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1 Use of carbonated residual brines as main component of filling grout

2
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6 Constructions), 135 avenue de Rangueil, F-31 077 Toulouse cedex 4, France

7
8 **Abstract**

9 This study deals with the reuse of an industrial waste rich in CaCO₃ as a mineral addition and agent
10 of stability in low-strength filling grout for soil reinforcement applications. The physical, chemical
11 and mineralogical characteristics of these Carbonated Residual Brines (CRB) were determined and
12 completed by a study of CRB behaviour in cement-based materials and of the optimization of a
13 composition of low-strength filling grouts rich in CRB filling. The results showed that it was
14 possible to use CRB in low-strength filling grout, in replacement of bentonite and fine sand, with
15 better performance - especially in terms of stability.

16
17 **Highlights**

18 CRB is essentially composed of calcium carbonates (91%).

19 CRB can replace both bentonite and fine sand in low-strength filling grouts.

20 CRB strongly improves the stability of grouts.

21
22 **Keywords:** calcium carbonate; grout; flow; stability; filling; bentonite; CO₂ capture.

23
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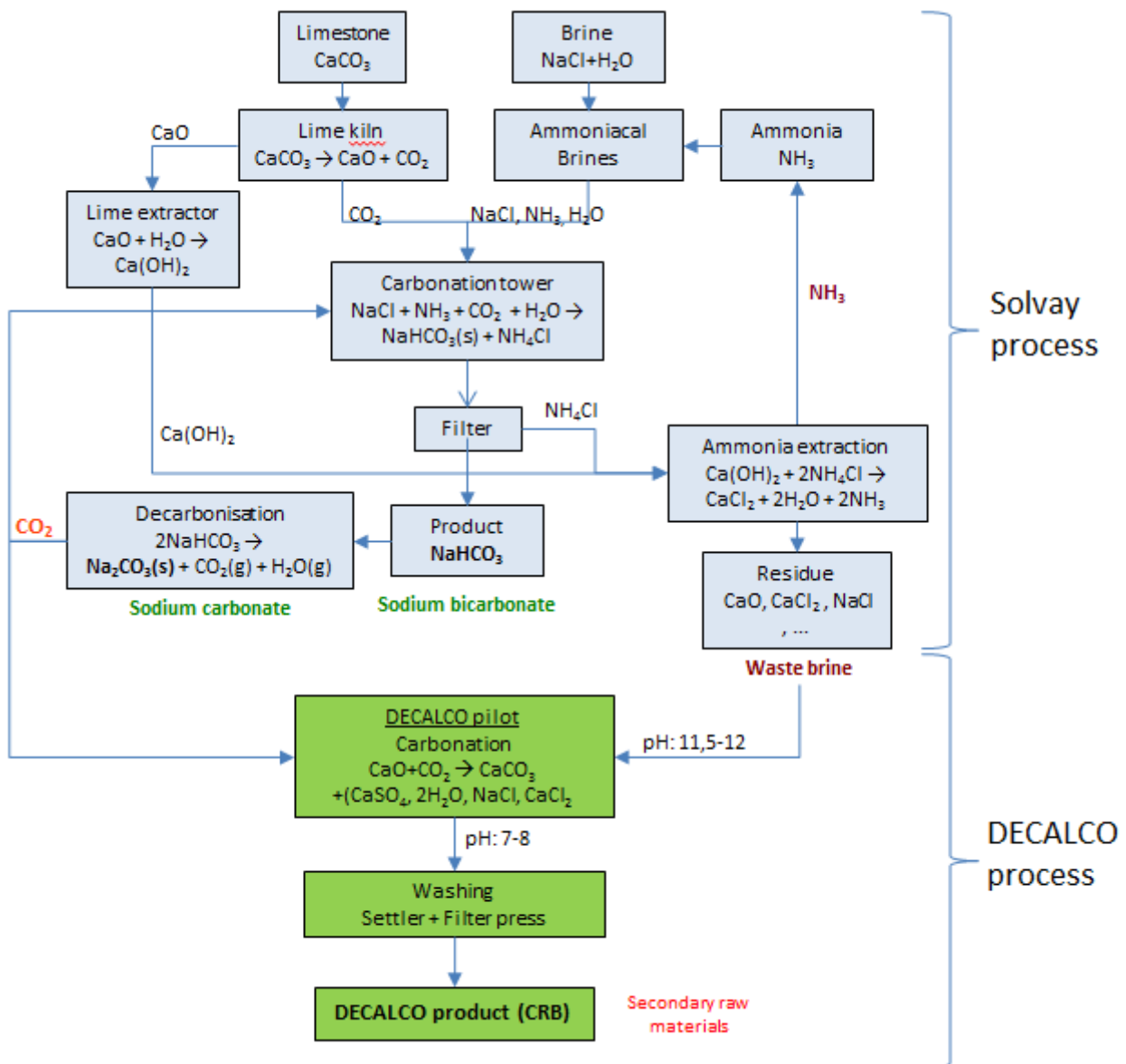
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26 **1. Introduction**

27 Waste management is a major challenge for modern society. The amounts of waste produced each
28 year continue to grow: world-wide production in 2006 was estimated at 3.4 to 4 billion tons of
29 waste, half of which was industrial waste [1]. These wastes are mostly stored in landfills, posing
30 significant problems (environmental, aesthetic and financial).

