LAB TESTS ON DRAKELOW 2A CORED SAMPLES

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CONTENTS

MAIN PURPOSE OF THE REVISION AND TYPE OF MODIFICATIONS
Original issue.

1. INTRODUCTION

The description of the samples prepared in the laboratory is summarized in the following tables.

The quality of the tested samples is checked by measuring their physical properties (density and sound velocity). A summary of these measurements is presented in the paragraph 2 of this intermediate report.

The main results of the tests performed on the salt samples are presented in the paragraph 3 and 4 for respectively the short-term and long-term tests.
The short-term tests (typical duration 1 day for uniaxial and triaxial tests) give the elastic and damage salt properties whereas the long-term tests (multi-step creep tests with an overall duration of about 80 days) are performed to derive the creep (viscoplastic) properties of the salt samples.

Finally, the results obtained from the short-term tests performed on the marl samples are presented in paragraph 5. Elastic properties and failure criterion for the marl formation are derived from the tests on the marl samples.

The data obtained from these geomechanical laboratory tests will be used as entry data for the geomechanical assessment and modeling of the HGSL caverns at DRAKELOW.

Description of the salt samples prepared in the laboratory

Facies	Sample reference	Depth interval (m)		Test
Salt-F1 Boxes 51 & 130	S46-2	682.72	682.90	Uniaxial compressive test
	S46-1	682.51	682.51	Triaxial test 2 MPa
	S18-3	573.02	573.15	Triaxial test 5 MPa
	S18-4	573.19	573.33	Triaxial test 8 MPa
	S18-1	572.66	572.79	Multi-stage creep test 5 MPa
	S18-2	572.86	572.99	Multi-stage creep test 5 MPa
	S46-1B	682.57	682.62	Brazilian test
	S18-5	Not available	Not available	Triaxial test 2 MPa
	S18-6	Not available	Not available	Triaxial test 4 MPa
	S18-7	Not available	Not available	Triaxial test 6 MPa
	Sample reference	Depth interval (m)		Test
Salt-F2 Boxes 61, 85 & 97	S34-1	635.73	634.87	Triaxial test 2 MPa
	S34-2	634.94	635.07	Triaxial test 5 MPa
	S34-3	635.11	635.24	Triaxial test 8 MPa
	S34-4	635.31	635.44	Multi-stage creep test 5 MPa
	S34-5	635.60	635.73	Multi-stage creep test 5 MPa
	S30-1	617.84	618.01	Uniaxial compressive test
	S30-1B	618.03	618.08	Brazilian test
	S22-1	Not available	Not available	Triaxial test 2 MPa
	S22-2	Not available	Not available	Triaxial test 4 MPa
	S22-3	Not available	Not available	Triaxial test 6 MPa
	Sample reference	Depth interval (ft)		Test
Salt-F3 Boxes 108 & 19	S38-1	651.94	652.07	Multi-stage creep test 5 MPa
	S38-1B	652.10	652.15	Brazilian test
	S7-1	527.61	527.74	Multi-stage creep test 5 MPa
	S7-2	527.91	528.08	Uniaxial compressive test

Description of the marl samples prepared in the laboratory

Facies	Sample reference	Depth interval (m)		Test
Marl Boxes 97, 19, 85 & 122	M43-1	672.30	672.42	Triaxial test 2 MPa
	M43-2	672.42	672.54	Triaxial test 4 MPa
	M43-1B	672.54	672.59	Brazilian test
	M42-1	667.37	667.49	Uniaxial compressive test
	M24-1	594.19	594.31	Triaxial test 2 MPa
	M23-1B	592.67	592.72	Brazilian test
	M23-2B	592.77	592.82	Brazilian test
	M14-1	554.47	554.58	Triaxial test 2 MPa
	M14-2	554.58	554.69	Triaxial test 4 MPa
	M14-3	554.69	554.80	Triaxial test 6 MPa
	M14-1B	554.80	554.85	Brazilian test

2. PHYSICAL PROPERTIES

The main physical properties of the salt samples are summarised in table 1 to table 4 below with some data derived from similar sites for comparison.

	Byley	Waha	Michigan	Salado
number of tests	14	30	15	33
density max	2276	2176	2175	2166
density min	2053	2106	2129	2088
density mean	2177	2147	2157	2128

Table 1. Salt density (unit : kg/m^3)

	Byley	Waha	Michigan	Salado
number of tests	14	30	15	33
Vp max	4432	4490	4611	4299
Vp min	3807	3308	3308	3018
Vp mean	4222	4137	4228	3664
uncommon value	1429	--	1171	2636

Table 2. Sound velocity measured on salt samples (unit : m/s)

	Byley	Waha	Michigan	Salado
number of tests	4	6	9	6
Rtb max	1.56	1.71	1.87	1.9
Rtb min	0.91	0.99	0.7	1
Rtb mean	1.24	1.31	1.39	1.4

Table 3. Brazilian tensile strength of salt samples (unit : MPa)

The uncommonly low sound velocity value shown in table 2 for the Drakelow 2A sample has been measured on sample S7-1 which has been used for a creep test. This sample has been damaged during the coring operation before testing. The creep test result obtained with this sample can not be considered as representative of the overall salt formation.

	Rtb	density	Vp
number of tests	4	10	10
max	5.02	2547	3940
min	1.45	2494	2229
mean	2.97	2514	2978
uncommon	--	--	1848

Table 4. Main physical properties of the marl samples (unit : same as salt)

The sound velocity measured on the marl samples in the lab is lower than the sound velocity measured in the field (borehole log measurement gives sound velocity in between 3600 and 4200 m/s for the marl layers). This can be explained with the following:

- cores are not fresh (it is preferable to perform the tests as soon as possible after the coring operation to avoid samples weathering during storage),
- the coring operation (both in the field and in the lab) can induce damaged of the samples,
- the sound velocity measured in the lab is performed without any confinement whereas confinement exists under in situ condition.

3. SHORT-TERM TESTS ON SALT SAMPLES

3.1. Uniaxial tests on salt samples

For each test performed the longitudinal (axial) strain variation is presented as a function of the axial stress:

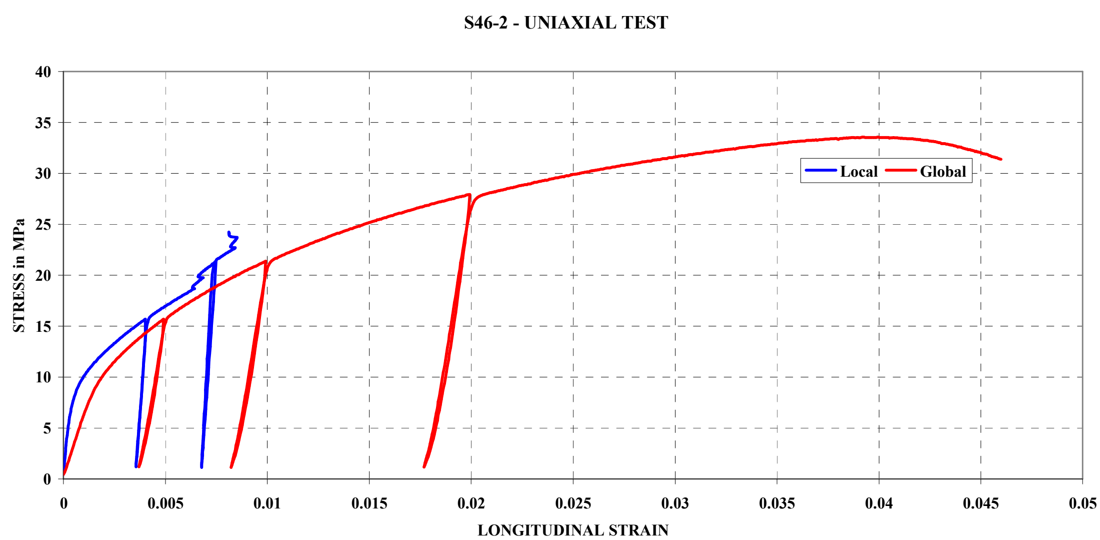

Figure 1 : Facies F1

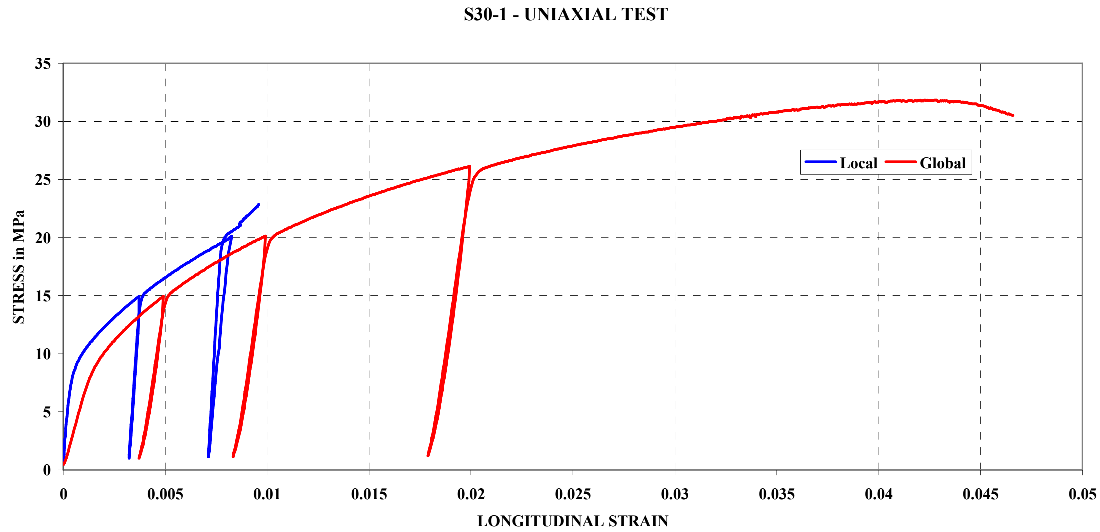

Figure 2 : Facies F2

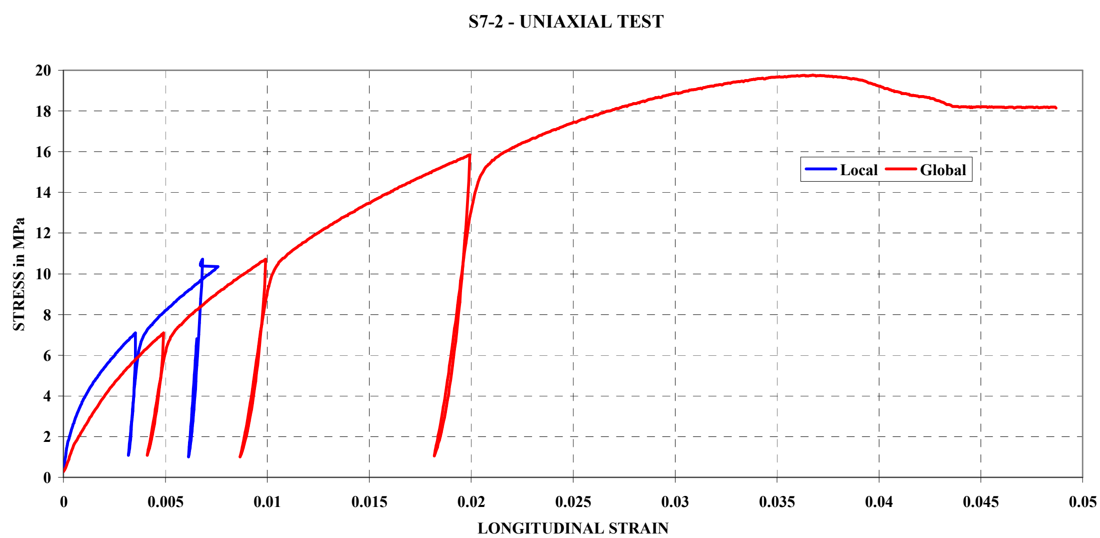

Figure 3 : Facies F3

	Byley	Waha	Michigan	Salado
number of tests	3	6	3	6
UCS max	33.5	23.8	24.1	25.5
UCS min	19.7	18.9	19.5	15.3
UCS mean	28.3	21.2	21.2	19.2

Table 5. Uniaxial compressive strength of salt samples (unit : MPa)

3.2. Triaxial tests on salt samples

For each test performed the longitudinal (axial) strain variation is presented as a function of the axial stress:

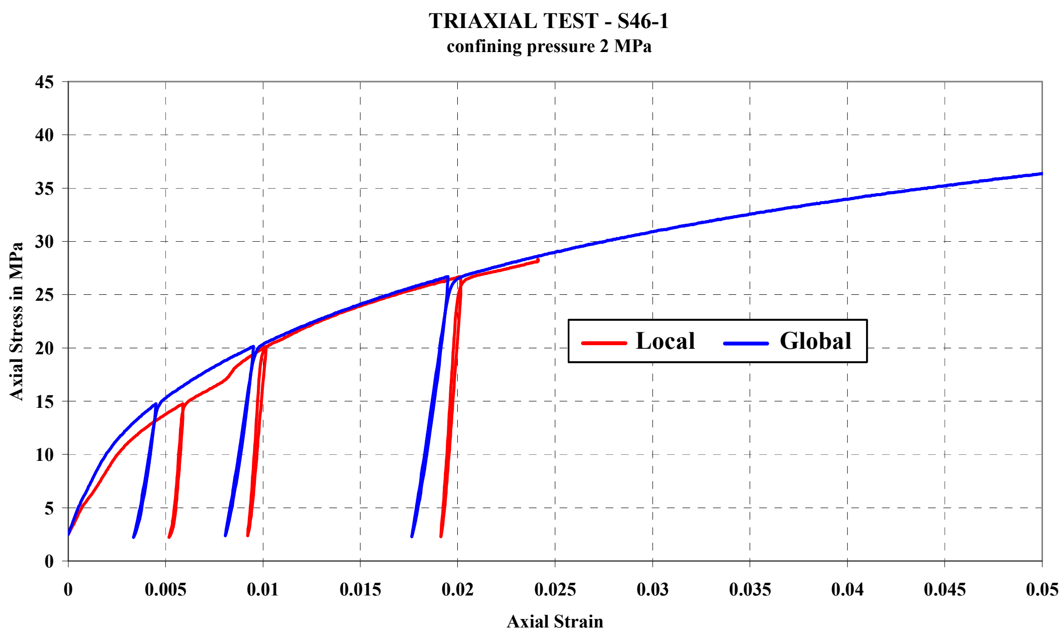

Figure 4 : Facies F1 – 2 MPa

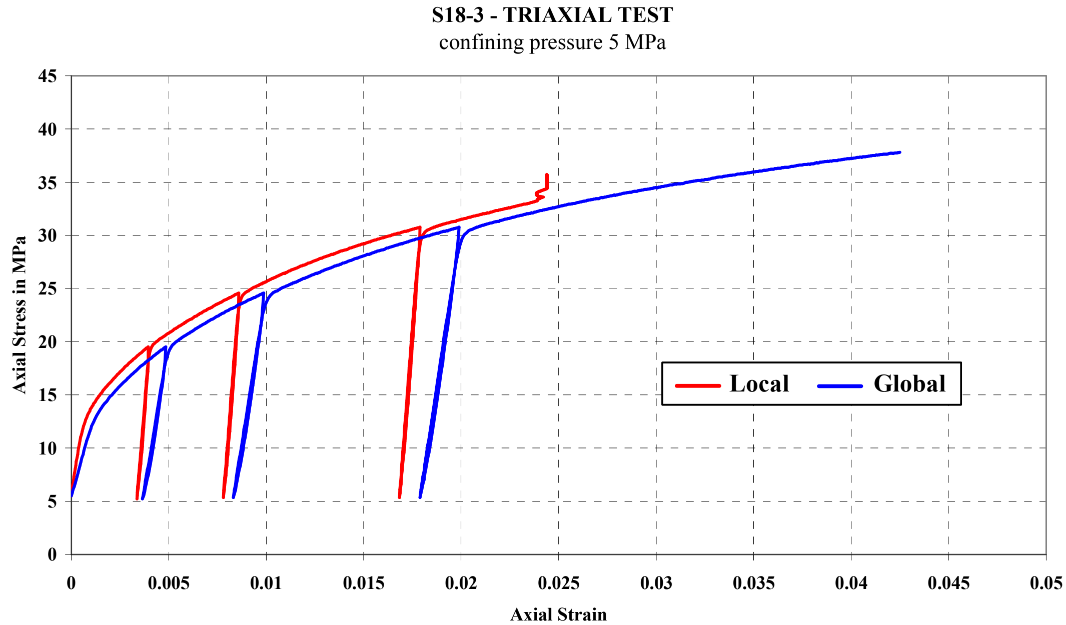

Figure 5 : Facies F2 – 5 MPa

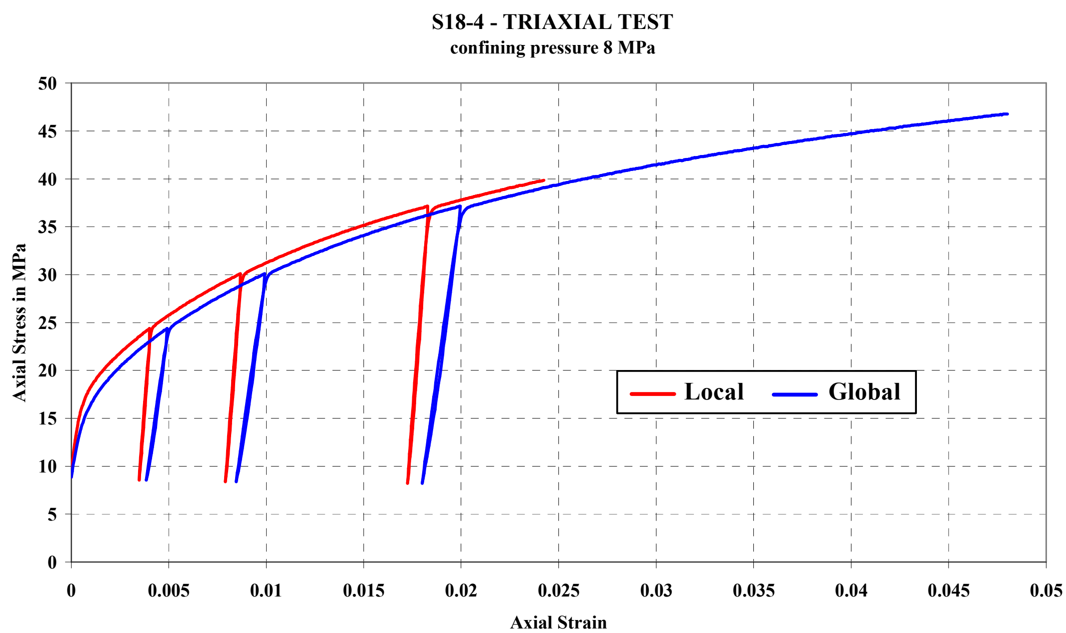

Figure 6 : Facies F1 – 8 MPa

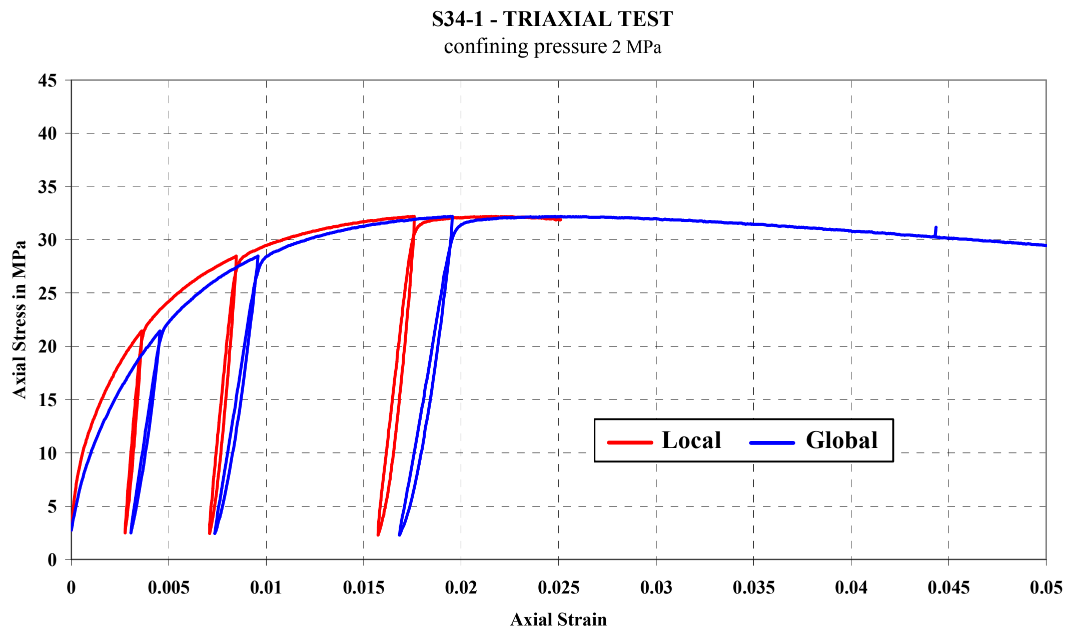

Figure 7 : Facies F2 – 2MPa

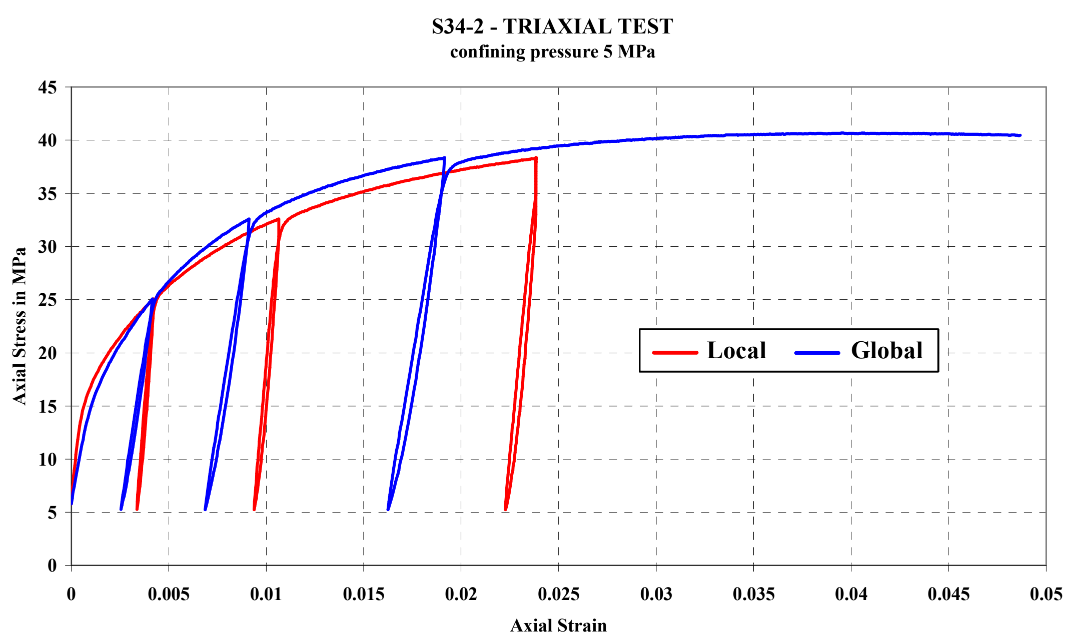

Figure 8 : Facies F2 – 5MPa

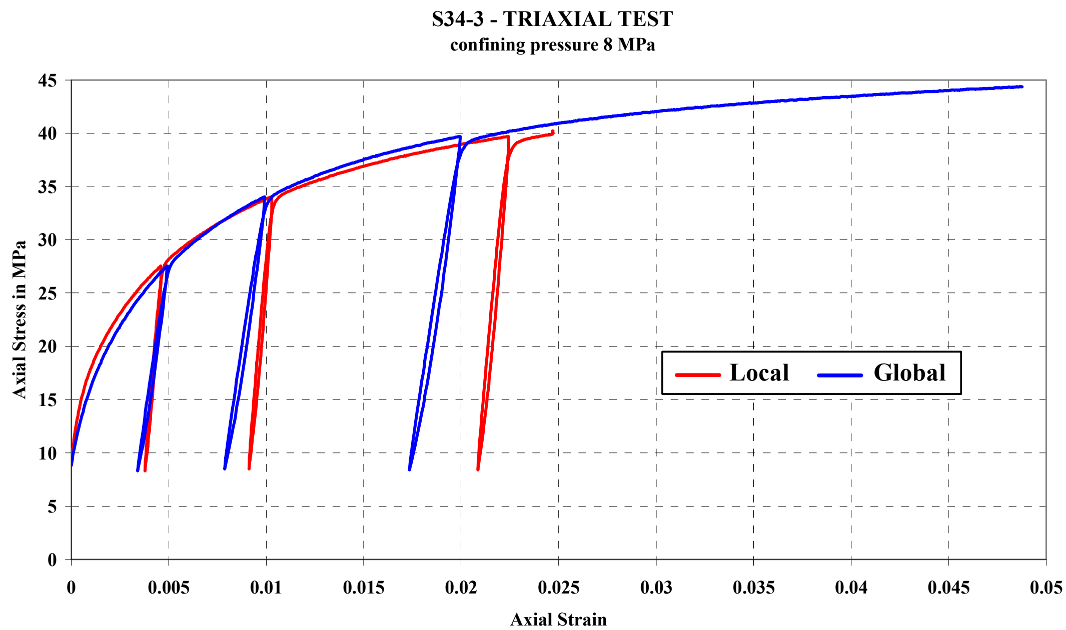

