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# Behavior of Recycled Self-Compacting Concrete

Kamal M.M.[1] , Safan M. A.[1], Etman Z. A.[1*] and Eldaboly E. A.[2]
*[1]Department of Civil Engineering - Faculty of Engineering- Menoufia University*
*[2] Civil Engineer and Postgraduate Fellow*
**Corresponding author's e-mail: dr_zeinab_2006@yahoo.com*
**Cell Phone: 00201009727355,  tel: 0020 482 238232*

## ABSTRACT

The effect of recycled materials as a recycled aggregate (crushed red brick and crushed ceramic) on the fresh and hardened properties of Recycled Self-Compacting Concrete (RSCC) was investigated. Recycled materials were used to replace coarse aggregate at different ratios of 25%, 50%, 75% and 100% to produce RSCC mixes. Twenty one concrete mixes were cast and test to fulfill the aim of this paper. This paper aimed at studying the properties of RSCC mixes and evaluating the behavior of RSCC beams under flexural loads. Nine tested loading simply supported concrete beams were tested in flexure. The fresh properties of RSCC were evaluated using slump flow, J-ring and V-funnel tests. Compressive strength, splitting tensile strength and flexural strength were performed in order to investigate mechanical properties. The density for different mixes was evaluated. The behavior of the tested beams was investigated with special attention to the deflection under different stages of loadings, initial cracking, cracking pattern, and ultimate load. The average of the compressive strength decreased by 34% and 26% for the mixes with crushed red break and ceramics, respectively compared to that of control mix was observed. In addition, the density for the mixes with crushed red brick decreased by 14 % compared to that of control mix. The obtained results presented the properties of this concrete were expected from a structure point of view, and that the recycled coarse aggregates can successfully be used for making of SCC.

يهتم هذا البحث بدراسة تأثير المواد المعاد تدويرها (كسر الطوب الأحمر-كسر السيراميك) على خصائص الخرسانة ذاتية الدمك وذلك فى الحالة الطازجة والمتصلده. لانتاج هذا النوع من الخرسانة تم استخدام المواد المعاد تدويرها بنسب ٢٥، ٥٠، ٧٥، ١٠٠ % كإحلال من وزن الركام الطبيعى (الدولوميت). تم استخدام اختبار مخروط الإنسياب، الحلقة ذات القوائم بالاضافة الى اختبار القمع على شكل حرف V لقياس الخصائص الطازجة لهذا النوع من الخرسانة. ولقياس الخواص الميكانيكية تم إجراء اختبار الضغط واختبار الشد غير المباشر واختبار الإنحناء كما تم حساب كثافة الخلطة كخاصية فيزيائية. فى هذا البحث تم صب عدد تسعة كمرات خرسانية ذاتية الدمك بإستخدام الركام المعاد تدويره مقارنة بالخرسانة ذاتية الدمك المستخدم بها الدولوميت كركام طبيعى وذلك لدراسة سلوك هذا النوع من الخرسانة تحت تأثير أحمال الانحناء. وتم التوصل الى إمكانية إنتاج خرسانة ذاتية الدمك باستخدام الركام المعاد تدويرة .