31 World production of sodium carbonate (Na_2CO_3) is estimated at 45 million tons per year, of which
32 about 75% is produced by the Solvay process. This process, developed in 1861 by Ernest Solvay,
33 produces Na_2CO_3 from sodium chloride and calcium carbonate according to the following equation:

34 $2\text{NaCl} + \text{CaCO}_3 \rightarrow \text{Na}_2\text{CO}_3 + \text{CaCl}_2$ (see details of the Solvay process in Figure 1). Ammonia also
35 occurs in the process but it is not considered as a secondary raw material because it is totally
36 regenerated and recycled in the process. This process generates large amounts of waste, essentially
37 in the form of alkaline brines that have so far been stored in desludging tanks or directly discharged
38 into the sea or rivers near industrial sites. Today, the storage of these residues in desludging tanks is
39 becoming impossible because of the large areas immobilized by this storage in the past hundred
40 years or so. Moreover, for obvious environmental reasons, the discharging of such residues in seas
41 or in rivers is not sustainable and replacement solutions must be found.



42

43 Figure 1: Chemical reactions of the Solvay process and of the DECALCO process.

44 The current context, with a rarefaction of natural resources, is in favour of alternative waste
 45 recycling solutions that produce new materials, especially in the field of road and construction
 46 materials. In this context, the project DECALCO was developed to reduce the impact of the Solvay
 47 process for the production of sodium carbonate. The method treats the waste brines using CO_2
 48 recovered from the industrial plant, which leads to the production of lime carbonates called
 49 Carbonated Residual Brines (CRB) [2]. This method makes it possible to reduce the environmental
 50 impact by transforming waste from the production of Na_2CO_3 into an inert and recoverable by-

51 product while reducing the CO₂ emissions of the industrial plant. The CRB obtained using this
52 process are in the form of a limestone filler, for which several uses in the field of civil engineering
53 materials can be considered, including that of filling grout, which is the subject of the study
54 presented in this article.

55

56 A grout is a stable suspension usually composed of a hydraulic binder (cement, hydraulic lime or air
57 lime and pozzolan) and water. Depending on the applications, the mechanical properties and the
58 rheological behaviour of grouts can be modified by the addition of substances such as mineral
59 fillers (sand, filler or other mineral additions), an agent of stability (clay, polymer), admixtures
60 (superplasticizer) or fibres [3-5]. There are several types of grout, which are used in various ways
61 according to their compositions and their performances, in particular their mechanical strength. For
62 example, some lime-based grouts are used to consolidate masonry by injection. For such
63 applications, the mechanical strength of the grout can be enhanced by the addition of silica fume,
64 coal fly ash and superplasticizer [6-9] but the compressive strength remains low (5 to 10 MPa) [10].
65 In contrast, it is possible to obtain cement-based grout, used for concrete repair, that reaches a
66 compressive strength ranging between 95 and 110 MPa [11]. Some grouts are also used for the
67 storage of radioactive waste [12-14], in which case their compressive strengths range from 10 to 70
68 MPa [15]. Grout can be used for heat exchanges in geothermal applications, where fly ash,
69 bentonite or superplasticizer [16, 17] are employed to improve the strength of the material, which
70 then ranges from 32 to 41 MPa [18]. Some cement-based grouts are used in mining and
71 geotechnical engineering for grouted rock bolts, providing ground anchorage, and for soil nailing,
72 used to treat unstable natural soil slopes or to stabilize retaining walls or existing fill slopes
73 (embankments). In such cases, the grouts have a high cement content and the compressive strength
74 of these materials is thus significant (from 17 to 82 MPa [19-21]).

75 Finally, low-strength filling grouts are used for soil reinforcement (improving soil stability during
76 the construction of a tunnel, improving soil bearing capacity, etc.), for filling underground cavities
77 (mining, quarries, etc.) and consolidating soils under foundations. The grout used in these cases
78 should have low viscosity and a grain size sufficiently small to allow the grouts to flow into the
79 cracks but high compressive strength is not required (1.5 MPa) [22, 23]. The volumes concerned by
80 this type of use are significant and in accordance with the need to find solutions for using the large
81 volume of residue produced each year by the production of Na_2CO_3 .

82

83 The objective of the work presented here was to develop low-strength filling grouts containing the
84 highest possible amount of Carbonated Residual Brines (CRB). The physical, chemical and
85 mineralogical characteristics of CRB are presented first. CRB could be considered as mineral
86 additions and it is conventional to characterize this type of materials using tests carried out on
87 cement-based pastes and mortars (consistency, setting time and activity index) as presented in the
88 second part of the paper. The specific properties of grouts (flowability and stability) are then studied
89 because the characteristics of grouts and cement pastes can differ considerably even though their
90 raw materials are similar but used in different proportions. This study leads to the optimization of a
91 composition of low-strength filling grouts rich in CRB that meet the specifications imposed for this
92 type of grout.

