Proceedings of the South Baltic Conference on
Dredged Materials in Dike Construction
Rostock, 10-12 April 2014
ISBN: 978-3-86009-409-9
www.dredgdikes.eu

GEOTECHNICAL AND MECHANICAL CHARACTERISATION OF THREE MARINE DREDGED SEDIMENTS TREATED WITH HYDRAULIC BINDERS

Malo Le Guern[1], Mohamed Boutouil[1,2], Lucile Saussaye[1,2], David Lescarmontier[1]

[1] ESITC Caen, F-14610 Epron, France; ec.geotech@esitc-caen.fr, dir.recherche@esitc-caen.fr; ecr.geotech@esitc-caen.fr; tech.laboratoires@esitc-caen.fr
[2] Université de Caen Basse-Normandie (UCBN), ABTE EA 4651, Bd Maréchal Juin, F-14032 Caen, France; dir.recherche@esitc-caen.fr

Abstract. Marine sediments from three different harbours were dredged twice with a gap period of at least one year between each dredging. All samples were characterized from a geotechnical point of view before an optimised treatment and from a mechanical point of view after the treatment. Results show that:
- It is necessary to characterise sediments after each dredging.
- The adopted formulation (quicklime and hydraulic binder added to a mix sediment/dredged sand) allows to pass French suitability tests.
- The achieved mechanical performances allow the circulation on the subgrade layer made from treated sediments.
- Organic matter content and optimal dry density have an effect on unconfined compressive strength.

Keywords: Marine dredged sediments, Hydraulic binders, Dredging sand, Subgrade layer, Suitability tests, Mechanical strengths

1. Introduction

Within the framework of the SETARMS project (Sustainable Environmental Treatment and Reuse of Marine Sediments), a methodology was developed to estimate the potential of valorisation of a marine dredged sediment in road construction. The project partners (started in October, 2009) got organised to realise the sampling of thirteen sediments on both sides of the Channel. Eight sediments were characterised from a geotechnical point of view, within the laboratories of ESITC Caen and the Douai School of Mines, and from a physicochemical point of view within one of the laboratories of the University of Caen Basse-Normandie, ABTE (Aliments Bioprocédés Toxicologie et Environnements), the LASEM (Laboratoire d'Analyses, de Surveillance et d'Expertise de la Marine) of Cherbourg and a laboratory of the Camborne School of Mines (Exeter, England).

The study continued in 2011 by a geotechnical follow-up of the suitability of the sediments to the treatment with hydraulic binders. A first formulation was applied to all the sediments, without distinction of geotechnical class, according to the recommendations applied to the soils treatment (LCPC-SETRA, 2000): 3 % of quicklime + 6 % of cement CEMII/B 32.5R.

From this first formulation study in the laboratory, as well as the technical and financial possibilities of a second sampling for ports, four of the eight french sediments were subjected to an important formulation study (Boutouil *et al.*, 2012). For three of the four sediments, the same optimised formulation was used: mix of 70 % of sediment and 30 % of dredged sand with 3 % of quicklime and 15 % of hydraulic road binder (HRB) ROLAC PI LH. This permits to have a physical stability and sufficient mechanical performances of the treated sediments. These three sediments are noted A001, C001 and G001.

Then a second dredging was organised in 2012 for these three sediments at the same geographical spot of the first dredging. As the first dredging, sediments are characterised from a geotechnical point of view. Then, the optimised formulation determined is performed in order to determine their mechanical performances. These sediments are noted A002, C002 and G002.

Table 1. Standard tests for soil characterisation according to French guide GTR [3]

Tests	Standard
Particle density	NF P94-054
Organic matter content	XP P94-047
Size particle distribution	XP P94-041
Methylene blue value	NF P94-068
Atterberg's limits	NF P94-051
Proctor compaction	EN 13286-2
Immediate Bearing Index	EN 13286-47

2. Methods and additional materials

2.1. Geotechnical characterisation

The geotechnical characterisation of sediments is based on the French guide on road construction (GTR) (LCPC-SETRA, 1992) (Table 1). The GTR classification allows determining the potential use of the raw material.

2.2. Mechanical characterisation

2.2.1. Indirect tensile strength test

The indirect tensile strength (ITS) test is performed according to European standard EN 13286-42. The force application rate is 0.04 kNs^{-1}.

