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TECHNICAL NOTES

Strength, Water Absorption and Porosity of Concrete Incorporating Natural and Crushed Aggregate

Saleh H. Alsayed and *Mohammad A. Amjad

*Civil Engineering Dept., College of Engineering, P.O. Box 800, King Saud University, * King Abdulaziz City for Science and Technology, Riyadh, Saudi Arabia*

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Abstract. This paper presents the results of an extensive experimental program which was carried out to study the influence of Riyadh area aggregates on the compressive strength, water absorption, and porosity of the concrete. Parameters involved were crushed washed aggregate, natural unwashed aggregate, and four different water cement ratios.

Natural aggregates are characterized as porous limestone rocks with high water absorption, low bulk specific gravity, excessively dusty degraded, and contain large quantities of very fine sand.

Test results indicate that with proper selection of mix proportions and adequate compaction both aggregates can be used to produce concrete with ultimate compressive strength that is usually specified for most concrete structural applications. Results also indicate that the natural aggregate concrete has less compressive strength, less porosity and higher water absorption compared to that of concrete made with crushed aggregate. This is true for 0.4, 0.45, 0.5, and 0.55 water cement ratios.

Introduction

Aggregates form about 75% of the volume of concrete, therefore, their parameters such as shape, texture, gradation, and maximum size have a major influence on the properties and the overall behavior of the concrete. Aggregate shape and texture primarily depend on whether the aggregate has been reduced to its current size by natural agents or by crushing in an aggregate processing plant. Natural Aggregate (NA) usually has a nearly spherical shape and smooth texture while the Crushed Aggregate (CA), has an irregular angular shape and rough surface. Spherical particles have lower surface to volume ratio and, therefore, they need less mortar to envelop them. On the other hand, irregular particles require more mortar and develop stronger aggregate-mortar bond which leads to concrete of higher strength.

Aggregate gradation also affects the properties of concrete. If all particles of aggregate are of uniform size, the aggregate may not be compacted properly. On the contrary, if the aggregate is well graded and its particles are composed of different sizes then at the time of compaction, the smaller particles fill the voids between the larger ones. Thus, concrete made of well graded aggregate is dense and contains fewer voids.

The maximum size of aggregate is in direct proportion with its specific surface area, therefore the amount of mixing water required to provide a certain level of workability reduces with the increase of the maximum size of aggregate. Reduction in the amount of water provokes an increase in the concrete strength and a reduction of the quantity of cement brings out an economically beneficial concrete, especially for mass concrete construction.

Aggregates that are mined and used for concrete production in Riyadh, Saudi Arabia, are predominantly porous limestone rocks with higher water absorption, lower bulk specific gravity, excessively dusty and degraded and contain large quantities of very fine sand. The very fine sand is 0.075 to 0.45 mm in diameter and constitutes 8 to 35% by weight of fine aggregate [1-3]. Due to the peculiar nature of this type of aggregate, question often arises as how the concrete made with such material will behave.

In practice, more than 20% of the concrete mixes in Riyadh, incorporate Natural Unwashed Aggregate (NUA). Concrete made with such aggregate is used mostly by contractors to construct private houses. The rest however are incorporating Crushed Washed Aggregate (CWA) that is supplied by quarries located around the Riyadh area. However, not enough information is available to reflect the effect of those aggregate types on the overall behavior of the concrete.

This investigation was carried out to study the influence of the two types of aggregate (NUA and CWA) on the behavior of concrete. The other variable in the study was the water-cement ratio. Engineering properties considered include; compressive strength, modulus of elasticity, modulus of rupture, water absorption and porosity of concrete.

Experimental Program

Materials

The material used in this test program consisted mainly of Ordinary Portland Cement (OPC) type I, crushed washed and natural unwashed aggregates. Aggregates gradations are shown in Tables 1 and 2 and their physical properties are tabulated in Table 3.