***Keywords:*** Self-compacted concrete; Red brick; Ceramic; Recycled materials; Flexural strength

## 1. INTRODUCTION

Recently, there is an increased interest in using self-compacting concrete (SCC). The frequency of using SCC is making it a common type of concrete in many countries such as Sweden and Japan, where SCC was originally developed. The classification and requirements of concrete mixes as SCC were present [1-4]. Numerous research papers studied the fresh properties of SCC depend on the type and the amount of additives which are used [5-7]. Felekoğlu et al [8] reported that using of SCC with its improving production techniques is increasing every day in concrete production. However, mix design methods and testing procedures are still developing the application of self compacted concrete which was investigated by Domone [9]. He carried out an analysis of sixty eight case studies. He reported that 31.2% by volume of concrete was coarse aggregate; 34.8% was paste content; 500 kg/m$^3$ was the powder content; 0.34 by weight was water/powder ratio and the 47.5% by volume was fine aggregate/mortar. Both fresh and hardened properties of self-compacted concrete (SCC) due to the effect of using different types of mineral admixtures were studied by Uysal and Yilma [7]. They noticed that the fresh properties of SCC were enhanced especially when used marble powder. On the other hand, Khaleel et al [10] illustrated that maximum nominal size, texture and type of coarse aggregate have a direct effect on improving SCC. They found that; decreasing in the flow-ability of SCC increasing in the maximum nominal size of coarse aggregate. Also the flowabiltiy of SCC decreases as using crushed aggregate. Zhu and Bartos [11] studied the permeation properties, which include permeability, absorption, diffusivity etc.. These parameters have been widely used to quantify durability characteristics of SCC. The results indicated that the SCC mixes had significantly lower oxygen permeability and captivity than that of vibrated normal reference concretes of the same strength grades. The SCC mixes containing no additional powder but using a viscosity agent were found to have considerably higher diffusivity than the reference mixes and the other SCC. Grdic et al [12] reported environmental advantages of SCC in comparison to the normal concrete. For producing SCC; coarse recycled aggregate obtained from crushed concrete was researched. In this research, three types of concrete mixtures were made. The percentages of recycled aggregated were 0%, 50% and 100% as a replacement of coarse aggregate. The results indicated that recycled aggregate can be used for making SCC. The potential for usage of coarse recycled aggregate obtained from crushed concrete for making of SCC was researched by Grdic et al [12]. The development of SCC was investigated by Hossain and Lachemi [13]. The used a high volume of cementing materials and viscosity modifying agent .A comparative study was conducted to determine the bond strength between deformed reinforcing steel bar SCC mixes and normal concrete (NC). A reduction in bond strength was less in SCC compared to NC, this is due to bleeding and inhomogeneous nature. Although the variation in bond strengths at different casting elevations was observed in SCC, the extent was less significant than that of NC. SCC also exhibited a less significant top-bar effect compared to NC. Tam et al [14] have pointed the importance rolls of the environmental problems in the construction. The methods of construction waste recycling were reviewed. Several recycled materials are studied, including: asphalt, brick, concrete, ferrous metal, glass, masonry, non-ferrous metal, paper and cardboard, plastic and timber. Tam [15] reported the environmental problems resulting from the construction industry. He reported that about 81% of the volume of demolitions in Australia for concrete. So the best method to minimize the demolitions of concrete is used in construction activities. Recycling concrete waste with 100% recycling that are used for new structural applications was in Japan. On the other hand, Tam [16] reported that recycling of construction material helps saving the limited landfill space. He presented that the recycling concrete as aggregate for new concrete production can provide a cost-effective method for the construction industry and help saving the environment. The properties of concrete made with crushed bricks were evaluated by Cachim [17]. 15% and 30 % of crushed brick was used as replacement ratios of natural aggregates. Water/cement ratios of 0.45 and 0.5 were used. Results indicated that there is no effect for 15% replacement of crushed ceramic on the compressive strength of concrete, while reductions were observed up to 20% for 30% replacement. This is due to the type and the manufacturing process of bricks. Rao et al [18] studied the possibility of treating and reusing waste as aggregate in new concrete, especially in lower level applications. The effect of using recycled aggregate on the properties of fresh and hardened concrete was summarized. Regarding that the use of recycled aggregate to make a self-compacted concrete has still been inadequately investigated.

## 2. Experimental Program

To achieve the aim of the research, two stages program were conducted. In the first stage, eight mixes were prepared to specify the optimum mix, which achieves the requirements of the technical specification for SCC utilizing dolomite as a coarse aggregate [4]. In the second stage, eight mixes were prepared using recycled materials (crushed red brick and ceramic) as a coarse aggregate. Different percentages of 25, 50, 75 and 100 % of recycled aggregates were used to replace the dolomite coarse aggregate. Nine beams were designed to evaluate the behavior of recycled self-compacted concrete beams under flexure loadings. Simply supported beams (100 × 150 × 1000 mm) were cast and tested until failure. The beams under investigation were reinforced with two lower and two upper rebars of 10-mm and 8-mm diameter respectively. The geometrical and reinforcement details of the tested beams are shown in Fig. (1)

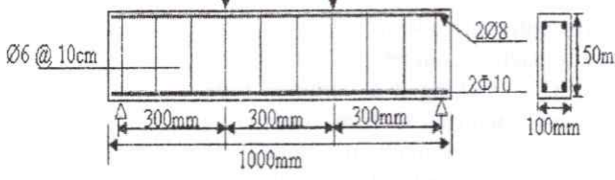


**Figure (1)** Geometrical and reinforcement details of the tested beams

## 2.1 Materials

Well graded siliceous sand was used with a specific gravity of 2.60, absorption of 0.78 %, and a fineness modulus of 2.61. Coarse aggregate of crushed dolomite with maximum nominal size of 10 mm was used, with a specific gravity 2.65 and absorption of 2%. Crushed red brick and ceramic were used as a coarse aggregate. Crushed red brick with a maximum nominal size of 10 mm was used, with specific gravity 1.64 and absorption of 4%. Crushed ceramic with maximum nominal size of 10 mm was used, with specific gravity 2.64 and absorption of 1.9%. Figure (2) shows the recycled aggregate used. Locally produced Portland cement (CEM I 42.5 N) conforming to the requirements Egyptian Standard Specifications (373/2005) was used. Imported class (F) fly ash meeting the requirements of ASTM C618 [19] with a specific gravity of 2.1 was used. The cement content was 400 kg/m$^3$ and the water cement ratio (w/c) ranged from (0.5-0.55). Tap water was used for mixing the concrete. A high range water reducer (HRWR) was used as superplasticizer meeting the requirements of ASTM C494 (type A and F) [20]. The admixture is a brown liquid having a density of 1.18 kg/cm$^3$ at room temperature. The amount of HRWR ranged from (1.5-2.5%) of the powder weight was used. High tensile deformed steel rebras (nominal diameters 10 mm) were used as tension reinforcement. The rebars had a proof stress of 500 MPa. Mild steel rebar were used for stirrups and stirrups' hangers with yield strength of 240 MPa.