Figure 9 : Facies F2 – 8 MPa

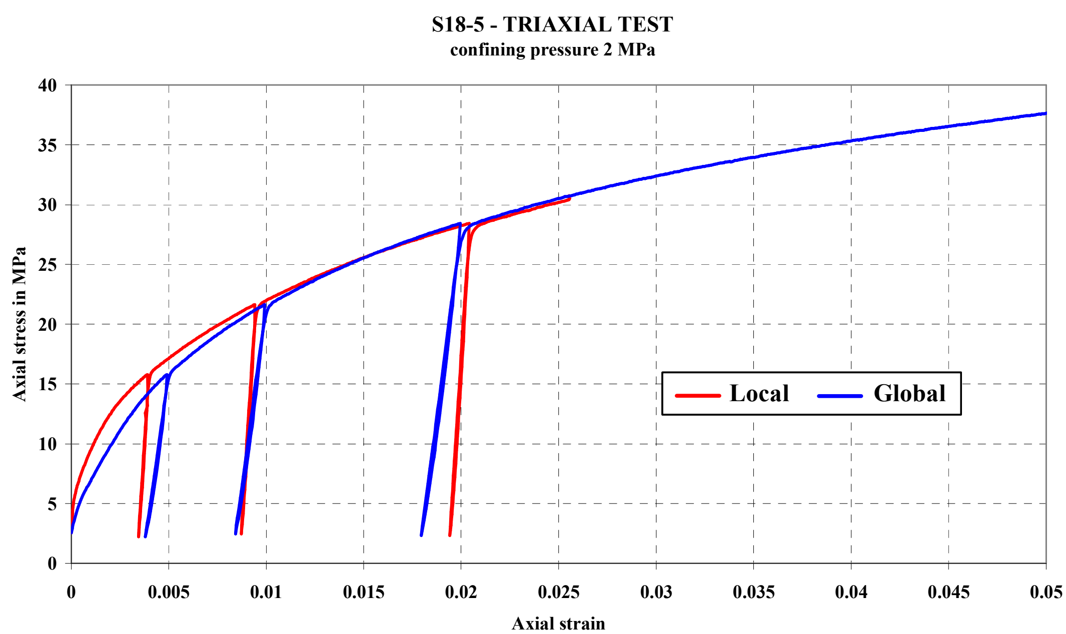

Figure 10 : Facies F1 – 2 MPa

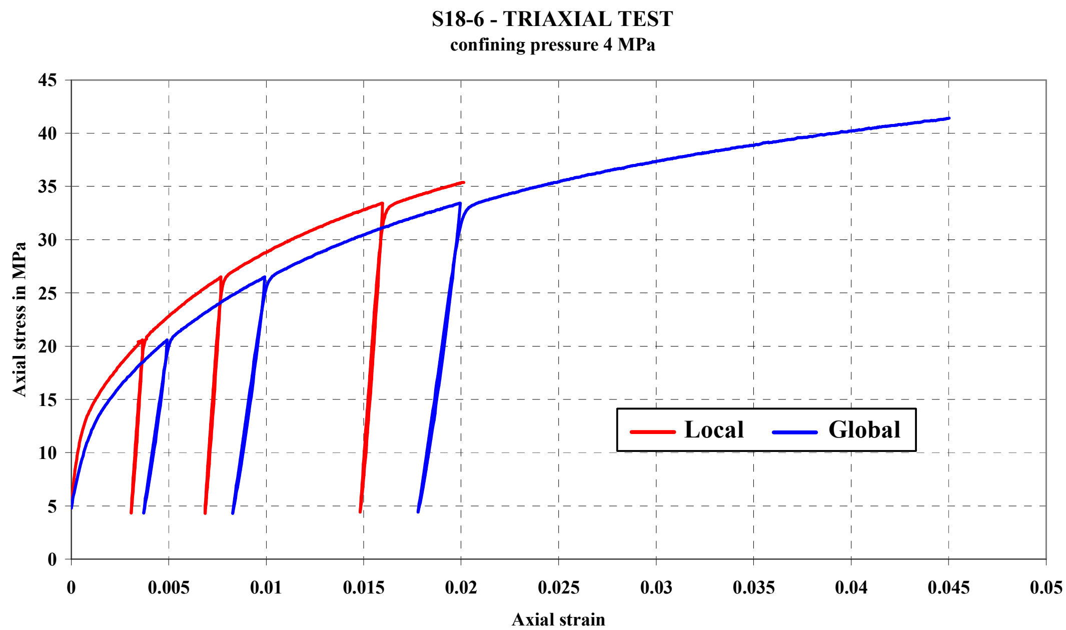

Figure 11 : Facies F1 – 4 MPa

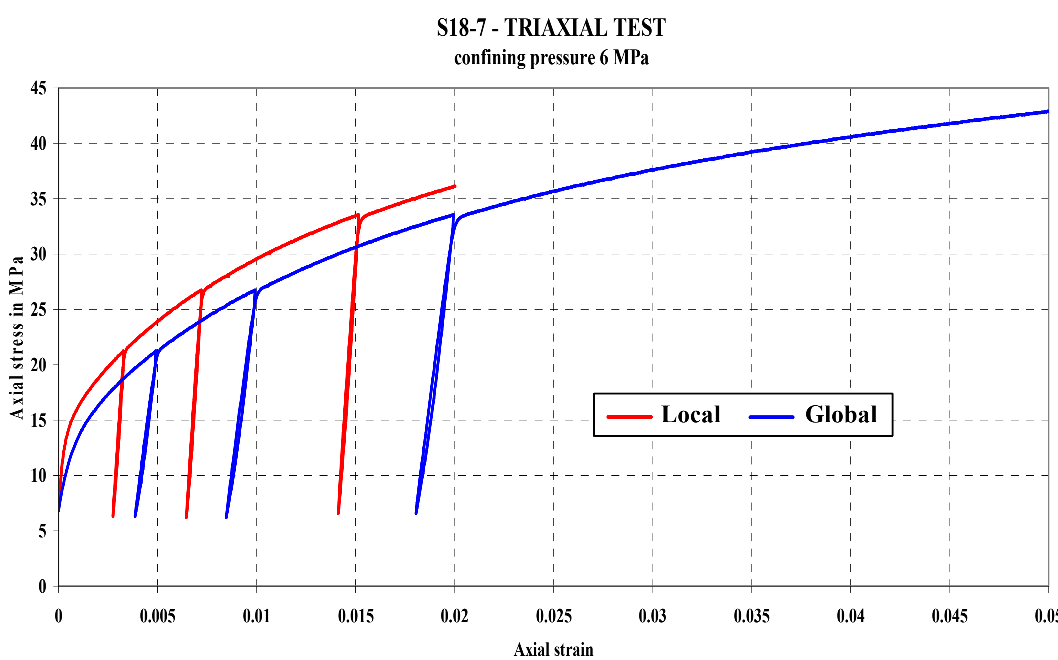

Figure 12 : Facies F1 – 6 MPa

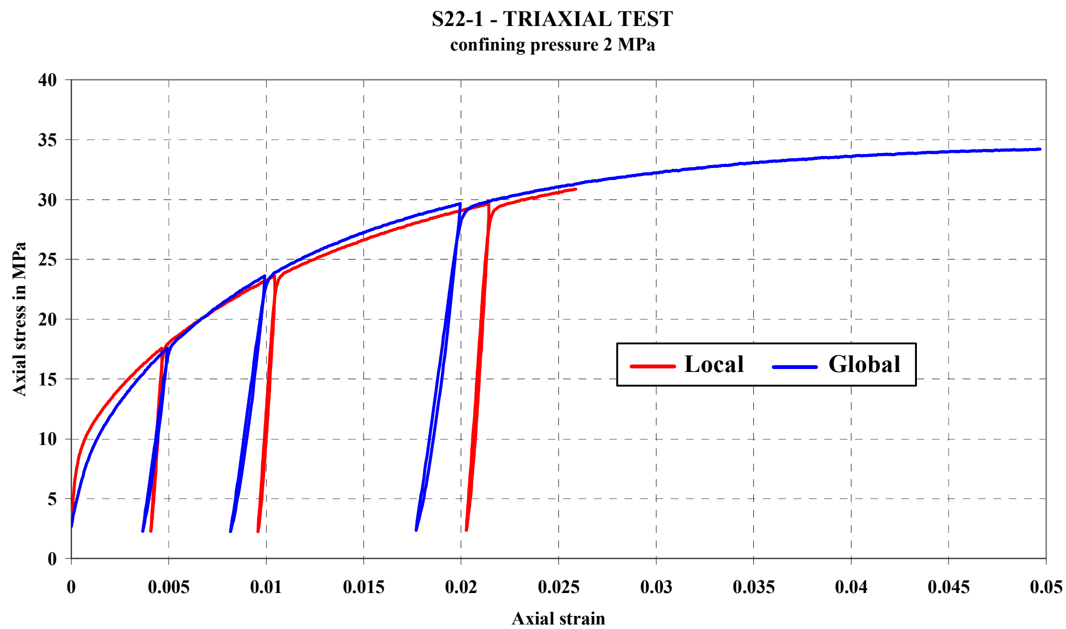

Figure 13 : Facies F2 – 2 MPa

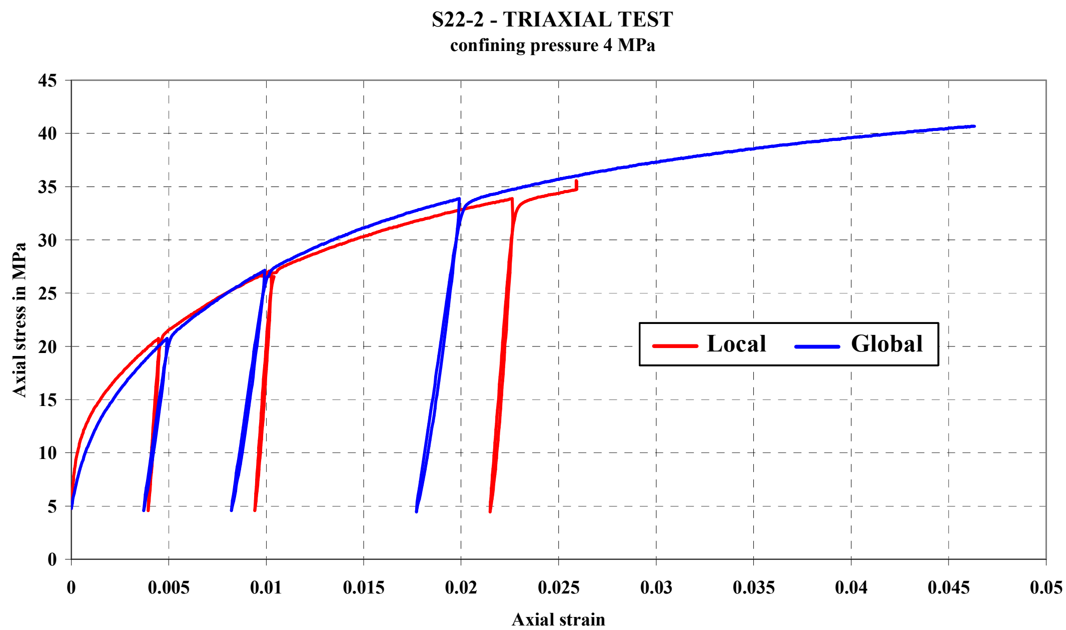

