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TESTS REGARDING FILLING PERFORMANCE OF THE MORTARS OBTAINED BY RADIOACTIVE RECYCLED SAND

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Abstract. Present research analyzes, using non radioactive original concrete, the various mortar recipes in order to identify those that meet the proposed specification for fluidity and allow obtaining of the highest fill ratio for mortar.

Key words: crushed concrete, recycled concrete aggregates, reuse and recycling of radioactive waste, waste disposal volume reduction, waste usage ratio.

1. INTRODUCTION

Radioactive concrete waste that will be generated from dismantled structures of VVR-S nuclear research reactor from Magurele (biological protection around the core and hot cells) represent an amount of about 70 tons. It was shown [1] that radioactive concrete recycling can be a main solution for volume waste reduction, helping in saving natural resources and ensuring environmental protection.

It was developed an innovative technology [2] in which radioactive concrete is recycled by crushing, yielding two size fractions:

– aggregate size, 10–50 mm (rubble);

– fine aggregate (sand) size < 2.5 mm.

The mortar made from recycled radioactive sand, cement, water and super-plasticizer agent is poured in container with radioactive rubble (that is pre-placed in containe) for cimentation. Is achieved a radioactive waste package in which the degree of filling of radioactive waste increases substantially.

Present research study, using non-radioactive concrete, various mortar recipes in order to identify those that meet the proposed specification [2] for fluidity and allow obtaining of the highest fill ratio for mortar. The parameters that influence pre-placed rubble and mortar fill ratio were analyzed by optimal properties identification of mortar having minimum water content. The research will continue, through the use of mortar additives having a better performance.

2. MATERIAL CHARACTERISTICS

For the tests, was used as reference concrete C25/30 whose characteristics are presented in:

- Table 1: reference composition of concrete;
- Table 2: the experimental values for fresh concrete;

Table 1

Reference concrete composition (for 1 m^3 of concrete) C25/30

Concrete type	Aggregate on sorts for 1 m^3 concrete [kg]	$S^{2)}$ from total aggregate (%)	$C^{3)}$ [kg]	$Ag^{1)}/C^{3)}$	$W^{4)}$	$W^{4)}/C^{3)}$	$Ad^{5)}$ (l)
C25/30	0/4 – 815.9 4/8 – 453.3 8/16 – 543.9	45	345.5	5.25	190	0.55	3.3

$^{1)}$Ag – aggregate; $^{2)}$ S – sand; $^{3)}$C – cement; $^{4)}$W – water; $^{5)}$Ad – Glenium 27 as super-plasticizer additive/ highly efficient water reduce.

Fine and coarse river aggregates on three sorts: 0–4; 4–8; 8–16. Maximum aggregate size: $d_{max.}$ = 16 mm; Passing: T_4 = 45%; T_8 = 70%; T_{16} = 100%; Size composition: 0–4 = 45%; 4–8 = 25%; 8–16 = 30%.

Table 2

The experimental values for fresh concrete C25/30

Concrete type	60 dm^3 concrete composition				Slump test (mm)	Fresh concrete density [kg/m^3]	Remarks
	Aggregate on sorts [kg]	Cement [kg]	Water (liters)	Additive Glenium 27 (ml)			
C25/30	0/4 – 49.0 4/8 – 27.2 8/16 – 32.6	20.7	11.4^{1}	198	20	2340	– workable – 4% entrapped air

The actual amount of water added (liters): $^{1)}$ 9.0.

- Table 3: the mass and density values of samples after 28 days water storage;
- Table 4: compression strenght values.

Table 3

Mass samples after 28 days of storage in water and apparent density values C25/30 for original concrete C25/30

Concrete type	Cubes mass (d = 15cm) at 28 days [kg]			Cylinder mass (d = 15cm h = 30 cm) at 28 days (kg)	Hardened concrete apparent density [kg/m^3]
	A	B	C		
C25/30	8018	8020	8078	12483	2382

Table 4

Maximum load and compressive strength for original concrete C25/30

Compression after 7 days				Compression after 28 days				Preliminary strength at 28 days
$F^{1)}$ (kN)			$f_c^{2)}$ (MPa)	$F^{1)}$ (kN)			$f_c^{2)}$ (MPa)	(MPa)
855	915	905	39.6	979	1035	1076	46.3	42
				1024	1100	–		

1) F – force; 2) f_c – compressive strength

3. RUBBLE TESTING TECHNOLOGY

3.1. EXPERIMENTAL CONDITIONS

In the decommissioning process of VVR-S nuclear reactor, concrete structures are cut into blocks using diamond wire cutting technology and Brokk demolition robot 50/ Brokk 160 to achieve size < 350 mm. Preliminary experiments were carried out on C25/30 original concrete blocks having dimensions of 150×150×150 mm, because now the demolishing of RN VVR-S structures has not started yet. To obtain coarse aggregate (rubble) for pre-placement, the cubes were crushed in stage 1 into a jaw crusher type Liebherr adjusted at nominal size of 50 mm. The rubble was sieved on mesh sieves of 50 and 10 mm to separate useful sort 10/50 mm, which was used for pre-placement tests.