### 2.2 Casting and mixing procedures

Coarse aggregate, fine aggregate, and the cement were mixed for at least 1 minute in the dry state before water, and the admixtures were added. The mixing time after slurry (water, fly ash, and HRWR) was added for (3-4) minutes to ensure full mixing of the SCC. The properties of fresh SCC were determined by different methods, which included the normal slump test, V-funnel test and J-ring test. The concrete specimens were cast and kept at the steel moulds for 24 hours. After 24 hours, they were removed from the molds and submerged in water at 20°C until. 2000 kN capacity compressive strength testing machine was used during the determination of the compressive strength and splitting tensile strength. Flexural strength testing machine with 100 kN capacity was used during the determination of the flexural strength of the prism. The flexural strength was determined by the four points loading. Test specimens were designed by letter C for ceramic aggregate or R for red brick aggregated followed by the percentage of recycle for examples C25% means that mixes with 25% crushed ceramic as a coarse aggregate.

## 3. Test Results

### 3.1 First stage

In this stage, eight mixes were prepared to specify the optimum mix proportions as shown in Table [1], which achieve the requirements of technical specification for SCC [4]. In this stage dolomite as a coarse aggregate with a maximum nominal size of 10 mm was used to achieve the requirements for SCC. Table [2] presents the properties of fresh SCC that were determined by different methods.

#### 3.1.1 Workability for trial self-compacted concrete mixes.

Table [2] illustrates a summary of the fresh SCC properties. Figures (3) and (4) show the flow diameter and flow time at 50cm ($T_{50cm}$) for the trial SCC mixes. From these figures, clearly the basic requirements of flow ability as specified by technical specification for SCC are satisfied for mixes L and I. For mix (L) the flow diameter and T50cm were 705 mm and 2.0 sec, respectively. For Mix (I), 650 mm and 2. 5 sec obtained for flow diameter and T50cm, respectively was recorded. The flowability of mixes I and L are shown in Figure (5).

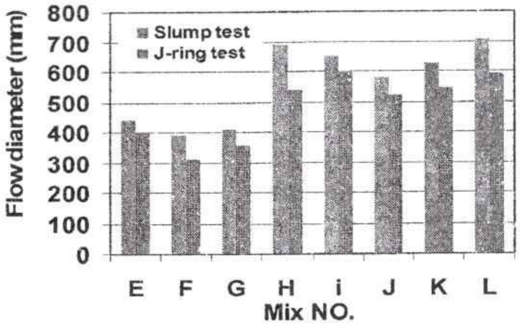


**Figure (3)** Relationship between the Flow Diameter and Mix No.

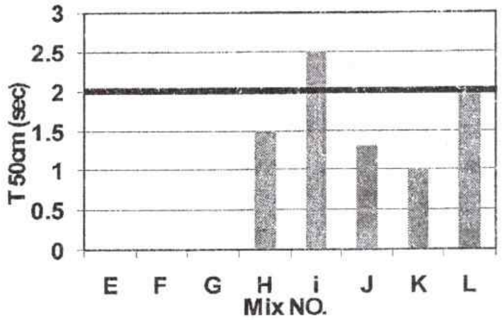


**Figure (4)** Relationship between the Flow Time (T50cm) and Mix No.

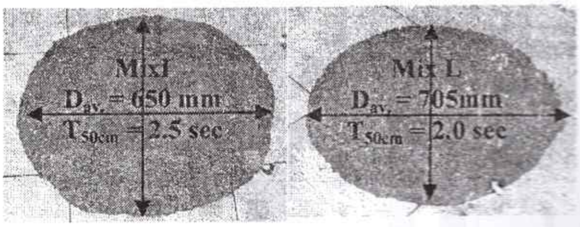


**Figure (5)** Flow diameter for trial mixes.

Figure (6) illustrates the V-funnel time obtained from V-funnel test. The flow time was 7.86 sec and 6.5 sec for mix L and mix I, respectively. Also the $H_2$-$H_1$ for J-ring test was evaluated as shown in

Figure (7). The values of $H_2$-$H_1$ were 5 mm and 10 mm for mix L and mix I, respectively. Theses results indicate that the requirements for self-compacted concrete were achieved for these mixes. Also the flowability of mix L was higher than that it for mix I.

