Effect of Coarse Aggregate Characteristics on Drying Shrinkage of Concrete

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Abstract:

Concrete is a composite material, consisting, mainly, of three phases: coarse aggregate, cement mortar, and the interface zone between them. The characteristics of the interface zone largely govern the bond between cement paste or mortar and aggregate. The restraining effect of aggregate to drying shrinkage strain depends much on the bond between aggregate and cement paste.

In this paper, it is aimed to investigate the effect of coarse aggregate characteristics, that affect bond strength, such as; type, shape, surface texture, and moisture content, on drying shrinkage. Four types of coarse aggregate were used. Three of them were normal-weight, while the fourth was a light-weight one. Each type of coarse aggregate was used in two moisture conditions, dry and saturated. The testing program extended to 150-days age and comprised; length change, modulus of elasticity, compressive and splitting tensile strength of concrete.

It is concluded that using saturated coarse aggregate always yields higher shrinkage strain than dry aggregate. The percentage increase seems to be affected by the aggregate water absorption. At early ages, After 28 days, there is large differences in relative shrinkage for different mixes. Later than 28 days, the variation in ratios settled to approximately fixed values
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Keywords: Coarse aggregate, Compressive strength, Drying shrinkage, Interface zone, Limestone, Modulus of elasticity, Porcilinite, Splitting tensile strength, Surface texture.

الخلاصة:

الخرسانة مادة مركبة ومكونة بشكل رئيسي من ثلاثة أطوار: الركام الخشن ومونة الاسمنت ومنطقة السطوح البينية. ان خواص منطقة السطوح البينية تتحكم بشكل كبير في قوى الارتباط بين عجينة الاسمنت (أو المونة) وبين الركام. كما أن الدور المقيد الذي يقوم به الركام تجاه انفعالات انكماش الجفاف للخرسانة يعتمد كثيراً على قوى الارتباط التي تتطور في منطقة السطوح البينية.

في هذا البحث تم التحري عن تأثير خواص الركام الخشن (مثل:النوع والشكل ونسجة السطح ومحتوى الرطوبة)على معدل ومقدار الانكماش للخرسانة عند الجفاف. تم اختيار هذه الخواص

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لما لها من علاقة قوية بقوى الارتباط بين العجينة والركام. تضمن البحث دراسة تاثير ثلاثة انواع من الركام الطبيعي الوزن ونوعاً رابعاً كان خفيف الوزن. الفحوصات التي اجريت على

الخرسانة كانت: التغير الطولي، معامل المرونة، مقاومة الانضغاط ومقاومة الشد بالانشطار وامتد البرنامج العملي الى عمر ١٥٠ يوم.
الخلطات الخرسانية المنتجة بالركام المشبع أظهرت دائماً انكماشاً اكبر من خلطات الركام الجاف وهذه الزيادة في الانكماش ارتبطت بقابلية الركام لامتصاص الماء. وعند اعتبار الانكماش النسبي للخلطات تبين أنه في الاعمار المبكرة يتغاير هذا الانكماش كثيراً في حين يستقر عند نسب ثابتة في الاعمار المتأخرة.

1. Introduction*:*

Drying shrinkage of concrete is but a fraction of that of neat cement as the aggregate particles not only dilute the paste but reinforce it against contraction [(1)]. The aggregate would restrain the amount of shrinkage that can actually be realized [(2)]. This restraining effect depends much on the bond between aggregate and cement paste.

Considering concrete as a three-phase composite material is an acceptable description. These three phases are coarse aggregate, cement mortar, and the interface zone between them. The characteristics of the interface zone largely govern the bond between cement paste or mortar and aggregate [(3)]. The interface zone has higher porosity than that of the bulk matrix. Porosity is maximum near the aggregate face and decreases towards the bulk matrix. Bourdette et al. [(4)] showed that porosity is not constant with time; it depends on the degree of hydration. Moreover, the water/cement ratio at the interface is higher than elsewhere [(2)]. Simeonov and Ahmed [(5)] state that the influence of this zone on overall elastic properties of concrete is strongly related to the water content and it changes from negative to positive with reduction of the water/cement ratio.

