

Characterization and Evaluation of Gum Arabic Coated Sand as Proppants for Hydraulic Fracturing Applications

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Abstract. Luwa sand was characterized and used to design a proppant for reservoir stimulation/hydraulic fracturing applications. This involves describing the sand in terms of its physicochemical properties, including Sieve analysis, proppant sphericity and roundness measurement, acid solubility measurement, turbidity test, bulk density measurement, proppant crush-resistance test and loss on ignition test (LOI). Additional tests on hardness and elemental (XRF) were also conducted. X-ray fluorescence analysis of the sand indicates that the sand contains higher percentages of Aluminium oxide (Al_2O_3) than Silicon oxide (SiO_2). The hardness test on the Mohs scale confirmed the sand materials as topaz, i.e. not purely corundum (a crystalline form of aluminium oxide) or purely quartz with a hardness value of 8. This value is more complex than silicon oxide, with a hardness value of 7, and less than corundum, with a hardness value of 9. The Luwa sand is uniformly graded; more than 90% of the sand falls within the specified particle range of 20/40 mesh size. The 20/40 mesh-designed proppant shows favourable qualities for consideration as a proppant. However, the sand exhibits low crush resistance at pressures of 3000 psi and, therefore, cannot be applied in reservoirs with closure stress of up to 3000 psi. Because of the low crush strength of Luwa sand, gum Arabic resin was used to coat the sand for improved mechanical and chemical stability. The new resin-coated sand was further tested for crush resistance and acid solubility. The result shows a significant improvement in the crush resistance above 3000 psi with less than 5% fines generated. Generally, the uncoated sand produces less than 10% fines at stresses less than 3000 psi and is considered to have a 2 K value, while the resin-coated proppant generates 10% fines above 6000 psi. The resin coated can be classified as having a 5K value and can be applied in reservoirs with closure stress of up to 5000 psi or less.

Keywords: Hydraulic fracturing; sand; proppant; resin; gum arabic; crush resistance; closure stress; reservoir stimulation.

INTRODUCTION

With increasing energy demand, a decline in conventional gas and a concomitant increase in energy prices, a vital aim will be to develop cost-effective Exploration & Production strategies. The key issue is thus developing strategies for high-grade prospects in terms of gas volumes and recoverability. Oil and Gas companies spend millions of US dollars on fracturing fluids and their additives to improve oil and gas production. Given the very low matrix permeability of unconventional systems (shale gas reservoirs, coal

bed seams, etc.), effective hydrocarbon recovery generally relies on enhancing permeability through the artificial creation of a fracture network known as hydraulic fracturing.

Hydraulic fracturing increases healthy productivity by pumping fluids into the well to create conductive fractures and bypass near-wellbore damage in hydrocarbon-bearing zones [1]. The net result is an expansion in the productive surface area of the reservoir compared to the unfractured formation. Selected materials and chemical additives impart predictable fluid prop-

erties, including viscosity, friction, formation compatibility, and fluid-loss control. However, there is a need to find cost-effective and environmentally friendly means of hydraulic fracturing.

A propping agent is placed in fractures to keep them open after pressure from hydraulic fracturing is released. A range of materials are used as proppants, including walnut hulls, natural Sand, glass, resin-coated Sand, and ceramic proppants (i.e., sintered bauxite, clay-based proppants, and fused zirconia) [2].

Natural sand proppants, also known as frac sand, are the first material used as a proppant in hydraulic fracturing operations to keep induced rock fractures both open and conductive. It has remained the most commonly used proppant for this process because of its economic advantages [3]. Natural sand is advantageous because it is relatively cheap and easy to obtain. It also has a low specific gravity, allowing it to travel further along the fracturing fluid before settling, creating more extensive fractures than denser alternatives [4].

The drawbacks of natural sand proppants are that they are not as strong as manufactured proppants, meaning they generally break at lower pressures [4]. They are also more susceptible to crushing and fine generation than reinforced proppants [4]. Most of the time, the material for proppants is treated silica sand based since it is the most common mineral in the Earth's crust, owing to its properties compared to other minerals [5].