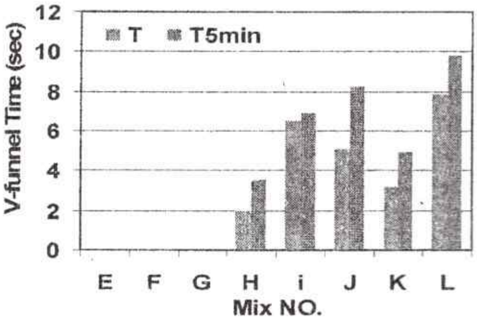


**Figure (6)** Relationship between the Time of V-Funnel Test and Mix No.

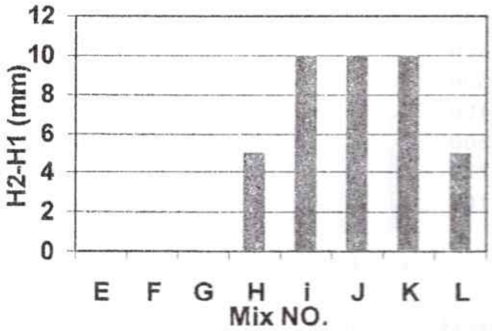


**Figure (7)** Relationship between the (H2- H1) and Mix No.

### 3.1.2 Mechanical properties of trial self-compacted concrete mixes

SCC mixes were prepared using 10-mm crushed dolomite as coarse aggregate. Figures (8) to (10) show the mechanical properties for the different trail SCC mixes under investigation. The compressive strength ranged between 28 and 36 MPa at 28 days. The mix L had a compressive strength of 36 MPa at 28 day. Also, the flexural and tensile strength were higher for mix L compared to the other trial mixes.

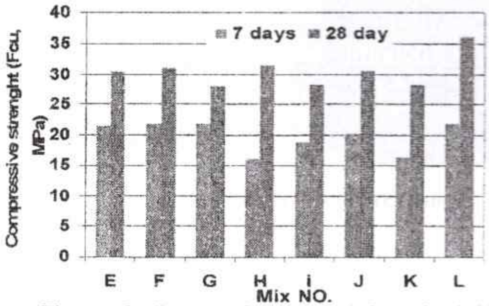


**Figure (8)** Compressive Strength for Trial Self-Compacted Concrete Mixes.

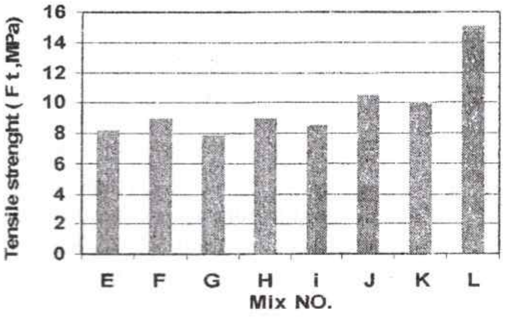


**Figure (9)** Splitting Tensile Strength for Trial Self-Compacted Concrete Mixes.

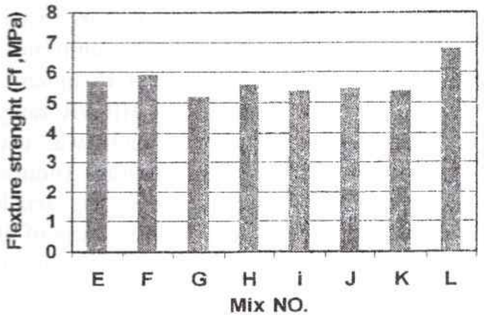


**Figure (10)** Flexural Strength for Trial Self-Compacted Concrete Mixes.

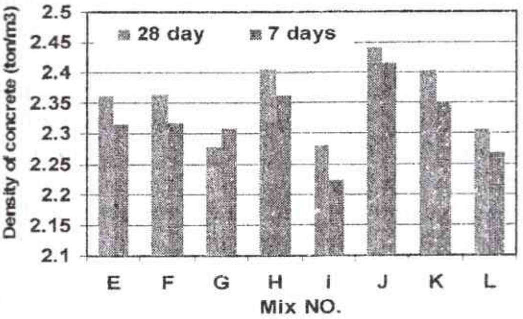


**Figure (11)** Density of Trial Self-Compacted Concrete Mixes.

### 3.2 Second Stage

This stage included SCC mixes made by using recycled aggregates (crushed red brick and ceramic) replacing dolomite. Recycled aggregate with a maximum nominal size of 10 mm were used to produce RSCC. Mix L was chosen from the first stage as a control mix to study the influence of replacement percentage of recycled aggregate on the fresh and mechanical properties. Table (3) shows the mix proportions of RSCC and control mix (mix L).

### 3.2.1 Workability for recycled self-compacted concrete mixes

The fresh properties of RSCC mixes are referred to as workability. The results of slump, V-funnel and J-ring tests were shown in Table (4). Figures (12) and (13) show the effect of the different percentages of recycled aggregate replacement on the flow diameter and $T_{50cm}$. Figure (12) shows that an increase in flow diameter as the percentage of recycled aggregate (crushed red brick and crushed ceramic) increased. All mixtures using crushed ceramic or red brick as a recycled aggregate showed a slump flow diameter between 705-1020 mm and achieved the requirements of SCC. This shows that all mixtures have enough deformability under their own weight. Figure (13) illustrated that an increase of $T_{50cm}$ as percentage of crushed red brick and ceramic increases. When using ceramic as a recycled aggregate T50cm ranged from 2 –3 sec. While in mixes with crushed red brick T50cm ranged from 2.5 –3.6 sec. This shows that all mixtures achieved the requirements of SCC and had enough viscosity to flowabilty. Figures (14) and (15) demonstrated the flowabilty of C25% and R25% mixes.

