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CONCRETE AGGREGATE AND CEMENT MASS CONTENT EFFECTS ON COMPRESSIVE STRENGTH

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Abstract. *The mass content of aggregate (m_a) and of cement (m_c) of concrete comprise coefficient calculated as m_a/m_c. Some methods used for designing of concrete mixtures take into consideration this coefficient. In this paper, concrete mixtures were prepared so that mass of cement, water cement factor and granulometric composition have been varied. Values of the coefficient m_a/m_c in experimental research ranged between 7,20 in concrete mixtures mixed with 250 kg of cement to 3,60 in concrete mixtures mixed with 500 kg per 1m^3. From the aspect of compressive strength of concrete, it has been established that optimum values of the coefficient m_a/m_c depend on the granulometric composition and water cement factor. At higher water cement factors, larger values of m_a/m_c coefficient are required to achieve the maximum strength under the given conditions.*

Key words: *aggregate mass, cement mass, concrete compressive strength.*

1. INTRODUCTION

The issue of building materials technology is always topical, which refers also to concrete, which is the most used material. A large number of scientists and researchers worked on the production of methodology aimed at determining the quantities of certain components needed for preparation of concrete of desired properties. Determined are the regularities between the characteristics and mutual ratio of quantities of concrete components on one hand, and the required properties of concrete on the other hand [1,2]. A large number of coefficients are present in the obtained correlation, which, considering the advance of technology and certain change of characteristics of components occurring in the interim period, are very often insufficiently accurate.

The earliest parameter of aggregate quality which attracted attention of numerous researchers is granulometric composition.

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In principle, for preparation of concrete, the granulometric composition should be chosen so that smaller grain occupy the space between the coarse grains of aggregate, than even smaller grains the remaining space and so forth, until approximately to the ultimate fineness of the cement. The cement paste fills in all the remaining (minimal) space and envelops all the aggregate grains in a thin film. After hydration, the cement rock connects all the aggregate grains into one compact whole [3, 4].

It is understandable that proscription of only one "ideal" granulometric curve would be excessive, because the granulometric curves of an aggregate of favorable granulometric composition lie in a wider range. Their position in the coordinate system, as well as their shape, depend on the maximum aggregate grain size, volume coefficient, quantity of cement etc.

Properties of fresh and set concrete to a great extent depend on the type and quantity of cement paste. Following this logic, it could be concluded that the concrete properties will grow better with the increase of the cement paste quantity. However, this holds only up to a certain limit, because the cement rock is characterized by a significant porosity, higher than a good aggregate [5,6 and 7]. In practice, application of excessive quantity of cement paste will produce negative effects in a number of concrete characteristics, such as: mechanical strength, water-tightness, frost action resistance, chemical aggression resistance, shrinking and creep of concrete, hydration temperature, cost etc. This brings us to a conclusion that an optimum quantity of cement paste should be applied in preparation of concrete which comprises application of an aggregate with appropriate granulometric composition.

2. Experiment

In preparation of concrete mixtures, the starting point was to obtain as wide a range of various mixtures in terms of granulometric composition, quantity of cement and quantity of water – water cement factor. Firstly, it was agreed to adopt three different granulometric compositions of aggregate - AS","ABS" and "BS". It was adopted that the quantity of aggregate is constant for all concrete mixtures, that is, 1800 kg for 1 m^3 of concrete. In the further procedure, for each granulometric curve the quantity of cement of 250 to 500 kg/m^3 was varied, with the 50 kg increments. Eventually, for each possible combination of aggregate and cement, the quantity of water expressed by water cement factor 0,46, 0,52 and 0,58 was used.

For preparation of concrete, only one type of cement was used, Holcim PC 20S 42,5N. This cement was chosen because it is very commonly and frequently used in engineering, which makes it significantly representative. According to corresponding Serbian standards, physical and mechanical characteristics of the mentioned cement have been tested.

In the experiment, the separated river aggregate from the South Morava river has been used, divided into four fractions: 0 ÷ 4, 4 ÷ 8, 8 ÷ 16 and 16 ÷ 31,5 mm. Granulometric composition for each particular fraction has been given.