According to the French guide of soil treatment (GTS) (LCPC-SETRA, 2000), determination of ITS allows, at short term, to estimate the necessary waiting period in order to get a frost resistance of treated material. To validate this criterion, ITS has to be superior or equal to 0.25 MPa.

2.2.2. Unconfined compressive strength test

The unconfined compressive strenght (UCS) test is performed according to European standard EN 13286-41. The force application rate is 0.10 kNs^{-1}.

According to GTS (LCPC-SETRA, 2000), determination of UCS allows, at short term, to estimate the necessary waiting period in order to allow a harmless circulation of construction equipment on the soil layer (trafficability criterion). For a use as a subgrade road layer, UCS has to be superior or equal to 1 MPa.

2.2.3. Suitability tests

Suitability tests are made up of volumetric swelling (VS) measure and ITS after 7 days of immersion in water at 40°C. This allows to determine quickly an incompatibility between the material and the treatment. The treatment is considered as suited if VS < 5 % and ITS > 0.2 MPa, as doubtful if 10 % > VS > 5 % or 0.2 MPa > ITS > 0.1 MPa and as unsuitable if VS > 10 % or ITS < 0.1 MPa.

2.3. Dredged sand

The sand characterisation is realised according to the standards in Table 2 (Particle size distribution analysis and associated coefficients and cleanliness). Physical properties of the dredged sand (DS) are synthesized in Table 3.

2.4. Treatment products

The main parameters of binders used (quicklime and ROLAC PI LH) are given in Tables 4 and Table 5 from producers data sheets.

Table 2. Physical characterisation of sands

Test	Standard
Particle size distribution	EN 933-1
Fineness Modulus	EN 12620+A1
Sand Equivalent	EN 933-8
Particle density	EN 1097-6
Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction	EN 13242+A1

Table 3. Dredged sand (0/2 mm smooth sand) characteristics (experimental data)

d_{10} (mm)	0.122
d_{30} (mm)	0.177
d_{60} (mm)	0.293
Uniformity coefficient	2.40
Bend coefficient	0.88
Particle density ρ_s (t/m^3)	2.64
Bulk density ρ (t/m^3)	0.98
Sand equivalent SE	92

Table 4. Proviacal® DS Quicklime (Lhoist) characteristics (producer's data)

CaO (%)	93.0
Passing through 2 mm (%)	100
Bulk density ($g.cm^{-3}$)	≈ 1
Reactivity t_{60} (min)	< 1

Table 5. ROLAC PI LH (Lafarge Le Havre-St Vigor) characteristics (producer's data)

Clinker K (%)	98.5
SiO_2 (%)	20.79
Al_2O_3 (%)	5.40
Fe_2O_3 (%)	2.22
CaO (%)	65.90
SO_3 (%)	3.40
Particle density ($g.cm^{-3}$)	3.12
Specific surface ($cm^2.g^{-1}$)	3492

Table 6. GTR characterisation of sediments A001, A002, C001, C002, G001 and G002

Samples	A001	A002	C001	C002	G001	G002
Organic Matter (O.M.) (%)	7.9	5.9	6.8	12.5	5.4	4.7
Clay fraction 0/2 µm (%)	7.3	7.3	10.0	4.9	13.5	5.8
Silt fraction 2/63 µm (%)	38.0	79.1	35.7	65.9	73.1	67.3
Sand fraction 63µm/2 mm (%)	54.7	11.2	54.3	21.3	11.9	24.5
Fine fraction 0/80 µm (%)	92.0	94.7	83.0	78.7	74.7	78.91
Particle density ρ_s (g/cm^3)	2.39	2.53	2.57	2.20	2.71	2.52
Liquidity limit w_L (%)	71	100	70	135	57	73
Plasticity limit w_P (%)	36	38	50	45	37	35
Plasticity index IP (%)	35	62	20	80	20	38
Methylene Blue Value (MBV) (g/100 g dry)	3.3	4.2	2.2	3.6	1.1	2.1
GTR class	F_{11}	F_{11}	F_{11}	F_{12}	F_{11}	F_{11}
Type behaviour	A_3F_{11}	A_4F_{11}	A_1F_{11}	A_4F_{12}	A_1F_{11}	A_1F_{11}
Unified Soil Classification System (USCS)	OH	CH	OH	OH	OH	OH

