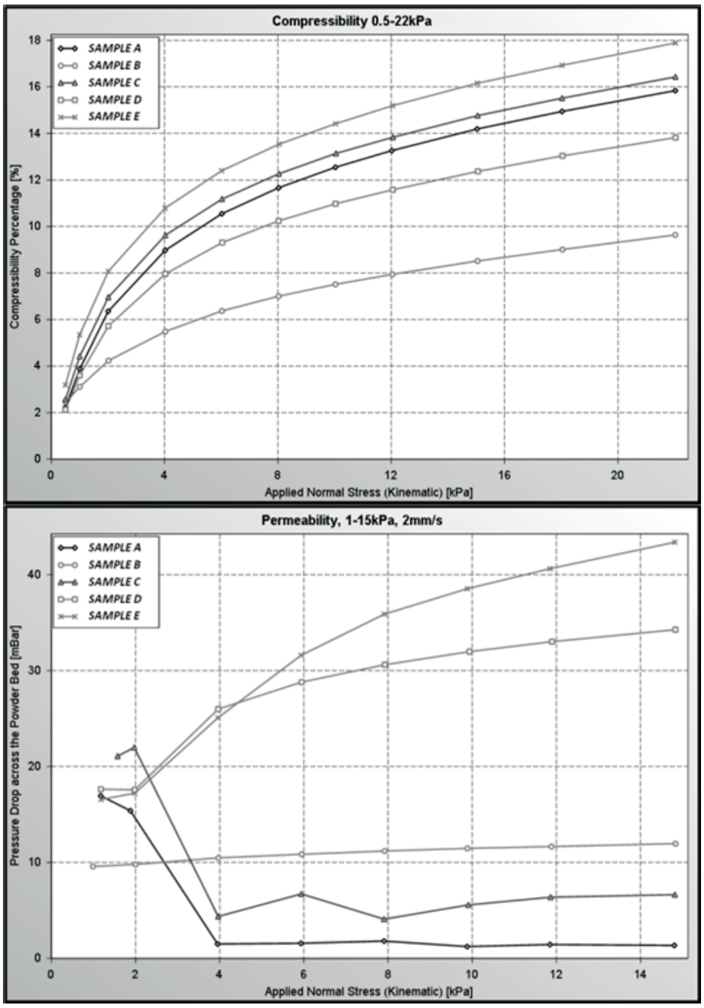
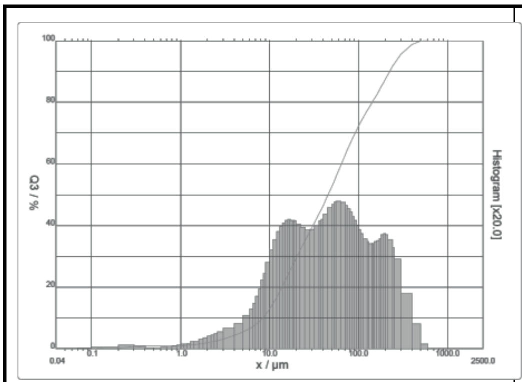


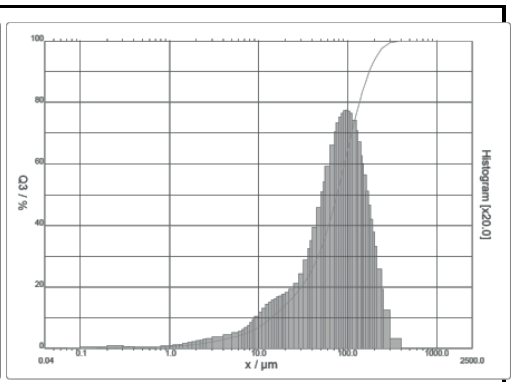
Fig. 4 Compressibility and Permeability
Rys. 4 Ściśliwość i przepuszczalność

