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Study to achieving a class of road concrete with slag powder addition at the cement mass and substitution with artificial aggregates

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Abstract. In order to notice the influence of slag in the form of powder used as an addition to the cement mass and the substitution of natural aggregates with artificial aggregates from crushed and sorted slag, first of all, mixtures of mortars were made for a reduced volume of material. In the mixes design of new road concrete, we have taken into account the results obtained on the most representative mortar mixes. We chose mixtures of mortar with 15% addition of slag powder in the cement mass and those in which the 0/4 mm natural aggregate was substituted in a ratio of 20%, 40%, and 60% with artificial aggregates of crushed and sorted slag from the by-products stockpiles resulting from the process of obtaining the cast iron in the furnaces. The intended objective is to obtain a BcR 5.0 road concrete class that can be used in all categories of traffic. From the results obtained on mortar and concrete mixtures, it can be seen that compressive strengths and flexural tensile strengths remain close both in mortars and in concretes. Also, the results show that the control mixture falls into the BcR5.0 road concrete class and the new mixtures are very close to it.

1. Introduction

Ecologically it is paramount to preserve the natural resources by use of artificial materials in concrete mixes for pavement works.

This category may include an artificial product known as blast furnace slag (BS) derived from iron smelting by cooling the quenchants from selected molten slags. During the steel fabrication processes the liquid (BS), which is collected at the bottom of the furnace is transported by special cooling carriages, hence air is frequently used as conventional quenching medium.

The use of ground granulated blast furnace slag (GGBS) in concrete mixes is determined by savings in energy, reduction of greenhouse effect gasses and less consumption of natural resources, see [1-3]. For those reasons, the use of (GGBS) and (BS) aggregates in concrete mixes is submitted to in-depth research worldwide.

Results published by Arash Aghaeipour et al. indicate that cement may be replaced by GGBS with percent 20%, 40% and 60% for pavements works. In their study, authors reported the use of powdered

GGBS having a relative density of 2,85 g/cm^3 and a specific surface area of 4500 cm^2/g. The conclusion of the study is that the replacement also lead to a reduction in water absorption, with the most impermeable concrete having a replacement ratio of 40% of cement by GGBS. In the 150 and then 300 cycle freeze-thaw tests, mixes with a 20% replacement ratio of cement by GGBS proved to be almost similar to the mixes containing only Portland cement clinker. The highest drop in strength was observed after 150 and 300 freeze-thaw cycles in those specimens that contained 40% slag in their mix design. In the mix designs containing 60% slag the lowest in modulus of rupture strength is around 1%.see [1].

Mohammed T.U. et al. investigated the use of coarse aggregates derived from BS and masonry wastes. BS was batched either as lightweight aggregates (SL), heavyweight aggregates (SH) or mixed aggregates (SM). Mixes with BS aggregates indicated lower water absorption levels as compared with masonry wastes as well as at least equal or greater compressive strengths. In the case of (SL) mixes, the compressive strength was superior to all other solutions investigated, see [4].

The current research aimed in a similar manner to develop a nationally labelled "BcR 5,0" road concrete grade that contains BS powder. As starting point, 3 mixes using both GGBS as well as ground ungranulated blastfurnace slag (GUGBS) in various replacement ratios were batched and casted in prismatic samples of 40x40x160 mm. The first set is represented by samples with cement clinker replacement ratios of 0%, 10%, 20%, 30%, 40%, 50% and 60% and a BS surface area of 4576 cm^2/g. The second set contains samples with 0/4 mm graded aggregates replaced by GUGBS as 20%, 40%, 60% and 80% ratios. The third set used throughout a 15% replacement ratio for cement, a substitution ratio of aggregates of 20%, 40%, 60% and 80% and a BASF superplasticizer admixture (Ad) at a dosage of 1,2% by weight of cement, with a BS surface area of 5770 cm^2/g. Cement was established to have a surface area of 4385 cm^2/g. Flexural tensile and compressive strengths show that set 1 samples (G1) exhibit a loss of strength as the ratio of cement replacement increases. Set 2 samples (G2) have similar mechanical properties regardless of the aggregates substitution ratios while set 3 samples (G3) yield greater mechanical strengths as compared with the reference mix. Table 1 lists corresponding values, see [5].

Table 1. Evolution of mechanical properties of mortar mixtures.

