PROPOSING A SAMPLE PREPARATION PROCEDURE FOR SANDING EXPERIMENTS

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Abstract
The Authors, during past few years, have performed research on sand production under true triaxial stress conditions. To simulate sanding, $100 \times 100 \times 100$ mm^3 cubic samples were placed in a true triaxial stress cell (TTSC) and three independent stresses were applied while the pore pressure was increased inside the cell. This resulted in sand grains to be produced through a drilled hole in the sample centre. The experiences obtained through testing several synthetic samples have indicated the significance of sample preparation to obtain valid results. Therefore, in this paper the procedure for preparation of synthetic samples suitable for a sanding experiment is proposed. Also, details of sample preparation for conventional rock mechanical tests to estimate rock physico-mechanical properties including deformability properties, strength parameters and permeability will be presented.

1.   Introduction

Sand production mainly occurs in unconsolidated or weakly consolidated sand formations (Morita and Boyd, 1991). To investigate the impact of different parameters, sanding has been simulated in laboratories since 1930's (Terzaghi, 1936). Unconsolidated sands are mainly tested to study the arching effect while applying stresses and fluid flow through the sample (Hall and Harrisburger, 1970, Tippie and Kohlhaas, 1973, Bratli and Risnes, 1981). The unconsolidated samples consist of loose sands without any cementing bond. On the other hand, weak consolidated sands are tested to study the failure mechanism in the vicinity of a borehole under different states of stress and fluid flow conditions. Weakly consolidated sands used for laboratory experiments are either real sample taken from the outcrop or manufactured synthetically (Papamichos et al., 2010, Nouri et al., 2004).
Although it is preferable to conduct tests on real samples, this is subjected to some limitations. Firstly, it is not practically possible to collect an intact sample of weak-consolidated sandstone from underground due to the sample being highly incompetent. Secondly, the physico-mechanical properties of real rocks taken from outcrop are not identical while it is possible to make synthetic samples with reasonably similar properties (Perkins and Weingarten, 1988). Therefore, it is more advisable to use synthetic samples for sanding tests. Sophisticated methods have been proposed to generate more realistic synthetic samples (Wygal, 1963, Heath, 1965, Holt et al., 1993). To obtain a sample suitable for this purpose it is important to establish a consistent sample preparation procedure. In addition, prior to the sanding experiment, a series of

conventional rock mechanical tests need to be carried out to obtain the physico-mechanical properties of the synthetic rocks. The procedure of conducting sanding experiments using these samples has been discussed in a separate paper (Younessi et al., 2012a). In the following sections the details of sample preparation, a review of the equipment used and some results obtained are presented.

2.   Mixture components

Synthetic sandstones are basically composed a mixture of sand, cement and water. The mechanical properties of the produced sample are a function of the individual components used in the mixture. The considerations to produce a synthetic sample for sand production experiments purposes are quite different from those used in civil engineering applications. For instance, in civil engineering concrete or mortar must have a minimum strength to sustain the loading when it is used in constructions; whereas in sand production experiments the sample must have a maximum strength limitation.

It has been observed that a small variation in properties of the initial components in sample preparation may have a significant change in the properties of the final product. This indicates the importance of careful selection the basic components.

The size of the grains selected for sample preparation depends solely on the purpose of the undergoing study. The size of the grains selected for our sanding experiments was selected to be 500 μm. This was decided based upon three main reasons. Firstly, the sanding experiments were conducted on $100\times100\times100$ mm^3 cubic samples with a borehole drilled at its centre. A 15 mm hole was found adequately small relative to the sample size to avoid the boundary effects on the stresses around the borehole. Secondly, it was planned to model the experiments numerically using particle flow code (PFC), which is a discrete element based software. In PFC 2D discs in 2D (balls in 3D) are used to model the rock grains and having large number of grains increases the computation time. Choosing 500 μm for the size of sand grains was found to be within a reasonable range for having comparable simulation models converged in a timely manner. Thirdly,
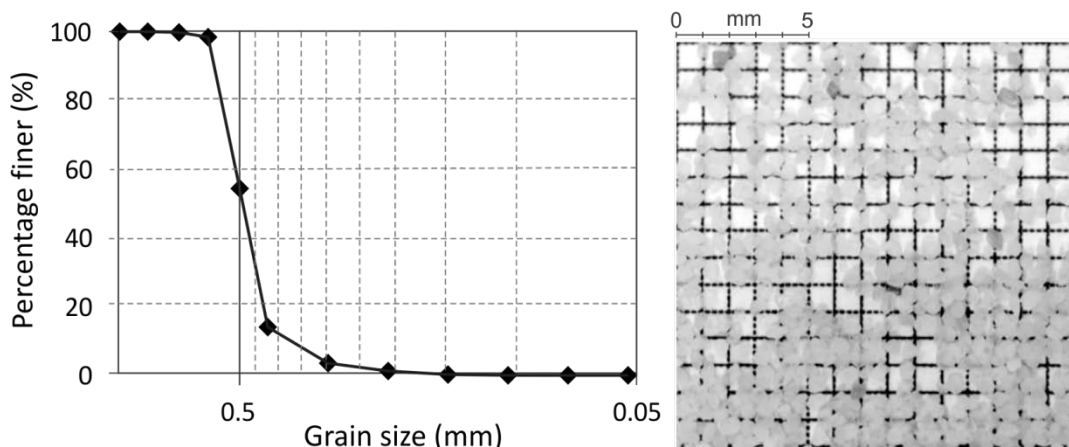