Granulometric composition of aggregate fractions was determined by the sieve test. The sieve passage percentage through the corresponding sieves for all the fractions is given in the table 1.

Table 1 Granulometric composition of aggregate fractions

Fraction	Sieve passage percentage											
[mm]	0,125	0,25	0,5	0,71	1	2	4	8	11,2	16	22,4	31,5
0 ÷ 4	0*	7	26	49	65	92	100	-	-	-	-	-
4 ÷ 8	0*	1	1	1	2	5	20	97	100	-	-	-
8 ÷ 16	0	0	0	1	1	1	1	25	89	100	-	-
16 ÷ 31,5	0	0	0	0	1	1	1	1	2	21	85	100

*) passage percentage is 0,3 %, but all the percents in the table are rounded to whole numbers

In this paper, three different aggregate mixtures, designated with "AS", "ABS" and "BS" have been used for preparation of concrete. The "AS" mixture was chosen so that, to a greatest possible extent, considering the granulometric composition of fractions, it corresponds to the boundary curve "A"; and the mixture "BS" so that it corresponds to the boundary curve "B". The third composed mixture "ABS", was chosen so that its granulometric curve goes along the middle of the area bordered by the boundary curves "A" and "B". Granulometric compositions of boundary and composed aggregate mixtures are given in the table 2 and figure 1.

Table 2. Sieve passage percentage of boundary and composed aggregate compositions

Mixture	Sieve passage percentage:								
	0,125	0,25	0,5	1	2	4	8	16	31,5
A	-	2	5	8	14	23	38	62	100
B	-	8	18	28	37	47	62	80	100
AS	0	1,3	4,5	11,8	16,8	20,8	39,4	62,9	100
ABS	0	2,2	7,5	19,1	27,3	32,5	51,9	72,6	100
BS	0	3,2	11,6	29,3	41,6	47,2	62,1	80,2	100

With "AS" aggregate the concrete mixtures were prepared with initial amounts of material as the in table 3. For those concrete mixtures prepared with the aggregate whose granulometric composition corresponds to the "ABS" mixture, the quantities of material as given in Table 4 were used. Eventually, a series of concrete mixtures with the aggregate whose granulometric composition corresponds to the mixture "BS" was prepared, with the quantities of material as shown in the table 5.

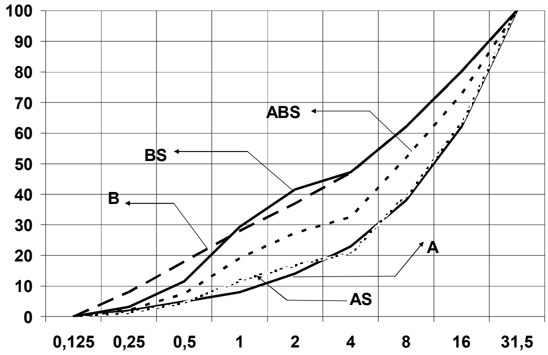

Fig. 1 Granulometric curves of aggregates AS, BS and ABS and boundary curves A and B