Figure 14 : Facies F2 – 4 MPa

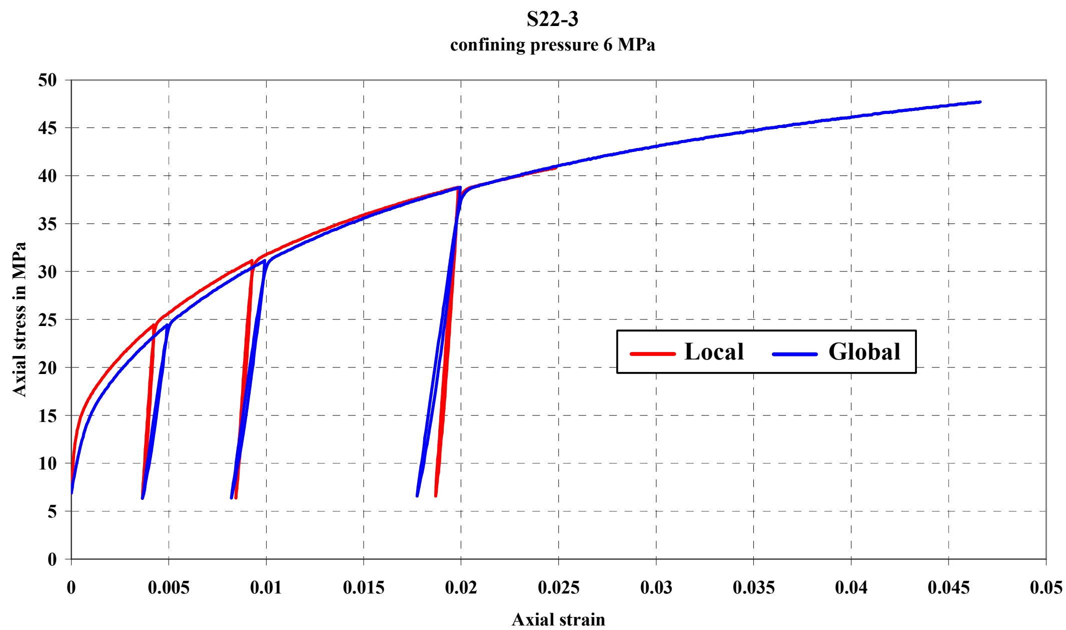

Figure 15 : Facies F2 – 6 MPa

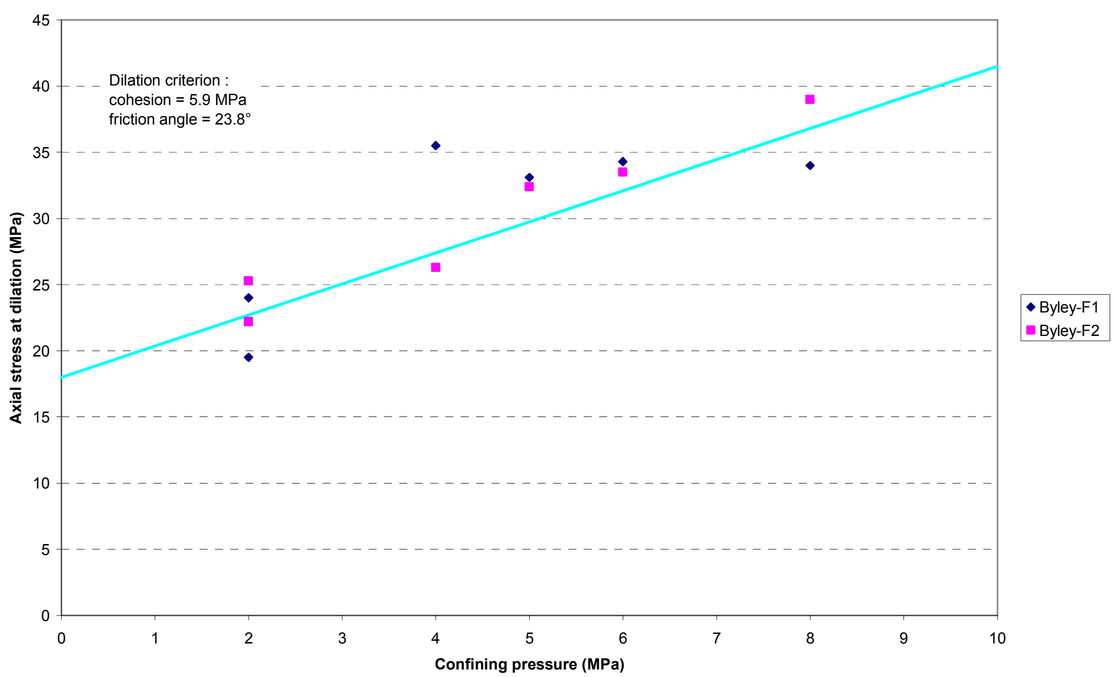

Figure 16 : Dilation – damage criterion for salt samples

From the above values, it appears that both the elastic and damage properties of the Drakelow 2A salt cores are within the typical range of values to be expected for a bedded salt formation.