Figure 1. Grain size distribution curve for a typical synthetic sample made for sanding experiments.

this grain size distribution resulted in a porosity of 0.25 to 0.35, which gives the sample mechanical properties close to what is expected for weakly consolidated to unconsolidated sandstone, i.e. similar to real samples prone to sanding in the field. In Section 6 typical physico-mechanical properties for a synthetic sample used for sanding experiments are presented. Figure 1 shows the grain size distribution of a typical sample manufactured synthetically for sanding experiments.

3.   Mixture preparation

Different mixes of sand, Portland cement and water were prepared and tested to obtain samples with desirable characteristics for sanding experiments. The main challenge was to obtain a mixing whose uniaxial compressive strength was less than about 7 MPa, which is similar to weakly consolidated sandstone. The proposed mixture was similar to what was proposed by Nouri et al. (2004), which consisted of sand-cement and water-cement weight ratio of 10 and 1.25, respectively.

The required volume of sand was estimated based on the number and size of the moulds used for sample preparation. Subsequently, the amount of cement and water were calculated. In Figure 2, the sequence of the mixing program followed in the lab is illustrated.

a) The components were precisely measured.

b) Aggregates and cements were mixed in a bucket. The cement was screened to ensure no cement coagulations were entered the mixture.

c) Aggregates and cements were mixed for at least 5 mins to prepare an even mixture.

d) Water was added gradually to the mixture in separate stages.

e) After adding the water, the components were mixed for at least 10 mins.

Figure 2. Mixture preparation steps.

4.   Casting process

Synthetic sandstones were casted in moulds with different shapes and sizes for different tests. Samples used for sand production experiments were $100\times100\times100$ mm^3 cubes. These samples were casted in standard concrete moulds. The procedure of casting synthetic samples is illustrated in Figure 3.

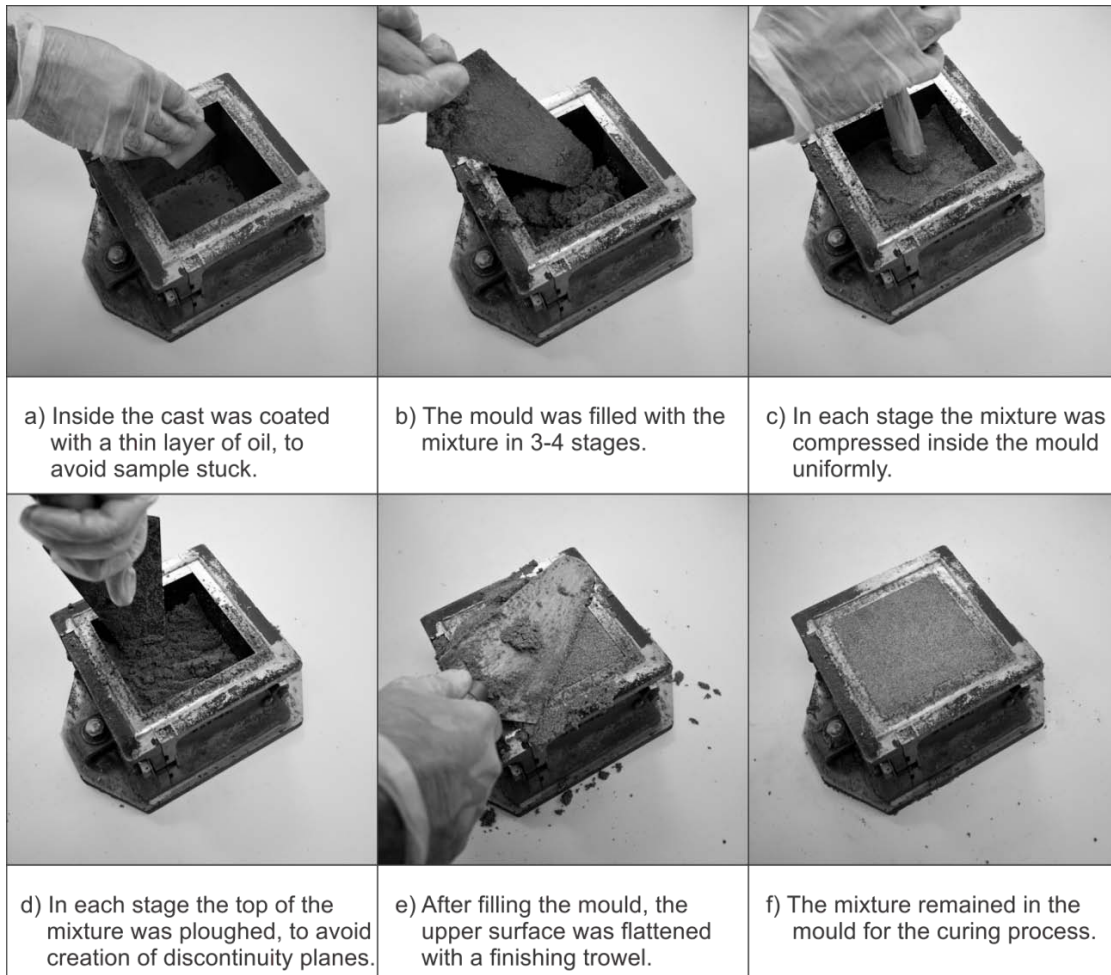a) Inside the cast was coated with a thin layer of oil, to avoid sample stuck.