Silica as sand is a versatile raw material used for various industrial purposes. A grain of silica sand is either round or angular in shape, white, milky or brown in colour and complex, measuring seven on the Mohs hardness scale. Naturally occurring silica sand contains undesirable impurities like clay kaolinite, titanium, iron, and heavy elemental oxides. The term 'silica sand' as a proppant is used to identify sand that conforms with the specifications of the main composition of about 95% SiO₂ with an impurity of less than 5% [6].

Although sand is found globally, its properties differ when sampled from other locations [3]. It is always necessary to experimentally assess its suitability for use as a proppant. Sands in Nigeria are mainly undescribed and undocumented for use in reservoir stimulation processes. Much of

the current knowledge on using proppants in hydraulic fracturing is based on experience with proppants produced in the USA, Europe, and the Middle East [5]. The problem is that whereas the systematics of sand suitable for fracking application in the USA have been well known, to the best of our knowledge, the systematics of sand as proppants in Nigeria could be better described and documented.

Nigerian exploration and production (E&P) industries rely on the costly importation of proppants for stimulation jobs despite being blessed with different grades of sand in over a thousand kilometres of shorelines and tens of hundreds of inland rivers holding tons of sand deposits. Therefore, sands in Nigeria can represent an entirely new, undescribed proppant type that differs from all known proppant types.

Design and prediction of the physicochemical properties of the sand and rheological and fluid flow properties of the polymer (resin) are central to suitable proppant for use in reservoir stimulation/hydraulic fracturing. Therefore, this research investigates the feasibility of using solely local materials, such as sand and polymer (Gum Arabic), to design industry-grade proppants for reservoir stimulation/hydraulic fracturing applications. The sand was subjected to surface modification with resin from the Gum Arabic as a natural polymer to form a new resin-coated proppant.

METHODS

This work was conducted in three stages; this involves first characterizing the sand in terms of its physicochemical properties, including Sieve analysis, proppant sphericity and roundness measurement, acid solubility measurement, turbidity test, bulk density measurement, proppant crush-resistance test and loss on ignition test (LOI). Additional tests on hardness and elemental (XRF) were also conducted. The second phase of the work involves the characterization of Gum Arabic, which was used as polymer resin to coat (modify) the proppant to improve its crush resistance ability. Finally, the proppant was designed according to (ISO) 13503-2, and crushing tests were conducted before and after modification to check the effect of the Gum Arabic polymer-based resin. Figure 1 is a flow chart of the methodology followed in this study.

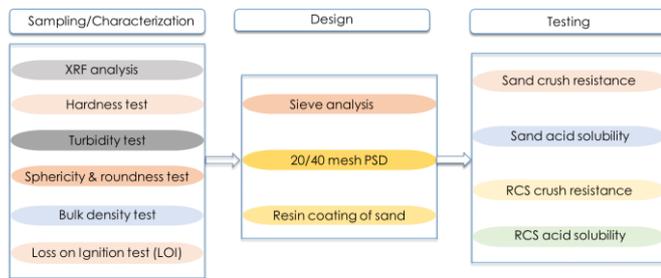


Figure 1 – Work Flow Chart

The materials used to conduct this research include the following:

Equipment and Material	Analyses
Luwa sand	Proppant design
Gum arabic	Resin formulation
A WF20X magnification microscope	Sand sphericity and roundness
Hydrochloric acid (HCl) of 37 % concentration	Acid Test
An analytical balance with an accuracy of 0.001g	Sample weighing and measurement
Krumbein/Sloss Chart, a 2500 kn hydraulic universal testing machine	Proppant Classification, crush resistance test
Beaker	Sample measurement
Volumetric flasks	Sample measurement
Turbidimeter	Turbidity Test
A stopwatch	Sample measurement
Xrf machine	Sand elemental analyses
FTIR machine	Gum Arabic Functional group characterization
Rheometer	Rheology measurements
Density meter	Sand density measurement
Sieve sets, STSJ – 4A high-frequency sieve shaker, weighing balance and brushes	Sand Sieve Analysis

The essential materials in this work are the Luwa River sand and Gum Arabic. The sand was obtained from the Luwa River in the Toro area of Bauchi, Nigeria (10°4'48" N and 9°9'40" E) with a tropical Savanna, wet climate. For laboratory analyses, 1 kg of the sand was collected randomly at five different locations 100 m apart along the river.