3. Sediments geotechnical characteristics

Physical characteristics of the three sediments sampled twice are listed in Table 6. Concerning Organic Matter, A002, C001 and G002 have respectively a lower content than A001, C002 and G001. This gap might be due to change in fauna and flora close to the dredging spot. However, other parameters as particle size distribution, Atterberg limits or Methylhene blue values show different values according to the dredging. Therefore, it seems that it is the nature of the sediment which has been shifted during the gap between each dredging. This can be due to either a lack of sedimentation which led to a dredging of the lower layer or a change in the nature of the deposited materials. Changes of geotechnical characteristics lead to a different GTR ranking for sediment A and C and a similar GTR ranking for sediment G. These results show the necessity of the characterisation for each dredging in order to determine valuing ways for these materials.

4. Mechanical performances of treated sediments

The optimised formulation used for the three sediments was defined after a formulation study including use of quicklime, cement, hydraulic road binders and grading correctors (Boutouil *et al.*, 2012). This optimised formulation is a mix of sediment (70%) and dredged sand (30%) with an addition of 3% of quicklime and 15% of hydraulic road binder ROLAC PI LH.

So, with this formulation, compaction parameters, immediate bearing index, suitability parameters (volumetric swelling (VS), indirect tensile strength (ITS)) and unconfined compressive strength (UCS) and ITS at 7 and 28 days in standard cure are measured.

4.1. Compaction parameters and immediate bearing

Compaction parameters and immediate bearing index of treated sediments are reported in Table 7. For C001, G001 and G002 sediments, of GTR class A_1, the treatment has to allow to reach an immediate bearing index (IBI) upper or equal to 15 to envisage a use in subgrade layer (LCPC-SETRA, 2000). For A001 sediment, A_3, the immediate bearing index must be upper or equal to 10. And for A002 and C002, A_4, no value of immediate bearing index is fixed by GTS. These results show that the formulation used permit to all sediments to reach the minimum value needed to a use in road subgrade layer.

According to geotechnical parameters of raw sediments, only sediment G showed similar values for the two dredging. Therefore, it is logical to have similar results from compaction parameters and bearing index as presented in Table 7.

However, results obtained for A001 and A002 are similar concerning compaction parameter and for C001 and C002 concerning immediate bearing. For sediment A, particle size distribution is different for the silt and the sand fraction. However, according to the fine fraction value, the sand fraction of sediment A001 contains 85 % of size grain between 63 and 80 µm. Thus, A001 and A002 have a similar content of fine fraction which permits to explain the similar compaction parameters.

Concerning sediment C, difference between compaction parameters for the two dredging can be due to a particle size distribution less similar than other sediments and, particularly, to an organic matter content twice higher for C002 than for C001. Indeed, organic matter has a swelling structure (Dubois, 2006; Tran,

Table 7. Compaction parameters and immediate bearing for treated sediments

Sediment	Optimal moisture content (%)	Optimal dry density (t.m^{-3})	Immediate Bearing Index
A001	19.1	1.64	12
A002	19.7	1.62	20
C001	17.3	1.67	16
C002	27.3	1.36	15
G001	16.5	1.71	26
G002	16.1	1.74	23

2009) which can explain the higher water content and the lower dry density observed for C002 relative to C001.

4.2. Suitability tests

Suitability tests were set up in order to know quickly (within 7 days) if a treatment is suited to the soil or sediment (LCPC-SETRA, 2000). This is to say that if the volumetric swelling is not too important (depend on sulphatic reaction) and the tensile strength is enough to allow trafficability at short term.

Results from volumetric swelling and indirect tensile strength of the different sediments are given in Fig 1. These results show that the formulation used does not cause a VS superior to 5 %. However, sediments A001, C001 and C002 have an ITS between 0.1 and 0.2 MPa. Therefore, the treatment is considered as suitable for A002, G001 and G002 and as doubtful for A001, C001 and C002.

G001 and G002 results show that sediments with similar geotechnical characteristics can respond differently with the same formulation. These differences can be due to the nature of the clay fraction, the mineralogical composition or the organic matter content and composition. For instance, G001 shows a clay fraction of 13.5 % and a MBV of 1.1 and G002 a clay fraction of 5.8 % and a MBV of 2.1. These results permit to say that the nature of clays is not the same for sediment G001 and G002.

