T1

Technical report

Soil and fibre characterisation, mixes choice and mixes characteristics

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ESITC Caen
1 rue Pierre et Marie Curie 14610 Epron
Tél. 02 31 46 23 06 / Fax. 02 31 43 89 74 / E-mail : malo.leguern@esitc-caen.fr

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I. Report content

This report presents the progress of the actions planned implementation in the T1, as well as the results of these actions. This progress concerns the T 1.1 activity which ended in April and which corresponds to soils and fibres characterisation.
For this, 12 soils and 6 fibres were selected. Concerning soils, they were named according to their origin: FR1 to 6 for French soils and UK 1 to 6 for English soils.

II. Soils characterisation

II.1. Test performed

Table 1 summarizes characterisation tests carried out on soils as well as the standards used.

Table 1. *Used standard tests.*

Characterisation type	Tests	Standard
Physical	Particles size distribution	XP P94-041
	Particles size distribution	NF P94-057
	Methylene blue value	NF P94-068
	Atterberg limits	NF P94-051
Mechanical	Proctor test	NF P94-093

II.2. Particles size distribution

The particles size distribution analysis allows to determine the dimensional distribution of grains in a material. These tests were carried out by wet sieving for the fraction greater than 80 µm and by LASER granulometry for elements smaller than 80 µm, the fines.
The results obtained are presented in Table 8 and Figure 1.

Table 2. *Particles size distribution.*

Sample	Clayed fraction (% < 2µm)	Silty fraction (2 < % < 63 µm)	Sandy fraction (63 µm < % < 2 mm)	D_{max} (mm)
FR1	1.14	9.99	46.60	50
FR2	7.64	69.14	15.94	50
FR3	12.85	63.32	14.47	50
FR4	2.55	7.75	18.22	20
FR5	9.35	74.89	15.37	50
FR6	7.97	26.01	28.05	12.5
UK1	2.72	30.43	14.70	50
UK2	7.52	42.04	43.20	20
UK3	12.83	66.66	20.07	20
UK4	5.59	55.94	19.44	31.5
UK5	3.59	33.92	19.99	50
UK6	9.05	60.01	23.72	12.5

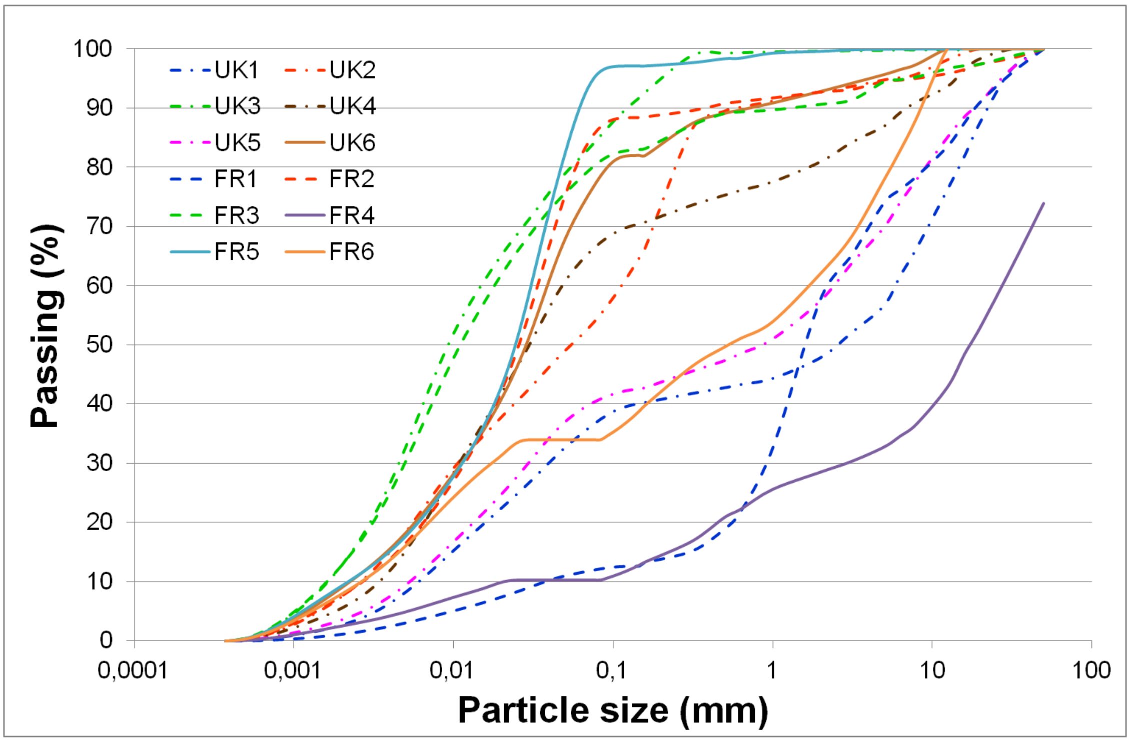

Figure 1. Soils particle size distribution

II.3. Methylene blue value

The value in the methylene blue of sediment (BV) allows to estimate the sediment clayey activity. The test is based on the particular adsorption potential of clays.
The results obtained are presented in Table 3.

