Credence of Elastic Properties of Ughelli Sandstone on Microstructure

A. G. Olugbenga, *Member, IAENG,* and S. J. Antony

***Abstract*—The elastic properties of sandstones depend on their geological environment. The differences in these geological structures are responsible for the challenges in establishing a common value for rock properties. The aim of this research is to obtain the Young's modulus and Poisson's ratio for sandstone using simulation and to compare the values with those derived from experimental Linear Variable Differential Transformers (LVDTs) method. The procedure included the determination of the Young's modulus, Poisson's ratio and bulk modulus for samples of sandstone. The porosities of the samples were obtained because they are relevant to the productivity of oil reservoirs. The next procedure employed the use of a photo-stress tomography for the micro-measurement which describe the microstructure of the material. All tests were performed on a commonly sourced core sample from Ughelli. Next, a particle- flow-code simulation was carried out. Three types of grains having different spherical index (sphericity) where generated by simulation, and were used to develop three samples of sandstone. Model 1, model 2 and model 3 were simulated and the porosities of the samples were 0.29, 0.27 and 0.25 respectively. Model 3 is the model represented by a grain having a combination of two dissimilar sphericity and it has a good fit with the porosity of the natural sandstone. Thus, the sample exhibit a steady increase in modulus when the confined pressure induces strain into the sandstone. As the compaction of the inter-granular contacts interferes with the porosity of the rock, the material exhibit quantitative changes in the compressive strength, Young's moduli and Poisson's ratio. The role of the microstructure of the rock on the porosity is hereby explained. Therefore, probing the microstructure of the rock is an important procedure in the simulation of sandstone.**

***Index Terms*— Reservoir sandstone, Young's modulus, Poisson's ratio, compressive strength, porosity, microstructure**

I. Introduction

THIS study on reservoir characterization requires that rock properties should be presented as a quantitative value. Sandstones, as a class of sedimentary rocks, are the common reserves for oil and gas. Their properties, in turn, control the deliverability of hydrocarbons. Their porosity and the associated grain parameter determine production efficiency and are yet to be fully understood. Therefore, the effective production from subsurface remains a stiff challenge in the oil industry.

The properties of sandstone and some equations that correlate these properties have been classified. An example is the study reported by [1]. These researchers provided three essential groups of parameter for rock. The first category of parameter has been named definitive parameter or primary parameter, because these are the basic description of oil reservoirs. The definitive properties are texture, grain composition, structure of the sedimentary rock which include the morphology and size of the reservoir matrix. These characteristics are described typically with the aid of the surroundings of deposition and by means of the source materials. Therefore, primary properties exert a number one control on different parameter of the rock, which consequently, had been referred to as dependent or secondary properties. The dependent or secondary parameter consist of the Schmidt hammer value (SHV), bulk density, permeability, effective porosity, factor load strength index, and other parameter yet to be found. A third class of properties has been called tertiary or latent properties. The logging done by geophysical means are the third category which yields data on radioactivity, sonic tour time and spontaneous potential.

Through the textural parameters, the index porosities or the secondary porosities of the sandstone are obtainable. [2] has reported on textural parameter. The predominant factors of texture are size of the grain, the packing of the grain and the degree of sorting. The grain size and the degree of sorting are the essential and generally measured factors. Assessing grain packing in a two dimensional (2D) segment of rock is complicated because the directions available for assessment is limited to two. Consequently, this 2D means are typically not accurate, and, is recommended that the assessment of reservoir rocks should not be limited to 2D. But the effect of sorting on index porosities should serves as an additional assessment. Adding a third direction can be explicit because of the three dimensional approach it reveals in the model structure. That is, the grain shape and size can be studied. Also, the grain size can be described and the direct influence of the sizes on porosity are somewhat realistic. The general description for reservoir sandstone are still understudied and are provided by a number of investigators [3]-[8]. In this paper, the changes in porosity are expressed through elastic properties by a change in the spherical index of grains using numerically modeled samples. The values of the elastic properties obtained due to the grain shape can be used as an indicator for porosities in reservoirs. This is significant and may be among other properties a quantitative results for reservoir characterization

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[24].