Gum Arabic, derived from the stems and branches of Acacia Senegal, is a mixture of hydrophilic carbohydrates and hydrophobic proteins. The hydrophobic protein component adheres to the surface of oil droplets, making it a good emulsifier. On the other hand, the hydrophilic carbohydrate portion prevents molecules from coalesc-

ing by generating electrostatic and steric repulsions. It is mainly made up of high molecular weight polysaccharides and their salts, which include calcium, magnesium, and potassium. When hydrolyzed, they release arabinose, galactose, rhamnose, and glucuronic acid. 5 kg of Gum Arabic was procured from the local market 'Muda Lawan' in Bauchi and used to prepare the resin. Absorption FTIR spectra were collected in transmission mode with an Agilent series spectrometer equipped with an ambient DTGS detector. The samples were analyzed over the 4000 cm⁻¹ to 650 cm⁻¹ wave-number range, collecting 140 scans at a resolution of 4 cm⁻¹, and a background scan was performed for every sample.

Sample Characterization. The grain size distribution (GSD) for Luwa sand was determined using the 20/40 mesh size, with the primary sieve, i.e. mesh No 20, which corresponds to 0.850 mm, and the secondary sieve mesh No 40, corresponding to 0.425 mm at a temperature of 25.0 °C. The sample weight retained on each of the 20/40 mesh sizes of the sieve stack was determined according to equations (1)-(6):

$$W_{DWS}(g) = W_{DWSP} - W_P \tag{1}$$

$$W_{DS}(g) = W_{DSP} - W_P \tag{2}$$

$$W_F(g) = W_{DS} - W_{DWS} \tag{3}$$

$$W_s = W_{spx} - W_p \tag{4}$$

$$\% \text{ passing } (\%) = \% \text{ passing last larger size} - \% \text{ retained} \tag{5}$$

$$\% \text{ retained} = (W_s \times 100) / W_{DS} \tag{6}$$

where W_p = weight of pan, g;

W_{DSP} – weight of total dry sand sample with pan, g;

W_{DWSP} – weight of total dry-washed sand with the pan, g;

W_{DS} – total dry sand, g;

W_F – weight of fines, g;

W_{DWS} – weight of total dry-washed sand, g;

W_{spx} is the weight of the sample and pan sp, while x stands for the mesh sieve numbers 16, 20, 25, 30, 35, 40, and 50, respectively.

The particle diameters were plotted in a log scale, and the corresponding percentages of gravel, sand, silt, and clay-size particles present

in sand were obtained from the particle size distribution curve as follows:

Percentage retained on any sieve:

$$= \frac{\text{weight of sand retained}}{\text{total sand weight}} \times 100\% \quad (7)$$

Cumulative percentage retained on any sieve:

$$= \sum \text{percentage retained} \quad (8)$$

Percentage finer than a sieve size:

$$= 100\% - \sum \text{percentage retained} \quad (9)$$

The particle size distribution curve was used to determine the adequate size, uniformity coefficient and coefficient of gradation. The diameter in the particle size distribution curve corresponding to 10% finer is defined as the proper size or D_{10} :

$$C_u = \frac{D_{60}}{D_{10}} \quad (10)$$

where C_u is the uniformity coefficient, and D_{60} is the diameter corresponding to 60% finer in the particle size distribution curve.

$$C_c = \frac{D_{30}^2}{D_{60}D_{10}} \quad (11)$$

where C_c is the coefficient of gradation, and D_{30} , the diameter corresponds to 30% finer.

The mean diameter, d_{av} , expressed in millimetres, was calculated according to:

$$d_{av} = \frac{\sum n \cdot d}{\sum n} \quad (12)$$

where $n \cdot d$ is the product of mid-size diameter (d) multiplied by the frequency of occurrence (n), the mean diameter is used to characterize proppant distribution for hydraulic fracturing applications.

Twenty random samples were selected from the 20/40 mesh sand and evaluated for sphericity and roundness by physical analysis through a magnifying microscope (30 times magnification) according to API/ISO and the visualized shape compared with the Krumbein and Sloss chart. The turbidity test was conducted on the sieved sand before washing it to determine the number of suspended particles. Turbidity of the Sand = (turbidity of distilled water + Sand) – (turbidity of distilled water). API/ISO standard should not

exceed 250 NTU for all proppants. The bulk density of Luwa sand was determined according to:

$$V_{cyl} = m_w / 0.9971 \quad (13)$$

where m_w is the net mass expressed in grams of water

To determine the amount of combustible materials in three representative samples, LS01, LS02, and LS03, a loss-on-ignition (LOI) test was carried out. The samples were heated to 900 °C in a furnace for 12 hours. The loss on ignition is recorded as mass before heating minus mass after heating multiplied by 100 %.