Tab. 2 Particle size and distribution

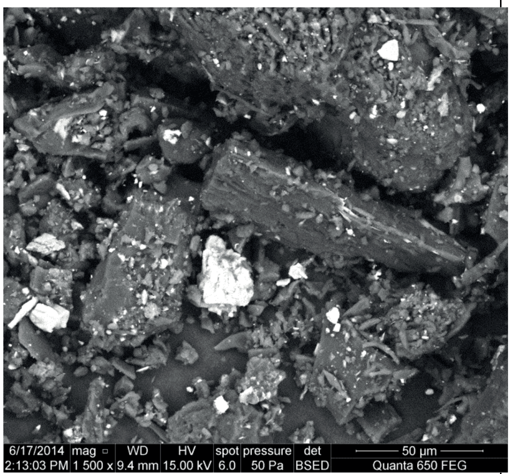
Tab. 2 Rozmiar i rozkład cząstek



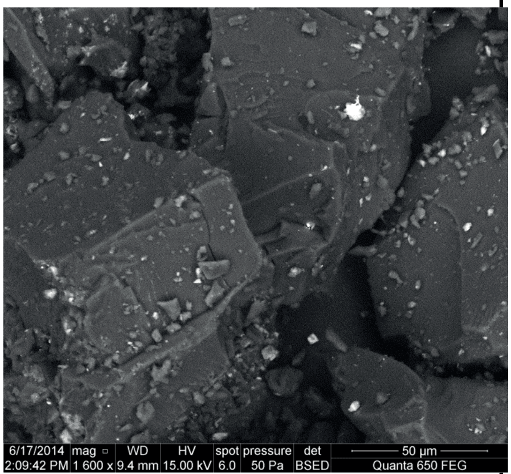
sample A



sample B



sample A



sample B

Tab. 3 Summary of the measurement results

Tab. 3 Podsumowanie wyników pomiarów

		Sample A	Sample B	Sample C	Sample D	Sample E
Cohesion	[kPa]	0,933	0,385	1,20	0,833	1,18
Unconfined Yield Strength	[kPa]	3,55	1,33	4,44	3,05	4,73
Major Principle Stress	[kPa]	25,7	23,9	25,3	24,8	29,7
Minor Consolidation Stress	[kPa]	6,12	7,57	6,10	6,50	6,23
Flow Function	[-]	7,24	17,9	5,69	8,14	6,28
Angle of Internal Friction	[°]	34,6	29,8	33,1	32,7	37,0
Angle of Internal Friction (E)	[°]	38,0	31,2	36,0	35,8	40,8
Bulk Density	[g/cm^3]	0,721	0,672	0,673	0,608	0,684
Compressibility (1kPa)	[%]	3,89	3,11	4,42	3,60	5,35
Compressibility (10kPa)	[%]	12,5	7,51	13,1	11,0	14,4
Compressibility (22kPa)	[%]	15,8	9,64	16,4	13,8	17,9

bottom ring, a ring of the same diameter lying above the bottom ring, and a lid. The lid is loaded centrally with a normal force. The upper part of the shear cell is displaced horizontally against the fixed bottom ring by a motor driven stem which pushes against a bracket fixed to the lid. The shear force – exerted by the stem is measured. Due to the displacement of the upper ring and the lid against the bottom ring, the bulk solid undergoes a shear deformation. The normal stress and the shear stress, acting in the horizontal plane between the upper ring and bottom the ring are determined by dividing normal force, and shear force by the cross-sectional area of the shear cell.

Figure 1 shows the principle of the shear cell of a ring shear tester (series RST-01). The ring-shaped (annular) bottom ring of the shear cell contains the bulk solid specimen. The lid is placed on the top of the bulk solid sample. The lid is fixed at a crossbeam. A normal force is exerted to the crossbeam in the rotational axis of the shear cell and transmitted through the lid to the bulk solid specimen. The counterbalance force also acts in the centre of the crossbeam. This force is directed upward and is created by counterweights. It counteracts the gravity forces of the lid, the hanger, and the crossbeam. To shear the bulk solid, the lid and the bottom ring of the shear cell must rotate relative to each other. This is accomplished by rotating the bottom ring in the direction of the arrow (Fig. 1), whereas the lid and the crossbeam are prevented from rotation by two tie-rods connected to the crossbeam. Each of the tie-rods is fixed at a load beam, so that the forces acting in the tie rods can be measured. [2]

The most commonly used parameter for the description of flowability of powders is the Flow Function as proposed by Jenike. It considers the Unconfined Yield Strength of a powder (with respect to the Major Principle Stress under which the powder is consolidated) to be the most relevant indicator of the powders ability to flow.

Comparative measurements of powdered coal

The goal of this paper is to show different properties of the same material. In this paper it is powdered coal which is frequently used in energy and metallurgical industries. Some measurements that are important for designing mechanical equipment were done and results are showed in this paper. Series of different properties measurement for 5 samples (sample A – E) were done using the Freeman FT4 Powder Rheometer. Cilas Particle Size Analyzer was used for particle size and distribution.

The most important method of measurement that is used for finding of flowability of powders is the shear cell program. In this case it was rotational shear cell test of the FT4 Powder Rheometer. Results of angle of internal friction can be seen on Figure 3. Comparing of different properties is showed in Table 1.