Table 3 Concrete mixtures prepared with the "AS" aggregate

No.	Mixture designation	Cementmass m_c [kg]	Aggr. mass. m_c [kg]	Watermass m_v[kg]	$\omega = m_v/m_c$	Mass ratio m_a/m_c	Compressive strength ($f_{p,b}$) after			
1	2	3	4	5	6	7	3 days	7 days	28 days	90 days
1	A1/250	–	–	–	–	–	–	–	–	–
2	A1/300	316	1894	145	0,46	6,00	26,3	31,3	36,4	42,1
3	A1/350	365	1876	168	0,46	5,14	27,1	34,0	40,9	47,9
4	A1/400	404	1817	186	0,46	4,50	26,2	35,9	47,2	53,2
5	A1/450	440	1762	203	0,46	4,00	25,2	33,3	44,0	52,9
6	A1/500	471	1695	217	0,46	3,60	22,6	31,6	42,9	50,8
7	A2/250	269	1938	140	0,52	7,20	19,6	25,4	34,2	38,9
8	A2/300	321	1927	167	0,52	6,00	21,5	28,9	38,4	44,9
9	A2/350	361	1855	188	0,52	5,14	22,1	29,4	39,9	47,1
10	A2/400	398	1789	207	0,52	4,50	21,9	30,9	40,6	46,8
11	A2/450	432	1730	225	0,52	4,00	19,1	27,3	36,9	43,7
12	A2/500	458	1650	238	0,52	3,60	18,7	27,1	36,7	42,4
13	A3/250	273	1966	158	0,58	7,20	19,2	25,0	35,6	40,1
14	A3/300	316	1897	183	0,58	6,00	19,8	27,3	37,0	43,2
15	A3/350	355	1824	206	0,58	5,14	18,6	25,5	36,7	42,3
16	A3/400	388	1747	225	0,58	4,50	14,7	22,7	34,2	39,7
17	A3/450	418	1672	242	0,58	4,00	13,3	20,6	31,5	37,4
18	A3/500	–	–	–	–	–	–	–	–	–

Table 4. Concrete mixtures prepared with the "ABS" aggregate

No.	Mixture designat.	Cement mass m_c [kg]	Aggr. mass. m_c [kg]	Water mass m_v[kg]	$\omega = m_v/m_c$	Mass ratio m_a/m_c	Compressive strength ($f_{p,b}$) after			
1	2	3	4	5	6	7	3 days	7 days	28 days	90 days
1	AB1/250	272	1959	125	0,46	7,20	19,6	24,6	33,6	36,1
2	AB1/300	325	1950	150	0,46	6,00	24,7	35,4	47,0	54,9
3	AB1/350	366	1882	168	0,46	5,14	23,1	33,3	45,3	54,6
4	AB1/400	402	1811	185	0,46	4,50	19,7	34,1	43,6	52,1
5	AB1/450	437	1748	201	0,46	4,00	19,7	35,6	47,0	56,2
6	AB1/500	468	1685	215	0,46	3,60	16,0	33,3	43,9	49,8
7	AB2/250	276	1987	146	0,52	7,20	18,0	25,4	36,2	43,4
8	AB2/300	320	1919	169	0,52	6,00	20,4	31,0	44,1	53,3
9	AB2/350	360	1852	191	0,52	5,14	20,0	28,7	43,1	52,2
10	AB2/400	396	1782	210	0,52	4,50	15,6	25,5	41,0	48,7
11	AB2/450	430	1719	223	0,52	4,00	14,7	24,6	40,1	47,5
12	AB2/500	461	1659	240	0,52	3,60	13,0	23,7	38,1	46,1
13	AB3/250	276	1985	160	0,58	7,20	17,0	27,8	41,7	52,0
14	AB3/300	316	1898	184	0,58	6,00	16,7	26,4	39,8	49,2
15	AB3/350	354	1817	205	0,58	5,14	16,9	26,4	40,7	48,3
16	AB3/400	388	1744	225	0,58	4,50	12,9	23,4	36,2	44,8
17	AB3/450	420	1678	243	0,58	4,00	9,6	20,4	33,3	40,0
18	AB3/500	447	1608	259	0,58	3,60	9,1	19,4	33,1	39,7