*2***. Research Significance:**

All the factors that affect the bond between coarse aggregate and cement mortar would affect the restraining action of aggregate and, in other words, would affect the rate and magnitude of drying shrinkage. It is aimed to investigate the effect of coarse aggregate characteristics, that affect bond strength, such as; type, shape, surface texture, and moisture content, on drying shrinkage.

3. Experimental Work:

The program of this work was designed to investigate the effect of coarse aggregate characteristics (type, shape, surface texture, and moisture content) on drying shrinkage of concrete. The materials used for making concrete mixes were: Type I Portland cement (IOS 5-1984) [(6)], natural siliceous sand with 2.76 fineness modulus as fine aggregate (IOS 45-1984, Zone 2) [(7)], and four types of coarse aggregate. Three of the coarse aggregates (limestone, crushed and uncrushed gravel) were normal-weight (IOS 45-1984). The fourth type (porcilinite) was a lightweight one. The maximum size (MSA) for all used aggregates was 19.0 mm. Table (1) shows the properties and measured characteristics of the used coarse aggregates.

Table (2) displays the details of used mixes. The proportioning was done on volumetric basis and according to the ACI Committee 211 recommendations (ACI 211.1-91 [8], ACI 211.2-98 [9]). Each type of coarse aggregate was used in two moisture conditions, dry and saturated. In both cases, the actual amount of needed water to make the aggregate in saturated surface-dry condition was calculated.

Standardized procedures were used for testing concrete specimens (100×100×400 mm prisms, 100×200 mm and 150×300 mm cylinders). The testing program was extended to 150-days age. The conducted tests were as follows:

1. Shrinkage strain or length change (IOS 54- 1989) [10].
2. Modulus of elasticity of concrete (ISG 370- 1993) [11].
3. Compressive strength (ISG 348-1992) [12].
4. Splitting tensile strength (ISG 283-1995) [13].

The results of these tests are shown in Table (3) and Fig. (1a and b).

4. Results and Discussion:

4.1 Effect of Moisture Content of Coarse Aggregate:

Table (3) shows that using saturated coarse aggregate in the mix, always yields higher shrinkage strain than is dry aggregate. There about 10% increase in drying shrinkage for all mixes, except in uncrushed gravel. The increase for uncrushed gravel was about 3% and that could be resulted from the low water absorption (0.98%) and smooth surfaces which make no difference between dry and saturated condition. Using dry aggregate causeds the water/cement ratio in the vicinity of the aggregate particles to be less than elsewhere because aggregate absorbed water to reach saturated surface-dry condition. The reduction in water content would improve the bond between cement mortar and aggregate and reduce the interface zone porosity and microcracking [2], and consequently, increases the restraining action of aggregate against drying shrinkage.

The same influence was observed with respect to the elasticity modulus, compressive, and splitting tensile strength of concrete. For porcilinite aggregate, the effect of moisture content was more obvious on elasticity modulus and splitting tensile strength than other types.

4.2 Effect of Stiffness and Type of Coarse Aggregate:

Reviewing the development of drying shrinkage with time that is shown in Fig. 1a and 1b, it could be concluded that mixes produced with porcilinite have higher final shrinkage than other mixes. This behavior may result from the lower modulus of elasticity of porcilinite in comparison with other types of aggregate. The final shrinkage of limestone concrete is less than that of uncrushed gravel concrete although gravel is stiffer than limestone. This may be due to the chemical reaction between limestones and cement paste which increases the bond strength of the interface zone [14]. Checking the development of strength and stiffness of concrete with age, would support the final justification.

4.3 Effect of Shape and Surface Texture of Coarse Aggregate:

Natural rounded uncrushed gravel has lower specific surface area and smoother texture than both crushed gravel and limestone. These characteristics cause the concrete produced by uncrushed gravel to exhibit higher shrinkage rate and final value than those made with crushed gravel or limestone.

Fig. 2 shows the development of relative shrinkage for different mixes with time. At early ages, less than 28 days, the cement matrix for different mixes would have almost the same shrinkage strain but these strains would face different restraining actions from coarse aggregate due to variation in specific surfaces. In such ages there are large differences in relative shrinkage. After that, after 28 days, the variation in ratios settled to approximately fixed values (1.5 for UCG/CG and 1.4 for UCG/L).

