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of cement composites using carbonaceous nano/micro inerts / R. A., Khushnood; Ahmad, Sajjad; Savi, Patrizia; Tulliani,
Jean Marc Christian; Giorcelli, Mauro; Ferro, GIUSEPPE ANDREA. - In: CONSTRUCTION AND BUILDING
MATERIALS. - ISSN 0950-0618. - ELETTRONICO. - 85:(2015), pp. 208-216. [[10.1016/j.conbuildmat.2015.03.069](https://doi.org/10.1016/j.conbuildmat.2015.03.069)]

Availability:

This version is available at: 11583/2598778 since:

Publisher:

Elsevier

Published

DOI:[10.1016/j.conbuildmat.2015.03.069](https://doi.org/10.1016/j.conbuildmat.2015.03.069)

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<http://doi.org/10.1016/j.conbuildmat.2015.03.069>

(Article begins on next page)

1 **Improvement in Electromagnetic Interference Shielding Effectiveness of Cement**

2 **Composites Using Carbonaceous Nano/Micro Inerts**

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28 **ABSTRACT**

29 The current study is focused to explore a cost effective material for enhancing the
30 electromagnetic interference shielding effectiveness of cement composites. Agricultural
31 residue in the form of peanut and hazelnut shells having little or no economic value was
32 investigated for the subject purpose. These wastes were pyrolyzed at 850 °C under inert
33 atmosphere and ground to sub-micron-size before utilization with cement. Dispersion of sub-
34 micron-carbonized shell was initially observed in water through visual inspection and later in
35 cement matrix using FESEM micrographs of fractured composites. Results displayed that
36 both carbonized peanut shell (CPS) and carbonized hazelnut shell (CHS) possess excellent
37 ability to get easily dispersed in host medium. The complex permittivity of sub-micron-
38 composites was measured in a wide frequency band (0.2-10 GHz) using a commercial
39 dielectric probe (85070D) and network analyzer E8361A. Due to strong polarization resulting
40 from well dispersed sub-micron carbonized shell inclusions, a significant increase in
41 measured dielectric constant (ϵ') and dielectric loss (ϵ'') of cement composites was observed
42 with direct relation to the added content. Numerically evaluated values of electromagnetic
43 interference shielding effectiveness showed remarkable improvement with the addition of
44 sub-micron carbonized shells in cement composites. Maximum increase of 353%, 223%,
45 126% and 83% was observed in shielding effectiveness at 0.9 GHz, 1.56 GHz, 2.46 GHz and
46 10 GHz frequencies respectively, by adding only 0.5% CPS by weight of cement, in
47 comparison to the pristine cement samples.

48 Based on experimental results, it is concluded that the investigated material is highly cost
49 effective (approx. 85% cost saving); very efficient in dispersion as compared to the carbon
50 nanotubes (CNTs) or graphene and quite effective in enhancing the electromagnetic
51 interference shielding properties of resultant cement composites.

52 **Keywords:** Cement composites; Dielectric properties; Electromagnetic interference;
53 Shielding effectiveness; Carbonized peanut shell; Carbonized hazelnut shell.

54 **1. Introduction**

55 Besides many advantages, modern developments in electronics especially in wireless and
56 communication systems are contaminating our surroundings with electromagnetic waves
57 (EMWs) pollution. Presence of EMWs in the environment at such an alarming level uplifts
58 the risks of electromagnetic interference (EMI), which may affect the normal
59 functionalization of many electronic and communication devices. Excessive exposure to such
60 radiations is hazardous to human health, as they can enhance the probability of tumors
61 growth in human body [1–4]. Such issues have motivated many researchers and scientists to
62 explore new ways and methods to provide shielding against the severe exposure of EMWs
63 [5–14]. Military stealth technology or LO technology (Low observable technology) also
64 demands new ideas concerning effective electromagnetic shielding.

65 Cement is the basic building material exhibiting vital role in construction industry. Cement
66 matrix possess poor shielding against EMWs. Some researchers and scientists have done
67 serious efforts to enhance shielding effectiveness of cement composites by making
68 conductive intrusions [15–22]. Wang et al. [23] investigated EMWs absorbing properties of
69 cement nano-composites with varying contents of CNTs and reported maximum absorption at
70 0.6 wt.% CNTs inclusion in the frequency ranges of 2–8 GHz and 8–18 GHz. Nam et al. [24]
71 analyzed the influence of CNTs dispersion on the electromagnetic interference shielding
72 effectiveness (EMI-SE) of CNTs/cement composites and attained maximum enhancement at
73 0.94 GHz, 1.56 GHz, 2.46 GHz and 10 GHz frequencies using 0.6 wt.% CNTs and 20 wt.%
74 silica fume. Kong et al. [25] used 3D carbon nanotubes/graphene (CNTs/G) hybrids to
75 achieve adequate dispersion and concluded that these hybrids meet the requirement of

76 impedance matching, lower EM reflection and improve the EMWs absorption capability of
77 cement matrix.

78 Although CNTs and graphene possess ideal properties in terms of high specific surface area,
79 low density, high aspect ratio and very high conductivity [26–30] but there are several major
80 concerns that normally restrict their utilization on large scales. One of them is their higher
81 production cost and another is their effective dispersion in cement matrix. Moreover, acid
82 functionalization is often used to improve the adhesion between carbon nanotubes and the
83 cementitious matrix, leading to an increase of the toxicity of CNTs, depending on their
84 degree of catalytic impurities and of a threshold [31].