An X-ray fluorescence (XRF) was conducted on the sand using Ra IGAKU SUPERMINI 200, Sa Sequential benchtop WDXRF spectrometer at EPRI, and the primary elemental composition was determined. The hardness of the samples was determined according to the Mohs scale; the sands were scratched by corundum, which has a hardness number of 9, and diamond, which has a hardness number of 10 on the Mohs scale.

Gum Arabic resin-coated sand. Gum Arabic resin-coated proppant was prepared by washing the sand and then drying it. The resin and hardener were measured and mixed in a ratio of 3:1, respectively, using a measuring cup. The mixture was stirred vigorously using wooden sticks; a dropper was used to drop the mixture on the sand. The sand and epoxy resin slurry were then mixed to ensure the resin encapsulated the whole sand. When the resin and sand mixture was about to be set, the individual grain with the resin coating was transferred to a plane surface and cured for 24 hours.

Crush Resistance Test. Crush resistance tests are usually conducted on samples to determine the amount of proppant crushed at a given stress. This test helps select and compare the crush resistance of proppants. Tests are conducted on samples that have been sieved so that all particles tested are within the specified size range of 20/40 mesh size and sand particles within the diameter size range of (850–425 μm). In a crushed cell, the amount of proppant material crushed at each stress level is measured using a 2500 kN Hydraulic universal testing machine. Evaluation of test results should indicate the stress level where proppant crushing is excessive and the maximum stress to which the proppant material should be subjected [7].

The crush resistance test in this study was conducted using a 2500 kN Hydraulic universal testing machine equipped with a cell for proppant crush resistance testing according to ISO 1503-2, 2010, at stresses of 1000, 2000, and 3000 psi for uncoated sand. The crush test was repeated for 1000–6000 psi at a 1000 psi interval for gum Arabic resin-coated sands, and the results were compared.

The mass, m_p , expressed in grams, of sand needed for each test (to the nearest 0.1 g) is calculated according to the equation (14):

$$m_p = 24.7 \times \rho_{bulk} \quad (14)$$

where ρ_{bulk} is the proppant bulk density, expressed in grams per cubic centimetre.

The force required on the cell to attain the prescribed stress is determined using the following formula:

$$F_{tc} = \frac{\pi \times \delta \times d_{cell}^2}{4} \quad (15)$$

where F_{tc} is the force required on the test cell, expressed in newtons (pound-force); δ is the stress on the proppant sample, expressed in pounds per square inch (psi); d_{cell} is the test cell inside diameter, expressed in millimetres.

The amount of crushed sand is calculated and reported as a percentage, m'_{pan} , of the mass of sand placed in the cell. Each sand test was run in triplicate at the same stress, and the results were averaged (equation 16).

$$m'_{pan} = m_{pan}/m_s \times 100 \quad (16)$$

where m_{pan} is the mass of fines generated in the test, expressed in grams; m_s is the mass of the proppant used as the sample aliquot, expressed in grams.

An acid solubility test was conducted to determine the amount of soluble materials (e.g., carbonates, feldspar, iron oxides, clays, etc.) that must satisfy the thresholds recommended by API/ISO for use as a proppant. The crush resistance and acid solubility of the new resin-coated sand were also determined.

RESULTS AND DISCUSSION

Chemical analysis for 20/40 mesh size Luwa sand. The XRF analysis of three representative samples (Table 1) shows that Luwa sand contains more Al_2O_3 with values ranging from 29-53 % than SiO_2 with values ranging from 29-49%.