Mc		Set 1: CEM I substituted as 10%, 20%, 30%, 40%, 50%, 60% GGBS ratios		Set 2: NA substituted as 20%, 40%, 60%, 80% GUGBS ratios		Set 3: 15% addition of GGBS, NA substituted as 20%, 40%, 60%, 80% GUGBS and 1.2% Ad	
f_{cm}28d (MPa)	f_{ctm}28d (MPa)	f_{cm}28d (MPa)	f_{ctm}28d (MPa)	f_{cm}28d (MPa)	f_{ctm}28d (MPa)	f_{cm}28d (MPa)	f_{ctm}28d (MPa)
51.55	4.19	52.07	3.89	46,51	4,65	71.59	5.84
-	-	43.99	3.49	49,71	4,60	72.23	6.67
-	-	43.91	3.52	53,10	4,61	75.92	6.68
-	-	38.10	3.31	57,21	4,78	70.19	6.05
-	-	33.14	2.84	-	-	-	-
-	-	26.98	2.22	-	-	-	-

The pool of results indicated the direction of research for obtaining a road concrete grade containing BS as addition to the cement clinker and as substitute to natural aggregates. Four mixes were prepared, one with conventional materials such as Portland cement type CEM I 42,5R and natural aggregates labelled S 0/0 ("zero cement" and "zero aggregates" replaced) and three trial mixes containing 15% addition of BS to the cement clinker in the form of a 63 μm powder interblended, labelled GGBS, and 20%, 40% and 60% substitution ratios of BS artificial aggregates labelled GUGBS. The corresponding notations for the batched mixes are S 15/20, S 15/40, S 15/60 [6-10].

2. Materials and methods

2.1. Prime unconventional materials

2.1.1. Blastfurnace slag (BS). The BS by-product may be used as artificial material in the construction industry. Depending of the cooling method, GGBS or GUGBS may be fabricated. GGBS is the result of fast cooling the quenchants from selected molten BS (1350-1450 °C) using water as conventional quenching medium (max 50 °C) in retaining basins, thus creating fine glassy spheres. GGBS is then excavated with a specific machine and is stored on drying platforms to allow the drainage of surplus water. The granules may be then grounded down to a white powder with a fineness similar to that of cement and may be used either intergrounded or blended with the Portland cement clinker. BS manifests latent hydraulic activity as well as some pozzolanic activity when reacting with the calcium hydroxide and other alkaline solutions produced by the hydration of Portland cement clinker. Deemed a type II addition to improve properties of concrete it is conforming to SR EN 197-1:2011 and SR EN 15167-1:2007, see [11,12] The reaction rate is determined by intrinsic properties such as surface area, chemical composition or the active phase content, see [13,14]. The BS in this study is provided by "ArcelorMittal Galaţi" and was grounded down to powder at the Aleşd cement plant. Laboratory Report no 848 dated 25.08.2016, [15] from ArcelorMittal indicates the granulometry and chemical composition of the BS powder as presented in Table 2.

Table 2. Summary of properties for BS.

GGBS used as type II addition in the cement clinker		GUGBS used as artificial aggregates	
Size of ungrounded BS d_{max}, mm	12,5	Granulometry	G_F 85
Sum of CaO+MgO+SiO2, (%)	84,05	Water absorption coefficient WA_{24}	$WA_{24}2$
Ratio of $(CaO+MgO)/SiO_2$, (%)	1,3	Fines content	f_3
Magnesium oxide MgO, (%)	5,80	Acid soluble sulphate content	AS $_{0,.23}$
Sulphates, (%)	0.58	Overall Sulphates	1,01

2.1.2. Artificial aggregates from blastfurnace slag (GUGBS). About 30% of the molten BS solidifies and may not be grounded down further because of the distance from the furnace to the granulation plant. The resulted product have a crystalline molecular structure that makes them unsuited to cement fabrication, so are further discharged on storage platforms and are submitted to slow cooling using air as conventional quenching medium. The resulted BS is delivered to a grinding mill where the proportions of the different sizes of particles are found by sieving and are "graded" as artificial aggregates, GUGBS. The indicated operations in the current study were performed by "ArcelorMittal".

The artificial aggregates exhibit an "open" internal structure created by disconnected pockets of entrapped air, hence the specific weight and density of the bulk material are rather small. On the other hand, the presence of such voids creates a better resistance to freeze-thaw actions. BS aggregates do not exhibit any alkali-silica reactions, are clean and free from clay or shale scale, organic or other harmful impurities so may be accepted easier in accordance with the provisions specified by current aggregate standards. The combined use of BS aggregates and air-entraining admixtures improves workability and durability of concrete subjected to freeze-thaw action, see [12].