3.2. CHARACTERIZATION OF RECYCLED AGGREGATES 10/50 mm SORT

3.2.1. Size distribution

Recycled coarse concrete aggregate derived out of class C25/30, 10-50 sort, used as aggregate pre-placed in a drum to immobilize the radioactive waste, was sieved on mesh sieves of 10 mm, 16 mm, 31.5 mm, 45 mm and 50 mm to measure aggregate size distribution (Table 5).

Table 5

Size distribution of recycled aggregate concrete C 25/30

	Sort (mm)			
wt. [%]	10–16	16–31.5	31.5–45	45–50
	15.20	34.60	36.60	13.60

3.2.2. The aggregate shape

The experimental results emphasize that both the shape index, SI (30.5%) and flattening coefficient, A (33.5%), has high values which makes that aggregate to be placed in unfavorable categories. The characteristics of the recycled aggregate form are inferior to the original unit.

3.2.3. The absorption coefficient of water in coarse aggregates

Water absorption coefficient was determined for recycled coarse aggregate sorts 10–16, 16–31.5 and 31.5–50, after 2 hours and 24 hours irrespective, see Table 6.

The recycled aggregate samples were kept in water at 22 °C. The results show that the water absorption of recycled aggregates is much larger than the original aggregate, due to absorption of particles attached on old mortar rubble. Also it is observed a decrease of water absorption coefficient with the increasing of aggregate size. This confirms literature data [3] according to which the most important difference between natural and recycled aggregates is higher water absorption in the case of recycled aggregates.

Table 6

Absorption coefficient values for recycled aggregate C25/30

Aggregate		Absorption coefficient of water in vol. [%]		
		Sort (mm)		
		10–16	16–31.5	31.5–50
Recycled aggregate kept in the water at 22°C	2 hours	5.59	5.10	4.64
	24 hours	5.74	5.32	5.12

Los Angeles abrasion test. Los Angeles coefficient was determined for a 5000 g sample of sort 10–16 for recycled aggregate obtained with a hammer crusher. The 46 % value obtained is significantly higher than in case of natural aggregate. This behavior is justified by the presence of the hardened mortar attached to the aggregate original. During Los Angeles test, the old mortar emerges as a very fine powder. According to ASTM C-33 [4] aggregates can be used to obtain concrete if mass loss Los Angeles does not exceed 50%.

4. PRE-PLACEMENT RUBBLE TESTS

4.1. THE RUBBLE FILL RATIO

The 10–50 mm rubble sort was pre-placed manually through a funnel, in a small cylindrical container (240 mm diameter and 220 mm height). It was determined rubble fill ratio as a percentage volume of container capacity, by replacing the volume of empty space in the container with water.

It was tested the following materials:

- natural river aggregates;
- recycled aggregates, 10–50 mm sort.

For natural river aggregates, the aggregate size fractions were mixed by mass in equal quantities. The tests were made on different dimensional sorts. Vibration of the container was made on a vibrating table 7.7 VT 6K Knauer type, to 50% vibration frequency for 1 minute. The results (Table 7) were compared with the results of the Ishikura *et al*. [5].

It is observed that:

- natural river aggregates show the highest filling ratio with aggregates for container (vol. %) compared with recycled concrete aggregates;
- the rubble fill ratio (vol. %) decreases with increasing size of aggregates;
- vibrating aggregates leads to the increase of fill ratio compared with no vibration of natural river aggregates pre-placement – vol. 2.76%, and recycled aggregates – vol. 8.4% respectively;
- the Ishikura *et al*. [5] statement is confirmed: rubble fill ratio at the distance pre-placement tests decreases by about 4–7% compared to the pre-manually placement.

Table 7

Dependence between the filling ratio and dimensional concrete aggregate sort

C 25/30

Sort (mm)	Natural river aggregate vol. [%]	Recycled concrete aggregate vol. [%]
10–16	59.8	46.9
16–31.5	58. 9	46.8
31.5–45	58.0	44.8
45–50	54.8	44.0
31.5–50	58.6	41.8
16–50	59.9	44.6
10–50	64.8	47.2
10–50 (vibrated)	67.6	55.6

This is due to the fact that the pre-placement of the distance tends to allow a higher volume of void;

– the results (rubble fill ratios of 41.8 ÷ 55.6 vol. %) are comparable to those obtained by Ishikura *et al.* [5] who found a fill ratio of the empty container for pre-placed rubble between vol. 40 ÷ 55%, depending on its size distribution.

5. PERFORMANCE TESTS ON MORTAR FILLING OBTAINED WITH RECYCLED AGGREGATE

5.1. TYPES OF MORTARS

To increase the usage ratio of the waste in the containers more than found in the past chapter were conducted specific tests on mortars.