Table 3. *Methylene blue value.*

	FR1	FR2	FR3	FR4	FR5	FR6	UK1	UK2	UK3	UK4	UK5	UK6
MBV (g/100 g)	0.30	0.55	5.34	0.62	0.69	0.84	0.61	1.22	3.64	0.83	0.38	0.80

II.4. Atterberg's limits

The Atterberg's limits are the reference water contents of state changes. When the water content increases, the soil passes gradually of a fragile material in a plastic material then in a viscous liquid.
The results obtained are presented in Table 4.

Table 4. *Atterberg limits.*

Soil	FR1	FR2	FR3	FR4	FR5	FR6	UK1	UK2	UK3	UK4	UK5	UK6
w_L (%)	48.9	34.1	53.3	20.1	22.7	28.9	38.5	18.6	25.7	24.8	29.6	30.4
w_P (%)	28.5	20.4	24.5	16.3	19.5	25.4	36.3	16.4	24.2	21.9	27.7	23.1
Ip (%)	20.4	13.7	28.8	16.3	19.5	25.4	2.2	2.2	1.5	2.9	2.9	7.3

II.5. Compaction parameters

The sediments compaction capacity is measured by normal Proctor test. This test consists in compacting the material with various water contents with a given energy. For every water content w is determined the material dry density ρ_d. The compaction parameters are determined from the maximum of the curve $\rho_d = f(w)$. This maximum (w_{OPN} ; ρ_{dOPN}) is the normal optimum Proctor.
The results obtained are presented in Table 5 and figures 2 and 3.

Table 5. *Compaction parameters.*

Sol	FR1	FR2	FR3	FR4	FR5	FR6	UK1	UK2	UK3	UK4	UK5	UK6
Optimum moisture content (%)	9.7	14.0	15.8	10.0	15.7	16.2	18.6	14.0	17.2	17.1	18.1	17.8
Optimum dry density ($kg.m^{-3}$)	2034	1827	1771	1916	1760	1620	1683	1777	1753	1745	1676	1709