Table 5. Concrete mixtures prepared with the "BS" aggregate

No.	Mixture designat.	Cementmass m_c [kg]	Aggr. mass. m_c [kg]	Water mass m_v[kg]	$\omega = m_v/m_c$	Mass ratio m_a/m_c	Compressive strength ($f_{p,b}$) after			
1	2	3	4	5	6	7	3 days	7 days	28 days	90 days
1	B1/250	–	–	–	–	–	–	–	–	–
2	B1/300	316	1895	145	0,46	6,00	26,7	32,9	43,9	48,0
3	B1/350	362	1860	166	0,46	5,14	28,9	36,5	48,5	56,1
4	B1/400	398	1793	183	0,46	4,50	27,3	36,6	47,6	53,1
5	B1/450	432	1729	199	0,46	4,00	25,7	35,0	46,6	53,7
6	B1/500	463	1668	213	0,46	3,60	22,0	30,2	42,4	49,7
7	B2/250	–	–	–	–	–	–	–	–	–
8	B2/300	317	1902	165	0,52	6,00	24,9	33,6	45,5	51,6
9	B2/350	355	1825	185	0,52	5,14	24,0	32,0	43,9	51,8
10	B2/400	390	1753	203	0,52	4,50	23,0	30,4	42,7	48,6
11	B2/450	423	1692	220	0,52	4,00	21,6	29,4	41,4	48,0
12	B2/500	459	1653	239	0,52	3,60	20,3	28,7	40,4	46,6
13	B3/250	269	1938	156	0,58	7,20	20,4	30,4	41,2	46,1
14	B3/300	311	1864	180	0,58	6,00	19,4	28,6	40,0	46,5
15	B3/350	347	1783	201	0,58	5,14	17,7	25,9	37,8	45,1
16	B3/400	383	1722	222	0,58	4,50	17,0	24,1	35,8	41,9
17	B3/450	414	1655	240	0,58	4,00	13,9	19,8	31,5	36,8
18	B3/500	-	-	-	-	-	-	-	-	-

The correlation dependency was determined between the compressive strength of concrete and the ratio of aggregate and cement. The compressive strength values at the age of concrete of 28 days was used (tab. 3, 4 and 5, column 10) for the corresponding values of m_a/m_c coefficient (same tables, column 7). The polynomial function of the second degree offered the best interpretation of the mentioned interdependence and had the best correlation coefficient:

$$f_{pb,28} = f(m_a/m_c) = a + b \cdot (m_a/m_c) + c \cdot (m_a/m_c)^2$$

The values of the coefficients from the previous equation and the correlation coefficient are given in the table 6.

Table 6. Dependence of compressive strength of concrete (fpb,28) on the mass content of aggregate and cement (ma/mc)

Aggregate type	ω_c	Coefficients			r^2
		a	b	c	
A	0,46	−17,78	28,88	−3,32	0,846
	0,52	1,96	14,72	−1,43	0,881
	0,58	−13,57	16,92	−1,40	0,982
AB	0,46	−43,61	34,43	−3,28	0,923
	0,52	−29,55	26,82	−2,45	0,974
	0,58	−11,86	17,49	−1,47	0,886
B	0,46	27,84	4,31	−0,23	0,999
	0,52	−39,12	36,07	−3,71	0,964
	0,58	−11,93	15,52	−1,13	0,980

Dependence $f_{pb,28} = f(m_a/m_c)$ has been presented in figures 2, 3 and 4 in the form of a polynomial function of the second degree, when the granulometric composition is constant, while the value of the m_a/m_c coefficient varies between 3,6 and 7,2, with the simultaneous change of water cement factor from 0,46 to 0,58.

The opposite situation, that is, change of $f_{pb,28} = f(m_a/m_c)$ in the conditions of the constant water cement factor and different granulometric composition is given in the figures 5, 6 and 7.

Lower values of the m_a/m_c coefficient correspond to the mixtures with the higher content of cement and vice-versa, the higher value of m_a/m_c corresponds to the concrete mixtures containing lower quantities of cement. At these, we might say, very high values of m_a/m_c which are round 7, with the simultaneously low value of water cement factor (around 0,46), lower compressive strength are attained, then when under same conditions the water cement factor is increased to 0,52 or 0,58 (figures 2,3 and 4). It reflects the less favorable structure and rigid consistency which the dry mixtures have in respect to those made with a higher water cement factor. Cohesion of such mixtures is very weak due to lack of cement paste, and is simultaneously characterized by a high rigidity due to the prominent friction between the aggregate grains, which usually dominates in the structure of those concretes. [8, 9, 10]. Pouring – compaction of such concretes with classical means, as demonstrated in the experiment, is very difficult because, along with the previous factors, it results in the relatively low strengths (below 30 MPa).