In order to carry out the tests, four types of mortar (R, L, DR and DP) were used with recycled fine aggregate having a particle size < 2.5 mm, obtained with C25/30 original concrete, crushed in first stage with Jaw crusher and in the second with a hammer crusher:

- **R mortar**, uses recycled aggregate with a certain proportion of a particle size sorts (Table 8);
- **P mortar**, using recycled aggregate with the same size distribution as R mortar for which sort 0–0.15 mm that displays an initial surface area of approximately 3000 cm^2/g, was ground in a ball mill to CEPROCIM up to a surface area of 5080 cm^2/g. Specific surface area of the powder was determined with a Blaine permeability-meter type 1-1974, manufactured in Bucharest at ICPILA and calibrated to CEPROCIM. It was used a laboratory mill with horizontal drum rotary batch having 540 mm diameter and 560 mm length, operating at a speed of 45 rev./min. Grinding was performed in batches of 20 kg each;
- **DR mortar**, using recycled aggregate with a particle size distribution of sorts resulting from crushing (Table 8);
- **DP mortar**, using recycled aggregate (with the same size distribution as DR mortar) and recycled powder obtained similar to that used in mortar P.

Table 8

C25/30 size distribution recycled aggregate (R, P, DR and DP)

Sort (mm)	R and P	DR and DP
	wt. [%]	
1.25–2.5	22.5	14.7
0.6–1.25	17.5	23.7
0.3–0.6	18.0	23.0
0.15–0.3	18.0	15.2
0–0.15	24.0	23.4

The results were compared with references mortars – N obtained with natural river aggregates. The sand was mixed in the proportions shown in Table 9 to produce mortars type N.

The size distribution obtained for recycled aggregates, sort 0–2.5 was measured using mesh sieves which are conforming to SR EN 933-2:2002 provisions for sieves.

The results showed a very close size distributions for recycled R, P, DR and DP fine aggregates. However, P and DP aggregates for which particles lower than 150 µm, were-replaced with fine aggregate grounded in ball mill, act surprising.

In fine aggregate DP was observed a higher proportion of 0.063 to 0.125 mm sort, which is not evident in the fine aggregate P perhaps because of agglomeration and /or adhesion of finer granules to coarse granules.

Although the proportion of ground powder mortars contained in P and that DP may be another parameter of the process, to simplify the results, it was kept constant being varied only W/C and N/C ratios. The mortar fill ratio was calculated from: volume of voids, the density of the mortar and the mortar mass.

5.2. NATURAL AGGREGATE MORTAR

For type N mortar made with river aggregate, sort 0–2.5 mm, was used four S/C ratio (0.8, 1.2, 1.5 and 2) and W/C ratio between 0.35 ÷ 0.60. Additive amount of super plasticizer (Glenium 27) was varied between 0.8 ÷ 1.0% of cement, and it replacing with air entraining additive Micro Air 107 showed that has positive effects on segregation and bleeding but negative effect on fluidity. Moreover, there was used 0.5% of the viscosity modifying agent Rheomatrix 150, relative to the amount of cement. All the mortars were made with cement CEM V A (S-V) 42.5 N (Table 9).

For fresh mortars was determined: density, flow time through the cone and some of them the air content. Hardened mortar specimens were maintained in accordance with applicable standards, by testing mechanical bending, compression. After 28 days there were determined bending strength, compressive strength and apparent density (Table 10) for hardened mortars (40×40×160 mm prismatic specimens). As expected there is a decrease, as evidenced by the regression curves with a high coefficient of correlation for flow time, bending strength and compression for all S /C studied ratios.

The **N mortar h**aving: W/C = 0.4÷0.75; S/C = 1.3 ÷ 2.1; SP Ad. = 1÷2% and MV Ag. = 0.5% is used as references for mortar made with recycled aggregates.

The N (N3, N4, N6, N14 and N21) mortar type, meet the criteria – fluidity and homogeneity – some of them displaying a slight segregation after an hour.

The fill ratio (mortar and voids volume percent for container coarse aggregates) range 54.0 % for N6 mortar to 99.5% for N3 and N14 respectively.

From those N3, N4, and N14 that meet the acceptance criteria, the N3 and N14 mortars fulfill the other target – min. 900 kg/m^3: recycled sand mortar percent less than natural sand mortar. Just N3 sample (compressive strength 58.8 MPa – min. 30 MPa required) fulfill the min. required, W/C ratio (the obtained ratio is 0.45).

Table 9

Flow time for mixture composition (mortar type N)