Artificial aggregates graded from blastfurnace slag (GUGBS) on sizes 0/4 mm used in the current study are provided by "ArcelorMittal Galaţi" and have the properties indicated in the Declaration of Performance no 13242-A.M, [16] as required by the applicable national code SR EN 13242: 2002+A1:2007 [17], see Tabel 2.

2.2. Prime conventional materials

2.2.1. Cement. Portland cement type CEM I 42,5R provided by "S.C. HOLCIM România S.A" from the Aleşd cement plant was used in the current study. Material properties are listed in the Declaration of

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Performance no CPR-043-AE [18], as required by the applicable national code SR EN 197-1:2011 [11], see Table 3.

Table 3. Cement properties, type CEM I 42.5R.

Clinker content (% of weight)	95÷100
Minor constituents	0÷5
Rate of hardening (min)	Min. 60
Stability/Expansion (mm)	Max. 3
Initial compressive strength (MPa)	Min. 24
Specified compressive strength (MPa)	Min. 46
Calcination losses (%)	Max. 5
Insoluble residue (%)	Max. 5
Sulphate content (as SO_3) (%)	Max. 4
Chlorine content (%)	Max.0,1

2.2.2. Natural aggregates (NA). Sand graded as 0/4 mm is delivered from the Beclenuţ quarry in Bistriţa-Năsăud county, coarse crushed (gravel) graded as 4/8 mm is delivered from the cement plant of "SC Smith Rotrans" in Cluj-Napoca, while coarse crushed rock (chippings) graded as 8/16 mm and 16/25 mm are delivered from the Bologa quarry owned by "SC Grandemar Cluj". Properties are those listed by Laboratory Reports no 545 dated 03.04.2018 and 956 dated 30.06.2017, [20,21] as required by the applicable national codes SR EN 13242: 2002+A1:2007, SR EN 12620+A1:2008 and SR 667:2001 [17,22,23], see Table 4.

Table 4. Selected properties of natural aggregates (na).

Property	0/4 mm grading	8/16 mm grading	16/25 mm grading
Granulometry	G_F 85	G_C 90/15	-
Grading limits, ratio of retained mass d_{max} (%) to mass passing the various sieves d_{min} (%)	-	-	3,82 / 8,06
Water absorption coefficient WA_{24}	$WA_{24}2$	$WA_{24}1,4$	-
Fines content, **f**	f_3	-	-
Freeze-thaw resistance, as loss of weight	-	0,20	-
Abrasion resistance (micro-Deval coefficient, %)	-	6	6
Dry crushing resistance	-	-	76
Petrographic source	River aggregates	Dacite	Dacite

2.2.3. Water (W). The water source used in the current study is drinking water available in the city of Cluj-Napoca, from the local water utility service, which is captured in the accumulation lakes at Tarniţa, Warm Someş and Gilău and is in accordance with the national standard SR EN 1008:2003, [24]. Water improves workability of concrete, hydration of cement and the interbonding of mix constituents, whether as fresh or hardened concrete properties. The water content is the quantity necessary to batch concrete, including chemically-bound water by the composition of liquid admixtures.

2.2.4. Admixtures (ad). For achieving desired workability, mechanical properties, freeze-thaw resistance and decreasing the water content of the mix, a superplasticizer admixture named "MasterGlenium SKY 527" with a typical dosage of 1,0÷1,2% by weight of cement having high range water reducing properties and an air-entraining admixture with a typical dosage of 0,3÷0,5% by weight of cement were used. Both admixtures are provided by BASF.

3. Methodology

3.1. Reference properties for designing road concretes

The road concrete mix was designed to achieve the flexural tensile and compressive strength specified in the national normative NE 014-2002 [25], Construction of Portland Cement Concrete Pavements for fixed-forms and slid-forms paving. The certification of a specified road concrete grade is based on the achieved flexural strength ($f_{c\,f}$), which is deemed to be the main property of the mix. The minimum threshold is the one indicated in the provisions of NE 014-2002 and C 22-92 [26]. Also used in the current study are the supplementary provisions of calculus methodology for road concrete blended with fly ash additions presented in the CD147-2002 [27], normative. Strength and durability parameters as specified in SR-EN 206-1: 2002, [28] are also considered in the performance assessment of investigated mixes, which presents durability properties as the result of exposure conditions. The combined exposure classes are stated to be XF4 (exposed surfaces to freeze-thaw with or without de-icing agents, intensity level 4, for high water saturation with de-icing agent or sea water conditions), XC4 (corrosion induced by carbonation, intensity level 4, for moderate humidity or cyclic wet and dry conditions), XD3 (corrosion induced by chlorides other than from seawater, intensity level 3, for cyclic wet and dry conditions) and XM2 (mechanical abrasion, intensity level 2, for strong abrasion). The aim is to certify the trial mix to be the nationally labelled "BcR 5,0-S" for all size vehicle traffic. A summary and comparison of results with the reference mix is presented in Table 5.