b) The mould was filled with the mixture in 3-4 stages.

c) In each stage the mixture was compressed inside the mould uniformly.

d) In each stage the top of the mixture was ploughed, to avoid creation of discontinuity planes.

e) After filling the mould, the upper surface was flattened with a finishing trowel.

f) The mixture remained in the mould for the curing process.

Figure 3. Casting procedure and considerations.

Figure 4. 10 cm cube (left) and cylindrical moulds (right) used for casting the samples.

Cylindrical samples were required to determine the physical and mechanical properties of the synthetic sandstones through performing standard laboratory tests. It was not possible to retrieve cylindrical cores from the cube samples. Due to low cement bonding strength, the outer surface of the sample was prone to severe damage during the process of coring, resulting in a rough surface. Therefore, customer-designed cylindrical moulds were manufactured to cast samples with similar dimensions of plugs used in petroleum applications, i.e. sample height of 7.62 cm and diameter of 3.81 cm. Figure 4 shows both cubic and cylindrical moulds used in this study.

5. Sample Curing

The cement was not strong enough to bond sand particles in the early stage of curing. Hence, the sample loses its integrity by taking it out of the mould earlier than three days. The samples were then submerged into water and cured for 18 days. In order to reduce the effect of over-curing, the samples must be dried after they were taken out of water. The samples were left in an oven with a temperature of 60°C for two days. Thereafter, to reduce the effect of weathering the samples were plastic wrapped and stored in a dry room environment. Figure 5 shows different steps of sample curing.
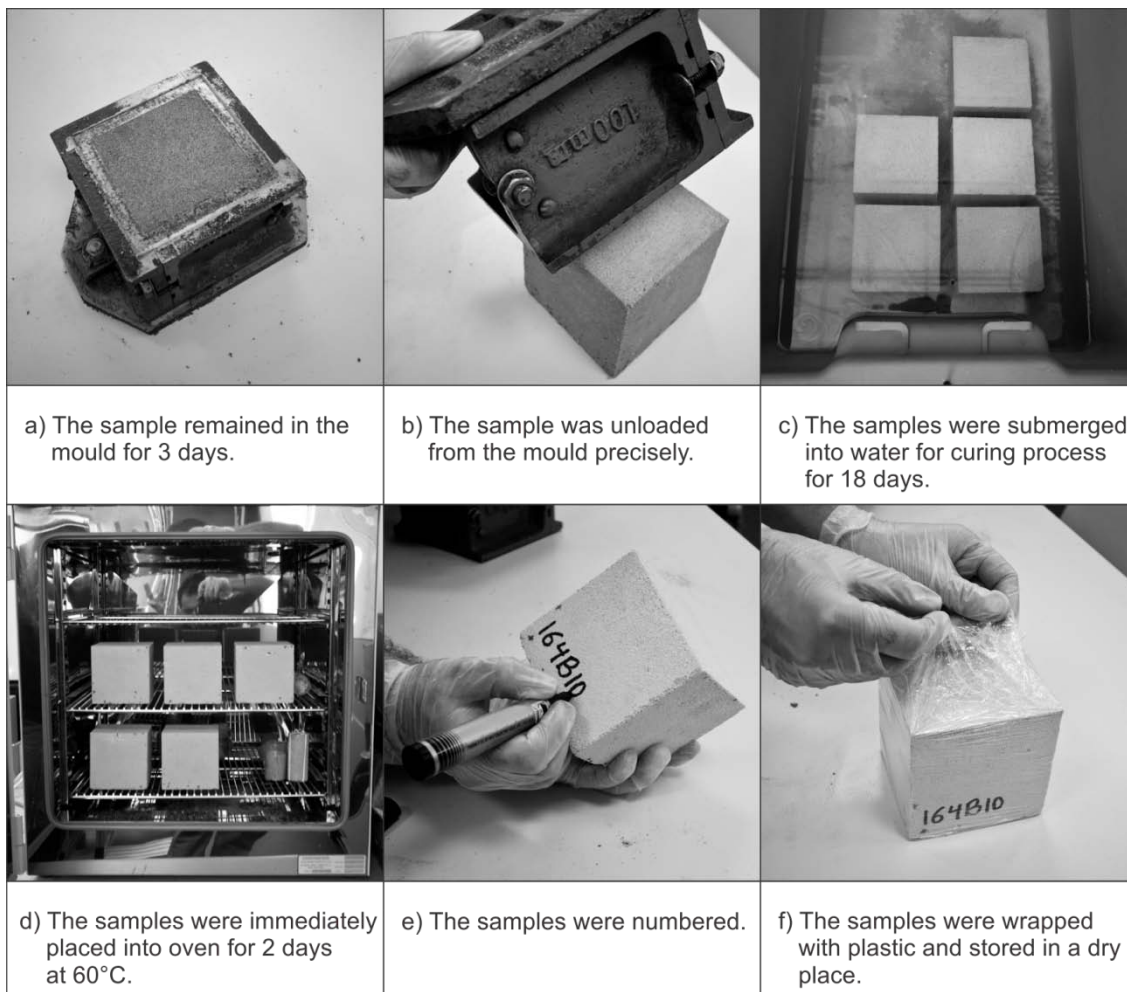

a) The sample remained in the mould for 3 days.

b) The sample was unloaded from the mould precisely.

c) The samples were submerged into water for curing process for 18 days.

d) The samples were immediately placed into oven for 2 days at 60°C.

e) The samples were numbered.

f) The samples were wrapped with plastic and stored in a dry place.

