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Looking for a new source of natural proppants in Poland

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Abstract. The importance of proppants is significant, because their properties affect hydraulic fracturing treatment effectiveness. Quartz sands are often used as propping agents. Due to their good properties and low price, they are still more likely to be used than, for example, modern ceramic proppants. Procedures of determination of each parameter are specified in ISO 13503–2:2010, and according to them, quartz sands from 4 Polish deposits, located in different areas of the country were tested. All results were compared with parameters of the Belgian sand (model sand), which is usually used during fracturing treatments in our region. The most important factor, which determines whether a kind of sand is useful as a hydraulic fracturing proppant, is its crush resistance. The tested sands are mostly low class because of their limited strength. There is only one type of sand from Bukowno deposit which has similar crush rate, sphericity, roundness and bulk density to the accepted model. Acid solubility and turbidity is higher than exemplary, but in acceptable range. Bukowno deposit could be a likely resource of proppants for domestic petroleum industry.

Key words: proppant, mechanical properties, hydraulic fracturing.

1. Introduction

Considerable dependence between the import of natural gas and a growing demand is the reason for the search for methods of increasing the domestic production of natural gas and renewable energy [1]. In Poland there are several prospective fields for unconventional hydrocarbon production. The method used to extract gas from low permeable rocks is hydraulic fracturing. Through increasing the number of high permeability pathways to the wellbore, by creating a network of cracks, high flow of reservoir fluid can be received. As a result, higher efficiency of production from the unconventional source can be achieved. Fractures generated during the treatment are filled with a proppant which prevents them from closing up.

Development of stimulation methods caused a huge progress in the field of proppant production. Proppants according to the PN-93-G: 11010 standard are a set of non-combustible solid grains fed into the rock gaps with a liquid medium, settling and thickening as mechanical support. The origin of the use of proppants dates back to 1950s. Previously, quartz sands were used, but with time, high strength ceramic proppants, resin-coated proppants or low density ceramic proppants were developed [2]. The quality of the proppant is determined by analysing the particle size, crush resistance, conductivity, specific gravity, sphericity, roundness, turbidity and solubility in acid.

In the USA, research as well as field fracturing stimulation using CO_2 and sand was done. A.T. Lillies and A.B. II Yost reported success using sand proppant from domestic mines [11, 14]. Up to now, there is no such field fracturing in Poland.

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Domestic mineral resources are considered suitable in civil engineering and ceramic proppant production [12, 13]. The paper presents part of innovative research in area of natural proppant resources.

Each hydraulic fracturing treatment consumes 1300–2400 m^3 fracturing fluid and 36–140 tonnes of proppant. Thus, a very significant factor is whether the proppant manufacturer is close to the location where the treatment is carried out. As the most commonly used material is still quartz sand, it is important to be sure whether the sands from the Polish deposits would be useful as a proppant [3]. Therefore in this study samples of quartz sands from deposits in the Malopolskie and Śląskie voivodeships were tested in a laboratory. Determination of parameters of the proppant is carried out by following the guidelines described in ISO 13503–2: 2010 [4]. The procedures are closely linked to the standards of the American Petroleum Institute [5].

2. Laboratory procedure

2.1. Tested parameters. A sieve analysis was the first step in laboratory tests. It determines the grain size distribution and helps to separate fractions of a different particle diameter, which allows further testing [6]. Proppant size designation requires a set, consisting of at least 7 sieves that meet the standards of the American Society for Testing and Materials (ASTM). It is also necessary to use analytical balance (maximum uncertainty of measurement is 0.1 g). The prepared sample used in this test should weigh 80 to 120 g. The data enables calculation of the mean grain diameter and determination of particle size uniformity [7].

The permeability of fractures is directly affected by both size and shape of the proppant [8]. Roundness and sphericity of grains has to be tested for each sample. The most common method for determining these parameters is the Krumbien/Sloss diagram. Sphericity determines the extent to which a single grain shape is similar to the shape of a sphere and the degree of rounding the corners.

For the proper implementation of the measurement, a microscope or similar devices capable of magnifying the scope 10 to 40 times, and the balance with uncertainty of 0.001 g are needed. A sample weighing (preferably) 1 g or 2 g is placed on a dark (in the case of a bright material) or bright (in the case of a dark material) substrate and spread to form a single layer, not thicker than the diameter of the grain. At least 20 grains have to be selected randomly and situated in the area of view of the microscope. Next, their shapes are compared with the diagram. A number that corresponds to the degree of sphericity and the number corresponding to the degree of roundness are assigned to each of them. For both parameters, the obtained value is the arithmetic mean [4].