The recorded data on formation rock have shown that their petro-physical and mechanical properties vary widely. These variations within the properties of sandstones, have been connected to the diversities in some petrographic structure which are peculiar to the geological formation [9]-[13]. The petrographic properties which affect the formation, consist of the degree of sorting, grain size, grain shape, the degree of grain interlocking, the grain packing and the binding mineral [14]. These elements may be obtained experimentally [8], [15] and are generally measured at some stage in thin section of rock under microscopy and diffraction methods [16]-[19].

Theoretically, porosity is independent of median grain size. Most often, the ideal numerical model of rock, which corresponds to the highest degree of sorting, is not found in natural formation. Recorded data have shown that natural deposit with well sorted grains have an effect on the porosity of the formation [20]. There are results that shows that porosity decline with growing median grain size. [21] In some characterization, the porosity of reservoir is between thirty nine percent and forty one percent, some are about forty one percent to forty eight percent, and forty four percent to forty nine percent, these values are for the coarse, medium and fine sandstone respectively. [22] stated that as the grain size become bigger in size, the corresponding porosity reduces slightly. This occurrence was observed for the three categories of cementation. The Niger Delta sandstone have a specific value of porosity reducing from approximately forty two percent to twenty six percent when the grain size extended from forty five to one thousand microns in diameter. The moderately sorted sand and well sorted sand in Niger delta was regarded to exhibit lower porosity with larger grain size [2]. This appears to contradict simple packing theory. Therefore a further research is needed for the Niger Delta sandstone. Prior to the report provided by [2] an evaluation was done by [7] for carbonate rocks, where larger grain size will increase porosity. He referred to the relationship between porosity and grain size to be general for detrital rocks using the petrographic rock image. [2] made use of sandstone, indicated that the connection between effective porosity and grain size is significant within some statistic values and there is a tendency for porosity to vary linearly with median grain size. Synthetic sand were generated by [23], the sample were well sorted, and it was shown that porosity does not depend on grain size. The same result was obtained by [24] where grain sizes were taken as perfect spheres. They found that, porosity is independent of median grain size. Additionally a poor correlation between medium grain size and porosity was provided by [25] proving that; a significant correlation between these properties are not obtainable. However Katre and Nair [4] advanced on the same line of study and modelled the sorted sandstone but the results of the former is yet to be validated.

Therefore, there are inconsistent facts on how the grain size affect porosity within the Niger Delta formation. The bulk density of reservoir are critical, it dependents on the composition of the grains. It affects porosity and any element tending to lower the porosity produces a growth in density. The procedure in this current research fixes micro-parameter (obtained from experiments) as constant while the adequate grain shape is sought for in using simulations. Hence the natural rock was reproduced numerically, characterized by the original strength and microstructure. The micro-measurement from the sandstone was adopted as a major procedure to validate the factor that controls the macroscopic response of the rock to stress.

II. METHODOLOGY

The test specimen is a reservoir sandstone. It was cored from a depth of 2000m from Ughelli. The petrographic and XRD analyses of the sandstone shows that it is moderately well sorted but it is a compacted sandstone comprising 65-72% detrital minerals (mainly quartz grains), the specimen has digenetic infill. The grains are bonded by clay cementation. The test specimen is a cylindrical core having 90mm in length and 38mm in diameter. This sample was simulated by generation of particle. By using Particle flow Code (PFC), the simulated specimen was tested. PFC is capable of testing a discreet sample of given length and and diameter. In the PFC, the variation of particle shape was included. Thus three sphericity were simulated and tested. The sphericity values were 0.959, 0.924, and 0.892 respectively. The porosity were estimated for the three model samples. In order to obtain the microstructural description, the progressive elastic parameter for the experimental sample were obtained using photo stress tomography. The details of this test is found in the research work done by [18]. In order to evaluate the possible matrix damage and extent of microstructural changes, overburden pressure (5MPa, 10MPa, 15MPa and 20MPa) were induced on the sandstone, next the porosities were measured from the weight of the dry and fully saturated specimen (as 25%). The Young modulus, compressive strength and Poisson’s ratio were determined by the ISMR procedure which is provided by [26].