85 The literature survey indicates that little attention has been paid on the exploration of cost
86 effective and dispersion free alternatives to improve EMI-SE of cement composites.
87 Therefore, the current study is focused on the utilization of sub-micron-sized, carbonized
88 agricultural residues; which include peanut shell and hazelnut shell to enhance the EM
89 shielding effectiveness of cement composites.

90 Peanut is one of the most popular and magnificently consumed dry fruit all over the world
91 especially in China and India that are ranked as its top two producers. According to the latest
92 survey of United States Department of Agriculture (USDA), world annual production of
93 peanut is almost 40.18 million metric tons with more than 60% contributions from China and
94 India [32]. Hazelnut is also getting renowned all over the world especially because of its vast
95 usage in many chocolate and ice-cream flavors. Food and agricultural production statistics of
96 United Nations reported that the world's hazelnut production was about 0.91 million metric
97 tons in year 2012, with major part coming from Turkey and Italy that makes about 90% of its
98 annual gross production [33]. Both hazelnut and peanut generate considerable amount of

99 residues in form of their shells with little to no specific value. Therefore it is important to
100 explore new ways to manage and utilize this bio-waste beneficially.

101 Peanut shell and Hazelnut shell yield high content of bio char on carbonization [34–37]. An
102 average yield of about 35% was reported for peanut shell at a temperature of around 500 °C
103 [36], while in case of hazelnut shell it was found more than 40% for the same range of
104 temperature [37]. The economic availability and excellent conversion efficiency of peanut
105 shell and hazelnut shell via pyrolysis, were the two main reasons that motivated the authors to
106 explore their use in cement composites for effective shielding against EMWs.

107 **2. Materials and methods**

108 **2.1 Materials and mix proportions**

109 The cement used for the research work was ordinary Portland cement (Type-1, grade 52.5)
110 confirming to the requirements of ASTM C150 [38]. The chemical composition and physical
111 properties of cement as per the product data sheet are presented in Table 1 & 2 [39]. A high
112 range water reducing admixture (HRWRA), based on modified acrylic polymers and
113 confirming to the requirements of UNI EN 934-2:2012 (admixture for concrete, mortar and
114 grout) was used to achieve sufficient workability. Distilled water was utilized for all the mix
115 formulations. The inert sub-micron carbonized particles used for enhancing the shielding
116 effectiveness of the cement composites were obtained from peanut shell and hazelnut shell
117 using the following procedure.

118 The raw peanut shell (PS) and hazelnut shell (HS) as shown in Figure 1 were washed with tap
119 water and dried in oven for 48 hrs at 105±5 °C. The washed and dried shells were then
120 pyrolyzed in a quartz reactor at 850 °C for 1 hour under inert atmosphere. For the provision
121 of inert atmosphere, constant flow of argon was maintained under 0.2 bar pressure in the
122 reactor throughout the pyrolysis process. Carbonized shells were ground in ethanol to sub-

123 micron scale by ball milling for 24 hrs followed by 2 hrs of attrition milling. The physical
 124 properties of ground sub-micron-carbonized shells are given in Table 3.

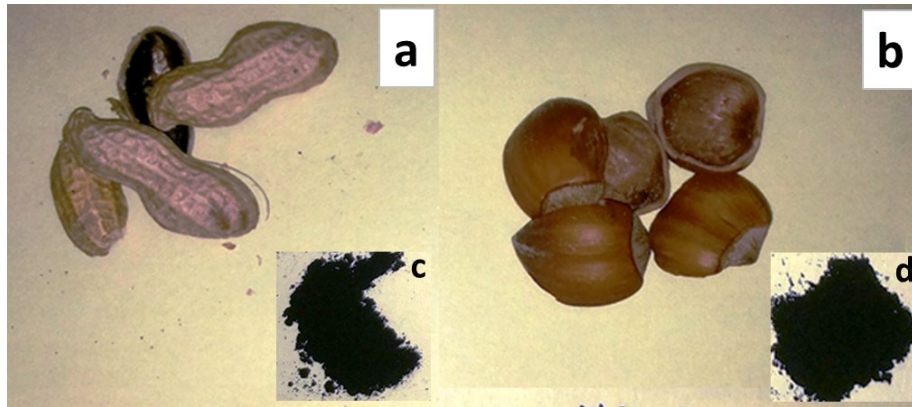


Figure 1: Peanut shell and hazelnut shell in raw form (a & b) and after carbonization and grinding (c & d)

125

126 **Table 1 Chemical composition of cement**

Oxides	CaO	SiO ₂	Al ₂ O ₃	Fe ₃ O ₄	SO ₃	MgO	K ₂ O
Content (% by mass of cement)	44	9.50	26.5	2.5	12	1.3	0.60

127

128 **Table 2 Physical and mechanical properties of cement**

Density (g/cm ³)	Color	Specific surface area (cm ² /g)	Compressive Strength (MPa)	
			3 d	28 d
2.80	Light grey	4800	50	65

129

130 **Table 3 Properties of sub-micron pyrolyzed shells**

Sub-micron carbonized shells (CS)	D 50 (nm)	D 90 (nm)	BET surface area (m ² /g)	Density (g/cm ³)
Carbonized peanut shell (CPS)	600	1200	19.4	2.20
Carbonized hazelnut shell (CHS)	750	1300	14.5	2.35

131

132 Five mix formulations were prepared including the reference one; detail mentioned in Table
 133 4. Sub-micron carbonized inerts were used as an additive in two proportions i.e. 0.2 and 0.5
 134 wt% of cement. Weight ratios of water and super plasticizer were kept constant at 35% and
 135 1.5% by weight of cement respectively.