Compressibility is a measure of how density changes as a function of applied normal stress. For powders, this bulk property is influenced by many factors such as particle size distribution, cohesive forces, particle stiffness, particle shape and particle surface texture. It is not directly a measurement of flowability, but nevertheless relates to many process environments, such as storage in hoppers or super sacks, or behavior during roller compaction.

Permeability is a measure of how easily material can transmit a fluid (in this case air) through its bulk. External factors such as consolidation stress are also likely to influence permeability by changing the porosity and particle contact surface areas, making it more difficult for the air to pass through the bulk. Permeability is of interest when trying to understand the effects of many process environments such as storage in and flow out of hoppers, pneumatic transfer, vacuum transfer and specific processes such as vial filling or dry dosage inhalation. Generally, cohesive powders consisting of mainly sub 30 micron particle size are the least permeable, whereas powders of a granular nature are typically the most permeable. Unfortunately two samples (A and C) cannot be measured correctly due chimneys creating inside the samples during the test. It shows the propensity of the material to ratholing and other flow failures.

Conclusion

This paper describes how granulometry influences mechanical and physical properties of the material. The tested material showed changes of its flow properties, compressibility, angle of internal friction, etc. in dependence on external environment. This fact might have an impact on functionality and good work of mechanical equipment and storage processes. In the worst case poorly designed equipment might cause major damage of property or injuries of people. Therefore, it is necessary to study behavior of bulk materials to avoid these situations. Comparison of different properties was described in the previous chapter. Compressibility differences between similar samples were up to 6.5% at normal stress 22kPa. Some relationships were found between the parameters of compressibility, angle of internal friction, etc. This fact might have an impact on functionality of mechanical equipment and storage processes. Differences in granulometry are shown in the Table 2. All important values of the measurements are showed in Table 3.

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Właściwości mechaniczne sproszkowanego węgla i ich wpływ na proces technologiczny

W ostatnich latach, rosnąca ludzka populacji jest coraz bardziej zależna od produkcji różnych wyrobów, które to są zależne od funkcjonalności technologii wytwarzania. Badania materiałów masowych rozwiązują wiele problemów dotyczących awarii przepływów w różnych technologiach i procesach pyłowych materiałów. Doskonałe zrozumienie zachowania proszków jest bardzo ważne dla optymalizacji procesów. Z powodu różnych właściwości mechanicznych i fizycznych szerokiego zakresu materiałów pyłowych bardzo trudne jest zaprojektowanie odpowiednich technologii. Celem tego artykułu jest objęcie pewnych próbek sproszkowanego węgla badaniami ich mechanicznych i fizycznych właściwości, ważnych dla składowania materiałów masowych. Prace eksperymentalne były wykonane za pomocą reometru proszkowego Freeman Technology FT4 i analizatora rozmiaru cząstek Cilas 1190. Urządzenie pozwala uzyskać znaczącą ilość wyników na temat zachowania proszków od podstawowej gęstości masy do tarcia lub blokowania mechanicznego. Odkryto, że dominującym parametrem w procesie przechowywania jest ściśliwość. Zaobserwowano zależność między ściśliwością i stosunkiem mikrocząsteczek do nanocząsteczek. Polegając na granulometrii próbek zaobserwowano różną ściśliwość i kąt tarcia wewnętrznego. Zmierzone własności sproszkowanego węgla zostały zużyte do wyznaczenia kohezji i reżimu łatwego płynięcia do swobodnego płynięcia. Celem tego artykułu jest przewidzenie zachowania dużej ilości ciała stałego na podstawie specyficznych właściwości takich jak ściśliwość, kąt wewnętrznego tarcia, tarcie o ściany, kąt repozycji, wilgoć, kohezja i inne. Potrzebne jest odnalezienie sposobu aby kompletnie opisać proszki i ciała stałe w dużej ilości kilkoma parametrami. Problemem jest ich duża złożoność i szeroki obszar ich specjalizacji. Laboratorium materiałów masowych na Uniwersytecie Technicznym w Ostrawie skupia się na pomiarach właściwości mechanicznych i fizycznych ciał stałych masowych i proszków i równocześnie zajmuje się wirtualnymi symulacjami materiałów pyłowych DEM (Discrete Element Method). W dzisiejszych czasach jesteśmy w stanie przewidzieć zachowanie materiałów masowych polegając na sprawdzonych modelach w symulacjach DEM i na badaniach właściwości przepływu. Symulacje te są używane jako innowacyjna metoda projektowania urządzeń do przechowywania i przetwarzania w każdej dziedzinie przemysłu.

Słowa kluczowe: pomiar właściwości przepływu, sypkość, faza stała, sproszkowany węgiel