III. RESULTS

Following the procedure in the methodology. It was necessary to obtain the microscopic image of the sandstone samples.

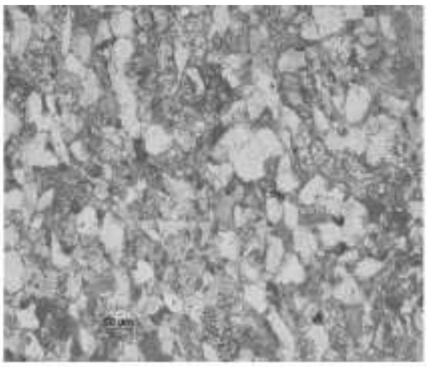

Fig. 1. Microscope Image of Ughelli Sandstone .

A thin sheet of the sandstone was prepared and the surface was gold plated. Fig. 1 presents the microscope view, an assembly of discrete grain with finite clay – cemented contacts were observed. Hence, the grain boundaries were visualized, the elemental points had the boundaries and interlock arrangement due to the varying grain shapes in the sample.

The distribution of the grain sizes lie between 80μm to 129μm which was within the specification of the coarse sizes, ranging into the fine grains (Fig. 1). Hence the observed variation in grain shape and sizes necessitated the choice of various sphericity in the simulation of the sandstone.

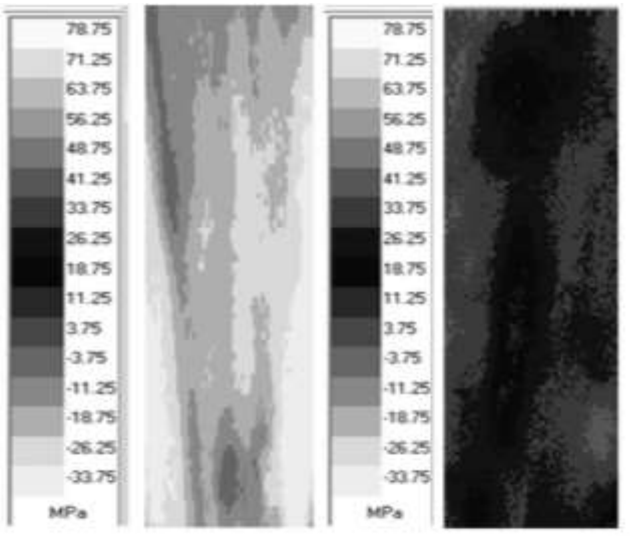

Fig. 2. Fringe patter on sandstone at 11MPsa (left) stress and at 26MPa stress (right).

The point modulus were obtained at stressed points inside the core sample (Fig. 2): The value of modulus increased linearly until the critical strength of sandstone was reached. The photo stress tomography is presented in Fig. 2. Under a progressive stress application. The stress changes was observed from the scale in the fringe patter in Fig. 2. This was validated by an investigation conducted by [27] where the mineral composition was the factor responsible for the sensitivity of modulus to the internal deformation in the sandstone. This implies that, some mineral type determines the crack density of the rock which they constitute. That is higher crack densities indicate lower Young modulus property of the rock. These minerals are therefore considered as the mineral supports that are responsible for the 78MPa yield stress and the 20.7GPa obtained for the yield stress and the bulk modulus respectively. Quartz and mica mineral are found in Ughelli sandstone. The porosity is 25%. Therefore the sample is porous (with the mineral support, the rock is characterized to have a strength of 78MPa). While pore space was observed in the sample; the compressive strength is also dependent on the porosity of the sandstone. Therefore, the Young Modulus is 20.7GPa and the Poisson’s ratio is 0.26. The mineral type distinguishes the mechanical behavior for the rock sample from other types of sandstone. [18]-[19].

