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INFLUNCE OF WATER CURING TEMPERATURE ON SOME MECHANICAL PROPERTIES OF SCC PRODUCED FROM RECYCLED AGGREGATES.

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Abstract

The utilization of recycled aggregates can minimize environmental impact and slow the huge consumption of natural resources used for concrete applications. However, recycled aggregates are not suitable for use in the production of High Performance Concrete (HPC) due to their relatively high absorption capacity, unstable properties and recycled aggregates' weaker strength. Such inadequacies can be overcome through carefully examining the characteristics of recycled aggregates and then adopting proper mixture proportions. The mechanical properties of self compacting concrete (SCC) are well understood. But there are no scientific investigations available on the influence of a heat water treatment on the properties of SCC produced from recycle aggregate. To evaluated the influence on the mechanical properties five mixture were designed, SCC without recycled concrete aggregate and four (SCC with 25% recycled concrete aggregate SCC with 50% recycled concrete aggregate, SCC with 75% recycled concrete aggregate and SCC with 100% recycled concrete aggregate) and exposed to heat of treatment water with different temperatures (40-100)C°. It has been found that there is possible to produce SCC with various percentage of recycled concrete by using a suitable dosage of SP which was a major component in producing good quality RCA(recycled concrete aggregate). Also found an influence of the composition of the concrete, especially the quantity of recycle aggregate and heat of curing water on mechanical properties of concrete (compressive strength, splitting tensile strength and flexural strength).

Keyword: Recycle Aggregate Concrete, SCC, Heat Water Treatment, Recycle SCC Concrete.

تأثير حرارة ماء الإنضاج على بعض الخواص الميكانيكية لخرسانة ذاتية الرص المنتجة من الركام المعاد

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الخلاصة

أن استخدام الركام المعاد يمكن من تقليل الأثر البيئي ويقلل كذلك من الاستخدام الضخم للموارد الطبيعية في تطبيقات الخرسانة. ومع ذلك يعتبر الركام المعاد غير ملائم للاستخدام في أنتاج خرسانة عالية الأداء بسبب خاصية الامتصاص العالية نسبيا , عدم استقرار خواص الخرسانة وضعف مقاومة الركام المعاد ويمكن التغلب على هذه النواقص من خلال دراسة خصائص الركام المعاد بعناية ومن ثم اعتماد نسب الخلط المناسبة . أن الخواص الميكانيكية للخرسانة ذاتية الرص مدروسة ومفهومة بشكل جيد ولكن لاتوجد دراسات علميه كثيرة حول تأثير ارتفاع درجة حرارة ماء الإنضاج على خواص خرسانة ذاتية الرص ألمنتجه من الركام المعاد استخدامه . ولدراسة هذا التأثير تم تصميم خمس خلطات

خرسا نية ، خرسانة ذاتية الرص لا تحتوي على ركام خرسانة معاد وأربع خلطات تحوي على ركام معاد بنسبة (25-100) % وتم إنضاجها بدرجات حرارة مختلفة لماء الإنضاج (40-100) درجة مئوية. وجد انه من الممكن أنتاج خرسانة ذاتية الرص وبنسب مختلفة من الركام المعاد استخدامه باستخدام جرعة مناسبة من الملدن المتفوق والذي يعتبر عنصر أساسي في أنتاج خرسانة ركام معاد. وجد هناك تأثير لمكونات الخرسانة وخاصة كمية الركام المعاد استخدامه وحرارة ماء الإنضاج على الخواص الميكانيكية للخرسانة (مقاومة الانضغاط, مقاومة الشد, مقاومة الانثناء).

1. Introduction

Self-compacting concrete (SCC) is a new category of high-performance concrete characterized by its ability to spread into place under its own weight without the need of vibration, and self - compact without any segregation and blocking. The introduction of SCC represents a major technological advance, which leads to a better quality of concrete produced faster and more economical concrete construction process. SCC was first developed in Japan, and was adopted in Europe, North America and the rest of the world. The elimination of the need for compaction may lead to better quality concrete; economic efficient (increased casting speed and reduction in labour, energy, and cost of equipment); enhancement towards the automation of precast products; and substantial improvement of working conditions (high consumption of industrial by products and reduced noise and health hazards) **(Bartos, et al, 2001)**. Mixture proportions for SCC differ from those of ordinary concrete, in that the former has more powder content and less coarse aggregate. Moreover, SCC incorporates high range water reducers (HRWR, super plasticizers) in larger amounts. Aggregates constitute the bulk of a concrete mixture, and give dimensional stability to concrete. Among the various properties of aggregate, the important ones for SCC are the shape and gradation. Many researchers have been able to produce self-compacting concrete with locally available aggregate. It is observed from these studies that self-compact ability is achievable at lower cement (or fines) content when rounded aggregates are used, as compared to angular aggregates. Although there have been several studies on the effect of coarse aggregate content on the flow behavior of SCC **(Grunewald and Walraven, 2001)**. In the case of SCC, rounded aggregates would provide a better flowability and less blocking potential for a given water-to-powder ratio, compared to angular and semi-rounded aggregates. Moreover, the presence of flaky and elongated particles may give rise to blocking problems in confined areas, and also increase the minimum yield stress. Many studies evaluating the use of industrial by - products as aggregate in concrete have been reported. **(Jepsen, et al., 2001)** reported that the use of industrial residual products in making concrete will lead to sustainable concrete design and greener environment. There is an urgent need to develop concrete with non - conventional aggregates for environmental as well as economic reasons. A review of earlier research **(Senthamarai and Devadas, 2005)** showed that industrial and other wastes were used in concrete-making in order to enhance the properties of concrete and to reduce cost. In the development of new technologies cost, durability and environmental friendliness are becoming increasingly important criteria**.** The recycling of construction and demolition waste (C & D) has been recognized to have the potential to conserve natural resources and to reduce energy used in production. In some countries it is a standard alternative for both construction and maintenance, particularly where there is a shortage of construction aggregate **(Rustom, et al. 2007)**. The use of recycled concrete obtained to this end by reducing the amount of natural resources extracted, reducing transportation, reducing the need to dispose of the debris and rubble product of demolitions and conserving space in existing landfills **(Rahal,2007) and (Gonzales and Martinez, 2008)**. In view of on increased awareness of the environmental impact of mining river sand and depleting supplies of the same, use of manufactured sand and other alternative fine

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aggregate has become essential in some parts of the world. In fact, river sand is simply not available in many areas. Although there are studies that have shown that quarry run could be used as a filler instead of limestone for SCC **(Sheinn, et al. 2002)**, there has not been sufficient documentation of the use of screened sand, either as a filler, in SCC. Further research on this topic will be useful**.**

(Al-Hussainy,2011) used five basic categories of self - compacting concrete to study recycled concrete as aggregate in producing (SCC): SCC without RCA (conventional), SCC incorporating (25, 50, 75, 100)%, the result showed it was possible to produced SCC with various percentage of recycled concrete aggregate by using only a suitable dosage of SP (4.5-7) l/m^3. It is results showed, that SCC with 25% coarse recycled concrete aggregate and SCC with 50% coarse recycled concrete aggregate have increase in compressive strength of (1.3-2.5)% at 28 days when compared to SCC conventional. While there is no significant difference in compressive strength at age 56 days between 25% and 50% recycled concrete aggregate compared with SCC conventional. (75 and 100)% showed decrease in compressive strength at different ages in range between (6.3-11.6)% and (8.9-16.8)% respectively. The results also indicated a decrease in splitting tensile strength, flexural strength, static modulus of elasticity and ultrasonic plus velocity were varied between(2.2-2.4)%, (2.9-32.1)%,(4.5-30.8)% and (0.21-8.9)% respectively measured relatively to conventional SCC at different ages.