Due to the use of the proppant in an environment, where it is exposed to acid, it was tested to check acid solubility. It enables determination of the content of soluble materials which include carbonates, mica, iron oxides, clays, etc. For tested quartz sands, the acceptable value of solubility in acid is 2% (in the case of grains greater than 30/50 mesh) or 3% (grain less than 30/50 mesh) [5].

Turbidity test specifies the number of solid particles suspended in the solution. It is determined by the optical properties of the suspension, resulting from scattering of light by particles suspended in the fluid. The measurement can be made by using a spectrophotometer set at a wavelength of 450 nm or turbidity meter. Additionally, in order to perform this test, it is necessary to have a wrist action shaker and a syringe. The measurement begins by pouring 20 ml of dry proppant in an Erlenmeyer flask. Next, 100 ml of distilled water is poured into the flask and the solution is allowed to stand for 30 minutes. Using a syringe, 25 ml of water is collected and the suspension from the inside volume of the solution is placed in a vial for testing. The sample is inserted into the previously calibrated device, and turbidity is recorded in FTU [4].

2.2. Importance of density. Among the parameters that characterize the material, there is bulk density, apparent density and absolute density. Bulk density includes the material with spaces between grains and is important in determining the weight of the proppant which is necessary to fill fractures or during storage and transport. Apparent density excludes presence of voids between grains, and the absolute density – without the presence of pores or voids which may exist between the particles of the material. To determine the bulk density a simple device is used, made according to the recommendations contained in the standard. Apparent density measurement is made using kerosene with viscosity of not more than 5 cP, scales and a pycnometer. Absolute density measurement corresponds to the Boyle's law. The pressure at the time of filling the chamber with the material, and then used to discharge it into the hollow chamber, allows to calculate the volume of the solid phase of the sample [4].

2.3. Crush test. The most important parameter that determines the possibility of using the material as a proppant is its compressive strength. The test consists of determining the quantity of the proppant, which is crushed at a given stress. In this way the stress level at which there is too much crushed material and the maximum pressure to which the proppant may be subjected is determined. According to standards, the test stress range for the natural sands is from 13.8 MPa (2000 psi) to 34.5 MPa (5000 psi) [9]. To do this test, a hydraulic press is needed with a liner consisting of a cylinder and a piston (Fig. 1).

Fig. 1. Insert: cylinder and piston

The test begins by sieving the sample through the main screen. For example, for the proppant labelled 30/50, the main upper sieve is a sieve of 30 mesh, and the main bottom sieve is a sieve of 50 mesh. After 10 minutes of the ongoing sieving, it is necessary to eliminate the material remaining on the upper sieve and the manifold (receiver). To perform a crushing test, the material retained on the bottom sieve is used, and the mass of the sample to be prepared depends on the bulk density of the tested proppant.

The cylinder has to be filled with sand in such a way to obtain a uniform consistency of the material and that the surface of the material is also leveled. The results of measurements of resistance to crushing to a large extent depend on the method of filling the cylinder, so it is necessary to avoid shaking. After filling the cylinder, it is placed in a hydraulic press. Next, force is exerted on the piston, while maintaining constant speed load increment until the planned value of stress. For 2 minutes the stress is maintained constant, and after it decreases to zero the insert is removed from the press. The contents of the cylinder should be poured on the previously used set of sieves and screen for 10 minutes. After this time the material from receiver is weighed with the uncertainty of 0.1 g. The data collected allow for calculation of percentage of the crushed material – crush rate, using the formula specified in the standard. The admissible value of the damaged material for silica sand shall be a maximum of 10% [10].

3. Laboratory research

Prior to testing the samples taken from the Polish deposits, the Belgian quartz sand used as a proppant in fracturing treatments was analyzed. This product is marked with granulation 40/70, hence it is known that the grain included in the sample should have a size of 0.212 mm to 0.425 mm. Sieve analysis carried out on a sample of 100 g, according to the previously described procedure, as defined in ISO 13503–2: 2010 showed that small part of the grains (Table 1) is out of this range.

Table 1
Sieve analysis of proppant (Belgian quartz sand) 40/70

Sieve size (US mesh)	Grain size range (μm)	Average size (μm)	Material weight (g)	Frequency (%)
25 – 30	710 – 600	655	0.3	0.3
30 – 40	600 – 425	512.5	4.3	4.3
40 – 45	425 – 355	390	12.3	12.3
45 – 50	355 – 300	327.5	32.8	32.8
50 – 60	300 – 250	275	36.0	36.0
60 – 70	250 – 212	231	11.9	11.9
70 – 100	212 – 150	181	1.6	1.6
100 >	150 >	75	0.6	0.6
		SUM:	100	100

These results were adopted as a model according to which the test sample was prepared from the Polish deposits. The sand obtained directly from the bed is not a proppant, because the granulation has a very wide distribution, with a diameter of several tens of microns to several millimeters. So it was sieved through a set of sieves 30, 40, 45, 50, 60, 70, 100, the receiver, and then the material from each sieve was collected to a separate container. The separated fractions were then mixed in such a way that the proportions of the resulting proppant corresponded to the model one.