Table 1 – Chemical composition (XRF analysis) results for 20/40 mesh size Luwa sand

Elemental oxides	Elemental composition (%)		
	Luwa sand A	Luwa sand B	Luwa sand C
SiO₂	45.6	44.7	29.85
Al₂O₃	53.0	49.6	29.37
Fe ₂ O ₃	0.61	1.43	0.06
CaO	0.152	0.35	0.07
MgO	0.00	0.00	2.83
MnO	0.07	0.23	0.01
K ₂ O	0.36	0.00	0.06
P ₂ O ₅	0.08	0.09	0.10
TiO ₂	0.00	0.53	0.02

This means that the Luwa sand contains less composition of SiO_2 to be classified as quartz since the specification of acceptable sand must contain SiO_2 in the 95-99 % [6]. Geological studies have indicated that sands with chemical compositions showing a high percentage of corundum (a crystalline form of aluminium oxide, i.e., Al_2O_3) are known to be topaz. In contrast, sand is an aluminosilicate material having intercalation of Al_2O_3 and SiO_2 and other elemental oxides as impurities [8]. The XRF results, therefore, indicate that the Luwa sand requires some form of resin coating for applications in reservoirs with high closure stresses [8].

Particle Size Distribution. The particle size distribution, 20/40 for Luwa sand, is 100 % as all particles are retained between the primary sieve (0.850 mm) and the secondary sieve (0.425 mm). The percent passing, also known as the percent finer of the sand, is plotted versus the particle diameter to get the particle size distribution, as shown in Figure 2. The particle size distribution of Luwa sand satisfies the API/ISO standards because more than 90% of the sand falls within the specified particle range of 20/40 size. The Effective size, uniformity coefficient, and coefficient of gradation of Luwa sand were obtained from the grain size distribution curve 0.50, 0.56, 0.64, 1.28 and 0.98, respectively (Table 2). The mean diameter determined for the Luwa sand is 0.025 in.

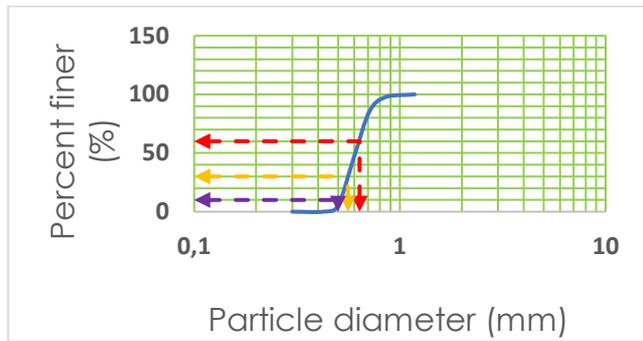


Figure 2 – Particle size distribution curve

Table 2 – Effective size, uniformity coefficient, and coefficient of gradation of Luwa sand

10 % finer D_{10} , mm	30 % finer D_{30} , mm	60 % finer D_{60} , mm	Uniformity coefficient C_u	Coefficient of gradation C_c
0.50	0.56	0.64	1.28	0.98

The sand is classified as densely graded for C_u greater than or equal to 6, indicating material with a considerable particle size range. In contrast, for C_u less than 4, the sand is classified as uniformly graded, which suggests that the material has a narrow range of particle size (used for maximum permeability). A densely graded sand has C_c greater than one but less than three if C_u is greater than or equal to 6 [7]. This indicates that Luwa sand can be classified as uniformly graded sand. This is highly desirable because of the potential of the sand to achieve maximum permeability when used as a proppant.

The sphericity of 20/40 mesh size Luwa sand, as well as the roundness of the sand, were determined to be 0.8 (Table 3). This implies that Luwa sand meets the API/ISO threshold of greater than 0.6 for sphericity and roundness and, therefore, can be considered for use as a proppant in the hydraulic fracturing of reservoirs [9]. The bulk density of Luwa sand was determined to be 1.64 g/cm³.

Table 3 – Sphericity and roundness results for 20/40 mesh size Luwa sand

Sample Code No.	Sphericity value	Roundness value	Sample code No.	Sphericity value	Roundness value
LS 1	0.7	0.9	LS 11	0.9	0.7
LS 2	0.9	0.7	LS 12	0.7	0.7
LS 3	0.7	0.7	LS 13	0.7	0.9
LS 4	0.9	0.9	LS 14	0.9	0.7
LS 5	0.9	0.9	LS 15	0.7	0.5