As previously mentioned, a certain increase of the water cement factor in these conditions may have rather a positive instead of negative effect. It is primarily reflected in attainment of consistency allowing realization of a higher compactness of poured concrete, and consequently, certain increase of compressive strength [11, 12, 13].

As the m_a/m_c coefficient value decreases, the structure of fresh and set concrete changes. With gradual increase of cement paste content and with the simultaneous decrease of the aggregate reduction (which entails reduction of the m_a/m_c coefficient value reduction), the concrete slowly transits from the structure III zone into the structure II zone, which is considered the most favorable one. Now the highest compressive strengths of concrete are achieved with the least water cement factor. If for these purposes, some boundary values of the m_a/m_c coefficient should be defined, then it is clear from the figures 2, 3 and 4 that the granulometric composition of the aggregate should be taken into account. For instance, in the case of application of "A" aggregate, the m_a/m_c coefficient value after which the favorable structure of concrete is attained, lies between 5,4 and 5,8,; in the case of application of "AB" aggregate this value amounts to circa 6,8, and in the case of application of "B" aggregate, the boundary value of m_a/m_c coefficient is 6,4.

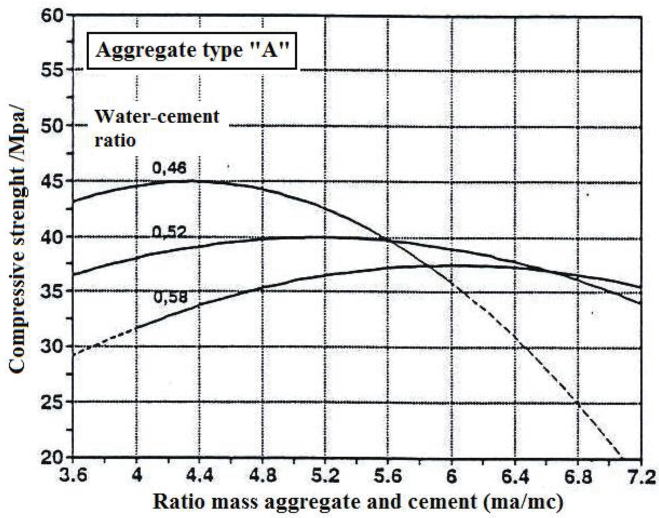

Fig. 2 Change of compressive strength (f_{pb}) of concrete produced with "A" aggregate depending on the ratio of aggregate mass and cement mass (m_a/m_c)

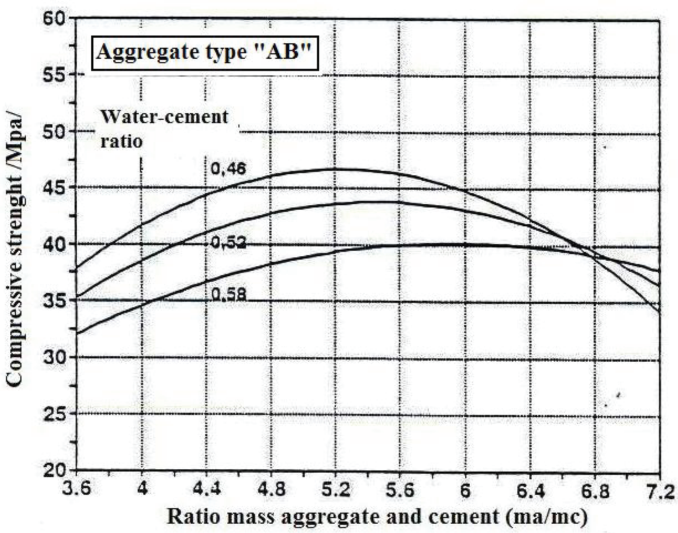

Fig. 3 Change of compressive strength (f_{pb}) of concrete produced with "AB" aggregate depending on the ratio of aggregate mass and cement mass (m_a/m_c)