93

94 **2. Materials and procedures**

95 **2.1 Materials**

96 **2.1.1 Raw materials**

97 ***Carbonated Residual Brines (CRB)***

98 The CRB studied in this paper came from the industrial site of Torrelavega, Spain. This material
99 was prepared in an industrial pilot equipped with a vertical carbonation column able to treat the

100 brines coming from the industrial production of Na_2CO_3 with a flow of $1.1 \text{ m}^3/\text{h}$. The brines were
101 introduced into the upper part of the column, while a mixture of CO_2 , air and water was injected
102 into the lower part [24]. A similar process was used for the carbonation of MSWI fly ash in another
103 work [25]. After this wet carbonation, the product was dried using a filter press and took the form of
104 sheets of agglomerated particles. The cohesion of these particles was relatively high and it was
105 necessary to crush the material to transform it into a powder usable for mortar or grout preparations.
106 A preliminary study showed that the use of CRB crushed to a powder would lead to a problem of
107 water demand because of the residual porosity of the small aggregates. It was thus preferred to use
108 CRB mixed with water in the form of a suspension. CRB-suspension was prepared by mixing CRB
109 and water in a turbo mixer with a 65-mm-diameter head (the same equipment that was used for
110 mixing the grouts) with a water/CRB ratio equal to 1.

111

112 ***Binders***

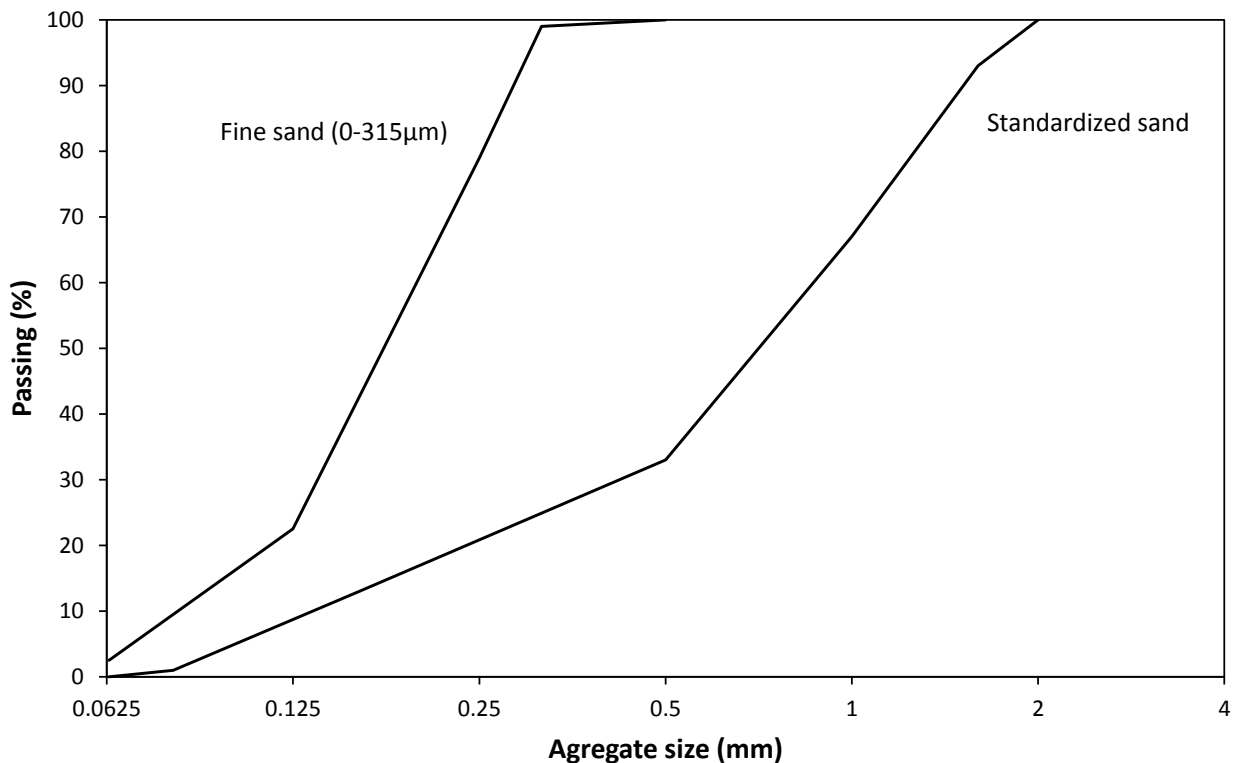
113 Two types of binder were used in this study: an ordinary Portland cement (OPC) containing more
114 than 95% of cement clinker (CEM I 52.5R), and a binary blend cement having a high Ground
115 Granulated Blast Furnace Slag (GGBFS) content, ranging between 81 and 95% (CEM III/C 32.5 N
116 PM-ES). CEM I was used to evaluate the reactivity of the CRB in accordance with EN 196-1 by
117 measuring their activity index. However, because of their origin, it is probable that CRB contained
118 sulfates and thus, for practical applications (low-strength filling grouts in the present case), it was
119 preferable to use sulfate resistant cement such as CEM III/C.