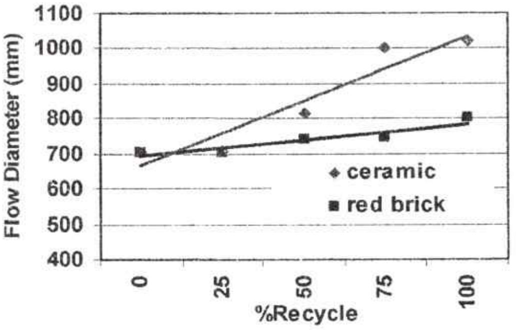


**Figure (12)** Effect of Percentage of Recycled as a Coarse Aggregate on the Flow Diameter.

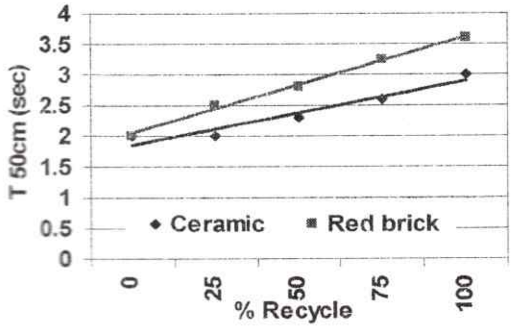


**Figure (13)** Effect of Percentage of Recycled as a Coarse Aggregate on the Flow Time.

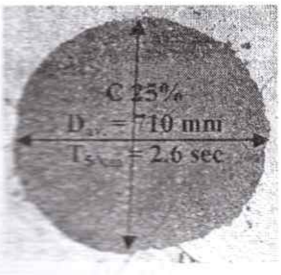


**Figure (14)** Flowabilty of Mix with 25% Crushed Ceramic (C25%).

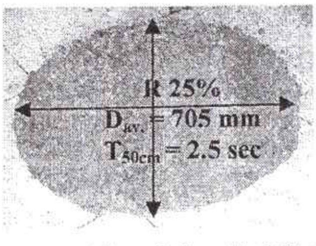


**Figure (15)** Flowabilty of Mix with 25% Crushed Red Brick (R25%).

Figure (16) illustrates the relation between the flow diameter and $T_{50cm}$ for RSCC. It can be shown that as the flow diameter decrease as flow time increases. The J-ring flow diameter provides information on restricted flowability of SCC due to the blocking effect of reinforcing bars. Table (4) shows that an increase in the percentage of recycled aggregate decreased the slump flow diameter of the J-ring test for the mixes with crushed red brick. While the opposite was noticed for crushed ceramic; which is similar to the slump flow test. Figure (17) shows that ($H_2$-$H_1$) decreased with increasing the percentage of recycle aggregate in both crushed ceramic and red brick. Moreover, the concrete mixtures with the crushed red brick yielded higher ($H_2$-$H_1$) in comparison to the concrete mixtures with the crushed ceramic for the same percentage of recycled aggregate results. This proved that the red brick have higher internal resistance to flow than the ceramic. Also the type and the manufacturing process of recycled materials seem to influence the properties of the resulting SCC.

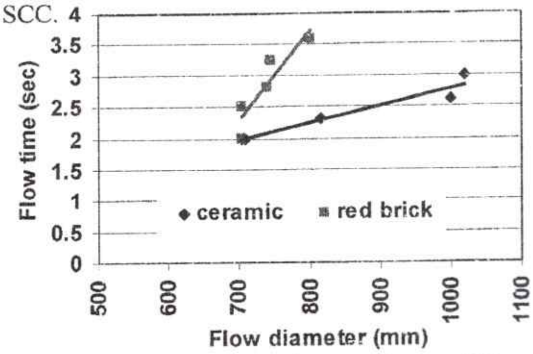


**Figure (16)** Relationship between $T_{50cm}$ and Flow Diameter for Slump Test.

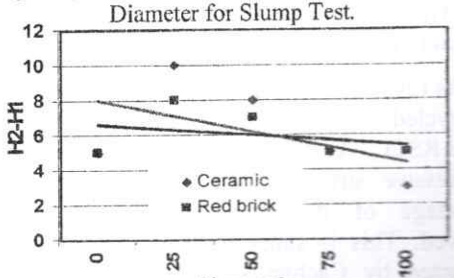


**Figure (17)** Relation between the Percentage of Recycle and $H_2$-$H_1$.

The V-Funnel Time (T) represents the fillingability of the concrete mixtures and measures the viscosity. Table (4) shows the fillingability as per Egyptian standard specification for SCC [14]. Figures (18) and (19) show that an increase in the percentage of recycled aggregate decreases V-funnel time for the concrete mixes with crushed ceramic and increases V-funnel time for the concrete mixes with crushed red brick. Moreover, the same trend was noticed in Figure (19); where V-funnel time after 5 min. The concrete mixes with crushed ceramic were higher than that of the concrete mixes with red brick for the same percentage of recycled aggregate. This may be because of the high possibility of the effect for the shape and surface of ceramic over the red brick narrow opening at the bottom of the V-funnel.

