ROCK PHYSICS FROM SMALL SAMPLES - SOMETIMES YOUR ONLY SOLUTION

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ABSTRACT

This paper illustrates the potential of using small shale samples, including cuttings, as a tool for determining rock physical parameters on field material. The measured static and dynamic mechanical results are basically consistent with those attained on larger, standard plugs in triaxial cells. Consequently, small samples can be used as a complementary tool to larger samples, providing faster and less expensive results with less material consumption, also allowing for larger test matrices. In some cases, use of small samples may actually be the only solution to obtain direct measurements on the shale material.

INTRODUCTION

To reach hydrocarbon reservoirs, one often has to drill through various shale sequences. Borehole stability problems may occur while penetrating these shale sections, potentially adding substantial costs to the drilling operations. In order to optimise the drilling procedures, this calls for a better rock physical characterization of the shales, as well as an understanding of how factors like mud composition affect the shale properties.

Consequently, dedicated experimental data is required. However, sufficient amounts of sample material are commonly not available from shale sections. This may be ascribed to the inherent low core retrieval, as well as to high drilling and sampling costs. One possible solution is to use smaller samples. In the first place, even when core retrieval is low, there may still be sample fragments left of the material. Actually, in some cases it may even suffice with cuttings from the drilling process. Last, but not least, the ability to perform experiments on small samples generally yields access to more sample material. This will allow for a larger test matrix in terms of test conditions, making the sample characterisation more complete. As such, it can be used for complementary in-fill testing together with standard tests on larger plugs when the latter are available. A by-product of utilising small samples for low-permeable shales is that since stress and pore pressure equilibrium is reached faster, rock mechanical tests are faster, and corresponding bulk fluid exposure effects will be observed earlier. This is relevant for tests where we want to simulate effects of exposure to drilling fluids, since optimisation of the mud composition may enhance the wellbore stability.

We have therefore developed experimental methodologies for static and acoustic measurements on small (mm-cm) samples. This paper illustrates the use of such small sample measurements on shales. We will present three different cases: 1) Velocities

back to contents

measured on drill cuttings at the rig-site, 2) Acoustic and mechanical characterization of small samples from cores, and 3) Mechanical effects of shale-fluid interactions.

RESULTS AND DISCUSSION

The portable Continuous Wave Technique (CWT) system for rig-site acoustic measurements on shale cuttings is described elsewhere[1]. Based on this system, a refined system named SAMSS (Static and Acoustic Measurements on Small Samples) was developed[2]. It allows for measurements of acoustic velocities on small samples subject to controlled axial stresses, as well as of the static Young's modulus (*E*) and the unconfined strength (UCS). The samples may be embedded in various fluids during measurements. A simplified sketch is shown in Fig.1. It illustrates a main frame of about 20 cm in height and diameter, with the sample placed between two ultrasonic transducers mounted into the corresponding pistons. The axial deformation (strain) is measured by means of three sensors mounted symmetrically around the sample circumference, and the axial load is applied though an external load source. Load is controlled by, and deformations are read by, a computer system. When samples exceed typically 1 cm in length and diameter, we may also employ another similar, but simpler, system.

Fig. 2 shows the results from rig-site CWT velocity measurements on shale cuttings, as well as a comparison to wireline sonic data acquired in the same well[1]. As can be seen, the cuttings show good agreement with the sonic log data in this case. In other cases, the agreement has been less. Some explanations for this are mechanical damage to the cuttings from the drilling process, as well as effects from heterogeneities and experimental conditions. This emphasises the importance of careful sample selection and preparation.

The next example comprises measurement of the static *E* on a "soft" shale (Tertiary Eocene, 28% porosity) and a "hard" shale (Middle Jurassic, 3% porosity)[2]. The samples have dimensions of 10 mm in diameter and 4 mm in thickness. Fig.3 displays the static axial stress *vs* strain for the soft shale, illustrating a load-unload-reload cycle. In Tab.1, the results are summarised and compared with corresponding results from triaxial tests on ordinary plugs from the same seal peels. The results are fairly consistent. Note however that a direct comparison of the results is difficult due to different experimental conditions.

The third example is taken from a field shale where sparse amounts of sample material were available. To determine UCS, two ordinary consolidated undrained (CU) triaxial tests with various confining stresses were performed on standard size samples. In addition, four small sample UCS tests were run on 14 mm diameter samples with various length-to-diameter ratios. The result is presented in Fig.4 in terms of a plot of maximum *vs* minimum effective principal stresses. As can be seen, the small sample results are consistent with the triaxial results, using a linear Mohr-Coulomb failure criterion. The spread of the small sample results as such illustrates effects of sample heterogeneities. Moreover, in the present case tests on small samples were actually used to identify consistent sample sets for ordinary triaxial tests due to the very heterogeneous nature of the field cores from this well.

The next example is on 2 mm thick samples made from an outcrop material, Pierre shale, with about 25% porosity. Some results are shown in Fig.5, where velocity measurements are performed on samples prepared both parallel and perpendicular to the bedding plane while the samples are subject to various axial stresses[2]. The results are consistent with those attained on larger samples, and basically illustrate two aspects: 1) Directional dependent, stress sensitive acoustic velocities, and 2) Determination of acoustic and static mechanical (not shown here) anisotropy from small samples.