2. Experimental Details

A. Materials

To investigate the influence of recycle aggregate on the fresh properties and a heat treatment on some mechanical properties of SCC(compressive strength, splitting tensile strength, flexural tensile strength, static modulus of elasticity), five mixture were designed. Ordinary Portland cement (Type I) manufactured by united cement company commercially known (KRSTEA) was used.

Tables 1 and 2 shown the Physical Analysis and Chemical Composition of the Cement

Table 1 Physical Analysis of the Cement.

Physical Properties	***Test Results***	***I.Q.S. 5: 1984 Limits***
Setting Time : Initial ; min Final hrs ; min	 120 2;00	 ≥45 min ≤10hrs
Compressive Strength(MPa) 3-days 7-days	 19.0 28.0	 ≥15 ≥23

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Table 2 Chemical Composition of the Cement.

Oxide	*%*	*I.Q.S.5: 1984 Limits*
CaO	62.61	_
SiO_2	18.79	_
Al_2O_3	4.79	_
Fe_2O_3	3.48	_
MgO	2.35	< 5.0
K_2O	0.09	
Na_2O	0.18	
SO_3	2.47	< 2.8
Loss On Ignition (L.O.I)	3.0	< 4.0
Lime Saturation Factor (L.S.F)	0.85	0.66 - 1.02
Insoluble residue (I.R)	1.28	< 1.5 %
Free lime (F.L)	99.92	_
Total		
Compound Composition	***%***	***I.Q.S.5: 1984 Limits***
C_3S	58.20	-
C_2S	12.89	-
C_3A	7.32	-
C_4AF	10.58	-

The natural fine aggregate from Al- Najaf sea region was used throughout this work. Tests were carried out to determine the gradation, fineness modulus, absorption, specific gravity, density and sulfate content. The results indicate that the grading and sulfate content are conformed to the requirements of **(IQS No.45/1984)** as shown in Tables 3 and 4 respectively.

Table 3 Grading of the Sand.

Sieve size(mm)	*Passing %*	*I.O.S.45:1984 Limits Zone (3)*
10	100	100
5	98	90-100
2.36	89	85-100
1.18	80	75-100
0.6	63	60-79
0.3	29	12-40
0.15	8	0-10

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Table 4 Physical Properties of the Sand.

Physical Properties	*Test Results*	*I.Q.S.45 : 1984 Limit*
Specific gravity	2.65	_
Fineness modulus	2.35	_
Absorption %	1.6	_
Sulfate content (SO_3) %	0.324	≤ 0.5
Clay %	2.3	≤3.0

Round gravel of 10 mm size from Al-Nebai region was used as a coarse aggregate in natural concrete mixes. Table 3 shows the grading of this aggregate, which conforms to the Iraqi specification **(IQS No.45/1984)**. The specific gravity, sulfate content, absorption and loose bulk density of coarse aggregate are illustrated in **Tables 5 and 6**. The recycled aggregate was prepared by manually crushing the cubes from old concrete having a strength of (23 -30) MPa as shown in **Plate 1**. Crushing products were screened into two size fractions (10 to 5 mm, and 5 to 2.36 mm) by using sieve shaker. In order to produce the recycled coarse aggregate, the two size fractions were recombined to give a grading similar to that of the natural gravel. After screening the aggregate was rinsed with water in order to remove dust fraction, then stored in air to be dry. The fine sand passing from sieve number 0.125 mm was prepared to used as a filler in this work.

Plate 1 Crushing Process.

Tap water was used in this work for all washing aggregate, mixing and curing of concrete. Glenium 51 was used in producing SCC as a high range water reducing admixture. Glenium 51 is considered one of a new generation of copolymer - based super plasticizer that complies with **(ASTM C494-01)** Type F. **Table 7** shows the typical properties of Glenium 51.

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Table 5 Grading and Physical Properties of the Coarse Aggregate.

Sieve size (mm)	*Passing %*	*I.Q. S NO 45 : 1984 Limits*
14	100	90 - 100
10	53	50 - 85
5	10	0 - 10
2.36	0	0

Table 6 Physical Properties of the Coarse Aggregate.

Physical Properties	*Test Results*	*I.Q. S NO 45 : 1984 Limits*
Specific gravity (S.G)		-
For natural aggregate	2.6	
Recycled aggregate	2.53	-
Absorption %		
For natural aggregate	0.9	
Recycled aggregate	5.91	
Sulfate Content (SO_3) %		
For natural aggregate	0.06	≤ 0.1
Recycled aggregate	0.1	

Table 7 Properties of Superplasticizer (Glenium 51)

Form	Viscous liquid
Color	Light brown
Relative density	1.1 @ 20ºC
pH value	6.6
Viscosity	128+/-30 cps @20ºC
Transport	Not classified as dangerous
Labeling	No hazard label required

B. Mix Proportions

In this experimental work, five types of mixes are prepared according to **(EFNARC,2002)** method: R_0, R_{25}, R_{50}, R_{75} and R_{100}. The details of the mixes used throughout this investigation are given in Table 8 where:-

R_0: SCC without Recycled Concrete Aggregate
R_{25}: SCC with 25% Recycled Concrete Aggregate.
R_{50}: SCC with 50% Recycled Concrete Aggregate.
R_{75}: SCC with75% Recycled Concrete Aggregate.
R_{100}: SCC with100% Recycled Concrete Aggregate.

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Table 8 Mix Proportions.

Mix Designation	*Cement kg/m³*	*Filler kg/m³*	*Sand kg/m³*	*Coarse agg. kg/m³*	*Recycled Coarse agg. kg/m³*	*SP l/m³*	*Water kg/m³*	*w/p ratio*
R_0	400	100	750	800	-	5	190	0.38
R_{25}	400	100	750	600	200	5.5	190	0.38
R_{50}	400	100	750	400	400	6	190	0.38
R_{75}	400	100	750	200	600	7	190	0.38
R_{100}	400	100	750	-	800	7.75	190	0.38

Note:
SP= super plasticizer (Glenium 51)
W= Water.
P= cement + filler

The mixing process was performed in a drum laboratory mixer of 0.05 m^3 to mix concrete ingredients, the mixer must be clean, moist and free from water. In this study the following mixing procedure is adopted in order to achieve the required workability and homogeneity of SCC mixes, SP was mixed with water in advance. The procedure carried out in this investigation was described by**(Emborg, M. 2000)** : The procedure used for mixing the batches was as follow:

*Adding the fine aggregate to the mixer with 1/3 water, and mixing for minute.
*Adding cement with another 1/3 mixing water and mixing for 1 minute.
*After that, the coarse aggregate (natural and recycle aggregate)) is added with the last 1/3 mixing water and 1/3 of super plasticizer, and mixing for 1.5 minute then the mixture is left for 0 .5 minute for rest.
*Then, the filler (fine sand) and remaining 2/3 of the super plasticizer is added and mixed for 1.5 minute.
* The mixture is then discharged, tested and cast; the total time of mixing was about 5 minute.