136

137 **Table 4 Mix proportion**

Denotations	Weight compositions (% mass ratio of cement weight)				
	Cement	Water	superplasticizer	(CPS)	(CHS)
CEM	100	35	1.5	0.0	0.0
0P2CPS				0.2	0.0
0P5CPS				0.5	0.0
0P2CHS				0.0	0.2
0P5CHS				0.0	0.5

138

139 **2.2 Preparation**

140 The entire preparation consisted of two steps. First step comprises dispersion of sub-micron
 141 carbonized shells (CS) in water with the aid of surfactant and bath sonication for 15 minutes.
 142 Second step covers mixing of resultant homogeneous solution with cement using mechanical
 143 mixer operated at 440 rpm (slow mixing) for 1.5 min and at 660 rpm (fast mixing) for 2.5
 144 min.

145 Mixed cement formulations were poured in associated labeled plastic molds of 6.5 cm in
 146 diameter and 1.0 cm in height. The molded specimens were kept in covered plastic box
 147 partially filled with water for initial 24 hrs. After that the specimens were demolded and
 148 immersed in water. Curing was done at room temperature (20 ± 2 °C) for 28 days [40]. The
 149 cured specimens were dried in oven at 50 ± 5 °C for 5 days and then stored in air tight bags.
 150 Typical cement specimen compared with one euro coin along scale is shown in Figure 2.

151 **2.3 Characterization**

152 To characterize structural order of CS, Raman spectroscopy was carried out by means of
 153 Renishaw micro-Raman analyzer with green laser of 514 nm wavelength. Laser beam was
 154 focused using 100X objective lens on specimen's surface in 2 μm spot size. The Raman
 155 spectrum was restricted in the wavenumber range of 500-3500 cm^{-1} . Field Emission Scanning
 156 Electron Microscopy (FE-SEM) along with Energy Dispersive X-Ray (EDX) spectroscopy

157 was performed to assess morphology, microstructure, elemental composition and dispersion
158 of carbonaceous material in the host cement matrix.

159 Complex permittivity measurements of cement composites containing sub-micron
160 carbonaceous fillers were performed in the frequency range 0.20-10 GHz with a commercial
161 dielectric sensor (85070D) and a network analyzer (E8361A; see Figure 3). The system was
162 calibrated for water and air before starting measurements. Such measuring system was
163 adopted keeping in view its feasibility to work on specimens with smaller dimensions and it
164 also allows wide-band characterization as well. In all measurements it was tried to ensure
165 perfect contact between sensor probe and specimen's surface. Measurements were taken at
166 six different sites of each single specimen to ensure homogeneity and reduce error margin;
167 reported results are the average of the six measurements.

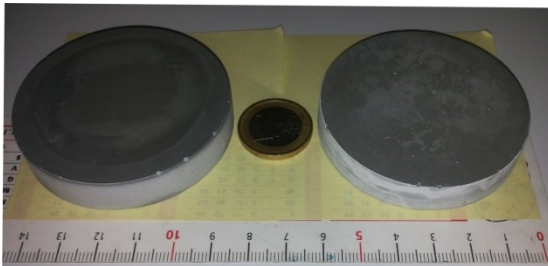


Figure 2 Typical sub-micron cement composite compared with one euro coin



Figure 3 Measurement setup. Agilent sensor (85070D) and Network Analyzer (E8361A)

168

169 3. Results and discussions

170 3.1 Raman spectra analysis

171 The most relevant wave number range related with Raman spectrum is $1000-1700\text{ cm}^{-1}$. It is
172 prominent due to the presence of D (defect grade I_D) and G (graphitization grade I_G) bands;
173 which are displayed at approximately 1341 cm^{-1} and 1595 cm^{-1} wavenumbers for CPS while
174 at 1342 cm^{-1} and 1592 cm^{-1} wavenumbers in the case of CHS respectively as shown in Figure
175 4. The ratio of the two bands is a good indicator related to the quality of carbonaceous filler;

176 there are quite high structural defects if these bands approach to similar intensity and vice
177 versa. The ratio of I_D to I_G band was similar in the two synthesized products (about 0.85)
178 which indicates that the two materials are equivalent and contain a limited amount of
179 amorphous carbon or of defective graphite crystals in these materials [41].

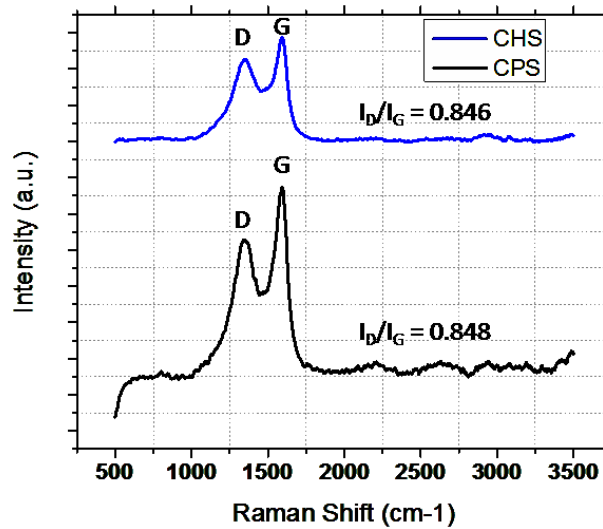


Figure 4 Raman spectra for carbonized peanuts and hazelnuts shells

180

181 3.2 Morphology and composition

182 SEM micrographs as shown in [Figure 5](#) demonstrate that CHS and CPS are in the form of
183 plates/flakes with shape varying from angular to flat and elongated. These plates exhibit
184 glossy and smooth texture with average plate size restricted to less than 800 nm and thickness
185 varying from less than 100 nm up to 300 nm. Such plates seem to be free from entanglement
186 problem as associated with nanotubes and therefore it would be easy to disperse them in
187 cement matrix. As they contain much variety in shape and size so it can be said that they will
188 be quite effective in filling voids of varying size (from gel pores to capillary pores) in cement
189 matrix and thereby enhance its EMI-SE as well as the mechanical performance.