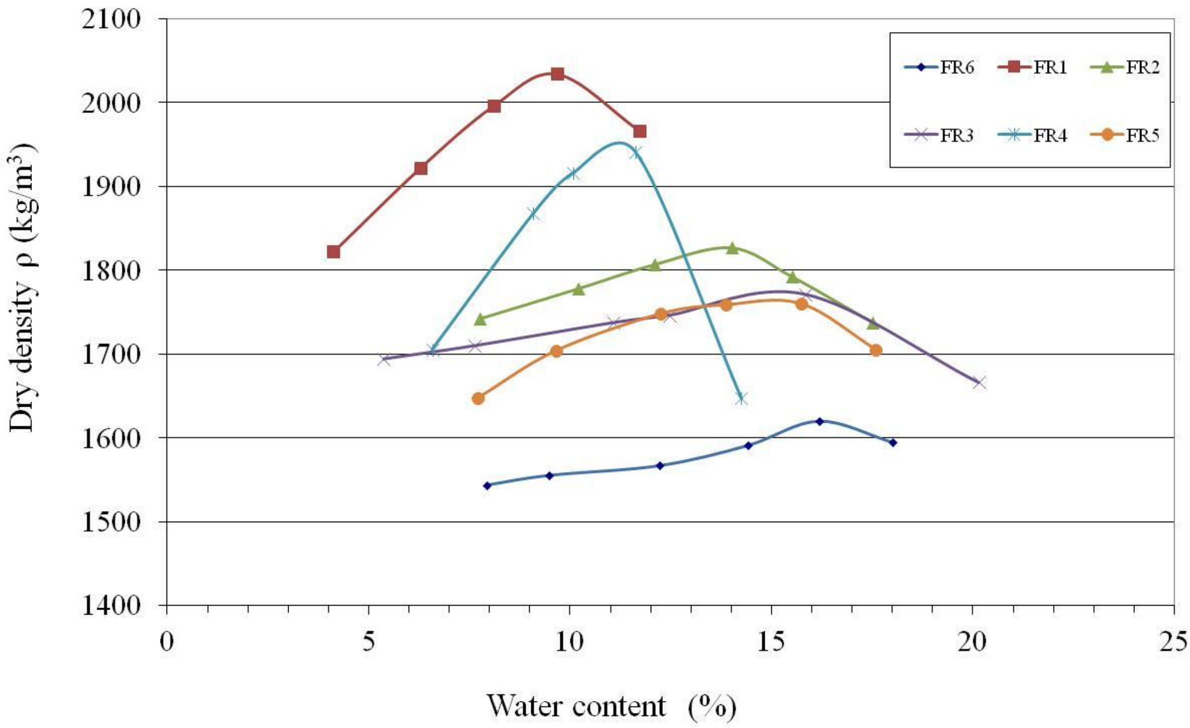

Figure 2. Proctor curves of FR soils

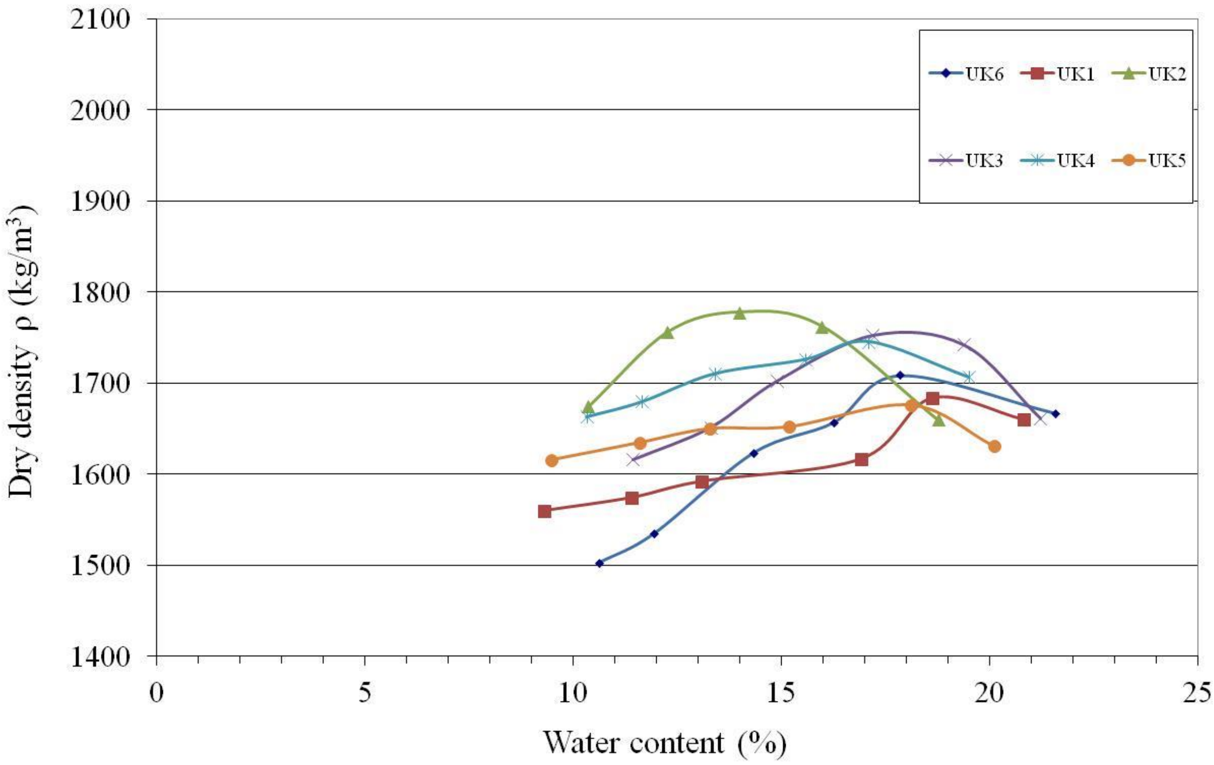

Figure 3. Proctor curves of UK soils

III. Fibres characterisation

III.1. Fibres types

With regard to the fibres, different plants were selected by their local nature, the quantity available and their current use. The selected fibres are wheat straw, flax straw, hemp straw, flax shiv, hemp shiv and reed.

III.2. Absolute density

The measurement of the fibres absolute density was carried out using an AccuPyc II 1340 type helium pycnometer of the trademark Micromeritics® (FIG. 5). It allows an accurate measurement of the solid phase volume of a known mass sample (ASTM B923, 2016).
The results obtained are presented in Table 6.

Table 6. *Absolute density of fibres.*

Fibre	Wheat straw	Flax straw	Hemp straw	Reed	Hemp shiv	Flax shiv
Absolute density ($g.cm^{-3}$)	1.182	1.337	1.391	1.390	1.410	1.455

III.3. Water absorption

The water absorption coefficient corresponds to the evolution over time of the water content of submerged fibres. This test is derived from an experimental protocol developed by RILEM group TC 236-BBM to measure the water absorption of fibres.

