# Comparison of Selected Properties of Natural and Ceramic Proppants Used in Hydraulic Fracturing Technologies

*Marcin LUTYŃSKI[1)], Dariusz JANUS[2)], Marcin ZIMNY[2)]*

[1)] Dr inż.; Institute of Mining, Faculty of Mining and Geology, Silesian University of Technology, ul. Akademicka 2, 44-100 Gliwice, Poland; email: marcin.lutynski@polsl.pl
[2)] Baltic Ceramics SA, Ul. Reymonta 9, 68–300 Lubsko, Poland

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*Abstract*

*Proppants are synthetic or natural grains used in the gas/oil well drilling industry to hold fractures open around the wellbore in order to enhance fluid extraction after hydraulic fracturing processes. Proppant shape, a significant factor in the hydraulic fracturing dynamic, has an impact on the proppant pack strength, permeability, and conductivity. Proppant should have an optimized spherical shape which is characterized by two values: sphericity and roundness. The other important feature of the proppant is acid solubility. Acid solubility test determines the suitability of a proppant for use in applications where the proppant can come into contact with acids. In this study we compared the roundness and sphericity as well as acid solubility of three ceramic proppants: Baltpropp 16/30 ISP Baltpropp 20/30 HSP and Baltpropp 30/40 HSP with two natural materials, namely sands from Katowice and Ostrowiec quarries and silicon carbide. In all performed tests ceramic proppants performed better than sand from the quarries in Katowice and Ostrowiec. The third ceramic material, silicon carbide had the lowest roundness and sphericity whereas its acid solubility was rather low.*

*Keywords: ceramic proppants, hydraulic technologies, shape, acid solubility*

## Introduction

Proppants are synthethic or natural grains such as coated sand or sintered bauxite ceramics used in the gas/oil well drilling industry to hold fractures open around the wellbore in order to enhance fluid extraction after hydraulic fracturing processes. The use of proppants in the oil and gas industry is particularly important in case of unconventional reservoirs such as gas shales where the necessity to keep the fracture open is essential in order to sustain economic flow rates to the well [1]. The sketch of properly propped fracture versus fracture propped with poorly sorted material is presented in Fig. 1.

It is clearly seen that proppant with sharp, angular shape clogs the fractures which results in the restriction of flow. In case of round proppants with soft edges and similar particle size fraction the flow channels are larger and the conductivity of propped fracture is higher. Ideally, the well rounded proppant with small variation in particle size gives should give a unimodal particle size distribution whereas a poorly sorted one a bimodal particle size distribution. In general, proppants can be divided into three groups (see Table 1) i.e. natural, ceramic and other.

Proppant shape, a significant factor in the hydraulic fracturing dynamic, has an impact on the proppant pack strength, permeability, and conductivity. Proppant should have an optimized spherical shape which is characterized by two values: sphericity and roundness. There are other properties of the proppant which may affect its performance in the reservoir and these are i.a.: acid solubility and turbidity [2]. Proppant testing methods are described in the EN:ISO standard 13503-2:2006 "Petroleum and natural gas industries – Completion fluids and materials – Part: 2 Measurement of properties of proppants used in hydraulic fracturing and gravel-packing operations" [3]. There are also other methods to assess proppant properties in contact with reservoir rock [4], [5]. The scope of this paper is to compare two important features of proppants – their shape described by the sphericity and roundness and acid solubility. For the purpose of comparison two natural proppants (sands), three ceramic proppants and one ceramic material i.e. silicon carbide were selected.

## Materials and methods

Three ceramic proppants selected for the study were manufactured by Baltic Ceramics SA. The market name for the proppant is Baltpropp and for the purpose of the study three typical sizes (in mesh) were selected i.e. 16/30; 20/30 and 30/40 which corresponds to the metric grain size fraction of 0.6–1.18 mm; 0.6–0.841 mm and 0.4–0.595 respectively. The sample of Baltpropp 16/30 ISP was an Intermediate Strength Proppant whereas Baltpropp 20/30 and Baltpropp 30/40 were HSP type (High Strength Proppant). Main components of