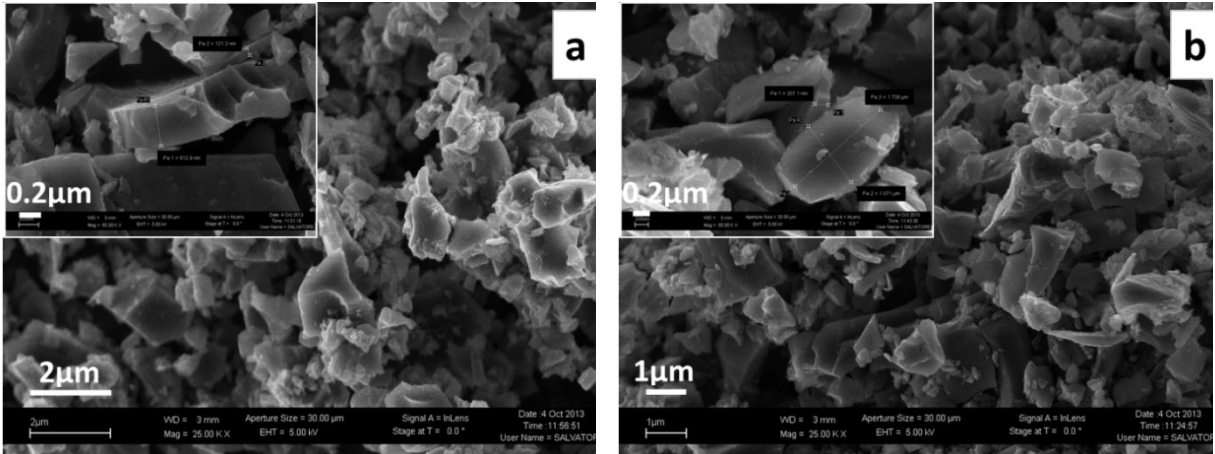


Figure 5 Micrograph of CPS (a) and CHS (b) observed by FE (field emission) SEM

190

191 EDX spectrum of CHS and CPS is shown in Figure 6. The spectrum displayed presence of C,

192 Mg, Al, Ca and Si in CS with detailed proportions mentioned in Table 5.

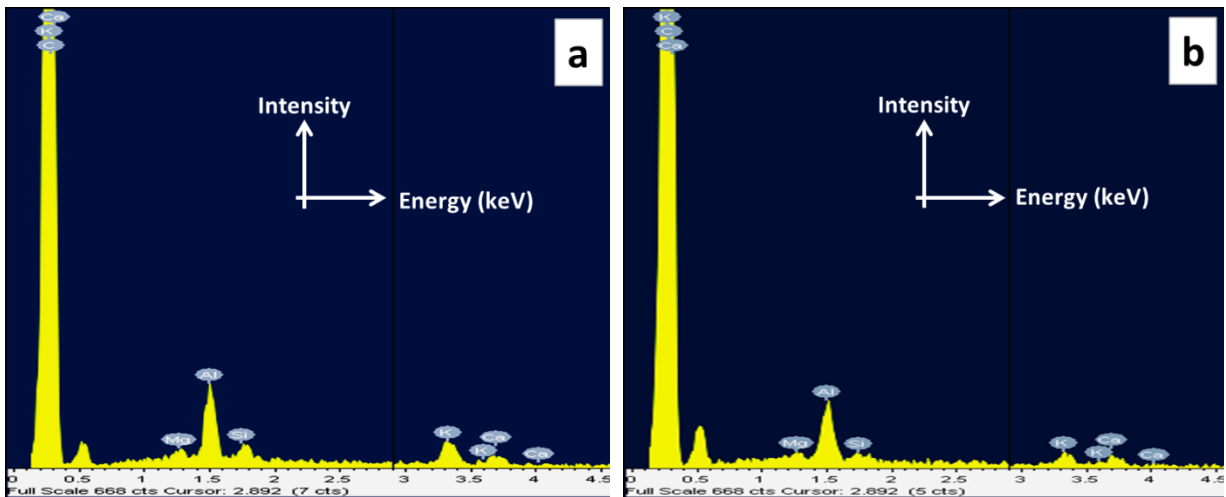


Figure 6 Energy dispersive X-ray spectra of CPS (a) and CHS (b)

193

194 **Table 5** Elemental composition of CPS and CHS

Elements	CPS (wt%)	CHS (wt%)
C	93.77	87.68
Mg	0.43	0.53
Al	3.01	5.09
Ca	1.20	1.65
Si	0.23	1.14

195

196

197

198

199 **3.3 Dispersion**

200 It was hypothesized by Nam et. al. [24] that a better dispersion state of CNTs in the cement
201 matrix can bring higher EMI-SE. CS were dispersed in water using ultrasonic treatment and
202 superplasticizer. To demonstrate that a good level of dispersion was achieved a small amount
203 of the solution (water + CS + SP) was diluted with a measured water content (1:5) in a test
204 tube and visually inspected. The color appeared uniform even after one hour of dispersion. If
205 CS were badly dispersed a certain quantity would have deposited at the bottom of the test
206 tube, as in case of 0.5 wt% CNTs dispersed in water for comparison as shown in Figure 7.