Figure 5. Sample curing and storing steps.

6.   Sample properties

Properties of the synthetic sandstone made for sanding experiments were estimated through conducting series of standard tests. The density and porosity of the sample were measured using the method suggested by international society for rock mechanics ISRM (Franklin et al., 1979). The permeability of the sample was measured using a pulse decay permeameter where Helium gas is used as the injecting fluid. The physical properties and permeability of a typical sandstone sample suitable for sanding experiments is tabulated in Table 1. A sample with properties close to those given in Table 1 is seen to be similar to a weakly consolidated sandstone which is prone to sand production during drilling or production from a reservoir.

Table 1. Physical properties and permeability of a typical synthetic sandstone made for sanding experiments.

Bulk density	Grain density	Porosity	Void ratio	Permeability
1815 kg/m^3	2500 kg/m^3	0.274	0.377	1.6E-13 m^2

Deformation properties (e.g. Young's modulus, Poisson's ratio, etc) and strength parameters (e.g. cohesion, friction angle, etc) are essential information required to estimate the stress distribution and failure zone around the borehole in a sand production laboratory experiment. These parameters were estimated through uniaxial and triaxial tests conducted on cylindrical samples.
A uniaxial compressive frame equipped with a 3.81 cm size Hoek triaxial cell was used to do these tests. The axial compressive stress was applied using a hydraulic cylinder connected to a double-piston pump. The confining pressure was controlled in a servo-control manner using a plunger pump. Axial and confining stresses and deformation of the sample were monitored continuously using a data acquisition system.
The ISRM suggested methods were followed to determine the unconfined compressive stress-strain curve of the sample and deformation properties (Bieniawski et al. 1979). The stress-strain curves under different confining pressures are depicted in Figure 6. Table 2 shows the deformation properties derived from the stress-strain curves.