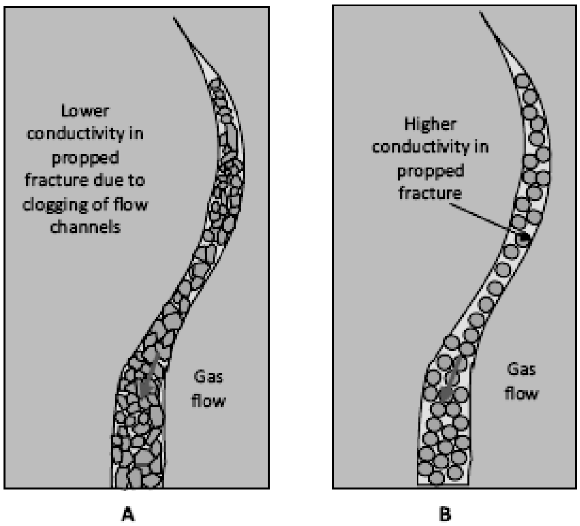



Fig. 1. Scheme of a fracture propped with poorly sorted grain material (A) and rounded ceramic material (B)
Rys. 1. Schemat załamania dla źle posortowanych ziarn materiału (A) i zaokrąglonych ziarn z materiału ceramicznego (B)

ceramic proppants are bauxite, kaolinite, clay and modifying additives. In order to compare the properties we have selected natural sands from quarries near Katowice and Ostrowiec which were sieved to the particle size fraction similar to that of proppants i.e. 20/30 mesh for Ostrowiec sand and Katowice sand. As the third material, silicon carbide was chosen as it is supposed to be resistant for acid solubility and with hardness compared to diamond. On the other hand it is mostly used as abrasive hence low roundness and sphericity. High density of this material (3,21 g/cm$^3$) is of great concern in proppant application since a preferable density should be near that of fracturing fluid. The particle size fraction of the silicon carbide was 30/35 mesh.

***Roudness and spherícty***

In order to assess the roudness and sphericity of tested materials we have followed the procedure described in the EN:ISO standard 13503-2:2006. In general, the procedure requires observing at least 20 grains of a representative sample (randomly selected grains) on a manual optical microscope and subjectively assigning a roundness and sphericity value, as given in Krumbein-Sloss diagram, to each by visually comparing the particles to the images in the table (Fig. 2) and assigning values listed on the chart.

Grains were analyzed under the stereoscopic microscope with digital camera. To obtain a better contrast of the grains on the background images were enhanced using CorelDRAW software. Each grain was assessed individually and an example photo of a set of 20 grains of Baltpropp 20/30 and Katowice sand 20/30 is presented in Fig. 3.

***Acid solubility***

The same standard as applied for the roundness and sphericity assessment gives recommendation on the acid solubility of proppants. This test determines the suitability of a proppant for use in applications where the proppant can come into contact with acids. Acid solubility indicates the amount of soluble materials i.e., carbonates, feldspars, iron oxides, and clays. Tests were conducted strictly according to the abovementioned EN:ISO standard 13503-2:2006. The procedure involves immersing 5g sample of the proppant for approximately 30 minutes at 66°C in the mixture of hydrochloric (HCl) and hydrofluoric acid (HF) – 12% by mass of hydrochloric acid and 3% by mass of hydrofluoric acid. Before placing the sample in the acid, the sample is dried at 105°C until its mass is stable, consequently the sample is weighted. After the immersion in acid the sample is rinsed, soaked on the filter and weighted again – the mass loss tells about the acid solubility (*S*) which can be calculated according to the following equation (1):

$$s = \frac{(m_S + m_F - m_{FS})}{m_S} \cdot 100\%$$

where $m_S$ is the mass of dried and untreated sample, $m_F$ is the mass of the filter used for soaking the sample, $m_{FS}$ is the mass of the treated sample on the filter.