120

121 ***Sands***

122 Two types of sand were used in this study. Firstly, a standard siliceous sand was used to make the
123 standardized mortars. The particle size of this sand was too coarse for use in grout and another type

124 of sand (0-0.315 μm) was used to make the grouts. This was a siliceous sand composed of 95%
125 quartz. The size distribution of the two sands is presented in Fig. 2.



126
127 Figure 2: Size distribution of the sands used

128

129 ***Bentonite***

130 Bentonite is colloidal clay that swells significantly in contact with water (original volume
131 multiplied by 3 to 18 [26]). It is generally used in small quantities in grouts to increase their
132 stability. The addition of bentonite to grouts allows the formation of a homogeneous colloidal
133 mixture that reduces the sedimentation of the fresh grout during its use but this addition often leads
134 to an increase in the setting time of the mixtures and a decrease in their compressive strength [27,
135 28].

136 The bentonite used in this study was a sodic bentonite CV 15 coming from the company Süd-
137 Chemie based in Munich. It was essentially composed of Montmorillonite.

138

139 **2.1.2 Compositions of cement pastes and mortars**

140 Pastes were formulated with cement and CRB and used for setting time measurements while
141 mortars composed of cement, CRB and coarse sand were used for activity index determination.
142 CRB was introduced into cement pastes and mortars to replace part of the cement. Two
143 compositions were studied: a reference cement paste (or mortar) (100% cement) and a CRB-
144 containing paste (75% cement and 25% CRB). In the rest of the paper, the term “binder” will be
145 used to mean the cement or the cement and CRB mixtures.

146 For cement pastes, sufficient amounts of water were added to obtain a normal consistency in
147 accordance with the standardized European EN 196-3 test method [29]. For the mortars, the
148 sand/binder and water/binder ratios were equal to 3 and 2 respectively.

149

150 **2.1.3 Grout compositions**

151 The low-strength filling grouts had to meet three specifications [23, 30-32]:

- 152 - the flow time, measured 1 min after the end of mixing by Marsh cone with a nozzle
153 diameter of 8 mm, had to be less than 15 seconds,
- 154 - the stability of the grouts was evaluated using a decantation test: the decantation of the
155 fresh grouts had to be lower than 5% after three hours,
- 156 - the compressive strength at 28 days had to be higher than 1.5 MPa.

157 In a previous work [32], Trinh optimized a low-strength filling grout composition using CEM III,
158 water, sand (0-0.315 μ m) and bentonite. Some tests were carried out to determine the most efficient
159 composition, the objective being to use the highest acceptable amount of CRB in grout and to
160 replace both sand (0-0.315 μ m) and bentonite if possible. Three types of mixtures were tested:

- 161 - a reference mixture containing cement, sand and bentonite,
- 162 - mixtures containing 50 wt.% and 100 wt.% of CRB in replacement of fine sand and
163 bentonite.

164 For these mixtures, the effect of water content on the grout characteristics was examined by varying
 165 the W/C ratio.

166

167 The grout compositions tested are shown in Table 1. The quantities given in the Table 1 are those
 168 used to prepare three 4x4x16 cm³ samples. The compositions are designated by two numbers, the
 169 first referring to the percentage of sand replacement by CRB and the second corresponding to the
 170 W/C ratio. In Table 1, the characteristics of fresh and hardened grouts are also presented but these
 171 results will be discussed in Section 3.3.

172

173 Table 1: Compositions and characteristics of grouts

Raw materials (g)					W/C	Ref.	Stability	Flow	fc ₂₈
CEM III/C	CRB	Sand	Bentonite	Water			(%)	time (s)	(MPa)
							<5%	<15s	>1.5MPa
140	0	754	16	441	3.15	0-3.1	5	13	1.6
140	0	754	16	490	3.50	0-3.5	8	12	1.6
140	0	754	16	539	3.85	0-3.9	11	12	1.3
140	385	385	0	623	4.45	50-4.5	0	14	2.0
140	385	385	0	683	4.88	50-4.9	1	12	1.8
140	385	385	0	742	5.30	50-5.3	2	11	1.4
140	770	0	0	735	5.25	100-5.3	1	71	2.8
140	770	0	0	805	5.75	100-5.8	0	24	2.2
140	770	0	0	875	6.25	100-6.3	0	18	2.0
140	770	0	0	910	6.50	100-6.5	0	15	2.0
140	770	0	0	945	6.75	100-6.8	0	13	1.9

174

175 **2.2 Procedures**

176 **2.2.1 Chemical, mineralogical and physical characterization**

177 The major oxides composition of CRB was estimated on the basis of the macroelemental analysis
178 carried out on digested samples by Inductively Coupled Plasma - Optical Emission Spectrometry
179 (ICP-OES) (Thermo Fischer ICap 6500). The chloride (Cl) and sulfate (SO₃) contents were
180 measured by ionic chromatography (Dionex ICS 30) after acidic dissolution.