Table 1. Comparison of the grading results of the fine aggregates with the ASTM grading limits

ASTM sieve	Pre cent passing by weight		
	Washed aggregate	Unwashed aggregate	ASTM C-33 limits
4	98.48	100.0	95–100
8	69.01	80.14	80–100
16	41.38	61.83	50–85
30	23.61	38.77	25–60
50	11.37	18.76	10–30
100	4.28	8.89	2–10

Table 2. Comparison of the grading results with ASTM-C33 grading limits (different sizes)

ASTM sieve	Course agg. No. 3 to No. 4		Coarse agg. No. 3/8 to No. 4		Combined agg. 1–1/2" to 0	
No.	Washed	ASTM	Washed	ASTM	Unwashed	*
1–1/2"	100	–	100	100	100	95–100
1"	100	–	100	100	90.71	65–85
3/4"	99.19	90–100	100	90–100	87.83	50–75
1/2"	46.25	20–55	92.47	40–70	78.83	35–60
3/8"	9.02	0–10	14.89	0–15	72.55	25–45
No. 4	–	0–5	0.18	0–5	58.47	20–35
No. 8	–	–	–	–	46.87	15–30
No. 16	–	–	–	–	36.18	10–25
No. 30	–	–	–	–	22.71	5–15
No. 50	–	–	–	–	11.02	0–5
No. 10	–	–	–	–	5.03	–

*Read Note No. 4 type grading (ref. 22)

Table 3. SSD specific gravity and absorption for washed and unwashed aggregates

Type material	Specific gravity	Absorption %
Washed sand	2.50	2.501
Washed agg. 20 mm	2.56	1.553
Washed agg. 10 mm	2.57	1.541
Unwashed combined agg.	2.46	2.594

Concrete mix

The concrete mixes considered in the investigation are shown in Table 4. Series A and B were composed of mixtures having CWA and NUA, respectively. The main variable in the concrete mixes was the water cement (W/C) ratios. The recommended ACI practice 211.1 [4, pp 1-34] was used in selecting the mix proportions of all mixes. Mix number one (1) of series A and Mix number one (1) of series B were composed of the same volume of aggregate, weight of cement, and weight of water. Except for the weight of water, mixes of the same series were identical. Concrete of all mixes except for mix number one of series B was homogenous in appearance. The slump varied from 70 to 95 mm. Mix number one of series B had a slump of 70 mm and during the casting some segregation was observed. Other details of all the mixes are shown in Table 4.

Table 4. Mix proportions

				Washed			Unwashed
Mix No.	W/C	Cement (kg)	Total water (Lt)	Sand (kg)	Agg. 10 mm (kg)	Agg. 20 mm (kg)	Combination (agg 10 mm + agg. 20 mm + sand)
1-A*	0.45	50	22.88+	70	35	70	–
1-B**	0.45	50	22.95+	–	–	–	201.84
2-A	0.5	50	25.38	70	35	70	–
2-B	0.5	50	25.59	–	–	–	201.84
3-A	0.55	50	27.89	70	35	70	–
3-B	0.55	50	28.09	–	–	–	201.84
4-A	0.6	50	30.39	70	35	70	–
4-B	0.6	50	30.6	–	–	–	201.84

*A = Crushed Washed Aggregate
**B = Natural Unwashed Aggregate
+ = Weight of the water adjusted to account for the water absorption

Test specimens and procedure

A total of thirty two 150 × 300 mm cylindrical specimens, sixteen 150 × 150 × 500 mm prisms, and sixteen 150 mm cubic specimens were cast. Half of the specimens were of series A and the other half were of series B. Cylindrical specimens were used to determining the compressive strength and modulus of elasticity, prisms to determine modulus of rupture, and cubes to determine water absorption and total porosity.

The specimens were demolded after 24 hours and cured continuously in a curing tank at a temperature of 25°C for 27 days. Compressive strength, modulus of elasticity and modulus of rupture tests wre performed according to ASTM C39[5], ASTM C 469[6], and ASTM C 78[7], respectively. Water absorption test of concrete was carried out according to BS:1881: part 5[8]. Porosity was measured by total water saturated method.

Test Results and Discussions

Strength

Table 5 shows the compressive strength and modulus of rupture of concrete specimens made using different W/C ratios. Results show that as far as the compressive strength is concerned both aggregates, regardless of the water content, produced concrete with an acceptable ultimate compressive strength, f'_c. However, as expected, f'_c decreases as the W/C increased. Results also indicate that f'_c for concrete made with CWA is always higher than the corresponding f'_c for concrete made with NUA (see Fig. 1). The average difference is 22% and the difference increases with increasing W/C ratios. This observation contradicts the findings of other resear-

Table 5. Compressive strength, modulus of elasticity, water absorption and porosity of concrete

Mix	W/C	Strength (MPa)	Modulus of rupture (MPa)	Elasticity (GPa) at 6 MPa	Water absorption (%)	Porosity, total volume (%)
A	0.45	42	3.8	31.6	4.48	4.1
B	0.45	33.1	2.5*	27.3	5.30	3.04
A	0.5	39.7	3.15	27.2	4.69	5.45
B	0.5	33.0	2.4	27.6	5.31	4.03
A	0.55	37.4	2.9	25.0	5.03	7.89
B	0.55	28.6	2.32	20.0	5.75	4.87
A	0.6	36.3	3.0	25.0	4.45	8.47
B	0.6	25.4	2.1	21.0	5.28	5.8