Tabelul 5. Performance conditions for road concretes.

Property	Minimum as per NE 014-2002	Minimum as per C22-92
Concrete grade, BcR	BcR5,0	BcR5,0
Characteristic strength at 28 days on prism samples, 150x150x600 mm (MPa)	5,5	5,5
Characteristic strength at 28 days on prism samples, 100x100x550 mm (MPa)	-	6,3
Characteristic strength at 28 days on cube samples, 150 mm (MPa)	50	50

3.3.1. Batching of road concrete trial mixes. Cement dosage is based on NE 014:2002 and SR EN 206-1:2002 so that the target compressive strength of 50 MPa may be certified. The upper limit of W/C is extracted from NE 014:2002 and the water demand is calculated by equation 1. The water-binder ratio (including additions ratio W/B) is calculated with equation 1 (as per NE 014:2002) or equation 2 (as per CD 147:2002). The lowest value was chosen for water-binder ratio.

$$W' = \left(\frac{W}{C}\right)_R \cdot C' \text{ l/ m}^3, (1);\ \frac{W}{B} = \left(\frac{W}{C}\right)_R \left(1 + I_A \frac{BS}{C}\right),\ (2)\ I_A^{28} = \left(\frac{f_{cm}^{28}(50\%BS)}{f_{cm}^{28}(0\%BS)}\right), (1)$$

where: $(W/C)_R$ – water to cement ratio;

(W/B) – water to binder ratio;
BS- blastfurnace slag powder;
I_A – reactivity index of BS powder at 28 days, as the ratio of the compressive strength of a mix containing 50% BS plus 50% cement to the compressive strength of a mix containing only cement.

Values as per Table 1, of 33,14 MPa for the mix containing BS and of 51,55 MPa for the reference mix were obtained. The reactivity index I_A, is 0,643 as by equation 1.

The W/C ratio is established in the trial mixes and the reference mix by accounting for the chemically-bound water in the superplasticizer, having a dosage of (1÷1,2)% by weight of cement, and in the air-entraining admixture, having a dosage of (0,3÷0,5)% by weight of cement.

The weight of aggregates is calculated as by equation 2 for the reference mix and as by equation 3 for the trial mixes.

$$W'_g = \rho_{ag}(1000 - \frac{C'}{\rho_c} - W' - \%air \cdot 100)\ \text{kg}, \quad (2)$$

$$W'_g = \rho_{ag}(1000 - \frac{C'}{\rho_c} - \frac{BS}{\rho_{BS}} - A' - \%air x 100)\ \text{kg}, \quad (3)$$

where: C'- cement dosage, equal to cu 360 kg;
BS- blastfurnace slag powder dosage, equal to 54 kg;
W'- water demand in kg ;
ρ_{ag} - specific weight of aggregates, equal to 2,7 kg/m^3;
ρ_c - specific weight of cement, equal to 3,0 kg/m^3;
ρ_{BS} - specific weight of BS powder, equal to 2,77 kg/m^3;
% - air- entrained air volume, equal to 3,5% and 35 dm^3/m^3, respectively;

A initial mixes was batched in which admixtures (water and additive) were gradually added until the desired slump was achieved. The specific weight of fresh concrete is calculated as by equation 4 in accordance to SR EN 12350-6:2002, [29].

$$\rho_b = \frac{m_1 - m}{V}\ \text{kg/m}^3, \quad (4)$$

where: m_1- weight of mould after filling it with concrete, in kg
m-weight of empty mould, in kg.

The specific weight of fresh concrete for the reference mix is established by equation 5, while for the trial mix the similar equation 6 was used.

$$\rho_b' = C' + A' + A_g' + A_d\ \text{kg/m}^3, \quad (5)$$

$$\rho_b' = C' + A' + A_g' + BS + A_d\ \text{kg/m}^3, \quad (6)$$

where: Ad- dosage of admixture.