C. Casting and Curing of Test Specimens

After assessing the necessary workability properties as guided by**(EFNARC, 2002)** the fresh concrete was placed in steel moulds of dimensions cubs (100×100×100) mm, cylinder (100×200) mm and prisms (100×400) mm and allowed to fill all the spaces of the moulds by its own weight. After 24 hr remould the moulds and late in water tank until days test, this for the moist curing test.

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D. Accelerated Curing Cycle

For accelerated curing test the procedure used is presented in the curing cycle as shown in **Figure 1**. The cycle includes the delay period (preset period), the temperature rise period, the period of the curing at the maximum curing temperature and the cooling period. It is designed according to **(ACI C517,1992)**. For accelerated curing test the moulds stay in accelerated curing tanks for different temperature (40, 60, 80, 100) C° for 1 day accelerated curing age, 1day accelerated curing +27 days normal curing age and 1day accelerated curing +55 days normal curing.

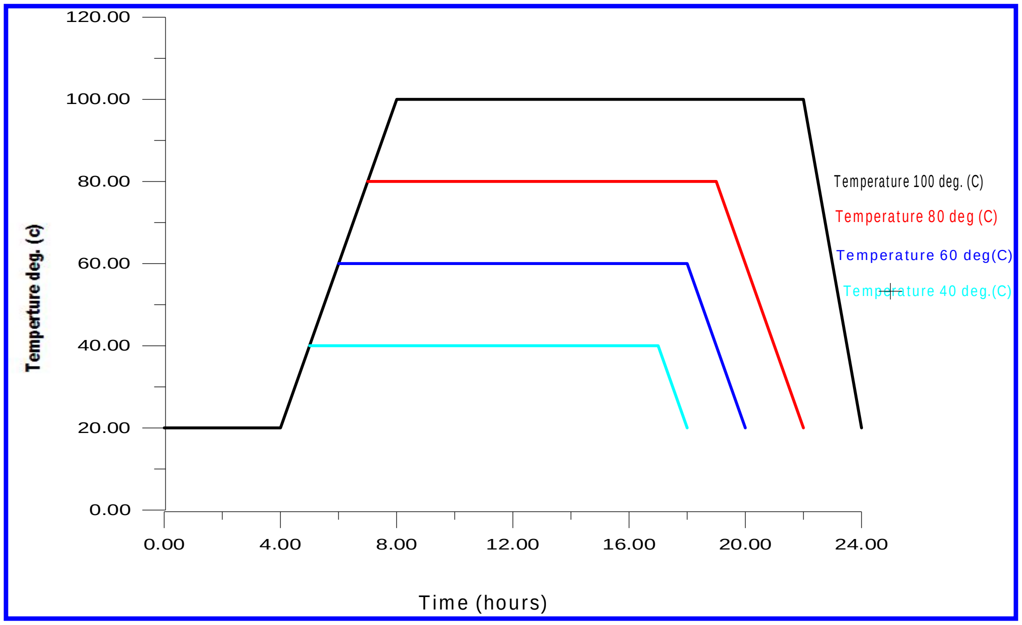

Fig 1 Proposed Accelerated Curing Cycle.

3. Results and Discussion

A-Fresh Properties of SCC

The properties of fresh SCC differ significantly from that of conventional fresh concrete. There are three distinct fresh properties of SCC which are fundamental to its performance both in fresh and hardened state. According to **(EFNARC, 2002),** a concrete mix can only be classified as SCC fulfilled. The three essential fresh properties required by SCC are filling ability, passing ability and resistance to segregation. To accomplish the workability properties, test such as slump flow, slump flow at T_{50}, V - funnel and L - box were carried out. All the tests were performed by following the European Guidelines for SCC. The test results of fresh properties of SCC are presented in Table 9. The results of the quantitative measurements and visual observations showed that freshly prepared concrete mix had good flow, filling and passing ability, and produced desired results and were within the range of SCC.

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Table 9 Results of Fresh Properties of SCC Mixes.

Mix Nation	*Slump- flow mm*	*T_{50} sec*	*V- funnel sec*	*V-funnel at T_{5min}*	*L-BOX H_2/H_1*
R_0	715	2.6	7	7.6	0.92
R_{25}	710	3	7.9	8.1	0.89
R_{50}	690	3.4	9	11.5	0.87
R_{75}	680	3.6	10.2	12	0.83
R_{100}	673	4	11	14	0.82
Acceptance Criteria **(EFNARC, 2002)**	600-850	2-5	6-12	0-3	0.8-1

As shown in **Table 9** the slump flow diameter, of SCC mixes, ranged from (673-715) mm. Similarly, the slump flow time was within the range of (2.6 - 4) sec. These results are conforming to acceptable criteria for SCC. Thus, all the mixes are assumed to have a good consistency and workability from the filling point of view. Results showed that it was possible to produce SCC by increasing the dosage of the chemical admixture **(Glenium 51)** only, at rates (10, 20, 40 and 55%) respectively compared to conventional SCC. It can seen from Fig 2 and Fig 3 that the lower slump value and higher T_{50} of concrete when the replacement ratio of recycled concrete aggregate increased compared with the natural aggregate concrete. The reason for this behavior is the particles of recycled coarse aggregate are more angular and rougher than the rounded gravel particle and as stated that as far as the effect of particle shape is concerned, the water requirement of concrete increases with the increase in angularity **(Popvics, 1982)**. However, even with 100% replacement of coarse aggregate it was possible to produce SCC which conform to limitations. **Table 5** shows the results of V- funnel test. The T_V and $T_{V\ 5min}$ for SCC mixes lies between (7- 11) sec and (7.6- 14) sec, respectively. These results are within the limits pointed out in the literature. Also there's no blocking or segregation is observed for all mixes.

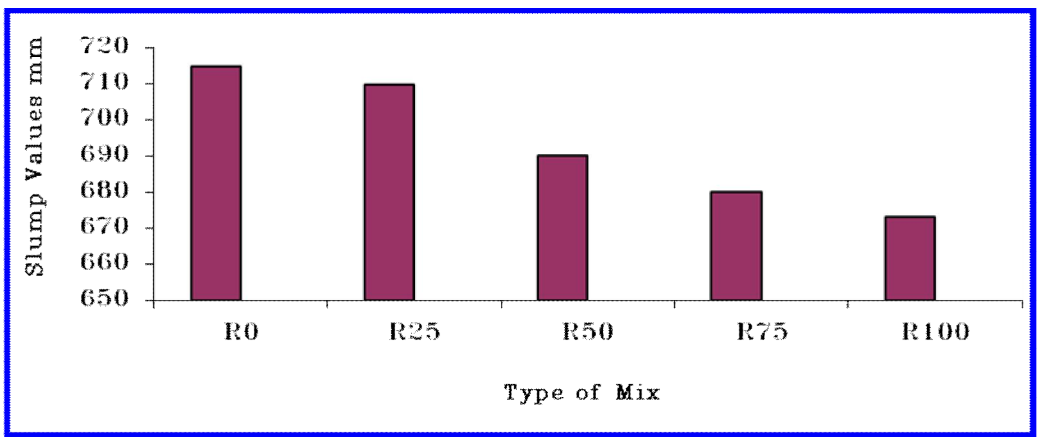

Fig.2 Slump Flow Diameter.