181 The crystalline phases were identified on a crushed sample using a Siemens D5000 powder X-ray
182 diffractometer equipped with a monochromator using a K α ($\lambda = 1.789 \text{ \AA}$) cobalt anticathode.

183 The size distribution of CRB in the form of a suspension was analysed using a laser particle size
184 analyser (CILAS 1090 LD) and its specific surface area was measured using a BET apparatus
185 (Flowsorb II 2300 (Micromeritics)). A scanning electron microscope (JEOL JSM-6380LV) was
186 used to study the morphology of the particles of CRB. These observations were carried out on
187 metallized powder stuck to an adhesive tape.

188
189 **2.2.2 Preparation and characterization of cement pastes and mortars**

190 The pastes were mixed and the setting time was measured according to the European standard test
191 method EN 196-3 [29].

192 The fluidity of fresh mortars was determined according to standard P 15-437 [33]. This method
193 involves measuring the time taken by a cement mortar to flow from the large compartment of a
194 workability measuring device and reach a fixed horizontal reference line cut into the wall of a
195 second compartment, when subjected to vibration. The 4x4x16 cm³ mortar prisms were cast in steel
196 moulds, demoulded after 1 day and then cured at 20°C under water according to the European
197 standard test method EN 196-1 [34].

198
199 **2.2.3 Preparation and characterization of grouts**

200 Before testing, CRB were deagglomerated in water using a turbo mixer with a 65 mm-diameter
 201 head for 15 min at a controlled speed of 4000 rpm. The bentonite was also premixed in water. Then
 202 suspensions were mixed with cement and sand (if necessary), using an automatic mixer for
 203 normalized mortar and paste for 5 min. The flow time was measured 1 min after the end of mixing
 204 by Marsh cone (nozzle diameter 8 mm) according to standard NF P 18-358 [35]. The stability of the
 205 grouts was evaluated using a decantation test (NF P 18-359) starting 4 min after mixing [36]. The
 206 test measured the ratio of the water volume collected after 3 h at the top of a test tube filled with
 207 grout relative to the total initial volume. Compressive strength tests were performed at 28 days on
 208 prismatic specimens of dimensions 4x4x16 cm³ according to standard EN 196-1. The hardening of
 209 the grouts being very slow, the grouts were kept in their polystyrene moulds and stored at 95% RH
 210 and 20°C for 28 days.

211

212 3. Results and discussion

213 3.1 Chemical, mineralogical and physical characterization of CRB

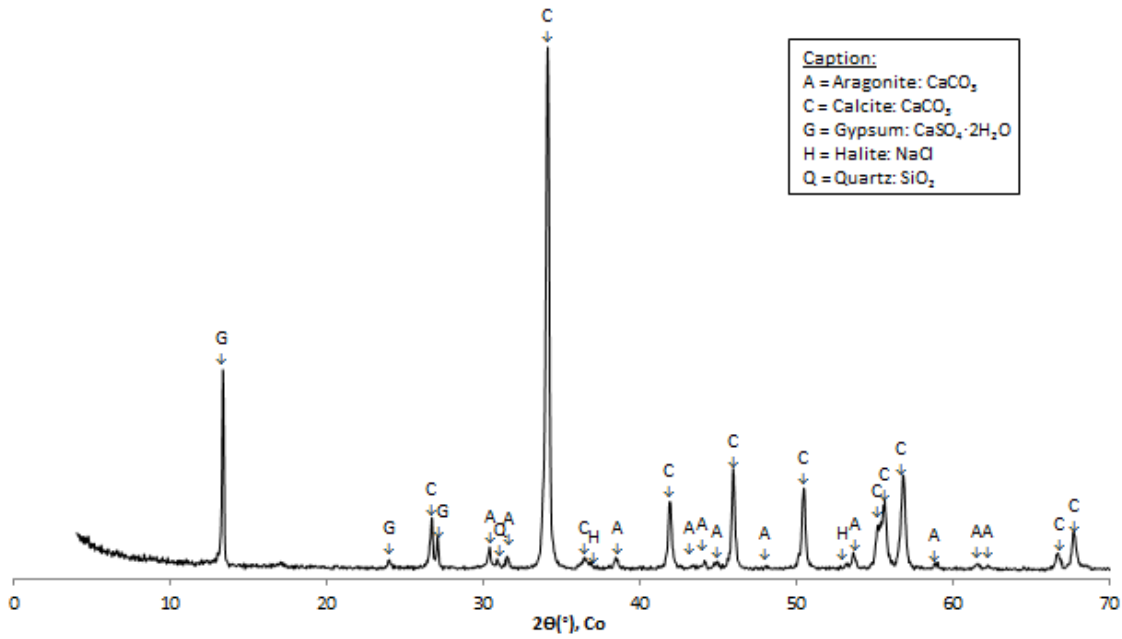
214 The chemical compositions of the materials used in this study are presented in Table 2 and the XRD
 215 pattern of CRB is presented in Figure 3.