The weight of aggregates is recalculated so that the difference between the specific weight of fresh concrete as by equation 5 and the specific weight of fresh concrete as by equation 5 or 6 is less than 20 kg/m^3 as per the C22-92 normative. The moisture of aggregates was added at amount dry aggregates by equation 6, and moisture content of aggregates is as by equation 7.

$$A_{wet} = A_{dry}\left(1+\frac{W}{100}\right) \text{ (7)}, \; W = \left(\frac{m_u - m}{m_u}\right) x100\,\% \qquad (7)$$

where: m_u- weight of wet aggregates in kg
m- weight of dry aggregates in kg (until no further decrease in mass is observed).

Each concrete mix was poured in 3 prism samples of 150x150x600mm, 3 prism samples of 100x100x550mm and 3 cube samples of 150x150x150 mm. After 24±2 hours the samples were removed from moulds and kept submerged underwater, as per the provisions in SR EN 12390-2:2002, [30] at a temperature of 20±2^{0}C, until testing at 28 days in accordance to SR EN 12390-3:2002, [31] for compressive strength and to SR EN 12390-5:2002, [32] for flexural tensile strength.

4. Results and discussions

4.1. Results

Aggregates were graded as 0/25mm for simulating a one-layer concrete road surface. The distribution of sizes is: natural sand as 0/4 mm (river source), artificial aggregates, GUGBS, as 0/4 mm (derived from BS), coarse aggregates (CA) as 4/8 mm (river source), 8/16 mm (quarry source) and 16/25 mm (quarry source) and were prepared by third-party grinding mills. The overall grading is as per SR EN 933-1: 2012, [33] and was determined by laboratory tests. After drying, the aggregates are sieved, the mass passing the various sieves or retained is weighted and the summary of result is listed as Table 6.

Table 6. Amount passing the various sieves.

Size	Percentage passing each sieve (%)								
	0.125	0.25	0.5	1	2	4	8	16	25
NA_0/4	5.12	18.92	46.36	71.36	86.81	98.25	100.00	100.00	100.00
GUGBS_0/4	4.85	14.65	32.62	54.76	77.99	97.88	100.00	100.00	100.00
CA_4/8	0.18	-	0.95	1.01	1.13	3.78	85.95	100.00	100.00
CA_8/16	0.02	-	-	-	0.16	0.17	2.6	94.80	100
CA_16/25	0.09	-	-	-	-	-	0.10	6.55	95.03

Table 7. Grading envelopes for continuously graded aggregates.

	Percentage passing each sieve (%)								
Mix	0.125	0.25	0.5	1	2	4	8	16	25
S 0/0	1,70	6.05	15.01	23.02	28.02	32.16	48.15	75.34	98.76
S 15/20	1,68	5,78	14,13	21,95	27,46	32,14	48,15	75,34	98,76
S 15/40	1,66	5,51	13,25	20,8	26,8	32,12	48,15	75,34	98,76
S 15/60	1,65	5,23	12,37	19,83	26,33	32,09	48,15	75,34	98,76
Lower limit	1.44	2.38	4.25	8.00	14.00	23.75	38.11	63.00	95.00
Upper limit	6.22	9.19	15.13	27.00	34.50	46.50	62.55	83.00	100.00

The grading sieves sizes for graded aggregates are specified in SR EN 933-1: 2012 while the amount of passing each sieve is identified by intra- and extrapolating a lower and upper limit as per NE 014-2002. Results are listed in Table 7.

The addition of a 15% by weight of cement increases the total mass passing the 0,25 sieve. Powdered BS represents 3,08% by weight of overall aggregates. Dosages/amounts used for cement, BS, admixtures and graded aggregated are listed in Table 8.

Specific weight of fresh concrete is determined as per SR EN 12350-6:2002, consistency as per SR EN 12350-2:2003 [34], and entrained air as per SR EN 12350-7:2009 [35], see Table 9. Water demand and weight of aggregates are further corrected and listed in Table 10.

The concrete grade is determined by compressive strength and flexural tensile strength testing at 28 days, by applying a uniform and continuous force increasing in increments of 0,5 MPa/s for compression and 0,05 MPa/s for tension on a loading machine type Advantest 9 of 300 tf.

Results are presented in Table 11.

Table 8. Cement, admixtures and aggregates for trial mixes.