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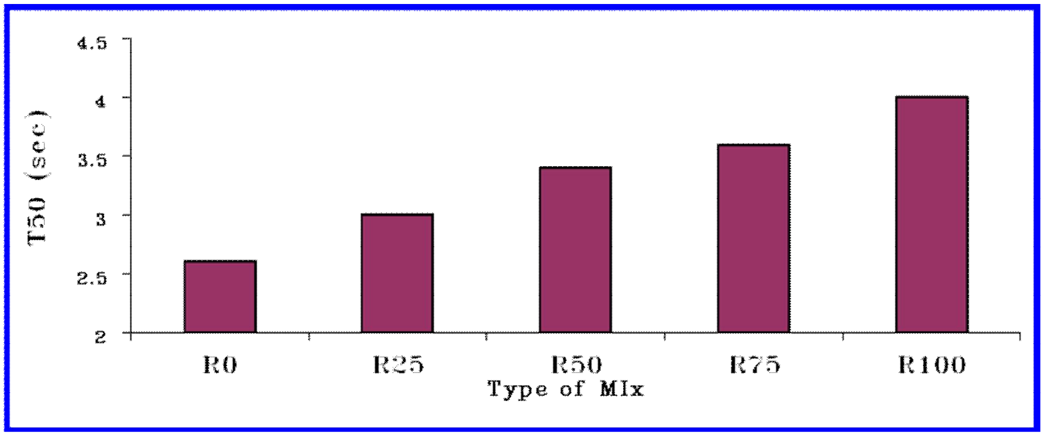

Fig.3 Slump Flow T_{50cm} (sec).

As shown in **Figure 4** the results of the V-funnel times (T_V and $T_{V\ min}$) were increased with increasing of RCA percentage in the mixes, due to more angular particles or recycled coarse aggregate. Whilst rounded aggregate improve the flow because of lower internal friction **(Okamura, et al, 1998).**

The results of L - box showed in Table **9 and Figure 5** show that the mixing SCC without recycled concrete aggregate (R_0) has a good passing ability due to the shape of gravel particles which have a smoother and spherical shape which causes sliding these particles very easily over each other, the results of R_{100} shows lower passing ability but still satisfy the limitation. This result may be attributed to the effect of increasing of the percentage of RCA, which leads to decrease the passing ability in the same way of decreasing the filling ability.

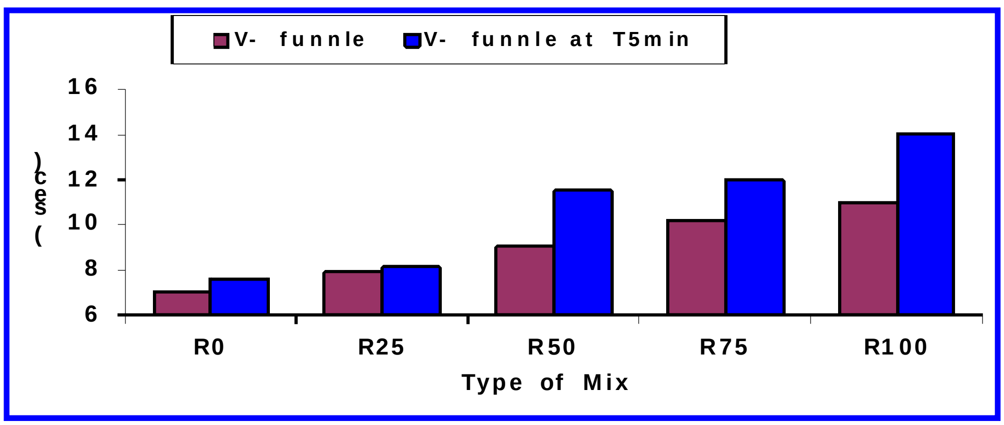

Fig.4 V- Funnel Flow and V funnel at $T_{5min.}$

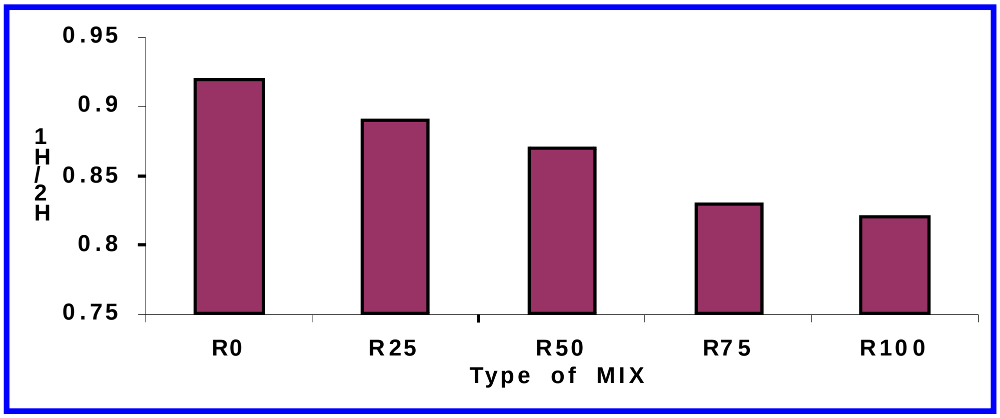

Fig.5 Results of L- Box Values (h_2/h_1)

B- Compressive strength of SCC

Compressive strength is one of the most common measures used to evaluate the quality of hardened concrete and is considered as the characteristic material value for the classification of concrete **(Komnitas and Zaharaki, 2007).** Compressive strength was carried and tested according to BS. 1881: part 116 :1983 a total number 210 cubes of 100 mm were tested by using 2000 KN Digital Compressive machine. For each test aset of three cubes was tested at the ages of 1 day accelerated curing age, 1 day accelerated curing age +27 days normal curing age and 1 day accelerated curing +55 days normal curing age respectively are presented in **Table 10**.

Table 10 Results of Compressive Strength, Splitting Tensile Strength and Flexural Strength for Normal Curing.

Mix type	*Compressive Strength MPa*		*Splitting Tensile Strength MPa*		*Flexural Strength MPa*	
	28 days	*56 days*	*28 days*	*56 days*	*28 days*	*56 days*
R_0	34.9	38.6	3.1	3.3	4.8	5.6
R_{25}	35.1	39	3	3.1	4.7	5.4
R_{50}	37	40.5	2.95	3.0	4.5	5.2
R_{75}	33.3	38	2.6	2.8	3.8	4.7
R_{100}	28	31	2.0	2.1	3.2	3.8

1.Effect of Recycled Concrete Aggregate on Compressive Strength

As shown in **Figure 6** SCC 25% with coarse recycled concrete aggregate (R_{25}) and SCC with 50% coarse recycled concrete aggregate (R_{50}) showed an increase in the compressive strength (0.6,6) % at age 28 days, (1,5) % at age 56 days respectively when compared to SCC conventional (R_0). This may be attributed to a number of causes. First, crushed RCA tend to improve the strength because of the interlocking of angular particles. Secondly, Chemical additive was increased up to 10% for R_{25} and 20% for R_{50} compared to SCC conventional. Finally, crushed concrete aggregates is prepared from concrete that has never been in service and thus likely to contain much lower levels of contamination **(Yong and Teo, 2009)**. SCC with 75% coarse RCA (R_{75}) showed a decrease in the compressive strength at ages (28 and 56) days in range at (4.6 and1.5) % respectively, while in the same manner SCC with 100% coarse RCA, the reduction of strength was in range (19.7 and 19.6) % respectively for the same ages. This reduction may be attributed to many causes. Firstly, the total porosity of the recycled aggregate concrete is more than that for the conventional concrete owing to the increase in the amount of porous mortar component. Secondly, the amount conventional concrete, recycled aggregate concrete contains bond areas between the old mortar and new mortar, these have the effect of multiple cold joints. Finally, the resistance of recycled coarse aggregate to mechanical action is lower than that of natural rounded aggregate **(Ravindrarjah and Tam, 1985).**