Sample	Mixture composition [kg]			SP[4] Ad. (%)	p-cone time (s) at min			Density [kg/m³]	Remarks
	W[1]	C[2]	S[3]		0	15	30/60		
N_1	0.41	1	0,8	0,8	69	–	–	2063	Plastic, fluid
[5]N_2	0.35	1	0.8	0.8	166	210	283	2060	Plastic, fluid, stops flowing after 30'
N_3	0.45	1	0.8	0.8	31	48	50	–	Plastic, fluid
N_4	0.50	1	0.8	0.8	20	24	24	1999	Plastic, fluid
N_5	0.55	1	0.8	0.8	12	12	13	1939	Separate water
N_6	0.40	1	0.8	0.8	57	73	80	2016	Plastic, fluid
N_7	0.41	1	0.8	0.8	62	82	107	2026	Plastic, fluid
N_8	0.41	1	0.8	0.5[6]	no flowing			2033	Plastic, workable
N_9	0.40	1	0.8	0.8	69	82	92	1963	4.4% air; fluid
N_{10}	0.40	1	0.8	0.5[7]	no flowing			2004	Workable, 2.5% air
N_{11}	0.40	1	1.2	1.0	75	85	98	2009	Slight separation
N_{12}	0.50	1	1.2	1.0	27	33	39	2036	High separation
N_{13}	0.40	1	1.5	1.0	77	91	101	2052	No separate water
N_{14}	0.50	1	1.5	1.0	37	39	44	2034	Slight separation
N_{15}	0.60	1	1.5	1.0	30	31	34	1963	High separation
N_{16}	0.40	1	2.0	1.0	138	160	189	2057	No separate water
N_{17}	0.35	1	1.2	1.0	130	180	223	2035	No separate water
N_{18}	0.35	1	1.5	1.0	150	200	–	2018	No separate water
N_{19}	0.45	1	1.2	1.0	35	39	–	2025	Slight separation
N_{20}	0.45	1	2.0	1.0	60	69	–	1915	No separate water
N_{21}	0.45	1	1.5	1.0	42	48	50/57	2000	No separate water
N_{22}	0.45	1	1.2	1.0	–			2139	Separate water, 2.4% air
N_{23}	0.45	1	1.5	1.0	–			2084	2.9% air
N_{24}	0.60	1	0.8	0.8	9	9	–	1925	Separate water
N_{25}	0.38	1	0.8	0.8	119	153	195	2051	Plastic, fluid
N_{26}	0.41	1	0.8	0.8	63	85	110	2015	Plastic, fluid
N_{27}	0.38	1	1.5	1	104	132	185	2050	Plastic, fluid
N_{28}	0.40	1	1.5	1	82	95	105	2044	Plastic, fluid
N_{29}	0.55	1	1.5	1	30	33	–	1970	Separate water
N_{30}	0.41	1	1.5	1	82	96	111	2046	Plastic, fluid
N_{31}	0.41	1	1.5	1	84	99	113	2053	Plastic, fluid
N_{32}	0.55	1	1.2	1	26	29	30	2011	Separate water
N_{33}	0.38	1	1.2	1	98	137	186	2030	Plastic, fluid
N_{34}	0.40	1	1.2	1	77	88	112	2018	Plastic, fluid
N_{35}	0.41	1	1.2	1	74	87	106	2021	Plastic, fluid
N_{36}	0.60	1	1.2	1	19	20	–	1999	Separate water
N_{37}	0.40	1	1.2	1	70	82	109	2020	Plastic, fluid
N_{38}	0.41	1	2.0	1	135	159	186	2043	Plastic, fluid
N_{39}	0.40	1	2.0	1	136	166	193	2030	Plastic, fluid
N_{40}	0.50	1	2.0	1	44	56	65	1978	Lack of cohesion
N_{41}	0.55	1	2.0	1	43	49	53	1910	Lack of cohesion
N_{42}	0.41	1	2.0	1	130	150	181	2050	Plastic, fluid

W[1] – water, C[2] – cement, S[3]-sand; [4]SP – super plasticizer; [5] N_2 – too fluid; 0.5[6] – Micro Air 107-1
0.5[7] – Micro Air 107-2

Table 10

N mortar type mechanical strength and density

Sample	Prismatic specimen mass (g)	Average apparent density (kg/m^3)	Bending		Compression		
			Force (daN)	Mean strength (N/mm^2)	Force (daN) a	Force (daN) b	Mean strength (N/mm^2)
N_1	553	2160	429	10.1	8133	8392	51.6
N_2	576	2250	547	12.8	9300	9925	60.1
N_3	552	2158	343	8.0	7750	7633	48.1
N_4	540	2111	280	6.6	6667	6700	41.8
N_5	523	2042	342	8.0	6642	6383	40.7
N_6	551	2151	439	10.3	7892	8250	50.4
N_7	556	2173	402	9.4	7600	7333	46.7
N_8	558	2081	434	10.2	8083	5 417	50.6
N_{11}	533	2181	503	11.8	8108	7767	49.6
N_{12}	558	2156	429	10.0	7633	7317	46.7
N_{13}	550	2148	521	12.2	7500	7850	48.0
N_{14}	560	2188	482	11.3	6967	7158	44.1
N_{15}	559	2185	337	7.9	5217	5450	33.3
N_{16}	564	2204	504	11.8	8225	8283	51.6
N_{17}	556	2173	572	13.4	9583	9667	60.2
N_{18}	561	2191	553	13.0	9650	9025	58.4
N_{19}	562	2195	386	9.0	8567	8350	52.9
N_{20}	571	2230	474	11.1	8208	8100	51.0
N_{21}	570	2228	423	9.9	8517	8417	52.9
N_{22}	555	2169	339	8.0	8500	8267	52.4
N_{23}	567	2214	343	8.0	8917	8850	55.5
N_{24}	509	1987	226	5.3	5650	5700	35.5
N_{25}	559	2185	474	11.1	8392	8 633	53.2
N_{26}	551	2153	401	9.4	7758	8117	49.6
N_{27}	558	2180	495	11.6	8883	8867	55.5
N_{28}	561	2191	538	12.6	8800	8783	54.9
N_{29}	557	2174	388	9.1	8467	7792	50.8
N_{30}	560	2188	482	11.3	5983	6050	37.6
N_{31}	562	2196	491	11.5	7800	7717	48.5
N_{32}	533	2080	247	5.8	7275	7233	45.3
N_{33}	563	2198	503	11.8	8550	8350	52.8
N_{34}	558	2180	512	12.0	8333	8642	53.0