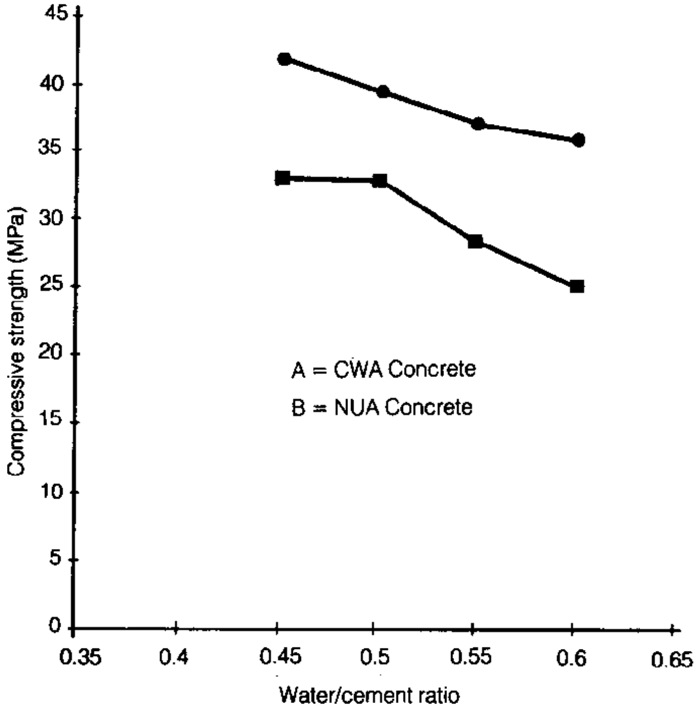

Fig. 1. Relationship between compressive strength and water/cement ratio.

chers [9, pp 453-465] [15]. This may be attributed to the higher water absorption of the NUA (see Table 3) due to the presence of excessive amount of the fine and porous particles. The excess amount of fine particles presents in the natural unwashed aggregate concrete (NUAC) makes it inevitable to use higher W/C ratio.

Compressive strength is customarily used to estimate many of the engineering properties of the concrete. Of the various properties of concrete which have received special attention from researchers are modulus of rupture and modulus of elasticity.

Measured values of the moduli of rupture of the crushed washed aggregate concrete (CWAC) and (NUAC) are shown in column 4 of Table 5. Results show that the modulus of rupture of the CWAC is always higher than the corresponding modulus of rupture of the NUAC. This agrees with the compressive strength results. Many empirical relaitonships which relate the compressive strength to modulus of rupture have been developed earlier. One of the most commonly used in the field of structural concrete is the ACI formula and is given by [16].

$$f_r = 0.7\,(f_c')^{0.5} \qquad (1)$$

Where f_c' is the compressive strength and f_r is the modulus of rupture of the concrete in MPa.

Comparisons of the results indicate that equation 1 overestimated the moduli of rupture of CWAC and NUAC by an average of 16% and 30%, respectively. The high error in estimating the modulus of rupture of NUAC may be attributed to the presence of high amount of fine sand and the deleterious materials in the NA. However it is believed that the modulus of rupture of NUAC could have been better estimated had the aggregate been washed before use.

The moduli of elascity of CWAC and NUAC are also presented in column 6 of Table 5. The tendency of the results is comparable to that of the moduli of rupture. Here, the error in estimating the moduli of elasicity for both type of aggregates using the ACI formula (shown below as equation No. 2(is 9%. The error is not as high as that of the moduli of rupture.

$$E_e = 4700\,(f_c')^{0.5} \qquad (2)$$

where f_c' = compressive strength of concrete specimen in MPa

E_e = modulus of elasticity of concrete in MPa

In general, the empirical relationships have the advantage of simplicity, but engineers should be aware of their limitations.

Water absorption

The water absorption for the two series of concrete is shown in Table 5 and Fig. 2. It can be seen in the table that the water absorption, for both series, increases as the W/C ratio increases. The maximum absorption was observed at W/C ratio of 0.55. As the W/C ratio becomes larger than 0.55, water absorption decreases. This decrease could be due to excess amount of water available for hydration and therefore more pores near to the surface of the specimens being blocked by the hydration products of OPC. Similar observation was also made by Al-Amri[17]. Although the water absorption cannot be used as a measure of the quality of the good concrete, the observed values are within the ranges of those of the good one[18]. Results also reveal that water absorption of the CWAC specimens is lower than that of the NUAC. This may be ascribed to the effect of the aggregate type where the natural aggregate absorbs more water than the crushed one[18].