216

217 Table 2: Chemical compositions of raw materials (wt.%)

	SiO ₂	CaO	MgO	Al ₂ O ₃	Fe ₂ O ₃	K ₂ O	Na ₂ O	SO ₃	Cl	LOI
CEM I	20.2	64.2	1.0	4.7	2.4	0.2	0.1	3.5	< 0.1	3.1
CEM III/C	32.3	43.9	6.3	10.5	0.8	0.6	0.5	2.3	< 0.1	3.1
CRB	1.4	51.5	1.0	0.4	0.3	<0.1	0.6	2.6	0.9	43.0

218



219

220 Figure 3: XRD pattern of CRB

221

222 Both the chemical composition and XRD pattern confirmed that CRB was essentially composed of
 223 calcium carbonates (CaCO_3) in the forms of calcite and aragonite. The chemical composition
 224 highlighted a significant amount of residual sulfates (2.6%) and chlorides (0.9%). The presence of
 225 these two elements is worrying for the potential use of CRB in cement-based materials: sulfates
 226 imply a significant risk of expansion due to delayed ettringite formation and chlorides are not
 227 compatible with the use of CRB in reinforced materials due to the risk of corrosion of the steel bars.
 228 The use of a sulfate resistant cement such as CEM III/C for this study would solve the problem of
 229 the high sulfate content and the choice of CRB for low-strength filling grouts that do not contain
 230 steel bars would be consistent with the chloride content of CRB. XRD analysis showed that sulfates
 231 were in the form of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and chlorides in the form of halite (NaCl). Finally, the
 232 chemical composition showed the presence of SiO_2 (1%) corresponding to the low quartz content
 233 identified by XRD. There was also a small amount of MgO that could be present in substitution of
 234 CaO in the calcium carbonates. Both chemical and XRD analyses allowed a mineralogical

235 composition of CRB to be calculated: calcium carbonates (91%), gypsum (6%), halite (1%) and
236 quartz (1%).

237

238 The physical characteristics of CRB are presented in Table 3.

239

240 Table 3: Physical characteristics of CRB

Particle size distribution (μm)	
D ₁₀	1.1
D ₅₀	5.7
D ₉₀	22.7
BET surface area (m^2/g)	9.94

241

242 The results of laser particle size analysis showed that CRB was very fine, its average size (D50)
243 being close to 6 μm . This is in accordance with the size distribution of calcareous filler reported in
244 the literature, which ranges from 1 to 60 μm [37]. This great fineness was confirmed by the
245 measurement of the specific surface area, which was close to 10 m^2/g whereas that of conventional
246 calcareous filler is much lower (from 1.2 m^2/g to 7 cm^2/g [38, 39]).

247

248 The morphology and size of the minerals were studied by Scanning Electron Microscopy (SEM).
249 Some examples of the observations are presented in Figure 4. The figure shows two grains (calcite
250 and gypsum) with dimensions close to 10 μm that are surrounded with small particles (less than 1
251 μm) of precipitated calcium carbonates. SEM observations show that CRB seem to be finer than
252 suggested by the laser particle size analyser measurements as a significant proportion of particles
253 were smaller than 1 μm .

254

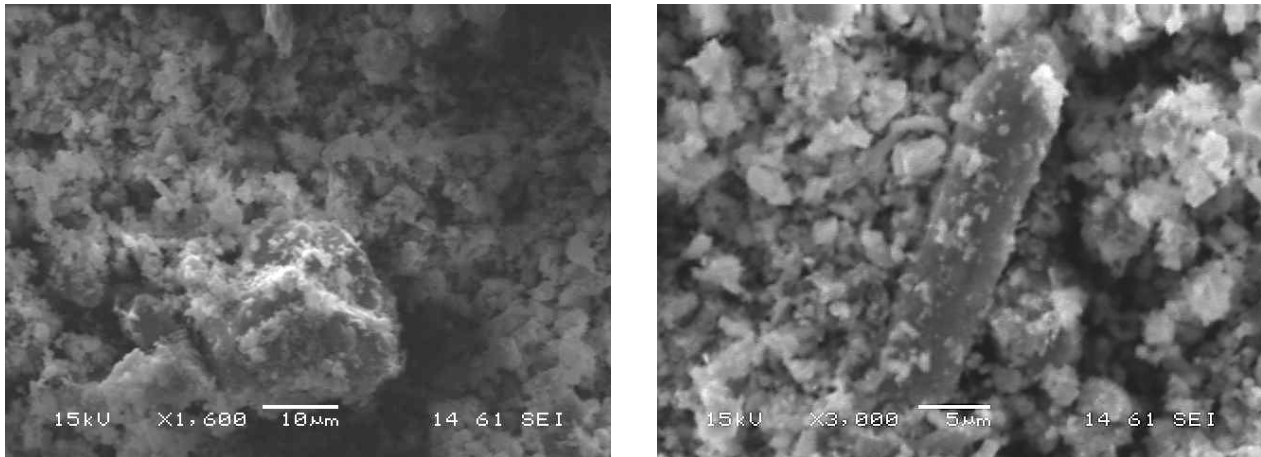


Figure 4: Scanning electron micrograph of CRB: grain of calcite (left) or gypsum (right) surrounded by precipitated calcium carbonates

255

256 3.2 Behaviour of CRB in cement pastes and mortars

257 The Water/Binder ratios necessary to obtain a standardized consistency and setting time for the
 258 cement pastes are presented in Table 4. These measurements were carried out on mixtures
 259 containing the two types of cement: CEM I used for the measurement of the activity index of CRB
 260 and CEM III used for the manufacture of the low-strength filling grouts.