Table 10 (continued)

N_{35}	557	2176	431	10.1	8683	8650	54.2
N_{36}	524	2047	192	4.5	6567	6717	41.5
N_{37}	560	2186	457	10.7	8325	8133	51.4
N_{38}	518	2023	461	10.8	7750	7683	48.2
N_{39}	524	2048	526	12.3	8567	8517	53.4
N_{40}	489	1910	393	9.2	6400	6433	40.1
N_{41}	480	1874	311	7.3	5550	5517	34.6
N_{42}	520	2029	469	11.0	8033	8217	50.8

The prism volume – 256 cm^3.

5.3. RECYCLED AGGREGATES MORTAR

To check the filling ratio with mortar having different ratio constituent's mixture were prepared batches that meet the criteria of flow time and compressive strength for mortar:

– **R mortar**: W/C= 0.4÷0.75; S/C= 1.3÷ 2.1; SP Ad. =1÷2% and VM Ag.= 0.5%;
– **P mortar**: W/C = 0.5÷0.8; S/C = 1.3÷ 2.3; SP Ad. =1÷1.5% and VM Ag = 0.5%;
– **DR mortars:** W/C= 0.5÷0.75; S/C= 1.3÷ 2.1; SP Ad.=1÷1.5% and VM Ag = 0.5%;
– **DP mortars**: W/C= 0.55÷0.75; S/C= 1.3÷ 2.1; SP Ad =1÷1.5% and VM Ag = 0.5%.

For fresh mortars it was determinate:

– apparent density for 1 dm^3 container;
– flow time through the nozzle of the funnel – 10 mm to 0, 15, 30 and 60 min;
– entrapped air using an air entrained apparatus having 1 liter capacity;
– bleeding – representing the amount of water separated from the mortar surface, after 3 rest hours.

At bleeding, for a fresh mortar sample, the separate water quantity per unit area (T_s) is given by:

$$T_s = V_s / S, \tag{1}$$

where: V_s – volume of separated water, extracted mortar surface after 3 hours [ml]; S – fresh mortar surface area [cm^2].

The mortars are fine concrete for which the bleeding is dependent on W/C and S/C ratios. The mortars with high cement content have reduced bleeding tendency.

It seems that it can be used simultaneously super plasticizer additive Glenium 27 and viscosity modifying agent Rheomatrix 150, mixed in certain proportions in mortars with recycled aggregate, so as to ensure optimum values of properties of interest (Tables 11–14).

For all types of mortar made, the correlation time of the mortar flow through the cone W/C ratio, indicate that mortars become more fluid the higher the water content is (for the same amount of cement).

Also, it is observed that:

- W/C ratio increasing determines the flow time decreasing for all S/C used ratios;
- the mortar having the same W/C ratio and a bigger quantity recycled aggregates, the flow time increases due to the higher friction, determinate by recycled aggregate grains.

5.4. RECYCLED AGGREGATE MORTAR FILLING PERFORMANCE TESTS

The rubble (10–50 mm sort size) was previously kept in water and pre-placed by hand in small containers having 240 mm diameter and 220 mm height. For each experiment was measured a volume of voids by void volume with water the replacing method.

The mortar was poured manually from the top of the container, with equal flow rate. Mortar fill ratio was measured in order to find the appropriate flow time which a filling ratio of mortar higher than 95%. The mortar batches, which meet the criteria of flow and compressive strength, were prepared in order to check the fill ratio (Tables 11–14):

- **mortar samples**, **the R (R_2, R_8, R_{11}, R_{15}, R_{16}, R_{19}, R_{20}) type** meet the criteria – fluidity and homogeneity – some of them displaying a slight segregation after an hour. The fill ratio ranges from 58.2% for R15 mortar to 99.8% for R11 mortar. Samples R2, R8, R11 and R19 meet the proposed requirements for min. 95% fill ratio. From them R2 and R11 samples fulfill the requirements (min. 900 kg/m^3 recycled fine aggreagate), thus 935.2 kg for R2 sample and up to 1012.4 kg for R11 sample. Just R11 sample (compressive strenght 35.5 MPa) fulfill the min. required, W/C ratio (the obtained ratio is 0.60).
- **mortars samples P (P6, P7, P12, P14, P17) type** are homogeneous and fluids and the fill ratio vary from 26.6% for P6 to 99.5% for P12. Only the samples P12, P14 satisfy the proposed requirements, min 95 %, fill ratio. The proportion of recycled sand in mortar is 939.2 kg for P14 and for P12 sample is 976.3 kg. Just P12 sample (compressive strenght 31.7 MPa) fulfill the min. required, W/C ratio (the obtained ratio is 0.55).
- **mortars samples DR (DR1, DR4, DR7, DR10, DR13, DR16) type** are homogeneous and fluids, some of them displaying a slight separation after an hour. The fill ratio vary from 90.4% for DR to 99.7% for DR4 and