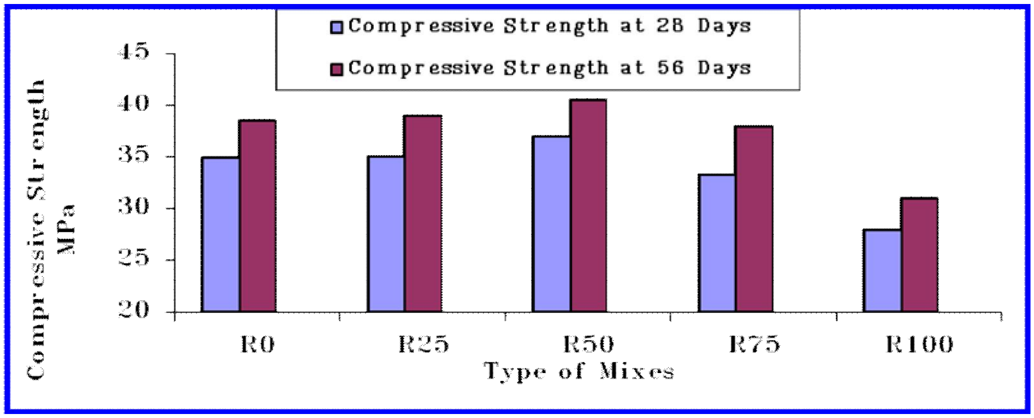

Fig. 6 Results of Compressive Strength for Mixes in Normal Curing Temperature at 28 and 56 Days.

2. *Effect of Curing Water Temperature on Compressive Strength*

The effect of water curing temperature on the compressive strength shown in **Table 11** and **Figures 7- 9**. Compressive strength is usually carried out at an elevated temperature in the range of (40 - 100) C°. Compressive strength results shown in **Figures 6-8** indicate that higher curing temperature does not ensure higher compressive strengths as claimed by **(Hardjito , et al. 2005)**, the concrete R_0 showed a increasing in compressive strength with increasing temperature. The same can be seen for R_{25}, R_{50}, R_{75} and R_{100} when increasing curing temperature of 40 C° by about (1.5 - 4.6) %, (2.3 - 7.4) % at ages (28, 56) days respectively. In general, and on the 60 C° curing temperature, the result indicate an increasing in compressive strength by about (5 - 6.5) %, (3.1- 13) % at ages (28, 56) days respectively for all mixes. While for 80 C° curing temperature, the best results are recorded for all mixes, the increasing in compressive strength about (12.3 - 18.3) %, (8.9 - 19.3) % at ages (28, 56) days respectively for all mixes. This is agreement with study stated by **(Metharonarat, 2004)**. The lowest results for all mixes are recorded on curing temperature 100 C°. The decrease in strength is about (10.8 - 28.5) % and (9.6 - 39.6) % at ages (28, 56) days respectively for all mixes when compared with the strength of concrete under normal curing. This behavior is attributed to the development of stresses in concrete when it is subjected to a temperature higher than 80C°, due to the differences between the thermal expansion of the

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liquid phase, the cement paste, the sand and the coarse aggregate. These stresses may be sufficient, under certain circumstances, to cause cracking in the concrete to and thus lower its strength and reduce its durability.

Table 11 Results of Compressive Strength, Splitting Tensile Strength and Flexural Strength for Accelerated Curing.

Mix type	*Temperature* C°	*Compressive Strength MPa*			*Splitting Tensile Strength MPa*			*Flexural Strength MPa*		
		1 day	*28 day*	*56 day*	*1 day*	*28 day*	*56 day*	*1 day*	*28 day*	*56 day*
R_0	40	30	36.2	40.5	2.88	3.2	3.44	3.7	4.83	4.9
	60	31.2	36.9	42	3.0	3.25	3.56	3.82	4.9	4.95
	80	34.6	39.2	45.4	3.1	3.4	3.9	4.1	5.1	5.1
	100	27	30.9	32	2.5	2.8	3.2	3.2	3.8	4.2
R_{25}	40	30.8	36.7	40.7	2.95	3.1	3.32	3.5	4.71	4.93
	60	32.7	37.4	42.9	3.2	3.2	3.44	3.7	4.73	5.1
	80	35.3	40.2	45.4	3.4	3.5	3.8	4.4	4.81	5.32
	100	27.5	31.3	33.2	2.61	2.3	2.7	3.6	3.9	4.36
R_{50}	40	33	37.9	43.5	2.9	3.17	3.3	3.8	4.5	4.6
	60	36.7	40.7	45.8	3.2	3.35	3.5	4.3	4.52	4.8
	80	40.9	43.8	48.3	3.45	3.7	3.7	5.2	4.7	4.95
	100	30	33.1	36.6	2.7	2.9	2.95	4.3	3.6	3.8
R_{75}	40	27.9	33.8	38.9	2.5	2.75	2.85	3.3	3.7	3.8
	60	28.4	35.2	39.2	2.8	2.9	3.0	3.4	4.1	4.0
	80	30.9	37.7	41.4	3.1	3.2	3.5	4.1	4.4	4.2
	100	20.4	25	29	2.1	2.2	2.3	3.4	3.4	3.1
R_{100}	40	23.1	29	32	1.97	2.2	2.3	2.7	3.3	3.32
	60	24.2	29.4	33.2	2.1	2.25	2.4	2.9	3.33	3.4
	80	27.9	31.5	35.5	2.4	2.45	2.6	3.2	3.6	3.52
	100	16.7	20	22.2	1.2	1.4	1.45	2.0	2.4	2.3

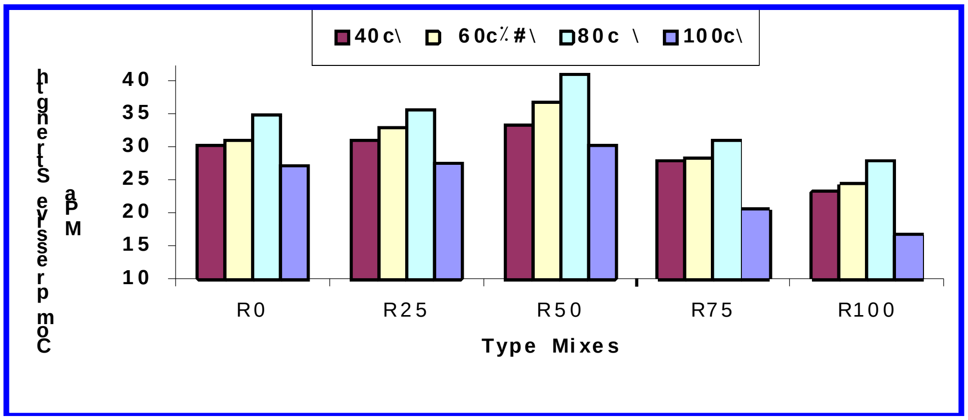

Fig.7 Results of Compressive Strength for Mixes in Different Curing Temperature at 1 Day Age.