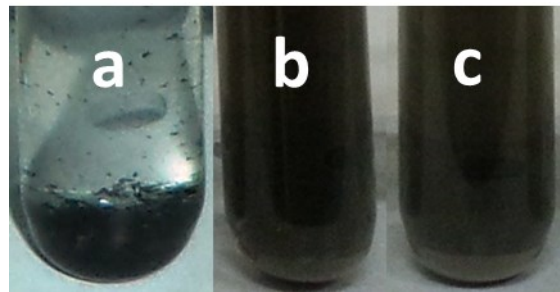


Figure 7 Dispersion level of 0.5wt% CNTs (a), 0p5CPS (b) and 0p5CHS (c) in water after 1hr of dispersion

207
208 FE-SEM analysis of fractured cement specimens given in Figure 8 showed better dispersion
209 of CS inside cement matrix. All particles are very well distributed and no signs of
210 agglomeration are visible. Better dispersion results in creation of more and more interfaces
211 which ultimately enhance EMI-SE by increasing absorption loss of EMWs.

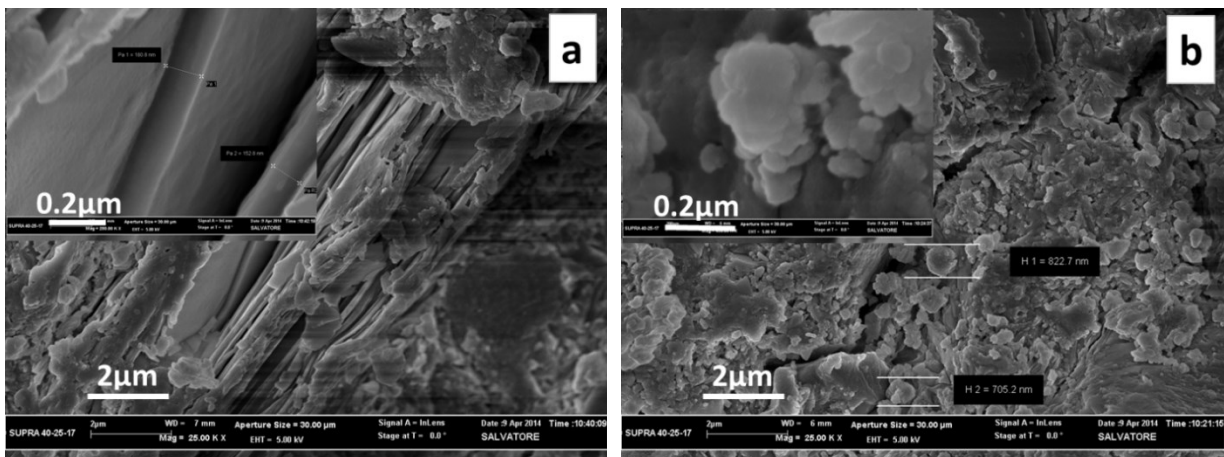
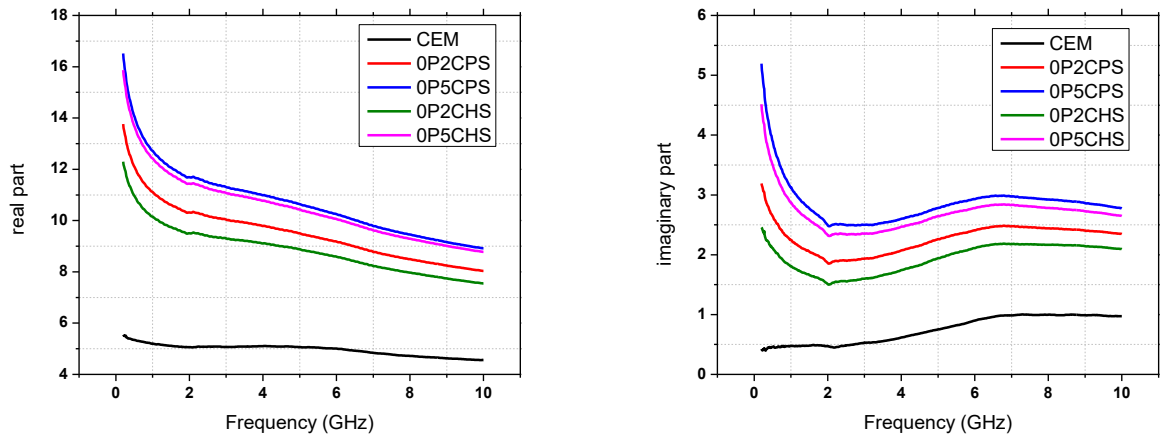


Figure 8 FE-SEM micrographs of 0p5CPS (a) and 0p5CHS (b) fractured cement specimens

212 **3.4 Complex permittivity measurements and analysis**

213 The relative complex permittivity ($\epsilon_r = \epsilon' - j\epsilon''$) was measured using dielectric probe sensor in
214 0.2-10 GHz frequency range. Figure 9 shows both real (ϵ') and imaginary (ϵ'') parts of
215 permittivity as a function of frequency for cement composites with and without CS
216 inclusions. The real part refers to the content of energy stored by material when exposed to
217 external electric field while imaginary part is the measure of dissipated or lost energy. An
218 appreciable increment was observed in the values of real and imaginary permittivity on
219 induction of filler in cement matrix.