DR16. DR4, DR7, DR10, DR13, DR16 samples meet acceptance criteria proposed for 95% minimum fill ratio. For the same samples is met the other target (the proportion of recycled sand mortar to be higher than that of aggregates naturae: minimum 900 kg/m^3) as sample DR13 is 925.2 kg to 992.9 kg sample DR16. Just DR 4 sample (compressive strenght 32.7 MPa) fulfill the min. required , W/C ratio (the obtained ratio is 0.60).

– **mortars samples DP (DP_7, DP_{10}, DP $_{11}$, DP_{15}) type** are homogeneous and fluids, some of them displaying a slight separation after an hour. The fill ratio vary from 93.1% for **DP_{10} mortar** to 99.8% for **DP_{11}** mortar. Just the **DP_{11} and DP_{15}** samples meet acceptance criteria proposed for 95% minimum fill ratio. For the same samples is met the other target (the proportion of recycled sand mortar to be higher than that of aggregates naturae: minimum 900 kg/m^3) as sample **DP_{11} is** 1001.6 kg far to 1003.6 kg for **DP_{15}** sample. Just DP11 sample (compressive strenght 30.2 MPa) fulfill the min. required, W/C ratio (the obtained ratio is 0.65).

There are no notable differences between the mortar fill ratios (Table 15), regardless of sand (natural/recycled). The hardened mortars prepared with natural aggregates displays a higher compressive strength than those prepared with recycled aggregates.

Table 11

Recycled R mortar composition and flow-time

Sample	Mix composition [kg]			SP4) Ad. (%)	p-cone (s) at min				Density [kg/m3]	Remarks
	W1)	C2)	S3)		0	15	30	60		
R_4	0.4	1	1.3	1.0	–	–	–	–	1988	Homogeneous flows in drops
R_5	0.5	1	1.3	1.0	69	85	–	–	1945	Homogeneous, fluid
R_1	0.5	1	1.3	1.0	54	60	72	–	2008	Slight sand segregation
R_{12}	0.55	1	1,.3	1.0	38	bleeding			1905	Homogeneous, fluid 6 ml bleeding
R_{15}	0.55	1	1.3	1.0	36	40	51	75	1923	Homogeneous, fluid
R_{11}	0.6	1	1.3	1.0	26	29	30	31	1912	Homogeneous, fluid
R_2	0.6	1	1.3	1.0	23	25	25	26	1929	Homogeneous, fluid, very slight segregation
R_{13}	0.6	1	1.3	1.0	25	bleeding			1928	Homogeneous, 28 ml bleeding
R_3	0.7	1	1.3	1.0	13	13	15	–	1870	Slight segregation, mixer throw mortar
R_{17}	0.55	1	1.7	1.0	78	89	126	–	2001	Homogeneous, fluid
R_7	0.6	1	1.7	1.0	48	63	82	–	1982	Homogeneous, fluid
R_{16}	0.6	1	1.7	1.0	45	61	84	–	1989	Homogeneous, fluid
R_8	0.65	1	1.7	1.5	28	32	39	51	1932	Homogeneous, very slight segregation
R_{18}	0.65	1	1.7	1.0	35	41	56	–	1921	Homogeneous, very slight segregation

Table 11 (continued)

R_{19}	0.65	1	1.7	1.5	26	33	38	51	1929	Homogeneous, very slight segregation
R_6	0.7	1	1.7	1.0	18	19	21	–	1903	Slight segregation mixer throw mortar
R_{22}	0.6	1	2.1	1.5	72	80	88	–	1934	Homogeneous, fluid
R_{10}	0.65	1	2.1	2.0	40	46	55	–	1916	Slight segregation, occluded air
R_{20}	0.65	1	2.1	1.5	35	41	53	–	1921	Slight segregation
R_{21}	0.7	1	2.1	1.5	24	29	41	59	1929	Homogeneous, fluid, slight segregation after standing
R_9	0.7	1	2.1	1.5	28	31	44	–	1936	Homogeneous, fluid, slight segregation after standing
R_{23}	0.75	1	2.1	1.5	17	19	20	–	1914	Homogeneous, fluid, slight segregation after standing

[1)] Water, [2)] Cement (V, A (S-V) 42.5), [3)] Sand; 4[)] SP additive (Gallium 27 super plasticizer – different vol. % relative cement quantity)
• VM agent (viscosity modifier Rheomatrix 150; 0.5 – vol. % relative cement quantity)