Mix	Cement (kg)+ bs (%)	Admixtures (%)	Grading of natural aggregates 0/4 mm (%)	Grading of bs aggregates 0/4 mm (%)	Grading of coarse aggregates 4/8 mm (%)	Grading of coarse aggregates 8/16 mm (%)	Grading of coarse aggregates 16/25 mm (%)
	C+SP%	Ad+Ad	NA_0/4	GUGBS_0/4	CA_4/8	CA_8/16	CA_16/25
S 0/0	360 kg+0%	1%+0,3%	32%	-	18%	25%	25%
S 15/20	360 kg+15%	1%+0,5%	25,6%	6,4%	18%	25%	25%
S 15/40	360 kg+15%	1,2%+0,5%	12,8%	19,2%	18%	25%	25%
S 15/60	360 kg+15%	1,2%+0,5%	19,2%	12,8%	18%	25%	25%

Table 9. Fresh concrete properties.

Mix	**C 01**	**S 15/20**	**S 15/40**	**S 15/60**
Consistency by slump test, class S 1 (mm)	14	13	16	15
Entrained air (%)	1,5	1,8	2,0	2
Specific weight as sum of all constituents ρ_b (Kg/m^3)	2379	2455,02	2402,37	2402,37
Specific weight ρ_a (Kg/m^3)	2399	2444,44	2417,78	2411,85
Specific weight difference (Kg/m^3)	20	10,58	15,41	9,48

Table 10. Constituents quantities for trial mixes.

Name of mix (Kg/m^3)	S 0/0	S 15/20	S 15/40	S 15/60
W/C or W/B	0,44	0,41	0,43	0,43
Cement (C')	360	360	360	360
Blastfurnace slag (BS)	-	54	54	54
Dried aggregates (A_g')	1864	1863	1810,35	1810,35
Superplasticizer admixture	3,6	4,14	4,97	4,97
Air-entraining admixture	1,08	2,07	2,07	2,07

$$f_{cf} = \frac{Fxl}{d_1 \cdot d_2^2}, \text{ N/mm}^2 \tag{8}$$

$$f_{cf} = \frac{2}{3}\frac{F \cdot l}{d_1 \cdot d_2^2}, \text{ N/mm}^2 \quad (9)$$

where, see equation 8:
f_{cf}- flexural tensile strength of concrete in N/mm^2;
F- the maximum load in N;
l- distance between supports (300 for 550 mm long prism and 450 mm for the 600 mm long prism);
d_1, d_2, the length of the side of the specimen in mm, measured at the nearest mm (100/150 mm);
where, see equation 9:
F- the maximum load in N;
l- distance between supports (150 mm);
d_1, d_2, the length of the side of the specimen in mm, measured at the nearest mm (100 mm);
Compressive strength is calculated as by equation 10 in accordance with SR EN 12390-3:2002.

$$f_c = \frac{F}{A_c}, \text{ N/mm}^2 \text{ or MPa} \quad (10)$$

Where, see equation 10:
f_c- compressive strength in N/mm^2
F- the maximum load in N
Ac- cross-sectional area of the section of rupture in mm^2.

Tabel 11. Tensile and compressive mechanical stresses at 28 days.

Mixture	f_{cfm} 28d (MPa)	f_{cfm} 28d (MPa)	f_{cfm} 28d (MPa)	f_{cm} 28d (MPa)	f_{cm} 28d (MPa)	f_{cm} min (MPa)
1	2	3	4	5	6	7
Calculated	Equation (8)	Equation (8)	Equation (9)	Equation (10)	Equation (11)	(50+8) MPa
S 0/0	5,55	6,57	6,71	78,28	68.34	58,00
S 15/20	5,64	6,68	6,42	74,97	65.45	58,00
S 15/40	5,57	6,63	6,38	74,45	65.00	58,00
S 15/60	5,42	6,45	6,25	70,74	61.76	58,00

Notes:
Column 2- f_{cfm} 28d, mean flexural tensile strength of prisms of 150x150x600 mm;
Column 3- f_{cfm} 28d, mean flexural tensile strength of prisms of de 100x100x550 mm;
Column 4- f_{cfm} 28d, mean flexural tensile strength of prisms fragments of 100x100x275 mm (L/2);
Column 5- f_{cm} 28d, mean compressive strength on cubes of 150x150x150 mm;
Column 6- f_{cm} 28d, corrected mean compressive strength on cubes of 150x150x150 mm;
Column 7- f_{cm} min, minimum mean compressive strength on cubes having an allowance of 8 MPa, (50 +8) MPa

All values that yielded below 20% of the mean are excluded from subsequent calculations.