Sphericity and roundness study was performed using a microscope and a camera with lens for macro photography. 20 randomly selected grains were attributed to the degree of sphericity and roundness (Fig. 2), the data were compiled in the table and the arithmetic mean was calculated (Table 2).

Table 2
Sphericity and roundness of Belgian quartz sand 40/70

Grain	Sphericity	Roundness	Grain	Sphericity	Roundness
1	0.3	0.9	11	0.8	0.7
2	0.7	0.8	12	0.7	0.8
3	0.9	0.8	13	0.8	0.9
4	0.9	0.9	14	0.5	0.7
5	0.9	0.9	15	0.7	0.5
6	0.4	0.9	16	0.3	0.6
7	0.8	0.5	17	0.8	0.8
8	0.8	0.8	18	0.6	0.4
9	0.8	0.6	19	0.3	0.1
10	0.8	0.6	20	0.5	0.8
			AVERAGE:	0.7	0.7

Each sample was tested for turbidity, using a turbidity meter WTW Turb 550 IR (Fig. 3). In contrast to the test using a UV/VIS spectrophotometry for this purpose, the use of a turbidity-meter simplifies and shortens the duration of the measurement. The turbidity value read for 40/70 Belgian sand is 73 NTU.

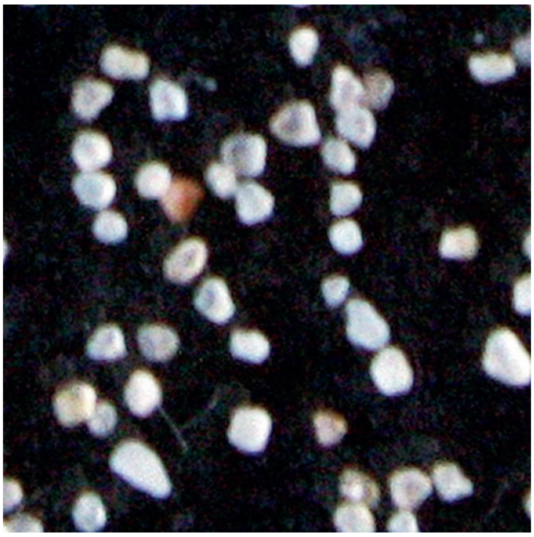

Fig. 2. Belgian proppant – sand 40/70

Fig. 3. Turbidity meter WTW Turb 550 IR

The tested sands were analyzed in case of crushing strength, by exerting stress on the samples: 13.8 MPa, 17.2 MPa, 20.7 MPa, 27.6 MPa, 34.5 MPa. The weight of the samples which fills up the measuring cylinder depends on the bulk density of the proppant. The test results of the Belgian quartz sand, with $\rho_{bulk} = 1.61$ g/cm^3, and $m_p = 39.52$ g are presented in Table 3.

Table 3
Crush test results of the Belgian quartz sand 40/70

Sample	Stress (MPa)	Crushed material (g)	Crush rate (%)
1	13.8	0.14	0.35
2	17.2	0.3	0.76
3	20.7	0.51	1.29
4	27.6	1.17	2.96
5	34.5	2.76	6.98

The characteristic of the proppant, including basic parameters described in Table 3, is given by the manufacturers most commonly in the simple form as in Table 4.

Table 4
Characteristic of the Belgian quartz sand 40/70

Parameter		Value
Average grain diameter		310 μm
Sphericity		0.7
Roundness		0.7
Acid solubility		1.02%
Turbidity		73 NTU
Bulk density		1.61 g/cm^3
Apparent density		2.50 g/cm^3
Crush rate	13.8 MPa	0.35%
	17.2 MPa	0.76%
	20.7 MPa	1.29%
	27.6 MPa	2.96%
	34.5 MPa	6.98%

Taking the Belgian 40/70 quartz sand into account as a model, which is used in the petroleum industry for fracturing, helps in deciding whether the tested material could be used as a proppant. We analyzed quartz sands from different Polish deposits in the Małopolskie and Śląskie voivodeships; they were prepared based the composition of the model. Finally four open pit mines were taken into consideration: Bolesław, Bukowno, Hutki II and Kuźnica Warężyńska. The same measurements were carried out for samples as for the model specimen. Results are presented in the Table 5.