Table 12

Recycled P mortar composition and flow-time

Sample	Mix composition [kg]			SP[4)] Ad. (%)	p-cone (s) at min				Density [kg/m^3]	Remarks
	W[1)]	C[2)]	S[3)]		0	15	30	60		
P_{10}	0.55	1	1.3	1	49	bleeding			1933	Homogeneous, 0.5 ml bleeding
P_7	0.6	1	1.3	1.5	28	30	33	38	1922	Homogeneous, fluid
P_6	0.6	1	1.3	1	38	49	57	–	1925	Homogeneous, fluid
P_{12}	0.65	1	1.3	1	25	27	30	34	1880	Homogeneous, fluid
P_{11}	0.65	1	1.3	1	22	bleeding			1874	Homogeneous, 14 ml bleeding
P_8	0.7	1	1.3	1	21	21	22	26	1861	Homogeneous, slight segregation after standing
P_{13}	0.75	1	1.3	1	15	15	17	–	1850	Homogeneous, hard segregation after standing
P_1	0.5	1	1.7	1.0	155	–	–	–	2011	Homogeneous, fluid, slight discontinuity in flowing
P_2	0.6	1	1.7	1.0	53	88	–	–	1981	Homogeneous, fluid
P_{15}	0.6	1	1.7	1.5	40	52	–	–	1990	Homogeneous, fluid
P_{17}	0.65	1	1.7	1.0	31	35	36	44	1956	Homogeneous, fluid
P_3	0.7	1	1.7	1.0	26	32	33	39	1934	Homogeneous, fluid
P_{14}	0.7	1	1.7	1.0	25	32	34	42	1937	Homogeneous, fluid

Table 12 (continued)

P_{16}	0.75	1	1.7	1.0	20	22	25	26	1926	Homogeneous, fluid, segregation after standing
P_{18}	0.65	1	2.1	1.0	111				1999	Homogeneous, fluid, slight discontinuity in flowing
P_4	0.7	1	2.1	1.0	43	68		–	1973	Homogeneous, fluid
P_5	0.7	1	2.1	1.5	30	33	35	56	1939	Homogeneous, fluid
P_{19}	0.75	1	2.1	1,0	31	34	41	53	1921	Homogeneous, fluid, segregation after standing
P_{20}	0.75	1	2.1	1,5	26	30	33	43	1934	Homogeneous, fluid, separate after standing
P_9	0.8	1	2.3	1.5	24	25	28	37	1934	strong separation of sand from the bottom

[1)]Water, [2)] Cement (V, A (S -V) 42.5), [3)]Sand; [4)]SP additive (Glenium 27 super plasticizer – different vol. % relative cement quantity)

• VM agent (viscosity modifier Rheomatrix 150; 0.5 ─ vol. % relative cement quantity)

Table 13

Recycled DR mortar composition and flow-time

Sample	Mix composition [kg]			$SP^{4)}$ Ad. (%)	p-cone (s) at min				Density [kg/m^3]	Remarks
	$W^{1)}$	$C^{2)}$	$S^{3)}$		0	15	30	60		
DR_3	0.5	1	1.3	1.5	68	89	–	–	1934	Homogeneous, fluid
DR_{11}	0.55	1	1.3	1	44	bleeding			1958	Homogeneous, 5.5 ml bleeding
DR_4	0.6	1	1.3	1.5	31	35	40	52	1926	Homogeneous, fluid, slight segregation
DR_1	0.6	1	1.3	1	34	37	45	54	1891	Homogeneous, fluid, slight segregation
DR_{12}	0.63	1	1.3	1	25	bleeding			1920	Homogeneous, 24 ml bleeding
DR_{13}	0.63	1	1.3	1	24	27	29	33	1925	Homogeneous, fluid, slight segregation
DR_2	0.65	1	1.3	1	15	17	18	21	1839	Strong separation after standing
DR_5	0.6	1	1.7	1	55	63	–	–	1937	Homogeneous, fluid
DR_6	0.7	1	1.7	1	23	24	30	32	1939	Homogeneous, fluid
DR_7	0.7	1	1.7	1.5	24	26	31	34	1871	Homogeneous, fluid, sand separation after standing
DR_{14}	0.75	1	1.7	1	15	16	18	21	1869	Homogeneous, strong segregation
DR_8	0.6	1	2.1	1	12 0	–	–	–	1924	Homogeneous, flow in drops

Table 13 (continued)

DR_9	0.7	1	2.1	1	43	65	–	–	1961	Fluid, slight segregation in time
DR_{10}	0.75	1	2.1	1	29	36	51	–	1958	Homogeneous, fluid, slight segregation in time
DR_{15}	0.75	1	2.1	1	27	33	46	58	1966	Homogeneous, time segregation
DR_{16}	0.75	1	2.1	1.5	24	29	36	49	1948	Homogeneous, time segregation

1)Water, 2) Cement (V, A (S-V) 42.5), 3)Sand; 4)SP additive (Glenium 27 super plasticizer – different vol. % relative cement quantity)