4. CREEP TESTS (LONG-TERM) ON SALT SAMPLES

The last temperature step (T=50°C) at constant deviatoric stress (12 MPa) is still under way.

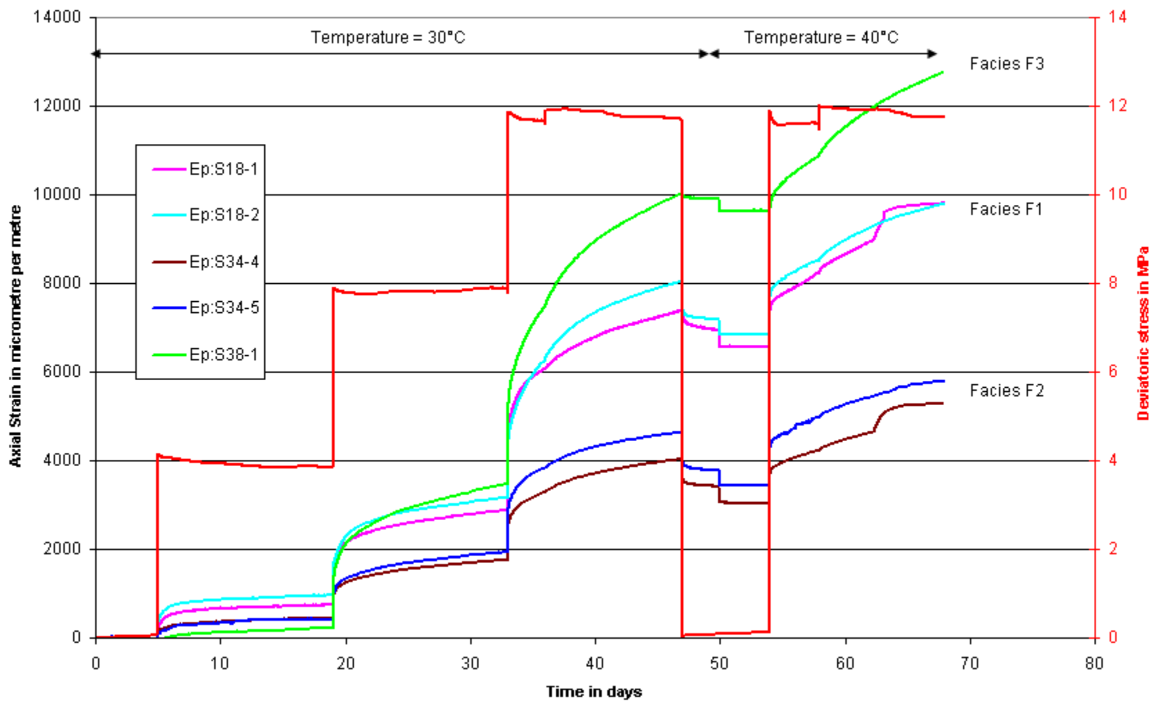

Figure 17 : Creep tests at increasing deviatoric stress (constant temperature) and increasing temperature (constant deviatoric stress)

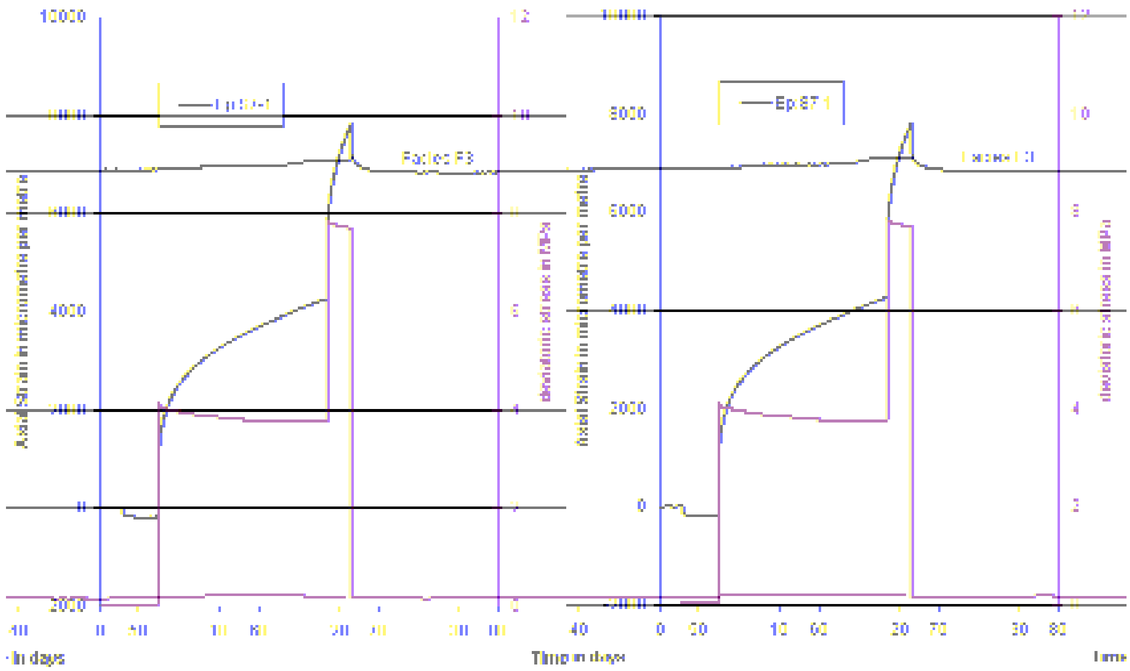

Figure 18 : Creep test on facies F3 (interrupted due to unconventional behaviour)

Preliminary creep parameters for the viscoplastic Lemaitre rheological law are given in the table 6 below. Creep ability of the Byley formation is rated in the low to medium range.

Facies	α	β	K MPa	Q/R °K	αvol /°K
F1	0.166	2.410	0.365	2217	40E-6
F2	0.107	2.112	0.291	2984	30E-6
F3	0.178	2.468	0.338	1887	40E-6

Table 6 - Creep parameters and thermal volumetric expansion coefficient (time unit is days)

5. SHORT-TERM TESTS ON MARL SAMPLES

5.1. Uniaxial test

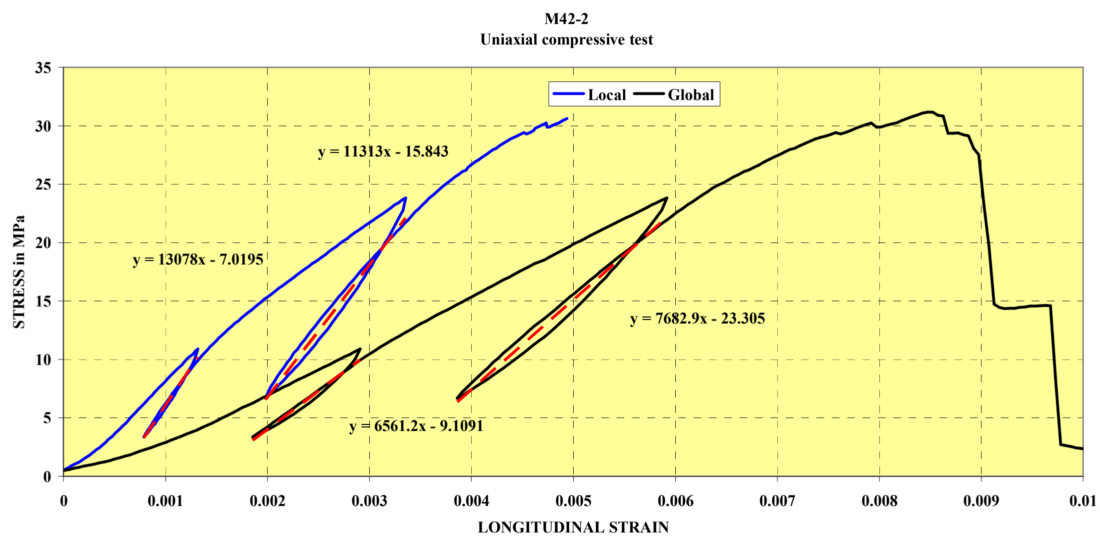

Figure 19. Uniaxial test on marl sample

Uniaxial compressive strength is equal to 31 MPa .