The development of the ratio of limestone concrete shrinkage to crushed gravel concrete shrinkage is also plotted in Fig. 2. Limestone, indeed, has higher specific surface and rougher texture than crushed gravel. In spite of that, crushed gravel concrete has always lower shrinkage strain than limestone concrete. This may be attributed to the higher modulus of elasticity of gravel which restrains shrinkage strain more effectively.

5. Conclusions:

1. Using saturated coarse aggregate in the mix always yields higher shrinkage strain than dry aggregate. There is about 10% increase in drying shrinkage for most mixes. The increase percentage seems to be affected by the aggregate water absorption.
2. For porcilinite lightweight aggregate concrete, the effect of moisture content of aggregate was more obvious on the modulus of elasticity and splitting tensile strength than other properties.
3. The final shrinkage of limestone concrete was lesser than that of uncrushed gravel concrete although gravel is stiffer than limestone. This may be due to the chemical reaction between limestone and cement paste which increases the bond strength of the interface zone.
4. At early ages, less than 28 days, there were large differences in relative shrinkage for different mixes. Later than 28 days, the variation in ratios settled to approximately fixed values (1.5 for UCG/CG and 1.4 for UCG/L).

6. References:

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Table 1: Properties of used coarse aggregates.

No.	Property		Aggregate type			
			Limestone (L)	Crushed Gravel (CG)	Uncrushed Gravel (UCG)	Porcilinite (P)
1	Sieve Analysis (IOS 30-1984)(15)	Sieve Size, mm.	% Passing			
		19.00	100			
		9.50	40			
		4.75	0			
2	Specific Gravity, SSD (IOS 31- 1984) (16).		2.59	2.63	2.61	1.31
3	Water Absorption, % (IOS 31- 1984).		1.13	1.02	0.98	30
4	Dry Rodded Unit Weight, kg/m^3 (IOS 31- 1984).		1550	1690	1760	790

Table 2: Details of used mixes.

Mix	Coarse Aggregate Type	Moisture Condition	Cement Content, kg/m^3	Fine Aggregate Content, kg/m^3	Coarse Aggregate Content, kg/m^3	Water Content, kg/m^3	
						Designed	Actual
1	L	D*	365	785	970	200	220.4
		S**					194.9
	CG	D					219.3
		S					197.8
	UCG	D					218.9
		S					201.7
2	P	D		744	498		358.8
		S					193.0

(*: D = dry, **: S = saturated)

Table (3): Concrete test results.

Test		Coarse Aggregate Type							
		L		CG		UCG		P	
		D	S	D	S	D	S	D	S
Shrinkage Strain in Millionths, at Age (days):	1	3.1	4.7	2.3	2.6	5.3	6.5	0.0	6.6
	3	12	15	9	11	17	20	30	33
	7	41	47	31	37	57	64	93	83
	14	102	114	78	89	118	136	182	160
	28	195	209	150	161	214	245	291	354
	56	246	283	210	238	364	371	440	511
	90	280	321	236	259	395	425	541	603
	120	293	325	264	284	419	436	576	637
	150	297	327	275	300	429	442	589	647
Modulus of Elasticity, GPa, at Age (days):	28	20.00	19.30	24.20	23.40	20.40	19.00	15.89	12.75
	90	24.11	23.40	25.13	24.26	21.20	20.4	17.84	15.21
Compressive Strength, MPa, at Age (days):	28	21.79	20.64	27.21	26.63	22.17	21.59	16.42	15.85
	90	28.21	26.86	31.44	30.59	24.90	23.45	19.12	18.83
Splitting Tensile Strength, MPa, at Age (days):	28	2.86	2.75	3.16	3.09	2.83	2.71	2.16	2.00
	90	3.20	3.11	3.41	3.35	2.98	2.88	2.37	2.21