220 Figure 9 Complex permittivity of pure cement paste and cement composites with varying contents of CPS and CHS.

221 Dielectric performance of a material depends upon its ionic, electronic, orientation and space
222 charge polarization. Ionic polarization is inversely related to frequency of EMWs with
223 nominal decrease observed at high frequencies. This is the reason why ϵ' and ϵ'' reduce on
224 increase in frequency of applied EMWs. Since CS contain carbon ($C > 85\%$ see Table 5)
225 which possesses free electrons and bound charges that account for encouraging strong
226 orientational polarization. Inclusion of very well dispersed CS in an insulating medium like
227 cement results in the formation of more interfaces with ultimate increase in space charge

228 polarization. All these factors contributed to enhance both dielectric constant (ϵ') and
229 dielectric loss (ϵ'') of cement composites containing CS; with direct relation to the added
230 content.

231 **3.5 EMI shielding effectiveness (numerical results)**

232 Shielding effectiveness (SE) is defined in decibels (dB) and mathematically expressed as
233 [19]:

$$234 \quad SE_{dB} = R_{dB} + A_{dB} + M_{dB} \quad (1)$$

235 The mathematical expression of SE clearly demonstrates its dependence upon three major
236 losses occurring while propagation of EMWs through the medium. R_{dB} is termed as reflection
237 loss which occurs due to reflection of EMWs at the material's interfaces. A_{dB} is absorption
238 loss of the wave as it proceeds through the barrier with strong relation to its thickness (t) and
239 skin depth (δ). Skin depth is defined as the material's thickness which can reduce the power
240 of EMWs by a factor of $1/e$ from its original power during propagation and it is given by
241 following relation:

$$242 \quad \delta = 2/\sigma\omega\mu \quad (2)$$

243 Here σ , μ and ω are the electrical conductivity, magnetic permeability of the material and
244 angular frequency respectively. There is some additional effect on total SE due to re-
245 reflections and transmissions phenomena of EMWs during their propagation through the
246 barrier; known as multiple reflection loss M_{dB} and can be neglected if SE exceeds 10 dB [42].

247 Total SE along with the three major contributors i.e. R_{dB} , A_{dB} and M_{dB} was numerically
248 evaluated in the frequency range of 0.2-10 GHz based on measured values of dielectric
249 constant (ϵ') and dielectric loss (ϵ''). Matlab script was used considering a sample material
250 with a thickness greater than skin depth ($t > \delta$). In the calculations conductivity,
251 permeability and complex permittivity are given by following set of equations respectively:

252
$$\sigma = \varepsilon'' \omega \varepsilon_o \quad (3)$$

253
$$\mu = \mu' \mu_o \quad (4)$$

254
$$\varepsilon = \varepsilon' \varepsilon_o \quad (5)$$

255 R_{dB} , A_{dB} and M_{dB} were calculated according to following expressions:

256
$$R_{dB} = 20 * \log_{10} \left| \frac{(Z_o + Z_m)^2}{4 * Z_o Z_m} \right| \quad (6)$$

257
$$A_{dB} = 20 * \log_{10} \left| e^{\frac{t}{\delta}} \right| \quad (7)$$

258
$$M_{dB} = 20 * \log_{10} \left| 1 - \left[\left(\frac{Z_o - Z_m}{Z_o + Z_m} \right)^2 * e^{-\frac{2t}{\delta}} * e^{-i * 2 * \beta * t} \right] \right| \quad (8)$$

259 Where Z_o and Z_m are the characteristic impedance of free space and barrier material
 260 respectively given as.

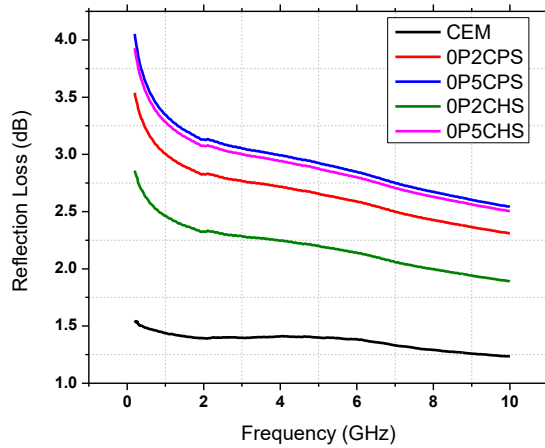
261
$$Z_o = \sqrt{\mu_o / \varepsilon_o} \quad (9)$$

262 μ_o and ε_o correspond to permeability and permittivity of free space

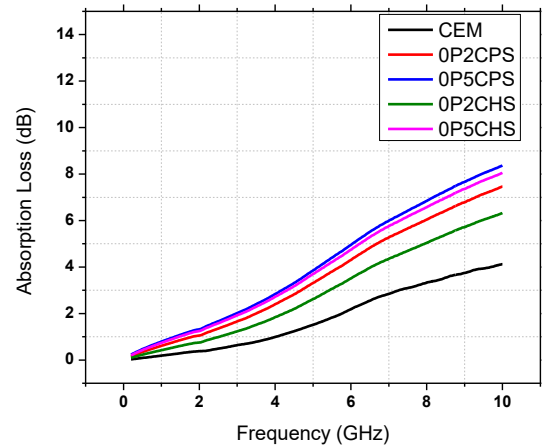
263
$$Z_m = \sqrt{\frac{i * \omega * \mu}{\sigma + (i * \omega * \varepsilon)}} \quad (10)$$