5.2. Triaxial tests

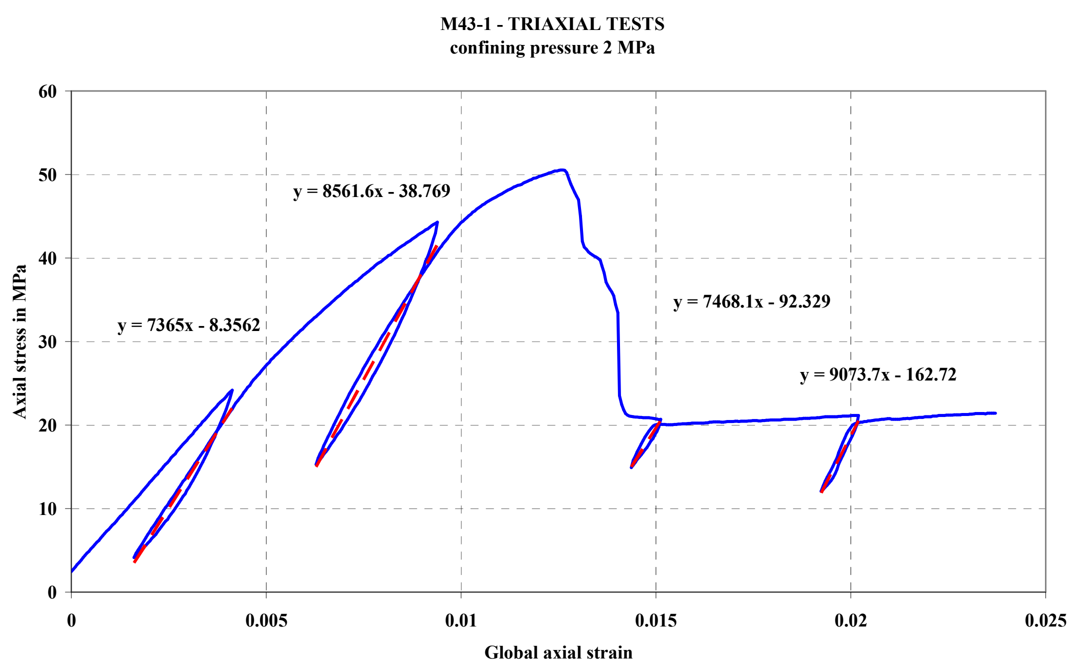

Figure 20 : MARL M43-1 – 2 MPa

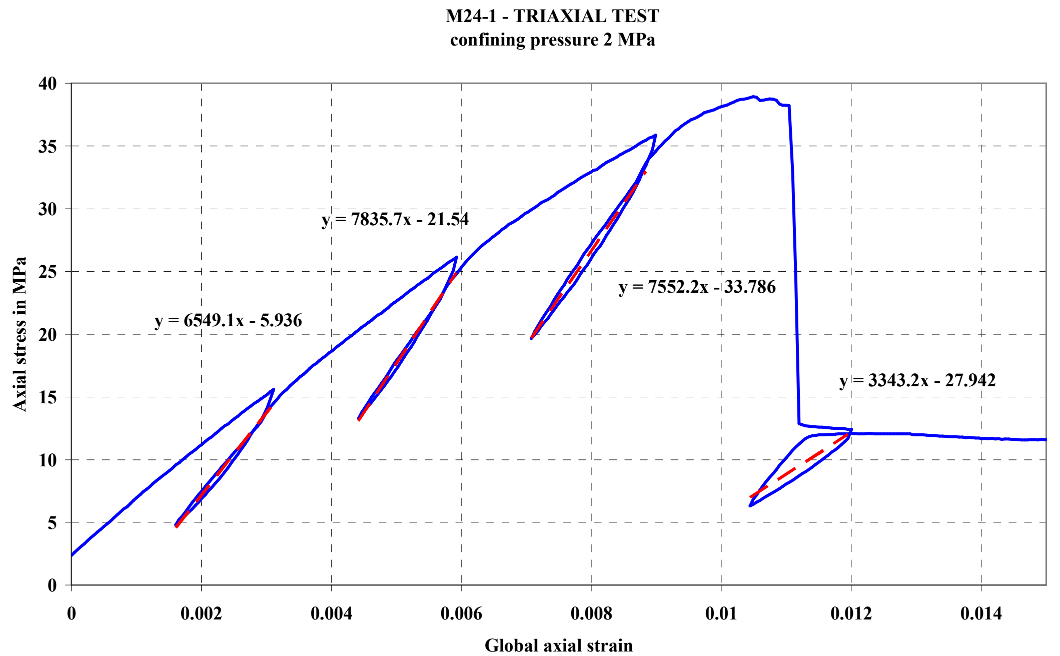

Figure 21 : MARL M24-1 – 2 MPa

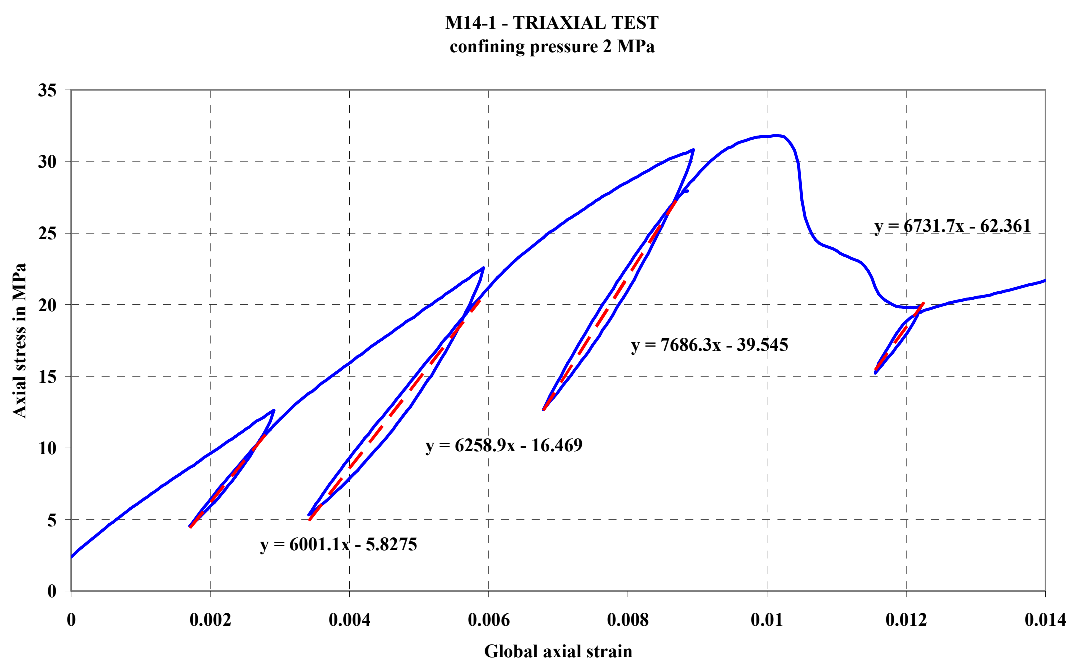

Figure 22 : MARL M14-1 – 2 MPa

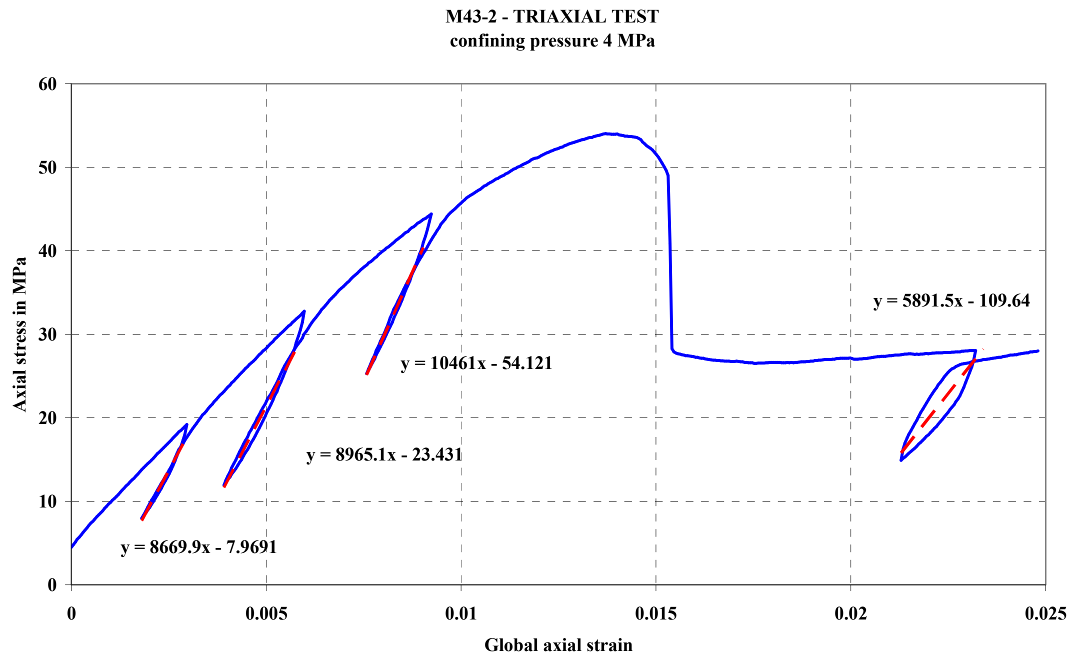

Figure 23 : MARL M43-2 – 4 MPa

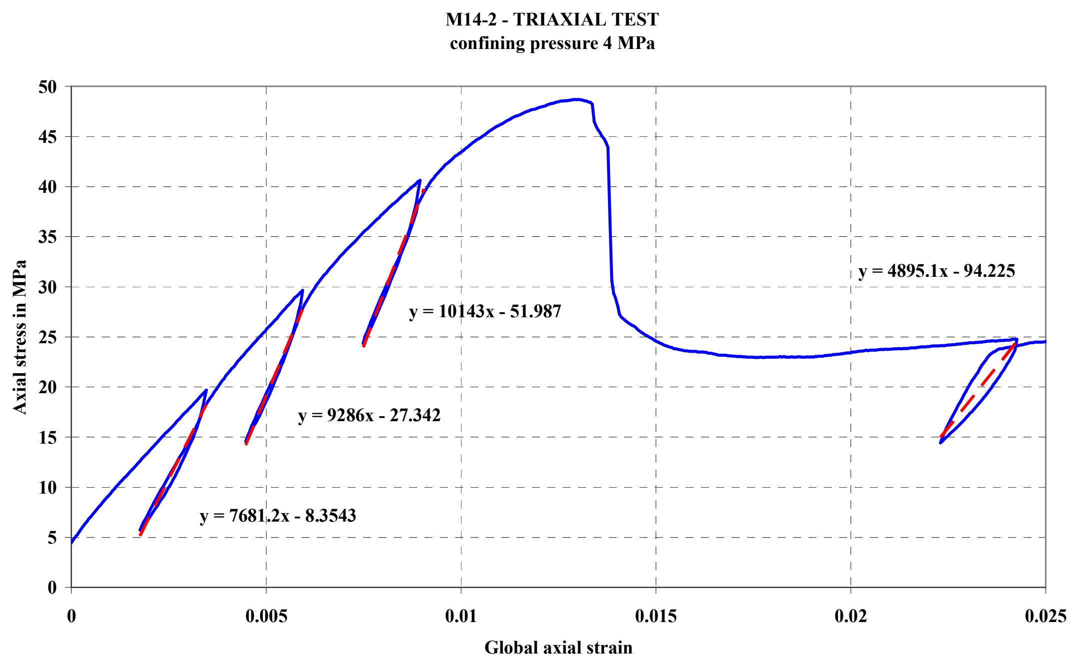