**Results and discussion**

The roundness and sphericity of the proppant batch is an arithmetic average of the values from 20 observations. Calculated values of round-

Tab. 1. Types of proppant

Tab. 1. Rodzaje proppantów

| Natural | Ceramic | Other |
|---|---|---|
| • Sands<br>• Resin-coated sands | • LWC – Lightwear Ceramics<br>• IDC – Intermediate Density Ceramics<br>• HDC – High Density Ceramics<br>• Resin-coated Ceramic Proppants | • Light weight polymers<br>• High density bauxite |

Fig. 2. Krumbein-Sloss diagram to describe roundness and sphericity of proppant grains

Rys. 2. Diagram Krumbeina-Slossa do opisu okrągłości i kulistości ziaren proppantów

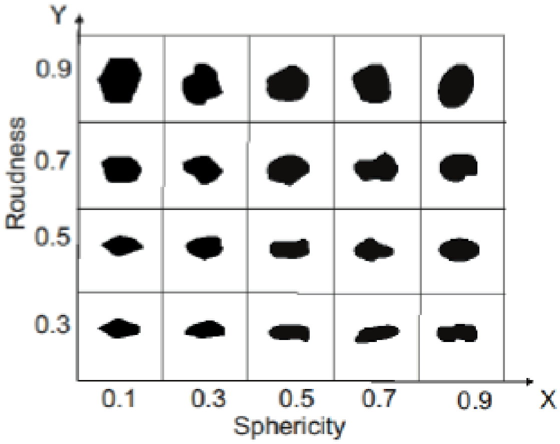
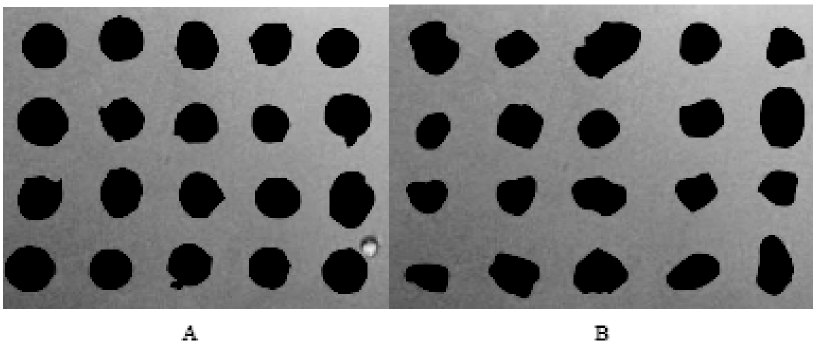



Fig. 3. Example microscope photo of grains under 5x magnification of Baltpropp 20/30 HSP (A) and Katowice sand (B)

Rys. 3. Przykład zdjęcia ziaren proppantu przy 5-krotnym powiększęniu, próbka Baltpropp 20/30 HSP (A) oraz piasku z rejonu Katowic (B)




ness and sphericity for the samples are presented in Table 2.

Results of tests show that ceramic proppants have superior properties (roundness and sphericity) to other materials than have been taken under consideration. The average values of roundness and sphericity are in the range of 0.82 to 1.00 which indicates shape similar to the sphere. The standard deviations as a measure quantyfing the dispersion of data show least variation as well. In case of natural proppants slightly better roundness and sphericity was exhibited by the Ostrowiec sand which somewhat was smoother than Katowice sand. Silicon carbide due to its nature as an abrasive shows, as expected, very low roundness and sphericity with slightly larger standard deviation than natural proppants and much larger than ceramic ones. Results of acid solubility tests are shown in Table 3.

Results of acid solubility test showed that none of the natural proppants (sands) is proper for applications where the use of acids in fracturing fluid

Tab. 2. Calculated roundness and sphericity of ceramic and natural proppants and silicon carbide

Tab. 2. Obliczone wartości okrągłości i kulistości proppantów ceramicznych, naturalnych i węglika krzemu

| Sample | Roundness [-] | Sphericity [-] | Standard deviation | |
|---|---|---|---|---|
| | | | Roudnness [-] | Sphericity [-] |
| Baltpropp 16/30 ISP | 0.90 | 0.90 | 0 | 0 |
| Baltpropp 20/30 HSP | 0.82 | 0.88 | 0.044 | 0 |
| Baltpropp 30/40 HSP | 0.89 | 1.00 | 0.100 | 0.062 |
| Katowice sand 20/30 | 0.21 | 0.61 | 0.210 | 0.140 |
| Ostrowiec sand 20/30 | 0.48 | 0.68 | 0.267 | 0.111 |
| Silicon carbide 30/35 | 0.15 | 0.17 | 0.214 | 0.258 |