261

262 Table 4: Water demand and setting time of CRB-containing cement pastes

Composition	Water/Binder ratio	Setting time (h)
100 wt.% CEM I	0.30	2.33
75 wt.% CEM I + 25 wt.% CRB	0.33	2.00
100 wt.% CEM III/C	0.33	4.00
75 wt.% CEM III/C + 25 wt.% CRB	0.34	4.50

263

264 The results in Table 4 show that the substitution of 25 wt.% of cement by CRB in the form of
 265 suspension had practically no effect on the Water/Binder ratio (only a slight increase could be

266 observed for both cements). The same conclusion can be drawn for the effect of CRB on the setting
267 time: only slight variations in setting time were observed for both cements, which should not pose a
268 problem for the potential reuse of CRB in cement-based materials.

269 The workability and the compressive strength of CRB-containing mortars are presented in Table 5.
270 As specified in the European standard on cement [34], only CEM I was used for this part of the
271 study to determine the activity index of CRB.

272

273 Table 5: Workability and compressive strength of CRB-containing mortars

Composition	Flow time (s)	Compressive strength (MPa)			Activity Index (28d)
		2d	7d	28d	
100% CEM I	2±1	35±1	54±1	70±2	
75% CEM I + 25% CRB	5±1	30±1	44±1	51±2	0.73

274

275 The results in Table 5 confirm those of Table 4 concerning the effect of the substitution of 25 wt.%
276 cement by CRB on the workability of cement-based materials: use of CRB in the form of a
277 suspension in mortars induced a slight decrease of workability but this was so limited that it does
278 not call into question the reuse of CRB in cement-based material, especially as a main component
279 of low-strength filling grout. Concerning the effect on compressive strength, the ratio between the
280 compressive strength of standard mortar specimens prepared with 75 wt.% test cement plus 25 wt.%
281 CRB by mass and the compressive strength of standard mortar specimens prepared with 100 wt.%
282 test cement permitted the activity index of CRB to be calculated. The activity index was equal to
283 0.73, which is very close to the standard activity index for conventional calcareous filler (0.71) [40].
284 This result shows that CRB could be considered as conventional calcareous filler from the
285 mechanical point of view and is encouraging for its use as a main component of filling grouts.

286

287 **3.3 Fresh and hardened characteristics of CRB-containing grouts**

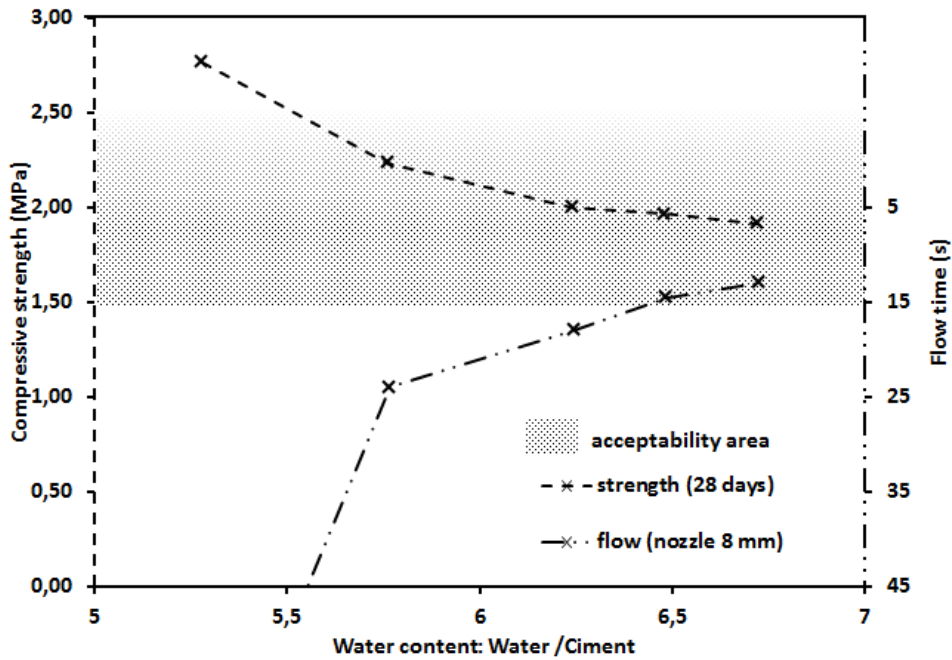
288 Table 1 presents the fresh (stability and flow time) and hardened (28d compressive strength)
289 characteristics of grouts. The minimal specifications of these characteristics that low-strength filling
290 grouts have to meet are recalled in the table [23, 30-32]. Table 1 shows the combined effects of
291 water and CRB additions on the fresh and hardened characteristics of grouts. The three
292 characteristics change in opposite directions: for example, for the reference mixture (0% of CRB),
293 an increase in W/C ratio improves the fluidity of mixtures but, at the same time, increases the
294 decantation and decreases the compression strength. The specifications were met for mixture “0-
295 3.1”, without CRB.