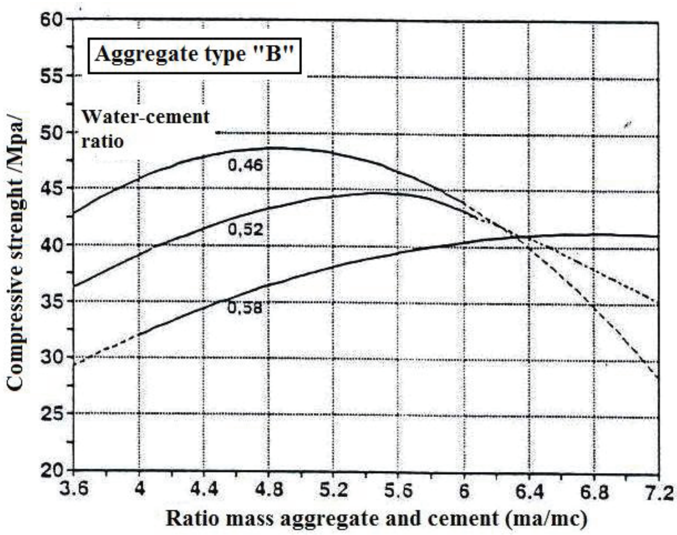

Fig. 4 Change of compressive strength (f_{pb}) of concrete produced with "B" aggregate depending on the ratio of aggregate mass and cement mass (m_a/m_c)

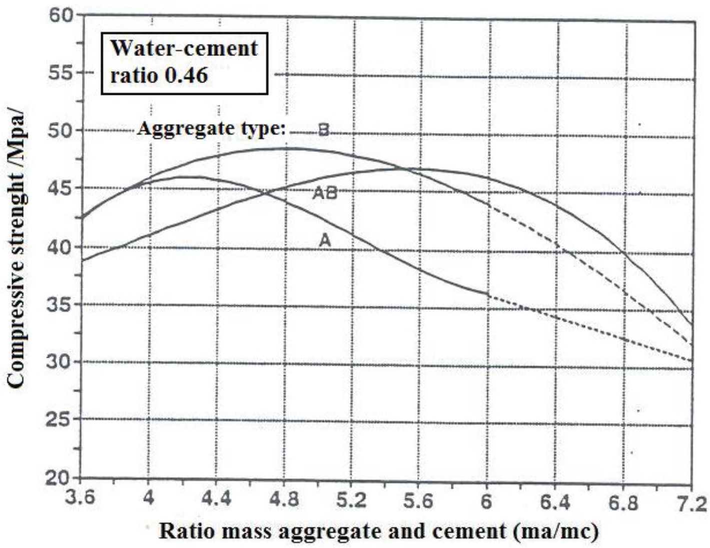

Fig. 5. Change of compressive strength (f_{pb}) of concrete produced water cement factor $\omega_c = 0,46$ depending on the ratio of aggregate mass and cement mass (m_a/m_c)

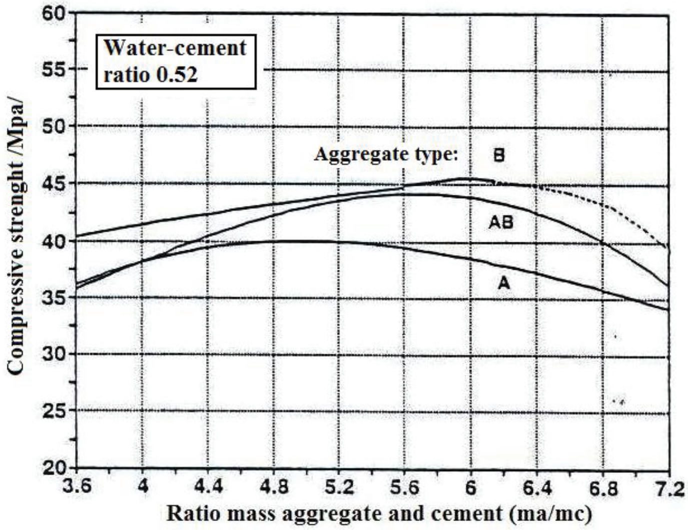

Fig. 6 Change of compressive strength (f_{pb}) of concrete produced water cement factor ω_c = 0,52 depending on the ratio of aggregate mass and cement mass (m_a/m_c)