The final example illustrates how small samples can be utilised to quantify shale-fluid interaction effects, employing material from a Tertiary Eocene shale. The samples were thin discs, 2 mm in thickness and 10 mm in diameter. After some initial stress cycling, the shale was first exposed to a 3wt% NaCl solution to remove capillary effects. Thereafter, 10 wt% KCl was added while the axial load was kept constant. Fig. 6 shows the resulting axial strain *vs* time for four samples from different parts of the seal peel. Again, the attained results are consistent with what is deduced from advanced triaxial test on ordinary plugs. In case of small samples, however, the tests provide results much faster.

CONCLUSIONS

The examples included here illustrate the basic principle that small samples (mm-cm scale) can be used to characterise in particular shales, yielding faster and less expensive results that are consistent with those attained on larger, standard samples tested in triaxial cells. Also drill cuttings may be used when of sufficient quality.

ACKNOWLEDGEMENTS

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	E [GPa]	
	SAMSS	Triax
Soft shale	0.48 0.84 0.84	~ 0.9
Hard shale	2.6 3.5 4.6	~ 3.7

Table 1. Comparison of Young’s modulus as attained from small samples (SAMSS) and large samples (Triax).

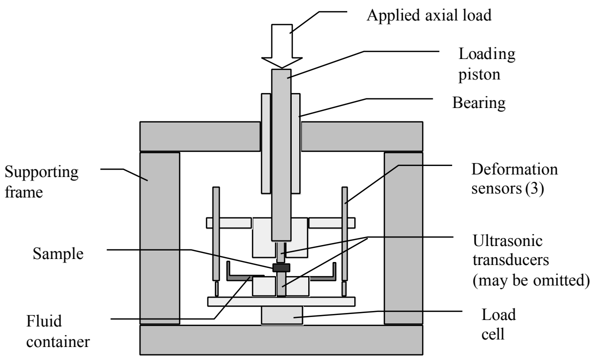

Figure 1. Experimental set-up (SAMSS) for measurement of static and dynamic mechanical properties on small samples.

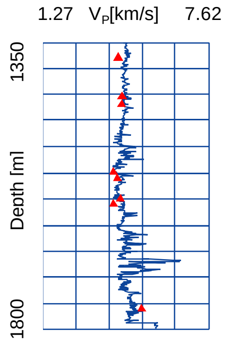

Figure 2. Wireline sonic log data (full curve), and rig-site CWT P-wave acoustic velocity results from measurements on corresponding shale drill cuttings (triangles).

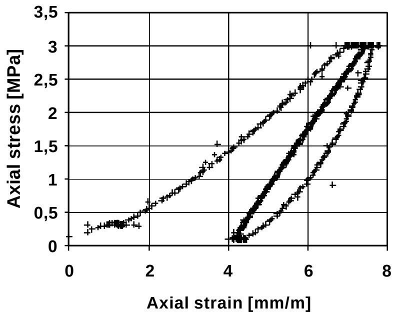

Figure 3. Axial stress *vs* strain loading-unloading-loading curves for a soft shale. The sample is 10mm in diameter and 4 mm thick.

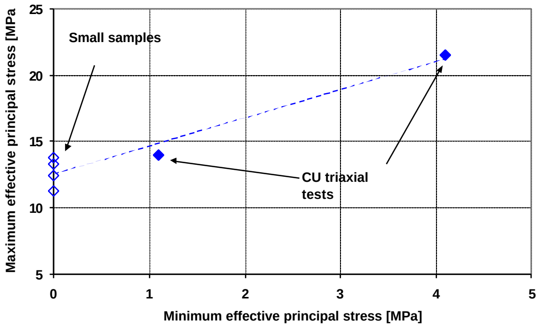

Figure 4. Mechanical strength results for a North Sea shale, including Consolidated Undrained (CU) triaxial tests on standard samples and UCS-tests on small samples (14mm diameter) with varying length-to-diameter ratios. The straight line is a linear fit to the data.

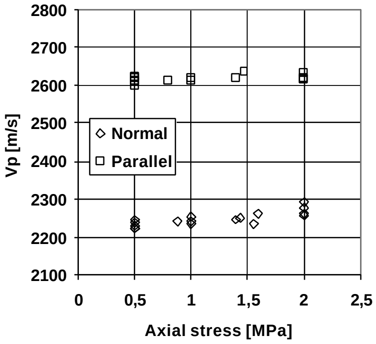

Figure 5. P-wave velocities measured parallel and perpendicular to the bedding plane at various axial stresses for 2mm thick samples made from Pierre shale.

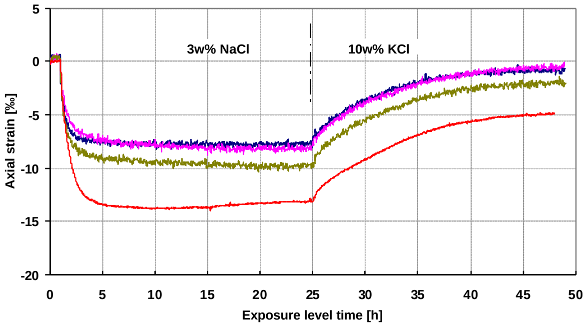

Figure 6. Axial strain for a North Sea shale as induced by exposure to various fluids. The four different curves correspond to various 2mm thick, 10mm diameter samples within the same depth interval.

back to contents