The mean compressive strength on cubes of 150 mm is further corrected as by equation (11) in accordance with C 22-92 to account for the nominal strength of cement $f_{c \text{ standard cement}}$=45.00 MPa, and the actual compressive strength at 28 days $f_{c \text{ effective cement}}$=51.50 MPa as in Table 1.

$$f_{cm\ concrete\ corrected}^{28} = \frac{f_{c\ s\tan dard\ cement}}{f_{c\ ceffective_{cement}}} x f_{cm}^{28}{}_{concrete}\text{, MPa,} \quad (11)$$

$$f^{28}_{cm\ concrete\ corrected} = 0.873 \text{ x } f^{28}_{cm\ concrete}$$

4.2. Discussions

Proportions of constituents used in the current study impact the fresh concrete properties, consistency, entrained-air, specific weight as well as the hardened concrete properties such as tensile and compressive strengths, so that the following apply:

Designed consistency is corrected by the admixture dosage, highly water reducing, so that W/B is upper limited to 0,45. Slump testing is the method used in evaluating the performance of concrete mixes so a target range of slump of 20 mm, plastic to stiff, frequently required for road concrete grades, may be achieved. For this purpose, different percentages of superplasticizer were used. Hence for 1% superplasticizer in S 0/0 and S 15/20 mixes, the mean slump yielded to be 14 mm with a W/B ratio of 0,44 and 13 mm with a W/B ratio of 0,41 respectively. A dosage of 1,2% yielded a mean slump of 16 mm for S 15/40 and of 15 mm for S 15/60 for a W/B ratio of 0,43, as presented in Figure 1. All mixes under scrutiny have as per NE012-1:2007 [36] a consistency class of S 1 (magnitude between 10÷40mm), yet less that the limit of 30±10 mm indicated in NE 014:2002, so the concrete mix is deemed to be stiff.

Supplementary, an air-entraining admixture with a dosage of 0,3% by weight of cement is blended in S 0/0 while for and S 15/20, S 15/40 and S 15/60 the dosage is increased to 0,5%. Entrained air was determined to represent 1,5% for S 0/0, 1,8% for S 15/20 and 2,0% for both S 15/40 and S 15/60. Mixes S 15/40 and S 15/60 contain more air voids as compared to S 15/20 although the same dosage of admixture was used, see Figure 1. A possible explanation may be that W/B for S 15/40 and S 15/60 is 0,43 which is above 0,41 as for S 15/20, so the additional water allowed a more uniform spreading of air voids in the mix during mixing. Specific weight of fresh concrete is close to 2400 kg/m^3 for all mixes, with slightly higher values for S 15/20, of 2444 kg/m^3, and decreasing for S 15/40, S 15/60, S 0/0, see Figure 2. A major influence on mechanical properties is the ratio of the volume of aggregates to the concrete weight. As in Table 9 and 10, the volume of aggregates is about 78% of the concrete weight for S 0/0, 76% for S 15/20 and 75% for S 15/40 and S 15/60. A higher content of aggregates in S 0/0 increased the compressive strength to 68,34 MPa on cube samples.

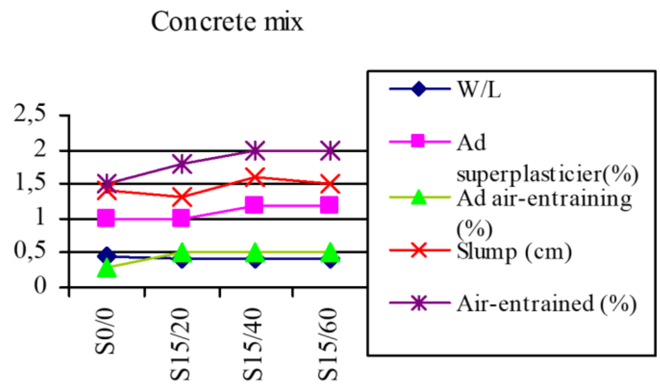

Figure 1. Caracteristics on fresh concrete.

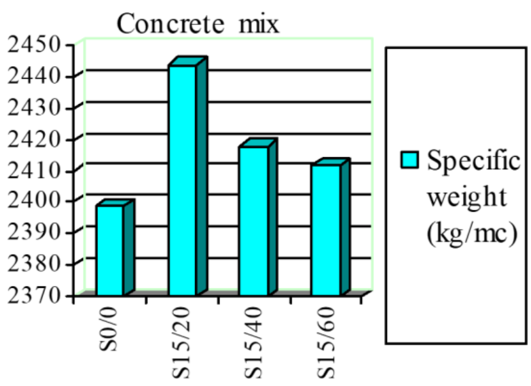

Figure 2. Density of concret mixtures.