4.3. Mechanical performances in standard cure

The mechanical strengths developed at 7 and 28 days in standard cure are given in Fig 2 and 3. The analysis of the mechanical performances shows an increase of strengths between 7 and 28 days for all sediments treated.

These tests allow to determine if the subgrade road layer can support the traffic of construction equipment and if there will be risk of cracking due to frost. French guide set up the limit value at 1 MPa in UCS for trafficability criterion and at 0.25 MPa in ITS for frost criterion (LCPC-SETRA, 2000). Results obtained show that all sediments reach or approach the limit of 1 MPa in UCS after 28 days which permit to assure circulation of construction equipment without damaging the sediment treated layer. On the other hand, only treated sediment G002 reach a sufficient value to satisfy frost criterion.

Concerning differences between dredging, results show that C001 and G002 has a higher UCS and ITS than, respectively, C002 and G001. For sediment A001 and A002, they have a similar UCS and a different ITS. These results show that the GTR class of sediment is not sufficient to predict the strength of the treated sediment.

However, it is interesting to study if some of the geotechnical characteristics have a particular influence

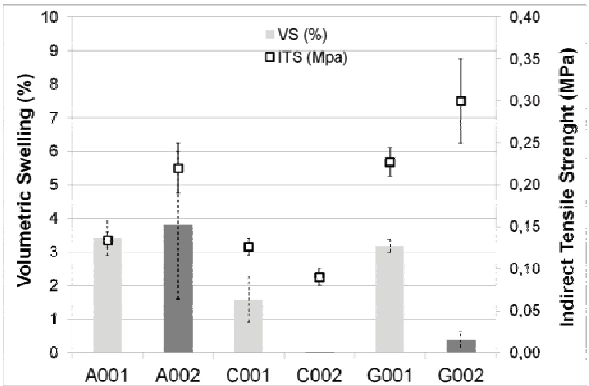

Fig 1. Suitability of the formulation for treated sediments

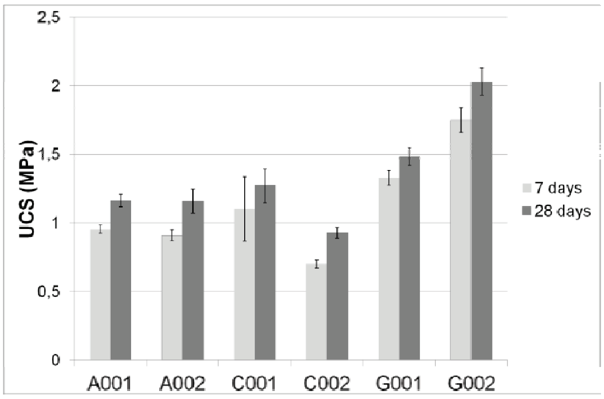

Fig 2. UCS of the sediments for treated sediments

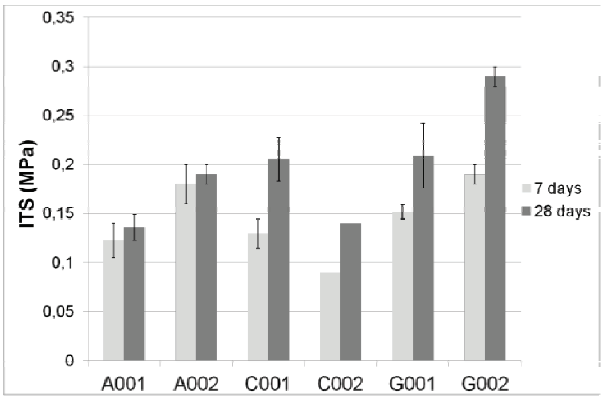

Fig 3. ITS of the sediments for treated sediments

in the strength of sediment samples. Fig 4, 5 and 6 present the variation of UCS values at 28 days versus, respectively, organic matter content, optimal dry density and bearing index. Figure 4 shows that organic matter content influences the unconfined compressive strength. This is due to the weak mechanical strength of organic matter's structure (Dubois, 2006; Tran, 2009). However, results from A001, A002 and C001 point out that knowing OM does not allow to predict UCS. According to Fig 5, results show that there is a correlation between optimal dry density and UCS. This correlation can be explained by the fact that a greater content of voids leads to a greater risk of stress concentration which mean a weaker strength resistance. Fig 6 shows that immediate bearing index does not