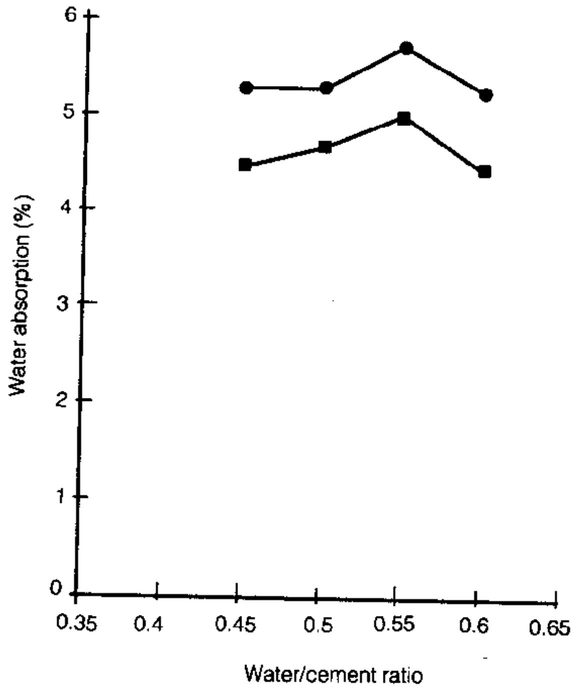

Fig. 2. Relationship between water absorption and water/cement ratio.

Interestingly, the results of this study as well as of others [17,20] have shown that no explicit relationship between compressive strength and water absorption occurs. Unquestionably, however, there exists an interaction between the water absorption and the compressive strength where the pores at the surface affect the bond between the aggregate and the paste and thus influence the strength of the concrete.

However, the compressive strength that resulted from the excess in the water absorption of the NUA over that of the CWA was offset by its round shape and smooth surface texture.

Porosity

The porosities of CWAC and NUAC are also shown in Table 5. Comparison of the rationship between the W/C ratio and the porosity is depicted in Fig. 3. The results show that the porosity of NUAC is always less than that of CWAC at any similar W/C ratio. They also show that the difference increases as the W/C ratio

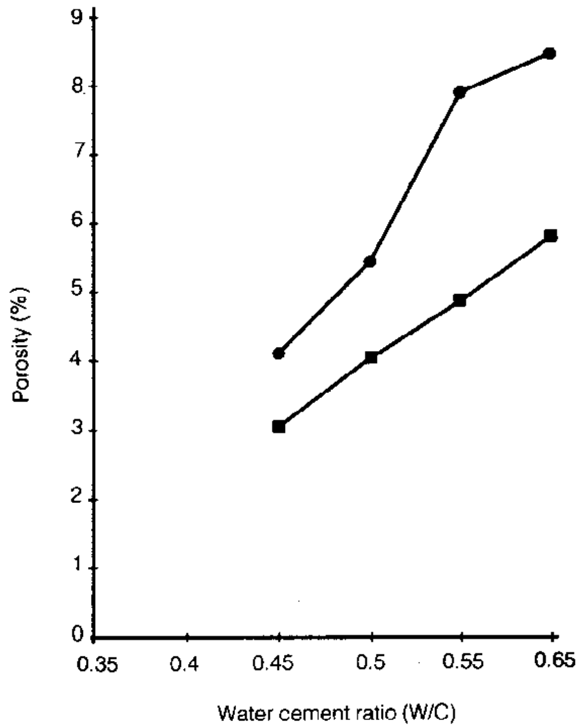

Fig. 3. Relationship between porosity and water cement ratio.

increases. Though the reason is not clearly known, it is believed that it is so because of the less number of the empty pores in NUA than of CWA. Earlier studies [14,18,19] showed that as the porosity decreases the permeability also decreases. It is to be pointed out here that the permeability plays a major role in durability because it controls the rate of ingress of the moisture into concrete. The rate of entry of water plays a major role in the deterioration of concrete structure as the chlorides and sulfate in combinaiton with water attack the concrete causing its deterioration. Since the concrete made with natural aggregates is less porous which reduces the intensity of attack to a considerable extent thereby producing more durable structure than the one made using CWAC.