Table 2. Deformation properties of a typical synthetic sandstone made for sanding experiments.

Young's modulus	Poisson's ratio	Shear modulus	Bulk modulus	Biot's constant
7.65 GPa	0.184	3.23 GPa	4.04 GPa	1

A series of triaxial tests were carried out under different confining stresses to derive the strength parameters of the synthetic sample (Figure 6). The tests followed the ISRM suggested methods (Franklin, 1983). The ultimate strengths for different confining stresses were used to define the failure envelope. The sample's yield envelope may also be defined from the yield points. However, in rock engineering problems it is more

common to use the failure envelope in the analysis, in addition to the fact that here the failure of the synthetic sample around the borehole is the main study focus.
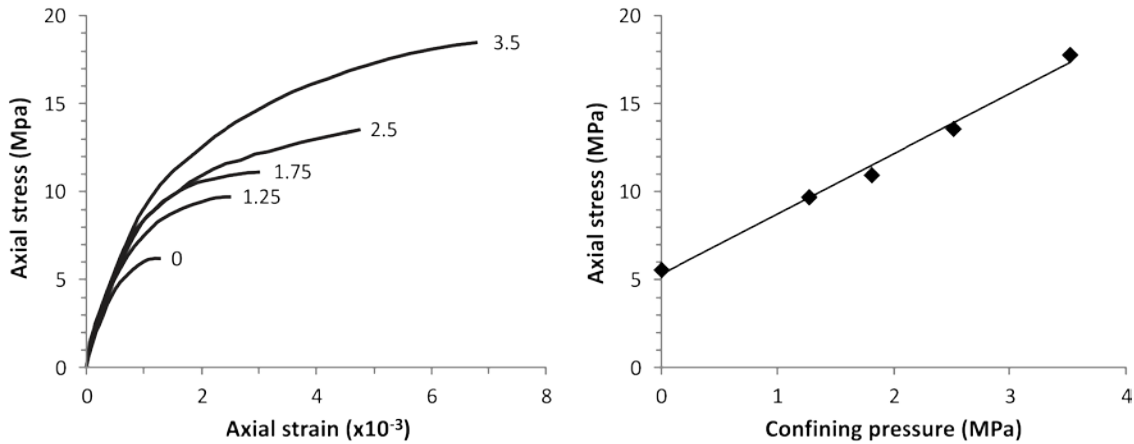

Figure 6. Stress-strain curves under different confining pressures in MPa (left), and the failure envelope of sample (right).

For the purpose of this study, two different failure criteria were used to model the sample failure in sand production laboratory experiments, i.e. Mohr-Coulomb and modified Drucker-Prager. These two failure models were used in the numerical analysis to simulate the laboratory experiments (Younessi et al., 2012b). Table 3 shows the strength parameters of a typical synthetic sample made for sanding tests.

Table 3. Strength parameters of a typical synthetic sandstone made for sanding experiments.

Uniaxial compressive strength	Tensile strength	Mohr-Coulomb		Modified Drucker-Prager		
		Cohesion	Friction angle	Shear yield stress	Friction angle	Flow stress ratio
5.4 MPa	0.7 MPa	1.5 MPa	32.6 deg	3.0 MPa	52.8 deg	1 & 0.8

The triaxial tests were initially conducted according to a multi-stage scheme. The setup of this test was similar to the single stage tests. The tests procedure followed the method suggested by ISRM (Franklin, 1983). However, for several reasons it is recommended to conduct single-stage test to obtain the stress-strain curves when dealing with synthetic samples. Some of the reasoning for this is that:
-   conducting the tests on different specimens and observing consistent results means that the samples have been generated uniformly. With synthetic samples there is access to many samples for testing purposes.
-   The axial loading in multi-stage tests must be stopped before the sample reaches its ultimate strength, or practically its yield point. This means that the estimated strength is not a correct representation of the actual rock strength. If one wants to derive the rock yield envelope instead of the failure envelope this approach may be preferable.

7.   Conclusion

In this paper the importance and the need for making synthetic samples for sanding laboratory experiments were discussed. The sanding experiment setup and procedure has been discussed in a separate paper (Younessi et al, 2012a). A sample mixing program presented to prepare synthetic samples representing a weakly consolidated sandstone: this is the type of sandstone prone to sanding in real field conditions. The process of casting and curing the sample was explained in detail. Finally, mechanical properties as well as the range of porosity and permeability of a typical sample made through the proposed preparation scheme presented. The samples obtained from the proposed mixture has mechanical properties similar to a weakly consolidated sandstone which is prone to sanding.

8.   References

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