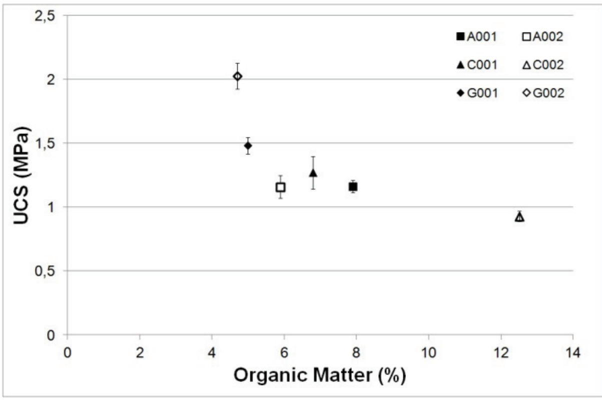

Fig 4. Variation of UCS according to the organic matter content of the treated sediments

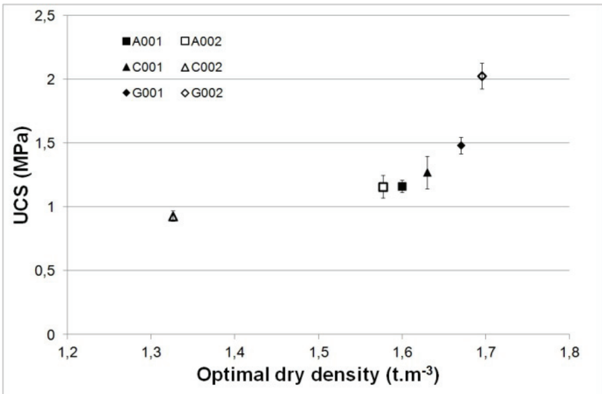

Fig 5. Variation of UCS according to the optimal dry density of the treated sediments

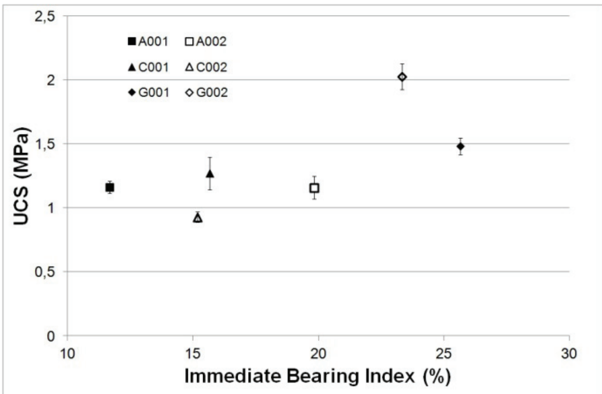

Fig 6. Variation of UCS according to the immediate bearing index of the treated sediments

allow to predict UCS values. French guide point out that there is a minimum IBI to reach in order to reuse treated materials. Thus, critic IBI level, which leads to sufficient strength, probably exists and, in this study, seems to be around 10.

Fig 7, 8 and 9 present the variation of ITS values at 28 days versus, respectively, organic matter content, optimal dry density and bearing index. Unlike results with UCS, Fig 7 shows that organic matter content does not seem to have a great influence on the indirect tensile strength. According to Fig 8, results show that, except A001, there is a correlation between optimal dry