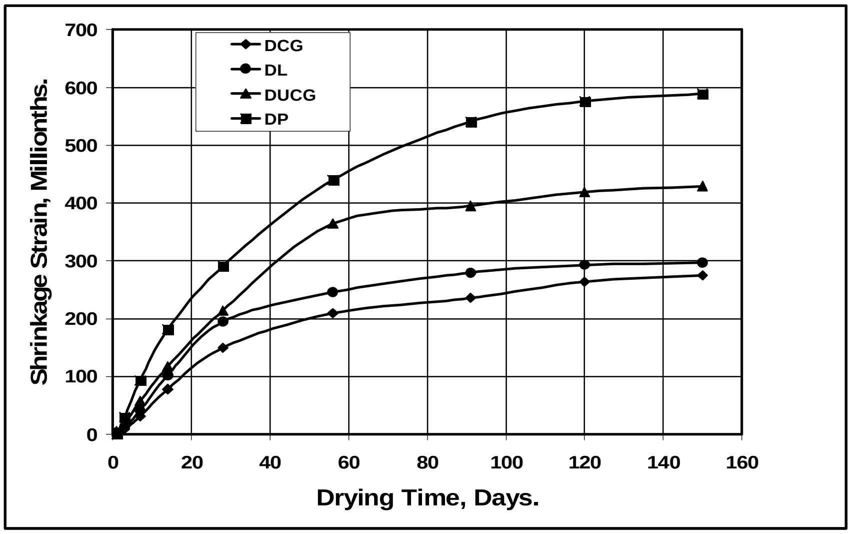

Figure (1a): The shrinkage strain development for concrete mixes made with dry coarse aggregate.

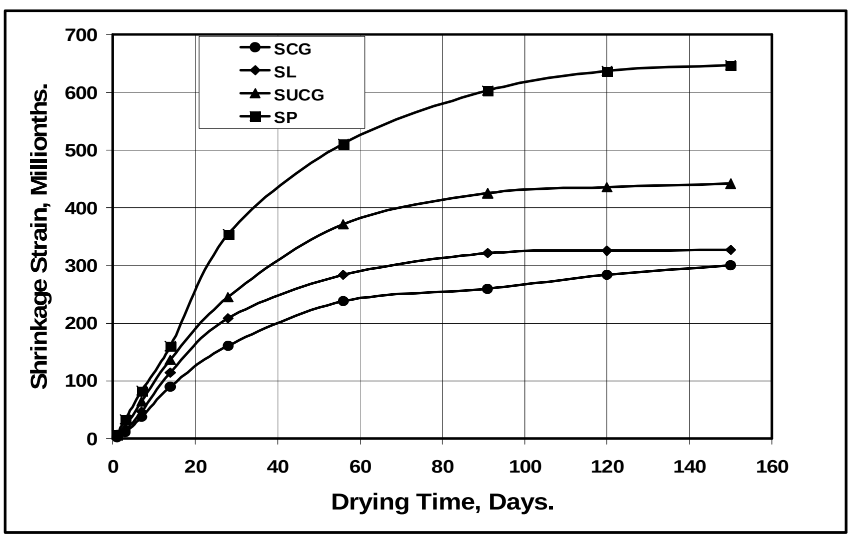

Figure (1b): The shrinkage strain development for concrete mixes made with saturated coarse aggregate.

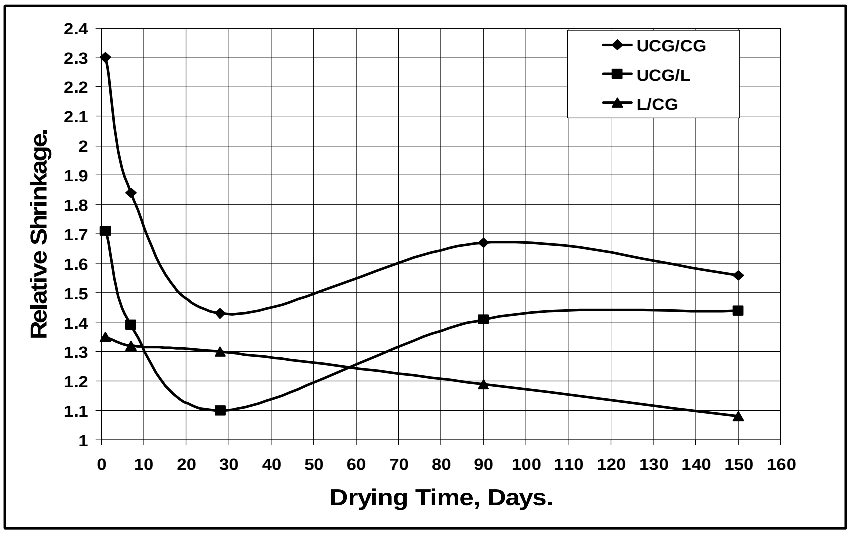

Figure (2): The relationship of relative shrinkage strain with drying time for different mixes.