• VM agent (viscosity modifier Rheomatrix 150; 0.5 – vol. % relative cement quantity)

Table 14

Recycled DP mortar composition and flow-time

Sample	Mix composition [kg]			SP4) Ad. (%)	p-cone (s) at min				Density [kg/m^3]	Remarks
	W1)	C2)	S3)		0	15	30	60		
DP_4	0.55	1	1.3	1	36	bleeding			1948	Homogeneous, fluid, 5.5 ml bleeding
DP_7	0.60	1	1.3	1	26	28	30	38	1929	Homogeneous, fluid, slight separation
DP_1	0.60	1	1.3	1	27	bleeding			1939	Homogeneous, fluid, slight separation, 12 ml bleeding
DP_8	0.65	1	1.3	1	17	17	18	23	1909	Homogeneous, fluid, segregation
DP_5	0.55	1	1.7	1	64	78	—	—	1974	Homogeneous, fluid
DP_9	0.60	1	1.7	1	40	56	63	—	1960	Homogeneous, fluid, slight segregation
DP_{10}	0.65	1	1.7	1	26	28	31	42	1942	Homogeneous, fluid, slight segregation
DP11	0.65	1	1.7	1.5	21	25	28	37	1933	Homogeneous, fluid, slight segregation
DP2	0.70	1	1.7	1	18	19	21	25	1910	Homogeneous, fluid, segregation
DP6	0.55	1	2.1	1	118	—	—	—	1983	Homogeneous, fluid, flow in drops
DP12	0.60	1	2.1	1	58	67	—	—	1986	Homogeneous, fluid
DP14	0.65	1	2.1	1	37	48	—	—	1976	Homogeneous, fluid, slight segregation
DP13	0.70	1	2.1	1	30	34	39	45	1953	Homogeneous, fluid, segregation
DP15	0,70	1	2.1	1.5	25	27	36	45	1965	Homogeneous, fluid, slight segregation
DP3	0.75	1	2.1	1	21	26	32	38	1947	Homogeneous, fluid, segregation

[1)]Water, [2)] Cement (V, A (S-V) 42.5), [3)]Sand; [4)]SP additive (Glenium 27 super plasticizer – different vol. % relative cement quantity); VM agent (viscosity modifier Rheomatrix 150; 0.5 – vol. % relative cement quantity)

Table 15

Fill ratio comparing for achieved mortars

Sample	W[1)]/ C[1)] ratio	S[1)]/C ratio	SP Ad. [%]	VM Agent [%]	p-cone time (s) at min				Compression strength (MPa)	Fill ratio vol. [%]
					0	15	30	60		
N_3	0.45	0.8	0.8	–	31	48	50	50	48.1	99.5
R_{11}	0.60	1.3	1.0	0.5	26	29	30	31	35.5	99.8
P_{12}	0.65	1.3	1.0	0.5	25	27	30	34	31.7	99.5
DR_4	0.6	1.3	1.5	0.5	31	35	40	52	32.7	99.7
DP_{11}	0.65	1.7	1.5	0.5	21	25	28	37	30.2	99.8

[1)]Water, [2)]Cement, [3)]Sand

[4)] SP additive (Glenium 27 superplasticizer – % vol. relative cement quantity)

[5)] VM agent (viscosity modifier Rheomatrix 150 – % vol. relative cement quantity)

6. FILLING TESTS USING A MOCK-UP

To confirm the results of pre-placement of rubble, obtained on a small scale, it made an attempt to fill the mortar in a container that simulates the final storage drums.

To attempts to fill the mortar DR_4 at real scale, it was used a conical carbon steel container size: (d_i = 270 mm, D_i = 285 mm, H_i = 355 mm, effective volume = 21.55 liters) which simulates final storage container. Into container, on the support of the reinforced concrete having 50 mm hight were pre-placed two cubic blocks (sides of 150 mm.) Then, in the space between the walls of the container were manually pre-placed rubble in 10–50 mm sort. Voids volume was measured by water replacing method. The mortar was poured on the top of the container. Was measured the mortar fill ratio (98.9%) compared with the results of laboratory tests and targets set out in the proposed specification. Although fill ratio obtained on the mock-up is lower by 0.8 vol. % compared to that obtained in the laboratory tests (99.7%), the result meets the specification criteria.

7. CONCLUSIONS

The fill ratio of containers with pre-placed recycled aggregate was determined using mortars that satisfy requirements of proposed specification. Was obtained good results for all processed mortars. The results obtained in the laboratory were confirmed at pilot. Research will continue to finalize the technological solution studied (use of mortar additives having a better performance).

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APPENDIX

Technical data regarding European Standards referenced in paper

SR EN 933-2:1998. Tests for geometrical properties of aggregates. Part 2: Determination of particle size distribution. Test sieves, nominal size of apertures

This Part of this European Standard specifies nominal aperture sizes and shape for woven wire cloth and perforated plate in test sieves used for test methods for aggregates. It applies to aggregates of natural or artificial origin including lightweight aggregates.

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