Based on Table 10 and the minimum threshold in Table 5, concrete tested at 28 days is certified to achieve the specified grades. By comparison, the mean flexural tensile stengths f_{cfm} 28 days in Column 2 based on prisms of 150x150x600 mm are above the threshold of 5,5 MPa for S 0/0, S 15/20, S 15/40 and below that said value for S 15/60, see Figure 3.

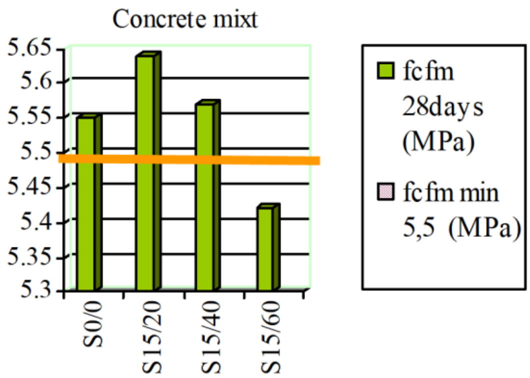

Figure 3. Flexural tensile strength.

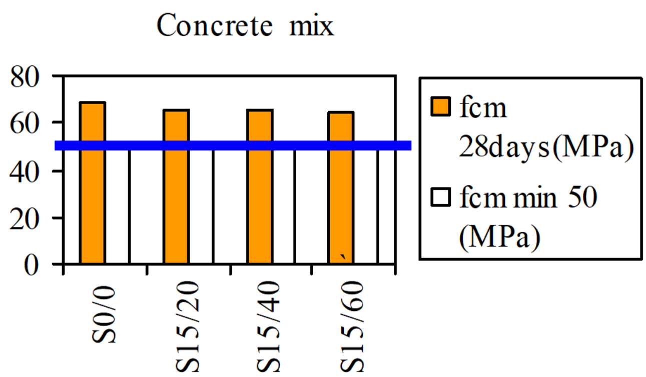

Figure 4. Compressive strength.

As by Column 3 that lists results on prisms of 100x100x550 mm, all values are above 6,3 MPa. Concluding, mixes S 0/0, S 15/20 and S 15/40 may be certified to be "BcR 5,0". While a similar comparison of strengths may be identified for S 15/60, it may be only certified to be "BcR 4,5" since it has a over value of 4,9 MPa.

Mean compressive strengths on cubes of 150x150x150 mm, see f_{cm} 28 days in Column 6, corrected based on the nominal compressive strength of cement, yield above 50 MPa for all mixes, see Figure 4. According to NE01-2007 the concrete grade S 0/0 is C55/67, while S 15/20, S 15/40, S 15/60 are C50/60.

Flexural tensile strengths established on prism fragments, see Column 4, allow the road concrete mixes S0/0, S 15/20 and S 15/40 to be certified as "BcR5,0" since all values are above 6,3 MPa while S 15/60 may be certified to be "BcR4,5" since it yielded below 6,3 MPa, but above the minim value of 4.9 MPa.

5. Conclusions

The aim of the current research was to create a mix like the nationally labelled "BcR 5.0" road concrete grade for use under all size vehicle traffic by using GGBS as addition to the cement mass and as artificial aggregates GUGBS substitute in various percentages, graded as 0/4 mm.

It is common knowledge that GGBS interblended with cement improves the workability and density of concrete, which results were also obtained in the presented study, (see workability of S 15/40 and S 15/60, and the specific weight all mixes). In the continuation of the study, the dosage of the additives should be increased to achieving slump a minimum 20 mm as per NE 014-2002.

Flexural tensile strengths for mixes S 15/20 and S 15/40 are above the reference S 0/0, but all three-cited mixes have similar magnitudes for the compressive strengths. Similarly, with S 0/0, those mixes may be certified as desired to be "BcR5,0" as per NE 014-2002. Mix S 15/60 may be certified to be "BcR4,5" to be used for medium size vehicle traffic.

All compressive strengths are above the lower limit of (50 +8) MPa. The reserve of 8 MPa is an allowance that accounts for differences from strict laboratory conditions to actual field practice.

The experimental program will be continued to improve the composition of all mixes under scrutiny by increasing admixture dosage as well as testing and certifying the fulfilment of durability parameters.

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