Further, compressive strength versus porosity graph is shown in Fig. 4. The results of each mix separately show that there is an inverse relationship, i.e., the higher the strength the lower the porosity. Howeve, there is no overall relationship that is valid for both mixes. This confirms the findings of other researchers[18,21].

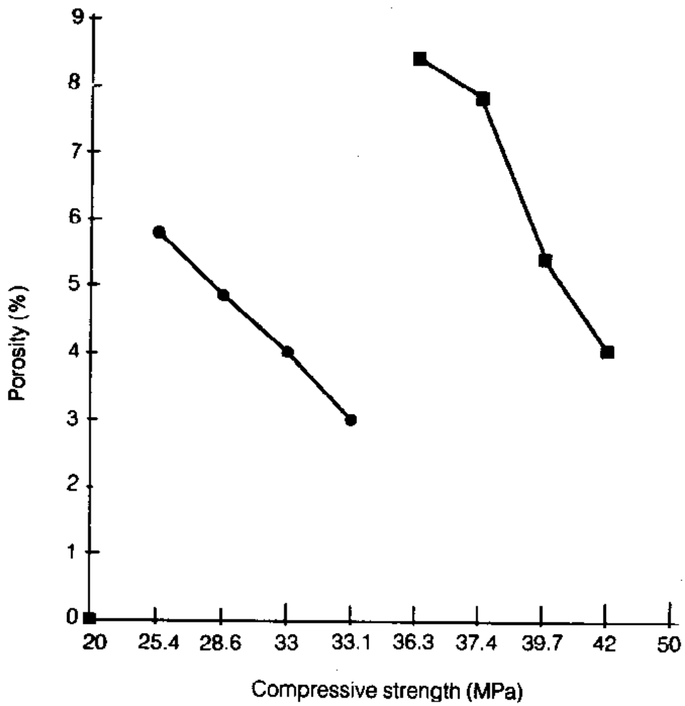

Fig. 4. Relationship between porosity and compressive strength.

Conclusions

The major findings of this study can be summarized as follows:

1. The compressive strength, modulus of elasticity, modulus of ruptures, of the crushed aggregate concrete are higher than those of the natural aggregate concrete.
2. Compressive strength for normal structures, ranges from 25 to 30 MPa, can be achieved easily using Natural Aggregate.
3. Natural aggregate concrete has lesser compressive strength, lesser porosity and higher water absorption than that of conrete made with crushed aggregate.
4. Empirical formulas available to estimate the mechanical properties of concrete may lead to a 30% error. Engineers should be aware of their limitations before use.

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مقاومة الماء وامتصاصه ومساميّة الخرسانة باستخدام الركام الطبيعي والمتكسر

صالح حامد السيد و محمد أمين أمجد*

قسم الهندسة المدنية، كلية الهندسة، جامعة الملك سعود، ص.ب ٨٠٠، الرياض ١١٤٢١؛

** مدينة الملك عبدالعزيز للعلوم والتقنية، ص.ب ٦٠٨٦، الرياض ١١٤٤٢؛ المملكة العربية السعودية*

(استُلم في ١/١٢/١٩٩٢م؛ وقبل للنشر في ٢٤/١٠/١٩٩٤م)

ملخص البحث. تعرض هذه الورقة نتائج فحوصات مخبرية أجريت لدراسة تأثير بعض أنواع الركام بمنطقة الرياض على مقاومة وخاصية امتصاص الماء ومسامية الخرسانة. المتغيرات التي أخذت بالاعتبار هي الركام الطبيعي غير المغسول وركام الكسارة المغسول وأربعة أنواع مختلفة من نسب الماء إلى الأسمنت.

إن الركام الطبيعي متكون من الحجر الجيري المسامي ذو خاصية عالية لامتصاص الماء وذو قيمة صغيرة للوزن النوعي ومغطى بطبقة من الغبار كما أنه يحتوي على كميات كبيرة من الرمل الناعم جدًا.

أثبتت النتائج بأنه باستخدام خلطة جيدة ودك عال فإن نوعي الركام يمكن استخدامهما لإنتاج خرسانة ذات مقاومة ضغط غالبًا ما تحدد في أكثر المنشآت الخرسانية. كذلك بينت النتائج أن خرسانة الركام الطبيعي تعطي أقل مقاومة وأقل مسامية وأعلى امتصاصية للماء مقارنة بخرسانة ركام الكسارة. هذا الاستنتاج صحيح عندما تكون نسب الماء إلى الأسمنت تساوي ٠,٤، ٠,٤٥، ٠,٥٠، أو ٠,٥٥٪.