Tab. 3. Results of acid solubility test of natural and ceramic proppants and silicon carbide

Tab. 3. Wyniki badań rozpuszczalności w kwasie proppantów ceramicznych, naturalnych i węglika krzemu

| Sample | Acid solubility [%] |
|---|---|
| Baltpropp 16/30 ISP | 5.9 |
| Baltpropp 20/30 HSP | 5.4 |
| Baltpropp 30/40 HSP | 5.3 |
| Katowice sand 20/30 | 15.0 |
| Ostrowiec sand 20/30 | 35.0 |
| Silicon carbide 30/35 | 3.8 |

is required. As a rule, the acid soluble material in proppants should not exceed 2% for all frac sand and resin-coated sand larger than or equal to 30/50 mesh. Frac sand and resin-coated sand smaller than 30/50 mesh allow a maximum solubility of 3%. Ceramic proppants and resin-coated ceramic proppants can be as high as 7% acid soluble. In this case it is evident that ceramic proppants and silicon carbide exhibit sufficient resistance to acid solubility. The slight difference in acid solubility of Baltpropp samples can be explained by the size – the larger the surface area the higher the solubility. Very low solubility of silicon carbide is obviously caused by its insoluble main component (SiC) and it can be suspected that only impurities were dissolved by the acid. In Figure 3, the sample of Katowice before and after treatment is shown. It is evident

## Conclusions

Ceramic proppants are a step forward in comparison to natural proppants such as sands. In this study we have compared two important properties of proppants i.e. roundness and sphericity and acid solubility. In all tests ceramic proppants manufactured by Baltic Ceramics SA performed better than sand from the quarries in Katowice and Ostrowiec. The third ceramic material, silicon carbide, which could be potentially used as a proppant has by far the lowest roundness and sphericity however its acid solubility is rather low. On the other hand high manufacturing cost of silicon carbide and its high density disqualify its use as a proppant. In order to assess suitability of a material as a proppant other tests have to be conducted and one of the most important ones is the proppant compressive strength which is particularly important in reservoirs at high depths such as shale reservoirs in Poland. Therefore, additional analysis will be done with the aim to compare also this property.

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*Porównanie wybranych cech naturalnych i ceramicznych propantów stosowanych w technologiach szczelinowania hydraulicznego*

*Propanty są to ziarna materiałów syntetycznych lub naturalnych stosowane w wiertnictwie gazu/ropy do utrzymywania stabilnych szczelin wokół odwiertu, w celu zwiększenia wydobycia płynu w procesie szczelinowania hydraulicznego. Kształ ziaren propantu jest istotnym czynnikiem dla dynamiki szczelinowania hydraulicznego, ma wpływ na ciśnienie, przepuszczalność i przewodność. Propant powinien mieć optymalną kształt (kulisty), który charakteryzują dwie wartości: sferyczność i okrągłość. Inną ważną cechą propantu jest rozpuszczalność kwasowa. Rozpuszczalność kwasowa określa przydatność materiału do procesu, w którym środek może mieć kontakt z kwasami. W artykule przedstawiono wyniki porównania współczynników okrągłości i kulistości oraz rozpuszczalności trzech ceramicznych propantów: Baltpropp 16/30 ISP, Baltpropp 20/30 HSP i Baltpropp 30/40 HSP oraz dwóch naturalnych materiałów: piasków z kopalni w Katowicach i węglika krzemu w Ostrowcu. We wszystkich przeprowadzonych badaniach propanty ceramiczne miały lepsze parametry niż piasek z kamieniołomów w Katowicach i Ostrowcu. Trzeci materiał ceramiczny, węglik krzemu miał najniższy wskaźnik okrągłości i kulistości, podczas gdy jego rozpuszczalność była raczej niska.*

*Słowa kluczowe: propanty ceramiczne, technologie ceramiczne, kształt, rozpuszczalność*