296 The addition of CRB strongly improved the stability of fresh grouts since, whatever the W/C ratio,
297 the stability criterion was satisfied for all mixtures (the decantation was close to 0% for all mixtures
298 containing CRB). This is a major result since the use of CRB in grout avoids the addition of
299 bentonite as a stability agent. However, replacement of sand by CRB also led to a significant
300 increase in the W/C ratio needed to meet the flow test criterion. This effect had already been
301 observed during the study of cement pastes and mortars but, in the case of grouts, the increase was
302 more significant as W/C increased from 3.85 for the reference mixture (0% CRB) to 4.45 for
303 mixtures with 50 wt.% of CRB and 6.75 for those with 100 wt.% of CRB. Nevertheless, it is
304 interesting to note that this increase in W/C did not lead to a strong decrease in the compressive
305 strength at 28 days. For mixtures with 50 wt.% and 100 wt.% of CRB, the strength at 28 days was
306 sufficient at all W/C ratios (except the “50-5.3” mixture, for which the increase of the W/C to 5.3
307 was not necessary because the specifications of fluidity were already met for the mixture having a
308 W/C ratio of 4.9).

309

310 From an economic and environmental point of view, it is obviously better to use the maximum
311 acceptable amount of CRB in the grout. Figure 5 sums up the results obtained for mixtures
312 containing 100 wt.% of CRB.

313



314

315 Figure 5: Fresh and hardened characteristics of low-strength filling grouts containing 100 wt.% of
316 CRB

317

318 Figure 5 shows that the specification for compressive strength was reached for all mixtures even if
319 the compressive strength decreased when the W/C ratio increased. The stability of the mixtures
320 containing 100 wt.% of CRB was always excellent. Thus, to meet the requirements, it was only
321 necessary to increase the W/C ratio until the required flow time was achieved (W/C equal to 6.5).
322 Moreover, it is interesting to note that the low-strength filling grouts containing 100 wt.% of CRB
323 performed better in the fresh and hardened states than the reference grouts containing fine sand and
324 bentonite, particularly with regard to their stability and compressive strength. It would thus be

325 possible, in a further optimization study, to reduce the amount of cement contained in the grouts
326 rich in CRB to reach the limit of 1.5 MPa at 28 days and thus to make the CRB-containing mixtures
327 even more competitive from the economic point of view.

328

329 **4. Conclusion**

330 This study has dealt with the reuse of Carbonated Residual Brines as a mineral addition and agent
331 of stability in low-strength filling grout for soil reinforcement applications.

332 The chemical and mineralogical characterization of this residue showed that it was essentially
333 composed of calcium carbonates (91%) but contained significant amounts of sulfates (2.6%) and
334 also chlorides (0.9%), which could be worrying for its reuse in reinforced cement-based materials
335 due to problems of delayed ettringite (sulfates) and corrosion (chlorides). Nevertheless, for the
336 application considered (low-strength filling grouts), this would not be a problem, on condition that a
337 low-C3A cement was used as was done in this study (CEM III/C). The physical characterization of
338 CRB highlighted the marked fineness of this precipitated carbonate (D50 equal to 5.7 μm).

339 The study on cement pastes and mortars revealed that the use of CRB did not lead to significant
340 modifications of the setting time or workability of cement-based materials. Moreover, the result of
341 compressive strength measured on mortars showed that CRB could be considered as a conventional
342 calcareous filler from the mechanical point of view.

343 The results obtained on low-strength filling grouts showed that CRB could advantageously replace
344 the fine sand and bentonite contained in conventional grouts. CRB could thus be an interesting
345 substitute for more expensive products and the results showed that the performance levels achieved
346 with the CRB-containing grouts were even better than those of the reference grout. The fact that
347 CRB has a very strong stabilizing effect certainly constitutes one of main findings of this study and
348 could be useful in industrial applications other than civil engineering. In addition, the reuse of CRB
349 would be interesting from an environmental standpoint for at least two main reasons: firstly, the

350 reuse of an industrial waste in replacement of conventional materials would help to save natural
351 resources and, secondly, the process that forms CRB reduces the CO₂ emissions of the industrial
352 plant. However the sulfate and chloride contents limit the possible fields of reuse of CRB in civil
353 engineering and it could be interesting to add an industrial washing step into the process to reduce
354 the amounts of these two soluble elements and thus to develop new potential applications. In
355 particular, the study showed that CRB had exceptional properties as an agent of stability, which
356 may be useful in the production of self-compacting concrete, for example.

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