264 α and β being the propagation factors of shield are related to its propagation constant γ as:

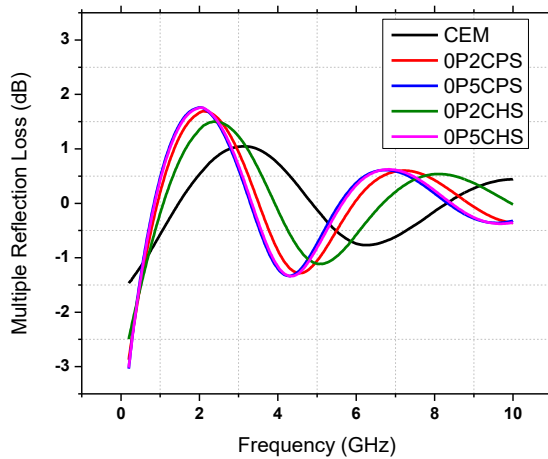
265
$$\gamma = \sqrt{i \omega \mu [\sigma + (i \omega \varepsilon)]} = \alpha + i \beta \quad (11)$$



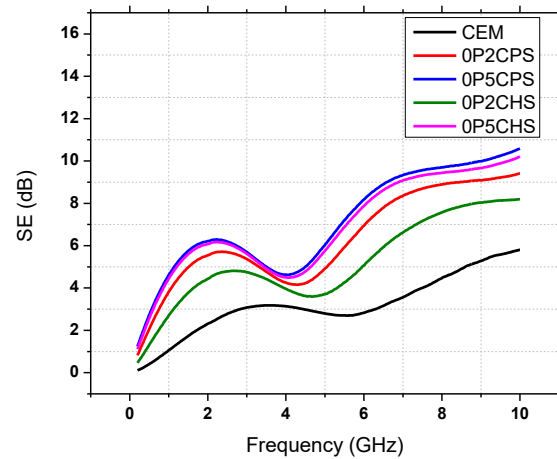
(a) EMW reflection loss of a 10mm thick cement composite sample with and without CS inclusions



(b) EMW absorption loss of a 10mm thick cement composite sample with and without CS inclusions



(c) EM wave multiple reflection loss of a 10mm thick cement composite sample with and without CS inclusions



(d) Total shielding effectiveness of a 10mm thick cement composite sample with and without CS inclusions

Figure 10 Variation in EMWs Reflection (a), Absorption (b), Multiple reflections (c) and resultant EMI SE (d) of cement nano-composites as a function of frequency

266

267 Figure 10 shows that inclusion of both CPS and CHS in cement composites increases their

268 SE and related losses in 0.2-10 GHz frequency range with direct proportionality to the added

269 amount. The observed enhancement pattern of EMI-SE attained on addition of the two CS is

270 almost similar with slightly better results observed in case of CPS; which may be associated

271 to its relatively high specific surface area (Table 1) in comparison to CHS. Another

272 explanation maybe also due to a higher number of particles distributed within the
 273 cementitious matrix, considering that CS additions were done in weight with respect to
 274 cement and that CPS have a slightly lower density with respect to CHS, but particles diameter
 275 are rather similar.

276 To have a better evaluation of results, total SE of all five formulations were compared at four
 277 different frequencies of 0.94 GHz (frequency of GSM mobiles), 1.56 GHz (frequency of GPS
 278 communication devices), 2.46 GHz (frequency of microwave ovens), and 10.0 GHz
 279 (frequency of radio communication devices) as done by Nam et al [24]. Figure 11 shows that
 280 maximum increase by 353% in SE of cement sub-micron composites was observed on
 281 addition of 0.5 wt% CPS at 0.9 GHz frequency. This percentage reduces to 223%, 126% and
 282 83% as we proceed towards high frequency values of 1.56 GHz, 2.46 GHz and 10 GHz,
 283 respectively. In case of 0.5 wt % CHS inclusions, a similar patterned increase of 335%,
 284 214%, 122% and 76% was achieved at the four specified frequencies in comparison to
 285 reference specimens.

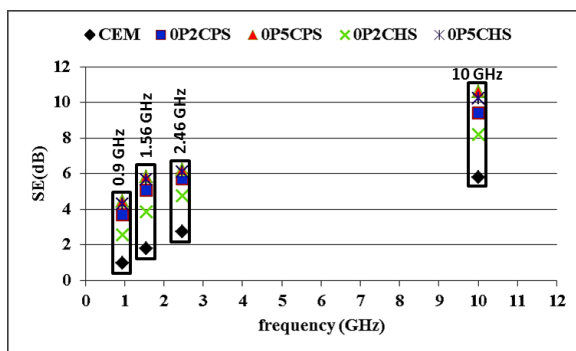


Fig 11 EMI SE of cement sub-micron-composites at specific frequency points with variation of CPS or CHS weight ratios added in cement matrix materials

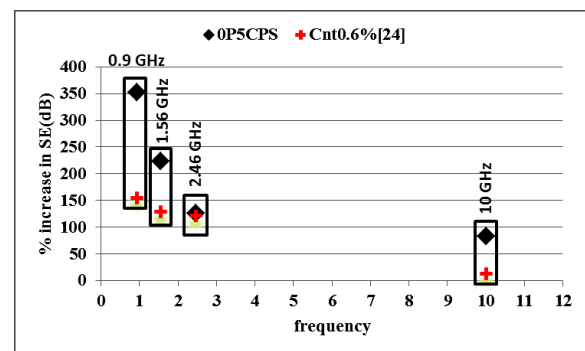


Fig 12 EMI SE comparison of cement sub-micron-composites containing 0p5CPS and 0.6wt% CNTs at specific frequency