Sample Code No.	Sphericity value	Roundness value	Sample code No.	Sphericity value	Roundness value
LS 6	0.7	0.9	LS 16	0.7	0.9
LS 7	0.7	0.9	LS 17	0.9	0.7
LS 8	0.9	0.9	LS 18	0.7	0.7
LS 9	0.9	0.5	LS 19	0.7	0.9
LS 10	0.9	0.3	LS 20	0.7	0.7
Sum of values (m)				15.8	15.0
Number of samples (n)				20	20
Average value (m/n) to the nearest 0.1 unit				0.8	0.8

The amount of suspended particles on the sand presented (turbidity) determined for the Luwa sand is 28.98 NTU (Figure 2), which is also within the acceptable limit recommended by the API/ISO standard for good proppants (it should not exceed 250 NTU for all proppants).

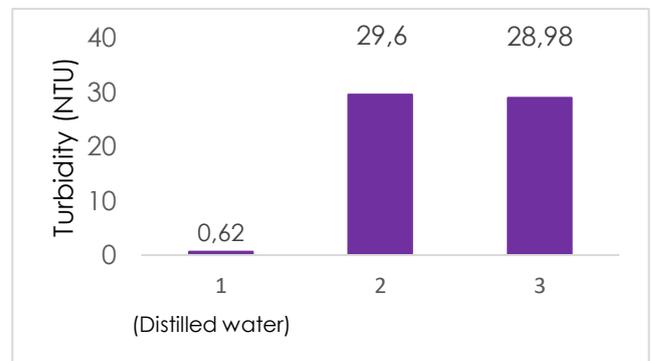


Figure 2 – Turbidity values for the Luwa Sand

Table 4 shows the acid solubility for the coated and uncoated 20/40 mesh-size Luwa sand. The acid solubility result indicates the amount of soluble materials (e.g., Carbonates, feldspar, iron oxides, clays, etc.) [10] and satisfies the range recommended by API/ISO.

Table 4 – Acid solubility for 20/40 mesh size Luwa sand

Sample	Initial weight (g)	Weight (g)	Solubility (%)
Luwa sand	5	4.965	0.70
Resin-coated proppant	5	4.784	4.32

FTIR analysis results for Gum Arabic. Figure 3 and Table 5 show the FTIRR spectrum of the gum Arabic used in this study. The spectrum displays the characteristic peaks illustrated in Table, similar

to typical gum Arabic peaks reported in other works [11].

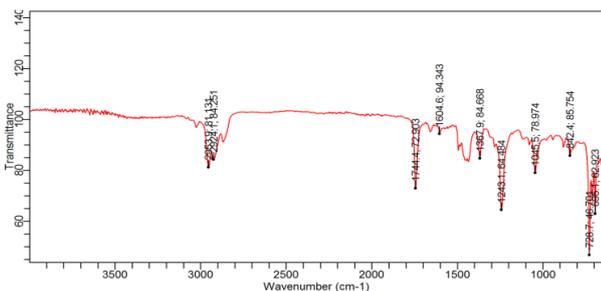


Figure 3 – FTIR Spectrum of Gum Arabic

Table 5 – FTIR Spectrum of Gum Arabic, characteristic peaks and functional groups

Frequency (cm ⁻¹)	Functional Group	Compound Class
3272.6	O-H stretching	Characteristic of a glucosidic ring
3310 – 3350	N-H amine stretching	Aliphatic primary amine
1636.3	C=O symmetric stretching	Cyclopentanone
1416.4	C-H bending	Alkane
1375.1	O-H bending	Phenol
1244.9	C-O stretching	Alkyl aryl ether
1036.2	S=O stretching	Sulfoxide

Crush Resistance of the Luwa Sand. The percentages of sand crushed at stresses of 1000, 2000 and 3000 psi for 20/40 mesh Luwa sand are presented in Table 6.

Table 6 – Crush resistance results for 20/40 mesh size for uncoated Luwa sand

Sample No.	Percentage crushed @ 1000 psi (weight %)	Percentage crushed @ 2000 psi (weight %)	Percentage crushed @ 3000 psi (weight %)
1	4.15	8.35	10.12
2	3.77	7.45	11.07
3	4.08	6.13	10.04
Average value	4.00	7.31	10.41

The test results indicate that the sand strength varies from 2000–3000 psi; suggesting that Luwa sand can be used for applications in wells with closure stresses of 2000 psi and less of that pressure. However, for wells with closure stress greater than 2000 psi, there is a need to coat the sand to make it more robust. Luwa sand has a 2 K value since it produces less than 10% fines at stresses less than 2000 psi [12, 13].