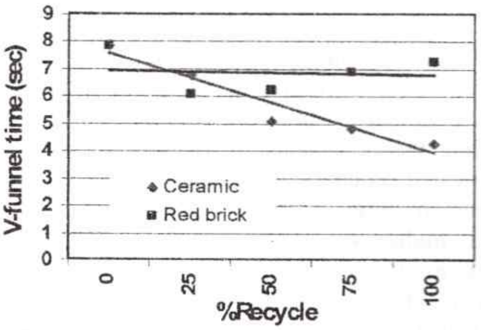
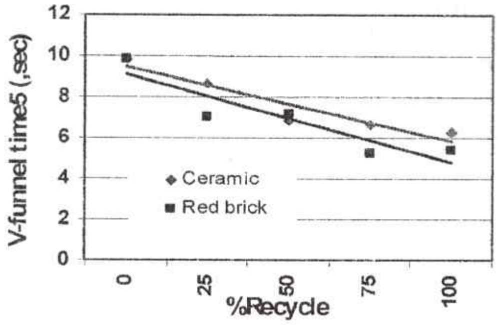


**Figure (18)** Effect of Percentage of Recycled on V-Funnel Time.



**Figure(19)** Effect of Percentage of Recycled on V-Funnel Time after 5 min.

### 3.2.2 Mechanical properties of recycled self-compacted concrete mixes

Figures (20) and (21) show the effect of percentage of recycled aggregate on the compressive strength of the RSCC. At 28 days, there is decrease in the compressive strength with the increases in the percentage of the recycle aggregate can be observed. This is supported by a previous study conducted by Cachim, (2009) and Grdic et al. (2010). This is due to the type, the manufacturing process and properties of the recycled aggregate used in the concrete mix. Figure (20) shows higher compressive strength for the concrete mixtures with crushed ceramic than for the concrete mixtures with crushed red brick for the same percentage replacement. At 7 days; the results indicated that reduction in the compressive strength for the concrete mixture with crushed red brick was (11%, 32% and 31%) compared to the control mix (L). The reduction in the compressive strength for the concrete mixture with crushed ceramic was (10%, 15% and 28%) compared to the control mix (L). These observations are also confirmed by the study conducted by Cachim, (2009). Moreover, the reduction in the compressive strength for mixes with ceramic was lower that that concrete with red brick. For example at 28 days; using 50% recycled aggregate, about 32% and 37% reduction in the compressive strength for concrete mixtures with crushed ceramic and red brick, respectively. The maximum compressive strength was (19.7 and 28.3 MPa) obtained for concrete mixture with 25% crushed ceramic at 7 and 28 days, respectively. The maximum compressive strength was (19.5 and 29 MPa) was obtained for concrete mixture with 25% crushed red brick at 7 and 28 days, respectively. A maximum reduction in compressive strength about 31% for concrete mixtures with crushed ceramic has been observed, whereas for crushed red brick was 45 % at 100% percentage of recycled aggregate.