286
 287 Total increase in SE and associated components on adding merely 0.5 wt% CS in cement
 288 composites is much higher in comparison to the ones reported by other researcher using
 289 expensive CNTs in same content along with heavy amount of costly dispersants [15,24]. To

290 make the comparison more significant, percentage increase in SE of cement sub-micron
 291 composites at the four prescribed frequencies using 0.5 wt% CPS (achieved by authors) was
 292 compared with 0.6 wt% CNTs [24] in Figure 12. Comparison shows maximum enhancement
 293 on addition of 0.5 wt% CPS in cement composites due to its much better dispersion in water
 294 (Figure 7) and then in cement matrix (Figure 8). Nam et al [24] also reported much better
 295 results of shielding effectiveness on effectively dispersing CNTs in cement with the addition
 296 of 20 wt% silica fume.

297 **4. Cost comparison**

298 To have an idea related to percent reduction in cost on utilizing CS instead of CNTs in
 299 preparing one cubic meter cement grout; cost analysis was performed as per the purchased
 300 price from the market (as of June 2014). Formulations containing 0.5 wt% additive fillers
 301 were selected as they attained much enhanced EMI-SE in comparison with pure cement
 302 composites. Based on Eq 12, detailed calculations of quantities and associated expenses are
 303 summarized in Table 6. After analysis, it appears that CS inclusions reduce the cost by
 304 approx. 88.5% in comparison with corresponding CNTs/cement composites.

305 Density of CNTs = 2.05 g/cm³ [43]

306 Density of SP (assuming Mapei SP1) = 1.09 g/cm³ [44]

307 Density of dispersant (assuming gumarabic) = 1.35 g/cm³ [45]

$$\begin{aligned}
 308 \quad 1 = & \left(\left(\frac{c}{(\text{density of } c)} \right) + \left(\frac{\text{wt of water } (0.35c)}{\text{density of water}} \right) + \left(\frac{\text{filler content } (0.005c)}{\text{density of nano filler}} \right) + \left(\frac{\text{SP wt } (0.015c)}{\text{SP density}} \right) + \right. \\
 309 & \left. \left(\frac{\text{disp wt } (6 * \text{CNTs})}{\text{disp density}} \right) \right) + 0.02 \text{ (air)} \quad (12)
 \end{aligned}$$

310

311

312 **Table 6 Comparison of cost analysis**

Materials	Unit Price (\$)*	CEM		0p5CNTs		0p5CPS		0p5CHS	
		Quantity /m ³	Price (\$)	Quantity /m ³	Price (\$)	Quantity /m ³	Price (\$)	Quantity /m ³	Price (\$)
Cement (kg)	0.15	1359.4	203.9	1314.4	201.2	1355.1	203.3	1355.4	203.3
CNTs (kg)	2000 [46]	-	-	6.57	13140	-	-	-	-
PS (kg)	0.01	-	-	-	-	6.78	0.07	-	-
HS (kg)	0.02	-	-	-	-	-	-	6.78	0.14
SP (kg)	100	20.4	2040	19.7	1970	20.3	2030	20.3	2030
Dispersant (kg)	110	-	-	39.4	4336	-	-	-	-
Processing cost (CS)	5.0	-	-	-	-	6.78	33.9	6.78	33.9
Total cost	-	-	2243.9	-	19647.2	-	2267.3	-	2267.4
Percent Increase (ref CEM)	-	-	100.0	-	776	-	1.08	-	1.08
Percent Reduction (ref 0p5 CNTs)				-	0.0	-	88.5	-	88.5

313 * \$ stands for US dollars

314 **5. Conclusions**

315 A new type of cost effective material in the form of cement composites containing carbonized
316 agricultural residue (comprising CPS and CHS) was proposed for shielding against EMWs.
317 CS/Cement composites were prepared in two different proportions of 0.2 wt% and 0.5 wt%.
318 Visual inspection of pre-dispersed CS in water and FE-SEM analysis of fractured composite
319 specimens showed their excellent dispersion capability in host medium. A significant
320 increase in permittivity, both real and imaginary parts, was observed in 0.2-10 GHz
321 frequency range with direct relation to the added content. Maximum increase in EMI-SE of
322 353%, 223%, 126% and 83% at 0.9 GHz, 1.56 GHz, 2.46 GHz and 10 GHz frequencies was
323 achieved in the case of 0.5 wt% CPS compared to the reference one.

324 The investigated material was found much efficient for EMI shielding applications, providing
325 advantage of better dispersion, simple manufacture at a much lower cost (cost saving > 85%)
326 compared to the corresponding CNTs based cement composite material. In future the
327 research will be extended to use other agricultural residues and study more wt% addition
328 levels to analyze their suitability for enhancing EMI-SE of cement composites.

329 **Acknowledgement**

330 The authors acknowledge the PhD grant provided by the Higher education Commission
331 (HEC), Pakistan. The authors are very grateful to Dr. Salvatore Guastella for FE-SEM
332 analysis and Dr. Pravin Jagadale for his help in synthesis of carbonaceous micro inerts. Dr.
333 Stefano Broggio (Mapei S.p.A.) and Dr. Fulvio Canonico (Buzzi Unicem) are also gratefully
334 acknowledged for having provided superplasticizer and cement, respectively.

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