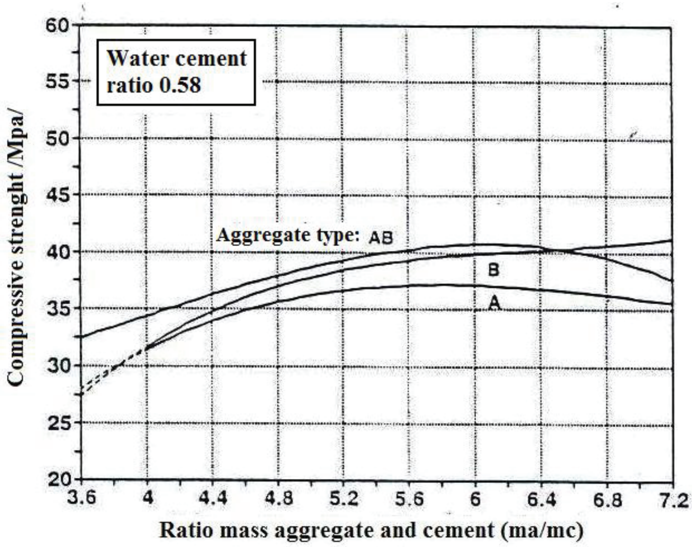

Fig. 7 Change of compressive strength (f_{pb}) of concrete produced water cement factor ω_c = 0,58 depending on the ratio of aggregate mass and cement mass (m_a/m_c)

CONCLUSION

On the basis of the preceding statements, it can be concluded that a lower value of water cement factor "calls for" a lower value of m_a/m_c, coefficient, but at the same time yields the highest strengths.

If, at a constant value of water cement factor, the granulometric composition were changed it would be noted that for the different aggregates also different are the values of the m_a/m_c coefficient, at which the maximum strengths are realized. For example, for the water cement factor $\omega_c = 0,46$ (Fig. 5) the maximum strength of concrete with the "A" aggregate was attained when $m_a/m_c \approx 4,2$, and if "B" aggregate was used, then the most favorable value is $m_a/m_c \approx 4,8$, and in case of "AB" aggregate application, it is the value $m_a/m_c \approx 5,6$.

When the values of m_a/m_c coefficient become lower than optimal, the structure of concrete passes from the structure II into structure I which is dominated by the effects of cement paste (that is, cement rock). As a logical consequence of such transformation the compressive strength of concrete decreases. [14].

The highest compressive strengths are achieved with the lowest values of water cement factor which is in direct relation with the structure and characteristics of cement rock.

The obtained values of m_a/m_c coefficient, covering a considerable range of possible concrete mixtures, give a significant contribution in designing of concrete mixtures, providing that it is taken into account that the concrete values refer to the used materials, and the practice a potential correction of concrete constituent components may be required.

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UTICAJ MASENOG UČEŠĆA AGREGATA I CEMENTA U BETONU NA ČVRSTOĆU PRI PRITISKU

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Pod masenim učešćem agregata (m_a) i cementa (m_c) u betonu podrazumeva se koeficijent koji se izračunava kao m_a / m_c. Neke metode koje se koriste za projektovanje sastava betonskih mešavina uzimaju u obzir ovaj koeficijent. U ovom radu betonske mešavine su spravljene tako da je varirana masa cementa, vodocementni faktor i granulometrijski sastav. Vrednosti koeficijenta m_a/m_c u eksperimentalnom istraživanju kretale su se od 7,20 kod betonskih mešavina spravljanih sa 250 kg cementa do 3,60 kod betona koji su spravljani sa količinom cementa od 500 kg po 1m^3. Posmatrano sa aspekta čvrstoće pri priitsku betona, utvrđeno je da optimalne vrednosti koeficijenta m_a/m_c zavise od granulometrijskog sastava i vodocementnog faktora. Pri većim vodocementnim faktorima potrebne su veće vrednosti koeficijenta m_a/m_c da bi se pod datim uslovima ostvarile maksimalne čvrstoće.

Key words: *masa agregata, masa cementa, čvrstoća pri pritisku betona.*