Figure 24 : MARL M14-2 – 4 MPa

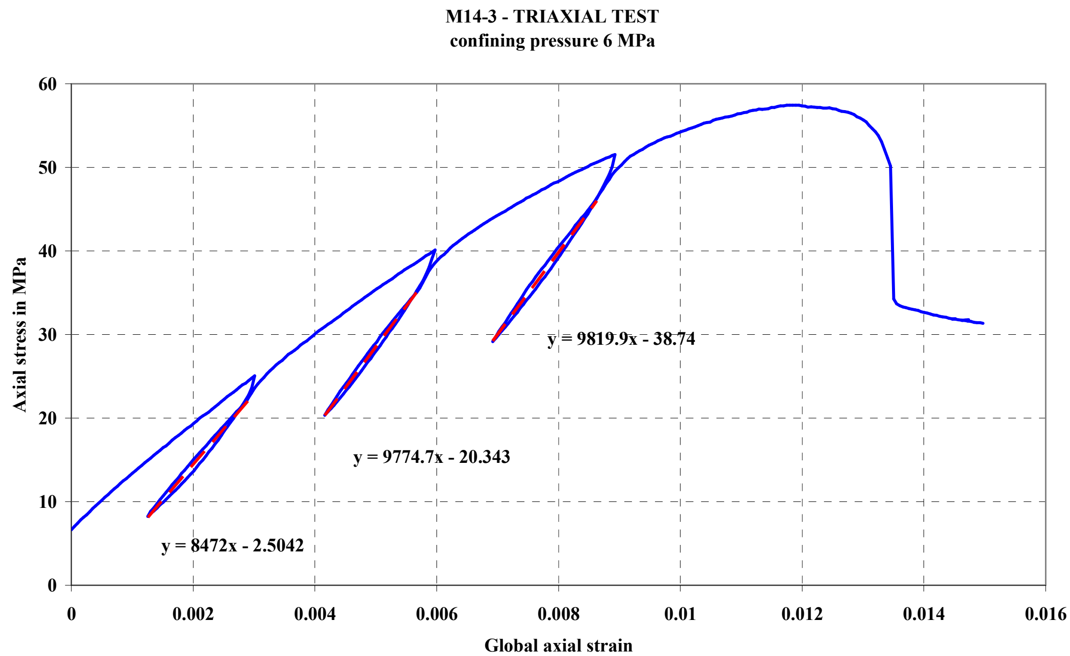

Figure 25 : MARL M14-3 – 6 MPa

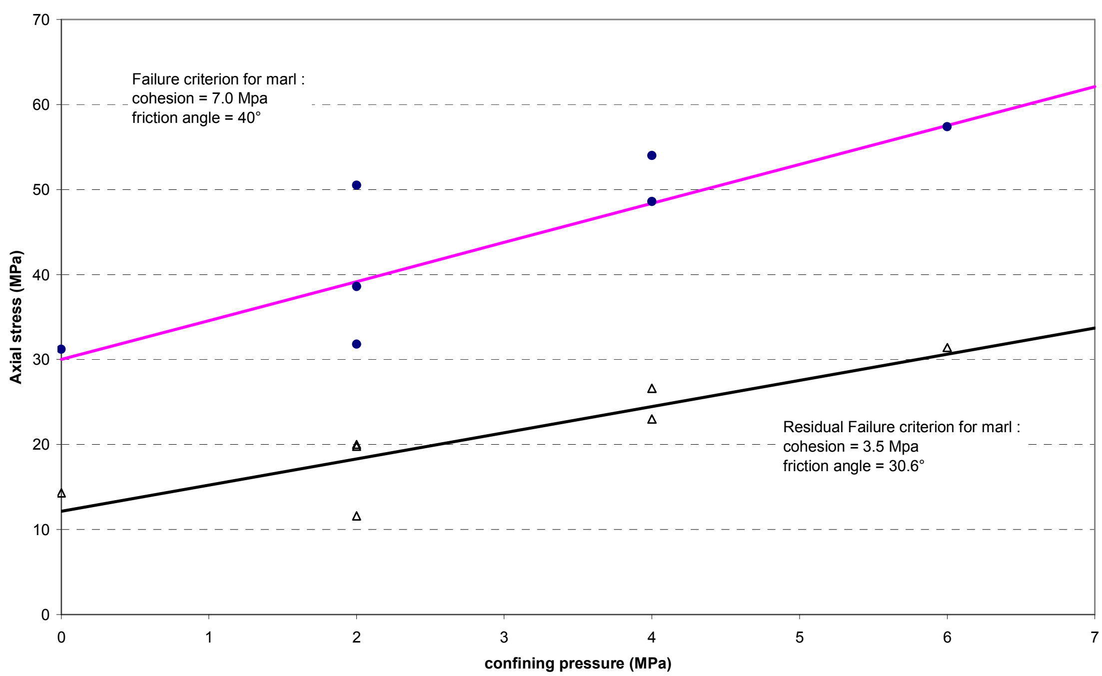

Figure 26 : Failure criterion and residual criterion for marl samples

The results obtained for the marl samples (elastic and failure properties) are consistent with data available in the literature.