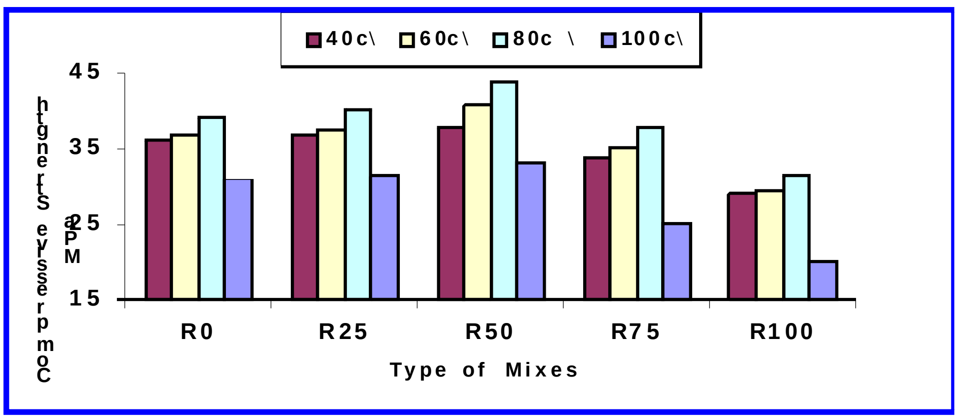

Fig.8 Results of Compressive Strength for Mixes in Different Curing Temperature at 28 Days Age.

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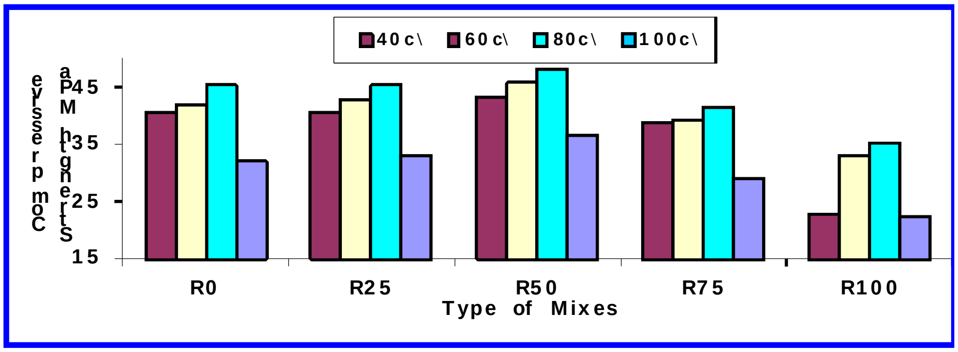

Fig 9 Results of Compressive Strength for Mixes in Different Curing Temperature at 56 Days Age.

C. Splitting Tensile Strength.

The splitting tensile strength was determined according to the procedure outlined in BS. 1881: PART 117:1983. A total number of 140 cylinders were cast, demolded and cured in a similar way as the cubes. Each splitting tensile strength result was the average of strength for two specimens.

1- Splitting Tensile Strength for Normal Curing

It is evident from results showed in **Table 10** and **Figure 10**, that the splitting tensile strength of RAC decrease with increases in the replacement percentages of natural coarse aggregates by the recycled aggregates in a mix. The rate of reduction ranged between (3.2 - 32.2)%,(6-39)% at ages (28, 56) days respectively for all mixes. This is due to the fact that the recycled coarse aggregate is much more deformable than the high quality natural aggregate. The reason behind that is attributed mainly to the inherent inferior characteristics of the recycled aggregate particles, which normally consist of considerable amounts of porous old mortars of different qualities, hence form zones of weakness in the concrete composite **(Ravindrarajah and tam, 1988)**.

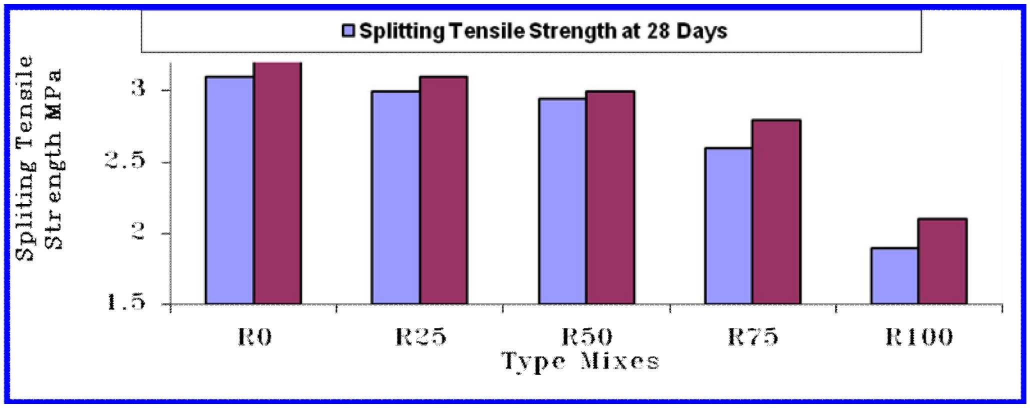

Fig.10 Results of Splitting Tensile Strength for Mixes in Normal Curing Temperature at 28 and 56 Days Age.

2-Splitting Tensile Strength for Accelerated Curing Condition

The results of the accelerated curing strengths for (1,28 and 56) day ages, for all type mixes are summarized in **Table 11.** These results are plotted versus the curing temperatures for all mixes at 1day accelerated curing age, 1day accelerated curing +27 days normal curing age and 1 day accelerated curing +55 days normal curing age respectively to draw **Figures11-13.** At 1 day accelerated curing age, with reference to Table 10 and its corresponding **Figure 12,** it can be seen that the ratios of the gained strength range from (80)% at 100 C° curing temperature to (96)% at 80 C° curing temperature.

The lower ratio value is recorded for R_{100}. The concrete R_0 showed a increasing in gained strength with increasing temperature. The same can be seen for R_{25}, R_{50}, R_{75} and R_{100} when increasing curing temperature of 40˚C by about (3.2-7.4)%, (1.8 -15)% at ages (28, 56) days respectively. In general, and on the 60˚C curing temperature, the result indicate an increasing in gained strength by about (2.3 - 13.5)%, (7.1- 16.6)% at ages (28, 56) days respectively for all mixes. While for 80 C° curing temperature, the best results are recorded for all mixes, the increasing in gained strength about (9.6- 25.4)%, (2.5-25)% at ages (28, 56) days respectively for all mixes. The lowest results for all mixes are recorded on curing temperature 100 C°. The decrease in strength is about (1.6 - 27.7) % and (7.6 - 30) % at ages (28, 56) days respectively for all mixes when compared with the strength of concrete under normal curing.