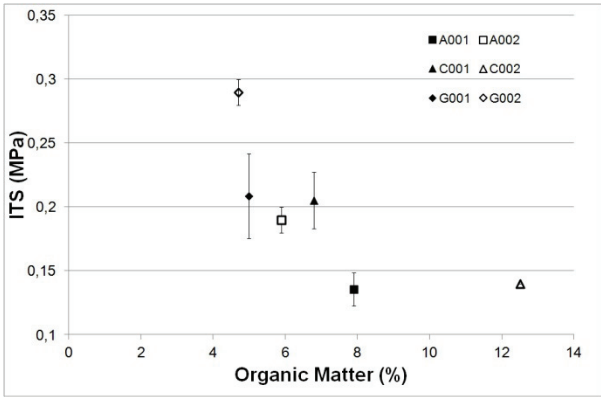

Fig 7. Variation of ITS according to the organic matter content of the treated

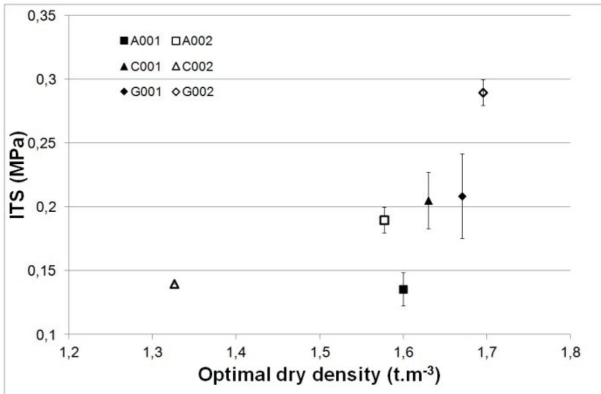

Fig 8. Variation of ITS according to the optimal dry density of the treated sediments

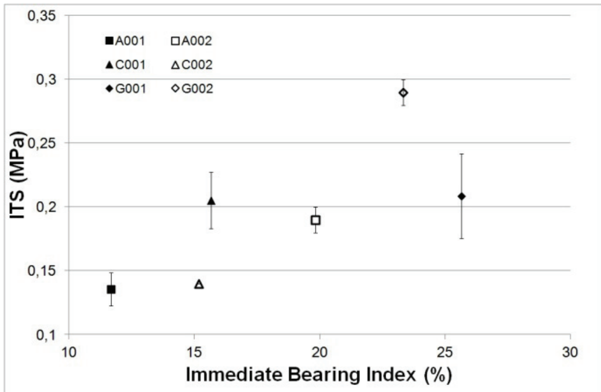

Fig 9. Variation of ITS according to the immediate bearing index of the treated sediments

density and ITS. But, results from sediment A001 point out that, compared to UCS, other mechanisms are in place in indirect tensile test. As for UCS results, Fig 9 shows that there is no correlation between IBI and ITS values. Moreover, for ITS, existence of IBI value stages does not seem to exist.

5. Conclusions

The SETARMS project is aiming at promoting the reuse of dredged sediment as a construction material in geotechnical applications. Thirteen sediments from France and England were investigated to enhance their mechanical and environmental properties according to the requirements. Three sediments, dredged twice with a gap period of at least one year, were presented in this paper. The following conclusions can be drawn:

1. According to the numerous parameters governing sedimentation, it is necessary to characterise sediments after each dredging.
2. Compaction parameters for a same formulation depend on particle size distribution and organic matter content.
3. Determining GTR class of a sediment does not allow to predict the suitability of a treatment.
4. Optimal dry density and organic matter have a great influence on unconfined compressive strength and a moderate one on indirect tensile strength.
5. Immediate bearing index does not allow to predict mechanical resistance of treated sediment.

Acknowledgements

This research work is a part of the Interreg IVA European Program SETARMS. Authors thank Région Basse-Normandie and ERDF for their financial support.

References

Boutouil, M.; Le Guern, M.; Saussaye, L. 2012. WorkPackage 3 Results. *SMOCS-SETARMS Workshop.* Available online :<http://smocs.eu/wp-content/uploads/2012/09/KNOT-Lucile-Saussaye-Malo-Le-Guern.pdf>.

Dubois, V. 2006. *Etude du comportement physico-mécanique et caractérisation environnementale des sédiments marins*. PhD thesis, ENSM Douai – Université d'Artois, 211p.

LCPC-SETRA 1992. Réalisation des remblais et des couches de forme. Guide technique des terrassements routiers (GTR), 100p.

LCPC-SETRA 2000. Traitement des sols à la chaux et/ou aux liants hydrauliques - Application à la réalisation des remblais et des couches de forme - Guide technique (GTS), 240p.

Tran, N.T. 2009. *Valorisation de sédiments marins et fluviaux en technique routière.* PhD thesis, Ecole Nationale Supérieure des Mines de Douai, 187 p.

EN 13286-41 Unbound and hydraulically bound mixtures - Part 41: test method for the determination of the compressive strength of hydraulically bound mixtures. Brussels, 2012. 12 p.

EN 13286-42 Unbound and hydraulically bound mixtures - Part 42: test method for the determination of the indirect tensile strength of hydraulically bound mixtures. Brussels, 2012. 10 p.