The crush resistance test on the resin-coated sand at stresses of 1000, 2000, 3000, 4000, 5000 and 6000 psi is shown in Table 7.

Table 7 – Crush resistance results for 20/40 mesh size for resin-coated Luwa sand

Sample No.	% crushed @ 1000 psi (weight %)	% crushed @ 2000 psi (weight %)	% crushed @ 3000 psi (weight %)	% crushed @ 4000 psi (weight %)	% crushed @ 5000 psi (weight %)	% crushed @ 6000 psi (weight %)
1	1.46	2.97	5.82	6.98	8.49	9.85
2	1.77	3.51	5.37	7.47	9.60	10.60
3	2.11	3.45	6.24	7.24	8.82	9.91
Average value	1.78	3.31	5.81	7.23	8.97	10.12

There is a significant improvement in the strength of the sand. Whereas the uncoated Luwa sand produced fines of 4.00%, 7.31% and 10.41% at pressures of 1000 psi, 2000 psi and 3000 psi, respectively, the resin-coated proppant produced fines of 1.78%, 3.31% and 5.81% fines generated at the same stress levels. This results in about 55.5% improvement of the proppant at 1000 psi, 54.7% at 2000 psi and 62.9% at 3000 psi due to coating. The resin-coated sand was ob-

served to generate more than 10% fines at a relatively higher pressure of 6000 psi, where 10.12% fines were produced. This is expected as high closure stress acting on proppants within the hydraulic fractures often crushes proppant grains into smaller fragments [12]. Authors [14] found that 5% fines can cause an over 50% reduction in the proppant pack conductivity, defined as the proppant pack permeability times the fracture aperture. Therefore, the resin-coated Luwa sand

can be classified as having a 5K value and can only be applied in reservoirs with a closure stress of 5000 psi or less.

The loss on the ignition test indicates that the Luwa sand has some ignitable materials as impurities, and their percentage composition ranges from 1.33% to 1.64%. However, the API/ISO recommends a range of less than 3.12% for consideration as a proppant. Table 7 is a summary of the proppant characteristics of the Luwa Sand. The hardness of three samples was determined to be eight as all sands scratched all the minerals on the Mohs scale, from talc with a hardness value of 1 to quartz with a hardness value of 7.

Table 8 compares the Luwa sand closely with the Ottawa and Brady sands and the API/ISO standards. Although the sand exhibits low crush resistance, a significant improvement was recorded when coated with gum Arabic resin polymer.

Table 8 – Summary of characteristics of the Luwa sand 20/40 mesh

Property	Result	Api / ISO requirement
Particle size distribution	100 %	Narrow size-distribution 90 % within the specified size ranges, e.g. 20/40 (850–425 μm)
Mean particle diameter	625.2 μm , 0.625 mm, 0.025 n	N/A
Roundness	0.8	≥ 0.6
Sphericity	0.8	≥ 0.6
Turbidity	28.98 NTU	< 250 NTU
Bulk density	1.64 g/cm ³	< 2.0 g/cm ³
Acid solubility	0.7% sand &	< 2 % Sand & < 7% RCP

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Property	Result	Api / ISO requirement
	4.32% RCP	
Crush resistance	2 K value (Luwa sand) 6 K value (RCP)	< 10 % fines
LOI	1.33%, 1.47%, 1.64%	< 3.12 %
Hardness	8 (Mohs scale)	N/A

CONCLUSIONS

The physical, chemical, and mechanical properties of Luwa sand, as shown by API RP/ISO 13503-2, exhibit promising potential for consideration as a commercial proppant. X-ray fluorescence (XRF) analysis results indicate the material as topaz, a mineral mainly used in refractories. Although quartz is ideal for proppant application, the Luwa sand can be fortified with polymer resins in reservoirs with closure pressures over 3000 psi. The 20/40 mesh designed proppant produces less than 10% fines at stresses less than 2000 psi and is considered to have a 2 K value, while the resin-coated proppant can be classified as having a 5K value and can only be applied in reservoirs with closure stress of 5000 psi or less.

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