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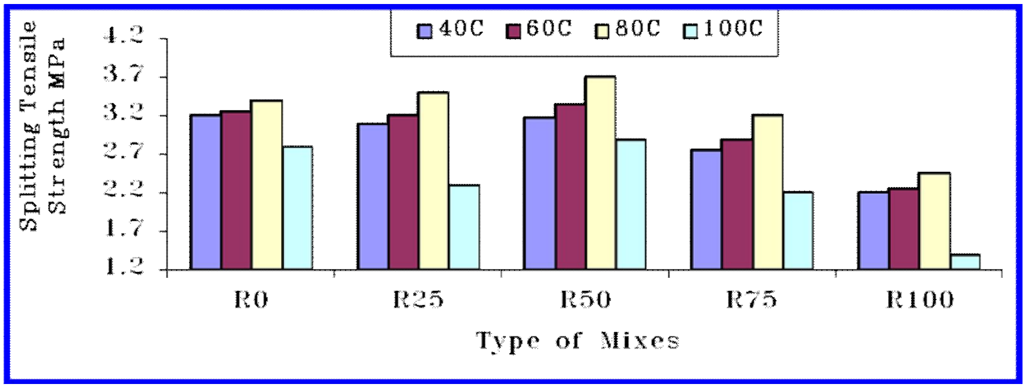

Fig.11 Results of Splitting Tensile Strength for Mixes in Different Curing Temperature at 1 Day Age.

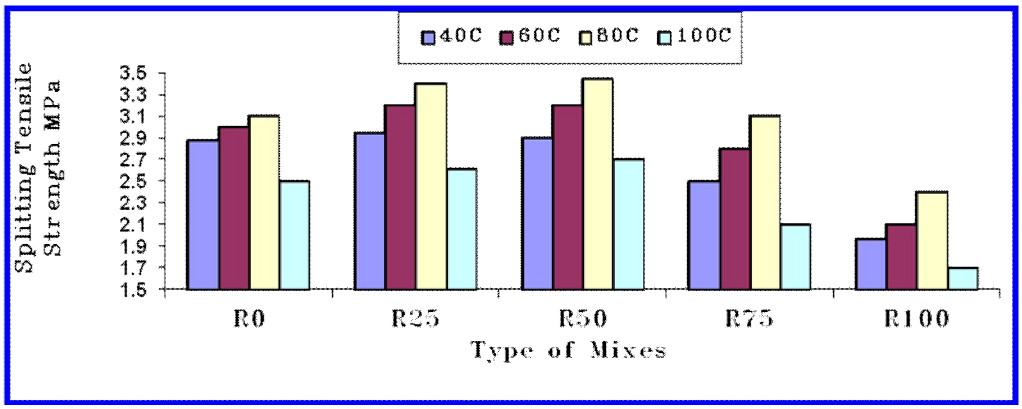

Fig.12 Results of Splitting Tensile Strength for Mixes in Different Curing Temperature at 28 Days Age.

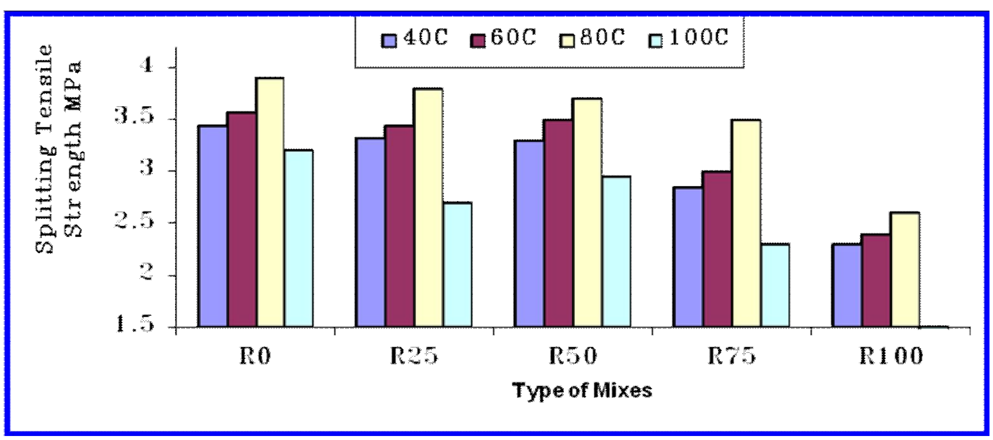

Fig.13 Results of Splitting Tensile Strength for Mixes in Different Curing Temperature at 56 Days.

D. Flexural Strength

1-Flexural Strength for Normal Curing

It can be observed from the results showed in **Table 10** and **Figure14**, that the flexural strength of RAC decrease with increases in the replacement percentages of natural coarse aggregates by the recycled aggregates in a mix. The rate of reduction ranged between (2-29.1)%, (3.5-32.1)% at ages (28,56) days respectively for all mixes.

This is attributed to the presence of old mortar, which is attached to aggregate particles in the recycled concrete aggregate.

The new and old mortars do not act as a one element due to a number of causes. Firstly, the old and new mortars almost have different qualities (strength). Secondly, there are a weak bond area between old and new mortars, the increased size of the recycled coarse aggregate concretes Interfaced Transtion Zone (aggregate – mortar surface) and micro -fracture within the old mortar, the fracture process zone near the crack tip will have less resistance to further propagation and become more susceptible to the formation of structural cracks in the concrete **(Poon. et al, 2004)**.

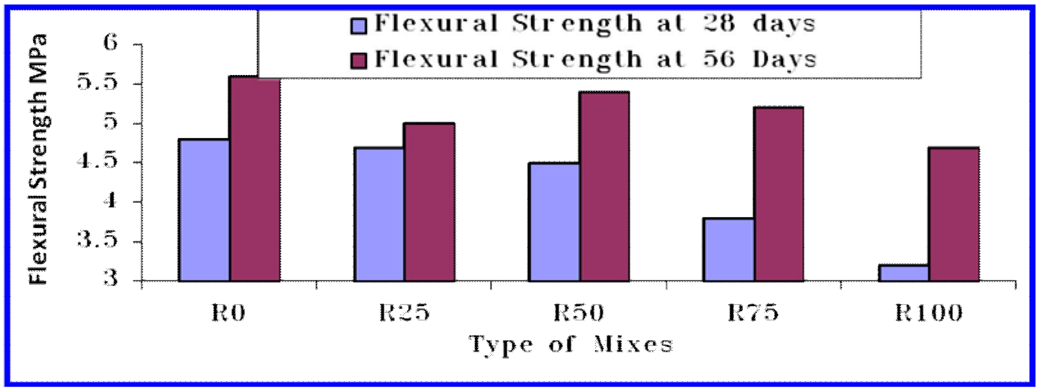

Fig 14 Results of Flexural Strength for Mixes in Normal Curing Temperature at 28 and 56 Days Age.