Table 5
Results of tests for all samples

		Belgian quartz sand 40/70	Bolesław	Bukowno	Hutki II	Kuźnica Warężyńska
Average diameter (μm)		310	310	310	310	310
Sphericity		0.7	0.7	0.7	0.8	0.8
Roundness		0.7	0.8	0.7	0.7	0.8
Acid solubility		1.02	3.58	2.32	4.68	6.40
Turbidity (NTU)		73	594	114	891	600
Bulk density (g/cm^3)		1.61	1.52	1.62	1.50	1.44
Apparent density (g/cm^3)		2.50	2.57	2.53	2.39	2.36
Crush rate [%]	13.8 MPa	0.35	10.73	1.57	8.12	13.77
	17.2 MPa	0.76	11.24	1.95	9.62	14.37
	20.7 MPa	1.29	13.61	2.17	9.92	15.99
	27.6 MPa	2.96	15.48	5.32	13.54	20.67
	34.5 MPa	6.98	20.51	8.80	18.17	24.67

The most important is the crush rate comparison (Fig. 4) because it allows for proppant association with proper crush class.

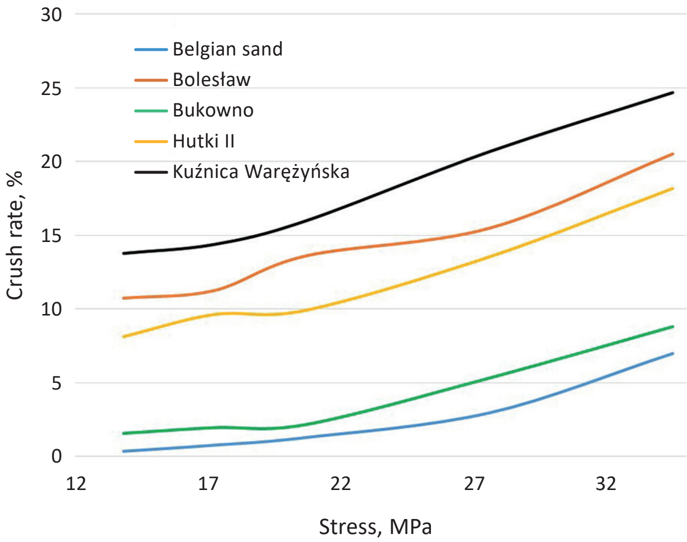

Fig. 4. Dependency of crush rate versus stress

The basic parameter that determines the quality of the proppant is its compressive strength. API RP 19C suggests classifying proppants by assigning the appropriate class to them, according to Table 6.

Table 6
Crush classification table [5]

10% crushed class	Stress (MPa)	Stress (psi)
1K	6.9	1000
2K	13.8	2000
3K	20.7	3000
4K	27.6	4000
5K	34.5	5000
6K	41.4	6000
7K	48.3	7000
8K	55.2	8000
9K	62.1	9000
10K	68.9	10000
11K	75.8	11000
12K	82.7	12000
13K	89.6	13000
14K	96.5	14000
15K	103.4	15000

The material is subjected to a compressive strength test, in order to find the value of the stress under which at least 10% of the particles is crushed. To be classified as class 4K, the quantity of crushed material under a stress of 27.6 MPa (4000 psi) cannot exceed 10%. The rule is: the higher the class – the higher the strength of the proppant. Looking at the results in Table 5, it can be stated that the highest class can be assigned to the Belgian quartz sand 40/70. Maximum stress exerted in the laboratory was 34.5 MPa (5000 psi), so this product can be assigned to class 5K.

None of the sands from the Polish deposits has passed the crushing test better than the assumed model. The most similar results were obtained for the samples from the deposit Bukowno, which can be assigned to the same class 5K, which also depends on the result of the test carried out at a stress of 34.5 MPa (5000 psi).

Next, the material from the deposit Hutki II was classified as class 3K, while other samples were damaged and destroyed within the range of more than 10%, under less than 6.9 MPa (1000 psi), so they could be assigned to the lowest class – 1K. For this reason Bukowno deposit could be considered as a likely source of proppants. Sphericity and roundness values are exactly the same as for the model sample, which indicates good ability of the new proppant to build highly permeable pathway in hydraulic fracturing. Also, bulk density and apparent density are almost the same. These values will result in proper suspension transport conditions in the formation. Unfortunately acid solubility is higher more than twice, but stays within the acceptable range of 40/70. Turbidity of Bukowno sand is also higher comparing to the model. However, it is still acceptable below 150 NTU.

4. Conclusions

- The most similar material to the adopted model in reference to compressive strength is the sand from the deposit located in the Małopolskie voivodeship in Bukowno. It has roundness, sphericity and gravity also similar to Belgian sand
- Bukowno sand has higher values of acid solubility and turbidity than the model, but still within the acceptable range.
- Bukowno as a local deposit in Poland assures low cost of proppant transportation for Polish petroleum industry, although improvement of material parameters can play significant role in the final price.

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