Another procedure includes setting the micro-parameters used for discrete modelling of deformability in sandstone: an ordered means of setting micro-parameters for deformability is to specify (1) the grain modulus (2) the normal to shear stiffness ratio of grain contact. These micro-parameters were set with the experimental quantitative value estimated from the experimental models carried out. Next three different particle shapes were used to represent the quartz grains shown in Fig. 3 to develop three discrete models.

Fig. 3. (a) a two-particle clump used to develop model 1, (b) a 3-particle clump used to develop model 2 and (c) a mixed particle clump used to develop model 3.

IV. DISCUSSION OF RESULTS

In Fig. 4-6, the fully unconfined compression test for both the experimental and the three discrete models were plotted. The modulus, the Poisson’s ratio and the Uniaxial Compressive strength were obtained from the standard test and are presented in the Fig. 4-6.

By providing experimental micro specification for the discrete model, we obtained a bonded-clumped-particle-model for the Niger Delta sandstone. The models tested includes 2-particle clump model (model 1), three particle clumped model (model 2) and mixed particle clump model (model 3) (Fig. 3). The three models show that the bond breakage stress dependents on the particle stiffness. Apparently, a relationship holds for degree of spherical-index and the model elastic response which implies that the stresses on the wall of a wellbore can be managed with particles with low spherical-index because they can bear higher stress. Therefore, the crack initiation and crack damaged stresses are raised by porosity collapse. If unstable crack growths are minimized and fracture propagation is hindered with particle shapes, then it is convenient to state that; these micro-features appear fundamental to rock deformation.

By approximation, model-1 has porosity value of 0.28, model-2 has a porosity value of 0.27 and the model-3 has a porosity value of approximately 0.25. The natural sandstone had a porosity of 0.25. This is because the textural properties of the clastic sandstone are the sorted arrangement which are at first connected with the depositional interaction.

Granular sorting alludes to the spread of the grain-size populace. Packing alludes to the amount of grain in the rock matrix. The two former descriptions are intently connected to porosity. For sorted granular packs in a similar strain condition, packing and sorting were observed as the prevailing systems influencing the formation porosity, and is by and large determined from rock-material. Some models are of spherical-shaped granular assembly [28]-[30]. Nonetheless, the reason for the need to search contact models is due to the unknown coordination number and the super position of utilizing perfect sphere to represent grains. Based on this fact, the coordination number was accounted for in the grain-contact model by varying the sphericity of the grain. As the simulation progresses by the generation of spheres with different spherical shapes, a sensible replication

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of the natural sandstone was achieved (Fig. 4-6).

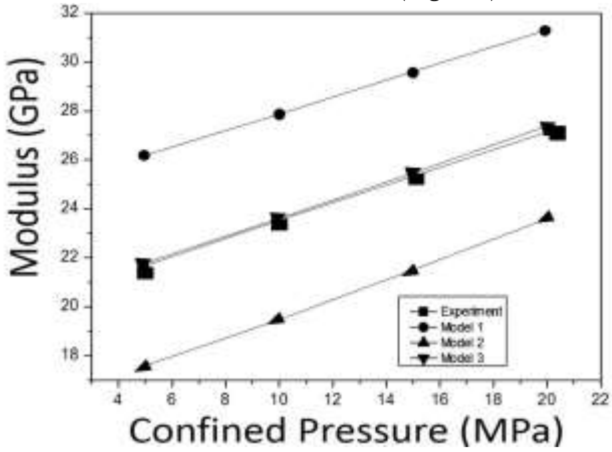

Fig. 4. Effect of Confined pressure on Modulus for Ughelli Sandstone.