2-Flexural Strength for accelerated Curing Condition

The results of the accelerated curing strengths for (1, 28 and 56) day ages, for all type mixes are summarized in **Table 11**. These results are plotted versus the curing temperatures for all mixes at 1day accelerated curing age, 1day accelerated curing +27 days normal curing age and 1 day accelerated curing +55 days normal curing age respectively to draw **Figures15-17**. At 1 day accelerated curing age, with reference to **Table 10** and its corresponding **Figure 17**, it can be seen that the ratios of the gained strength range from (70)% at 100 C°. Curing temperature (96)% at 80 C° curing temperature. The concrete R_0 showed a increasing in gained strength with increasing temperature. The same can be seen for R_{25}, R_{50}, R_{75} and R_{100} when increasing curing temperature of (40 - 80) C° by about (0.6 - 2.3)%, at age (28) days for all mixes. While the best results are recorded for all mixes for 80 C° curing temperature. The lowest results for all mixes are recorded on curing temperature 100 C°. The decrease in strength is about (10.5) % at ages (28) days for all mixes when compared with the strength of concrete under normal curing. This results could be attributed to the increase in temperature of curing significantly which affects the interfacial transition zone between the neat paste and the aggregate ; the increase in temperature expand the range of the interfacial transition zone as a consequence flexural strength is reduced. At age of 27days and 55days after accelerated curing conditions it is obvious from the Table 10 and **Figures 17,18**, that significant reduction in the percentage of increment in strength of concrete is noticed when the age increase from 28 to 56 days when compared with normal moist curing for the curing temperature 100 C°, but there are a considerable enhancements occur for some mixes on the (80 and 6) C° curing temperature.

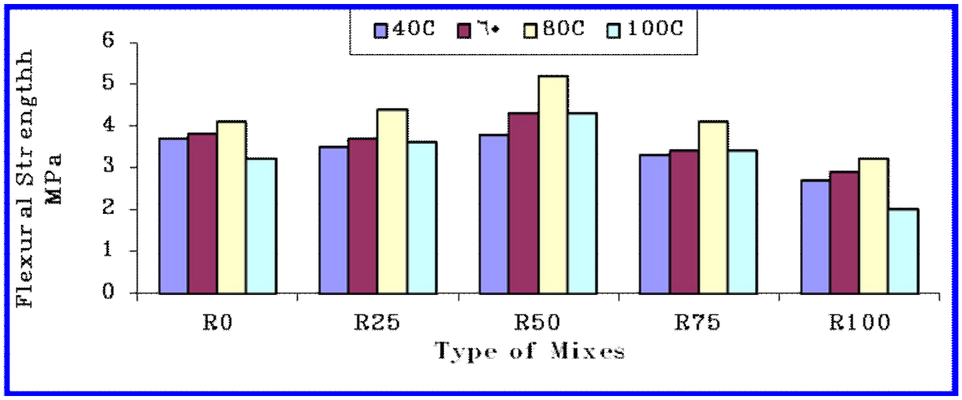

Fig.15 Results of Flexural Strength for Mixes in Different Curing Temperature at 1Day Age.

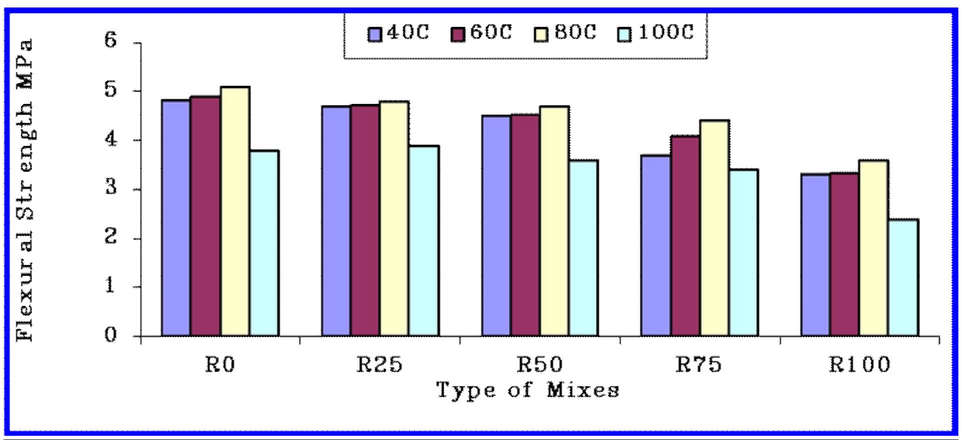

Fig.16 Results of Flexural Strength for Mixes in Different Curing Temperature at 28 Days Age.

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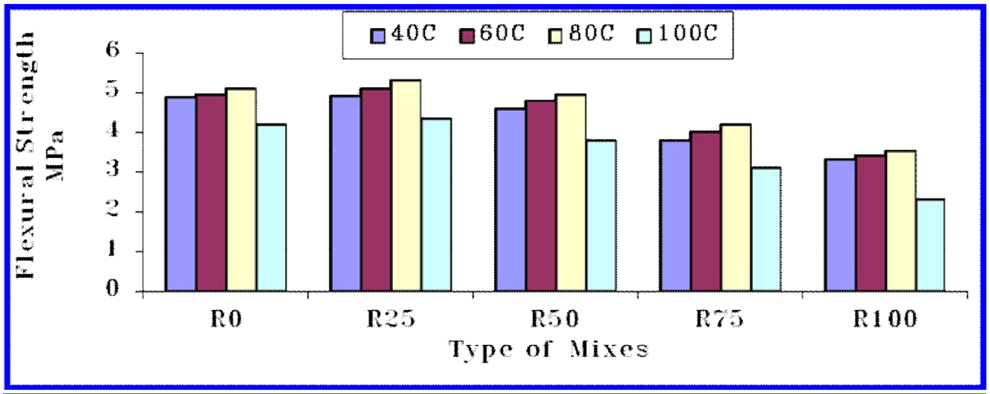

Fig.17 Results of Flexural Strength for (SCC- RCA) Mixes in Different Curing Temperature at 56 Days Age.

Conclusions:

1-SCC (R_{25}) and SCC (R_{50}) showed an increase in the compressive strength by about (6% , 5%) at ages (28, 56) days respectively . SCC (R_{75}) showed a decrease in the compressive strength at ages (28 and 56) days in range at (4.6% and1.5%) respectively, while in the same manner the reduction of strength of SCC (R_{100}) was in range (19.7% and 19.6 %) respectively for the same ages.

2-All type mixes showed increasing in compressive strength when increasing curing temperature of 40 C° by about (4.6 %, 7.4 %) at ages (28, 56) days respectively. Also the result indicate an increasing in compressive strength by about (6.5 %,13)% at ages (28,56) days respectively for all mixes on the 60 C° curing temperature, the best results are recorded for 80 C°, the increasing in compressive strength about (18.3,19.3)% at ages (28, 56) days respectively, The lowest results are recorded on curing temperature 100 C° . The decrease in strength is about (28.5, 39.6) % at ages (28, 56) days respectively for all mixes.

3- The results of this work indicate that higher curing temperature dose not ensure higher compressive strengths.

4-The splitting tensile strength of RAC decrease with increases in the replacement percentages of natural coarse aggregates, the rate of reduction ranged between (32.2, 39) % at ages (28, 56) days respectively for all mixes. The splitting tensile strength increasing when increasing temperature, the best results are recorded for 80 C° curing temperature, the increasing in gained strength about (25.4, 25) % at ages (28, 56) days respectively. The lowest results are recorded on curing temperature 100 C°. The decrease in strength is about (27.7, 30)% at ages (28, 56) days respectively for all mixes.

5- The flexural strength of RAC decreases with increases in the replacement percentages. The rate of reduction ranged between (29.1, 32.1) % at ages (28, 56) days respectively for all mixes. When increasing curing temperature of (40 - 80) C° the strength increasing by about (2.3)%, at age (28) days. Best results are recorded for 80 C° curing temperature and the lowest results are recorded on curing temperature 100 C° .The decrease in strength is about (10.5) % at ages (28) days for all mixes.

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