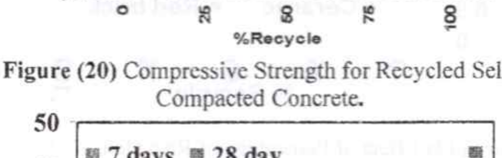


**Figure (20)** Compressive Strength for Recycled Self-Compacted Concrete.

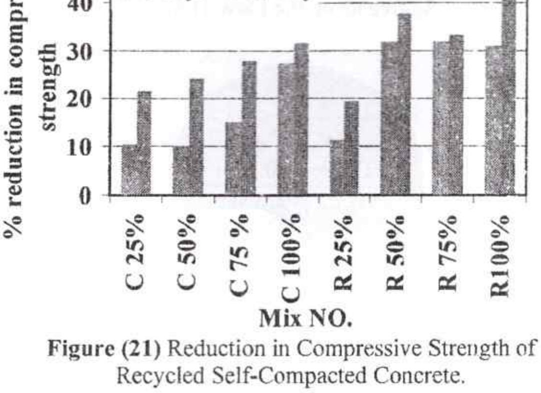


**Figure (21)** Reduction in Compressive Strength of Recycled Self-Compacted Concrete.

Figures (22) and (24) represent the 28-day tensile strength and flexural strength of all RSCC concrete mixtures. Figure (22) indicated that the tensile strength for concrete mixtures with crushed ceramic falls between (9.5 and 14 MPa). The tensile strength with concrete mixtures with crushed red brick falls between (6 and 9.5 MPa). A maximum reduction increase in tensile strength of about 47% for concrete mixtures with crushed ceramic has been observed, whereas for crushed red brick was 60% at 100% percentage of recycled aggregate. Moreover, the percentage of reduction in concrete with crushed ceramic was lower than of crushed red brick by about 28%. Figure (23) shows that the fracture modulus for concrete mixtures with crushed ceramic falls between (4.66 and 5.5MPa), whereas for crushed red brick, ranged (3.38 and 4.65 MPa). Also maximum reduction in fracture modulus was about 32% for concrete mixtures with crushed ceramic have been observed, whereas for red brick was 50% at 100% percentage of recycled aggregate. The density of concrete varied from 2.2 to 2.19 ton /m$^3$ for crushed ceramic and 2.12 to 1.9 ton/m$^3$ for crushed red brick as illustrated in figure (24).

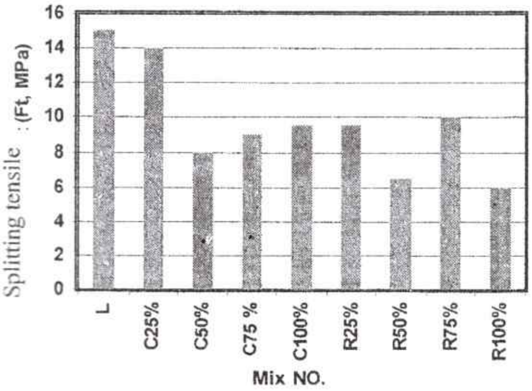


**Figure (22)** Splitting Tensile Strength for RSCC.

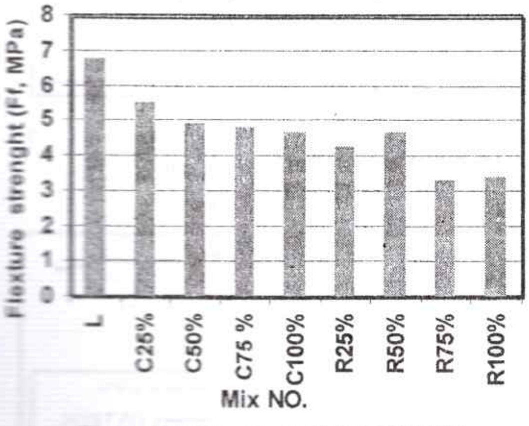


**Figure (23)** Fracture modules of RSCC.

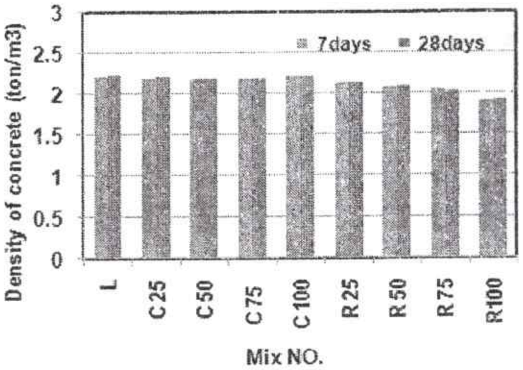


**Figure (24)** Density of RSCC.

## 3. Analysis and Discussion of Test Results

### 3.1 Cracking and modes of failure

Figure (25) shows the cracking patterns for the tested beams at failure. The cracking behavior and modes of failure described ductile fracture based on the experimental program. All beams were cracked in the early stages of loading in the maximum moment region within the middle third of the beam. These flexure cracks propagated upwards with loading and were followed by shear cracks near the supports in the shear zone. Failure took place due to shear in all beams as planned. As the load was applied, a vertical crack initiated in the maximum moment region, while other flexural-shear cracks formed in the shear region .The vertical cracks in the maximum moment region started propagating upward as the load was gradually increased. Failure finally occurred because concrete reached its ultimate compressive strength and crushed. Table [4] shows the cracking and ultimate load for each beam. The values for the ductility index ($\Delta u/\Delta y$) as a measure of ductility were computed. The ductility ratio for the test beams ranged from 1.08 to1.89. The increase of the yield load and its corresponding deflection resulted in this reduction of the ductility ratio, as defined in this investigation, in comparison to the control beam. The number of cracks at failure as shown in Table (5). It can be seen that the number of flexure cracks increased in the beam with RSCC compared to the control beams. The increased number of cracks reflects enhanced steel-concrete bond characteristics. The number of cracks in beams with different percentage of crushed ceramic (C50%, C75% and C100%) compared to their control were observed. Comparing the performance in terms of stiffness, ultimate loads, ductility and cracking patterns were investigated. Figure (28) shows that the load-deflection curves consisted of only two parts: a linear relation up to yield and a yield plateau. A significant reduction in stiffness can be observed in beams with 75 and 100% recycled materials compared to the stiffness of control beams.