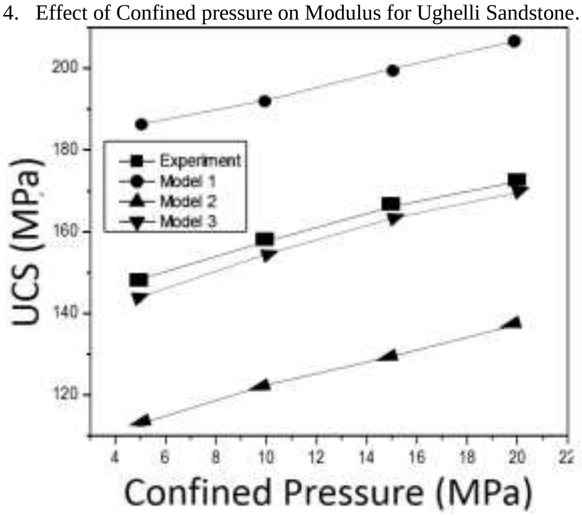

Fig. 5. Effect of Confined pressure on UCS for Ughelli Sandstone.

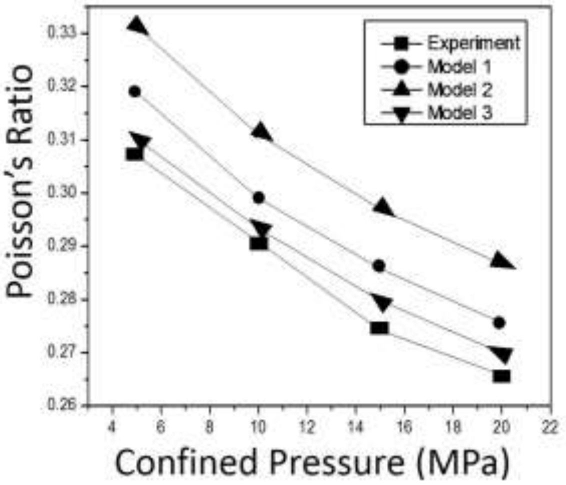

Fig. 6. Effect of Confined pressure on the Poisons ratio for Ughelli Sandstone.

That is; the sorting and the packing of the simulated sandstone was actualized because the Young Modulus and the Poisson's ratio obtained after simulation were in agreement with the laboratory test on the sandstone.

The impact of the clay-cemented contact model

It is known that the unconsolidated sands turns out to be the consolidated sandstone in the process of digenesis. The bonded grain might be digenetic quartz, calcite, albite, or any of the peculiar minerals in the depositional environment in Ughelli where the sample was taken. The cementation therefore has an inflexible, hardening impact, on the grounds that; the grain contacts are stuck together [28]. Regarding the clay-cemented contact, [29] and [30] have emphasized the impact on sandstone properties. Adding that; the distribution of cementation is additionally a key boundary that influences the modulus of the sandstone hence the pore collapse, Fig. 1 and Fig. 4-6 can serve as quantitative and qualitative values to describe the microstructure of the samples.

Some other investigators [31] demonstrate that porosity by and large is influenced by the sorting of the grains having a linear relationship. Our results showed that when two grain sizes are blended the natural sandstone is adequately simulated. Also when two grain shapes are mixed porosity is decreased until both grain sizes are available in around equivalent ratio. This is in agreement with the theory reported by [32] and [33].

V. CONCLUSION

The estimated contact model is deduced because the experimental data from natural sample was successfully simulated to generate the numerical sample. The mixed clump shape representing grain shape is proposed to be contained in sandstone. This is because, the strength and elastic properties were the same for both the experimental and numerical results even under overburden pressure. It is also important to note that, the strength characteristics of rock includes associated matrix of the cement binding the constituent grains.

The behavior of the natural rock can be predicted from simulation results if data from natural rocks are used as calibrations. Uniaxial compressive test coupled with photo stress analysis is a synergy/route to micro-property estimations. Clearly visible fringes revealed grain-overlaps which enhance the identification of contact model between contacting grains.

Grain morphology affect elastic properties which is crucial to strain localization occurring along the isochromatic fringe path. The impacts of grain shape on porosity by rule means that; porosity diminishes as sphericity because of the tight granular packs which correlated with high indexed-shaped grains.

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