Table 7. *Fibres water absorption.*

Fibre	Wheat straw	Flax straw	Hemp straw	Reed	Hemp shiv	Flax shiv
Water absoprtion at 24h (%)	309	185	336	200	266	320

III.4. Tensile strenght

Tensile tests were carried out on fibres unit under ambient conditions. 10 cm length fibres were used to determine the tensile strength. This implies that flax shives and hemp shiv have not been characterised for this parameter. To prevent damage to the fibres in contact with the jaw, both ends of the fibre were protected by tape on a length of 3 cm on each side. Therefore, the initial fibre length is considered equal to 4 cm for calculating the sample bend. The fibre is then placed in the manual clamping jaws of the testing machine. The loading speed is set at 1mm / minute throughout the test.

The results obtained are presented in Table 8.

Table 8. *Fibres tensile strength.*

Fibre	Wheat straw	Flax straw	Hemp straw	Reed	Hemp shiv	Flax shiv
Tensile strength (MPa)	29	112	73	129	/	/

IV. Mixes choice

Regarding mixes, it was chosen to develop two mixes types: structural and insulating. Soils and fibres selection was made on the basis of materials properties, craftsmen experience and final objective (structure or insulation).

Concerning the water content, it was chosen to work at equivalent consistency by using two tests: the ball test for structure mixes and the puddle test for insulating mixes. Concerning the ball test, a ball of 12.5 cm diameter is dropped at 1 m high. Dry mix has to have a diameter of 17.5 cm and wet mix a diameter of 25 cm. Concerning the puddle test, 100ml of soil is poured from a height of 100mm onto glass. Dry mix has to have a diameter of 7 cm and wet mix a diameter of 14 cm.

Chosen mixes are presented in Table 9.

Table 9. *CobBauge mixes*

Mixes type	Mix	Soil	Fibre	Fibre added mass content (%)	Water content (%)
Structure	1	FR2	Hemp straw	5	25.0
	2	FR2	Hemp straw	5	28.5
	3	FR2	Hemp straw	2.5	28.5
	4	FR2	Flax straw	2.5	28.5
	5	UK1	Flax straw	2.5	31.4
	6	UK1	Reed	2.5	29.3
	7	UK3	Flax straw	2.5	37.0
	8	UK3	Wheat straw	5	37.0
	9	FR6	Flax straw	2.5	31.0
	10	FR6	Wheat straw	2.5	31.0
	11	FR6	Reed	2.5	31.0
	12	FR6	Wheat straw	5	31.0
Insulation	1	UK3	Hemp shiv	50	65.6
	2	UK3	Hemp shiv	50	107.3
	3	UK3	Hemp shiv	25	107.3
	4	UK3	Reed	25	107.3
	5	FR3	Reed	25	131.3
	6	FR3	Hemp shiv	25	131.3
	7	UK4	Reed	25	62.1
	8	UK4	Reed	50	62.1

V. Mixes characteristics

V.1. Compressive strength

Compressive strength was measured on cylindrical sample with dimensions of Ø100×H200mm. Uniaxial compression test was carried out using an IGM press with a capacity of 250 kN. The loading speed used is 0.05 kN/s.

Results obtained are presented in Table 10. Two values of compressive strength are given: the maximum compressive strength and the compressive strength at 2 % shrinkage. It is the second value which will be consider because this value is more representative of the building behaviour.

Table 10. *Compressive strength results*

Mixes type	Mix	**R_{cmax} (Mpa)**	**$R_{c2\%}$ (Mpa)**
Structure	1	3.59	1.11
	2	2.63	1.01
	3	2.07	1.45
	4	1.87	1.50
	5	1.47	0.57
	6	0.76	0.46
	7	/	/
	8	/	/
	9	1.39	0.95
	10	1.28	0.77
	11	0.93	0.89
	12	1.21	0.30
Insulation	1	0.39	0.09
	2	0.49	0.14
	3	0.73	0.34
	4	/	/
	5	/	/
	6	/	/
	7	/	/
	8	/	/

Results show that 5 structural mixes have a compressive strength at 2 % shrinkage greater than 0.9 MPa. So, these mixes can be used to build a R+1 building.

V.2. Thermal conductivity

Thermal conductivity was measured on prismatic sample with dimensions of L300×W300×H200mm. Thermal conductivity test was carried out using HFM 436 Lambda. Cold plate temperature is fixed at 0°C and hot plate temperature is fixed at 20°C.

Results obtained are presented in Table 11.

Table 11. *Thermal conductivity results*

Mixes type	Mix	**λ (W.m^{-1}.K^{-1})**
Structure	1	/
	2	0.593
	3	/
	4	/
	5	/
	6	/
	7	/
	8	/
	9	/
	10	/
	11	/
	12	/
Insulation	1	0.121 / 0.104
	2	0.153 / 0.109
	3	0.191 / 0.209
	4	0.181
	5	0.172
	6	0.193
	7	0.160
	8	/

Results show that thermal conductivity of insulation mixes goes from 0.10 to 0.21 W.m^{-1}.K^{-1}.