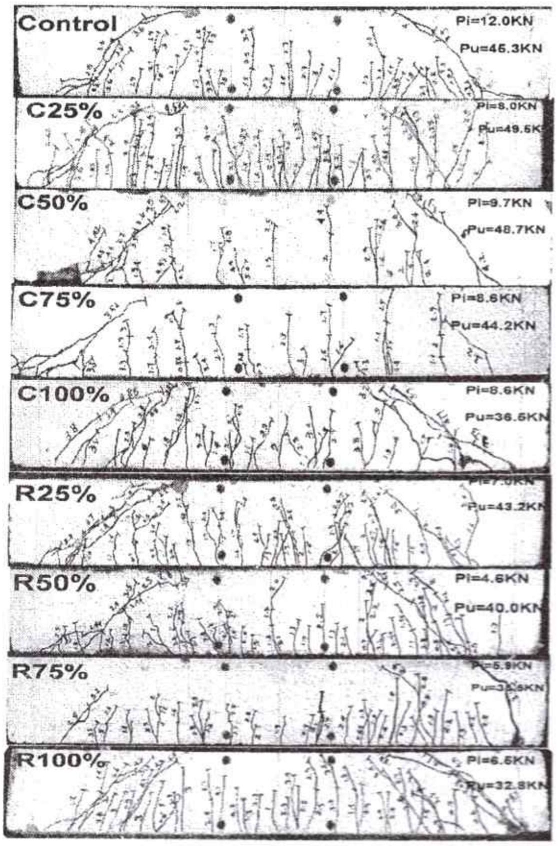


**Figure (25)** Cracking Patterns for all Tested Beams.

### 3.2 Load – deflection curve

The mid-span deflection curves throughout the loading course for the tested beams are illustrated in Figure (26). Load-deflection curves of tested beams were slightly curved after cracking. All curves showed a change of the slope of the first flexure cracking load decreasing by using the recycled materials as a coarse aggregate. The tested beams cast with ceramic as coarse aggregate presented better stiffness than other with red brick as coarse aggregate. It can be seen that, the maximum deflection for beam control beam was 3.52 mm at 45.3 kN. By increasing the percentage of ceramic as a recycled material the reduction in the initial and the ultimate loads were 27% and 1% respectively. About 50% and 17.8% reduction in initial and ultimate load were observed for the beams cast with red brick as a coarse aggregate at different percentage of recycled materials. At the same load, the deflection for beams cast with ceramic less than the beams with red brick. The initial cracking loads for the beams cast with ceramic were higher than the beams with red brick. The beams cast with recycled materials demonstrated better behavior and yielding of reinforcement, while the initial stiffness was as low as the stiffness of the control beams. For beams C25%and C50%, the ultimate load was higher than the control beams by 9.3% and 7.5% respectively. This figure shows a good behavior and stiffness for the beams cast with recycled materials. Figure (27) shows the load -stain curve for the tested beams.

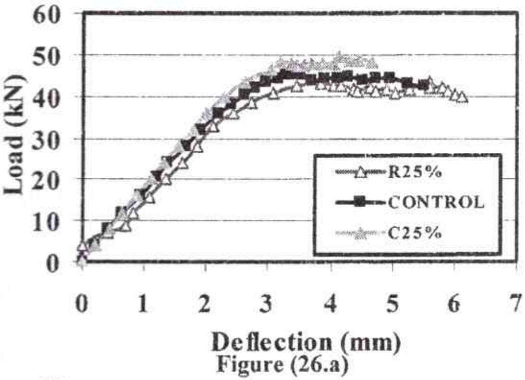


Figure (26.a)

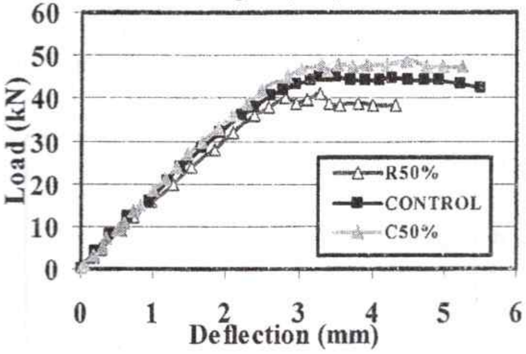


Figure (26.b)

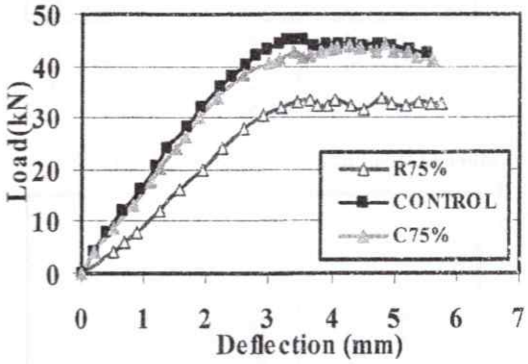


Figure (26.c)

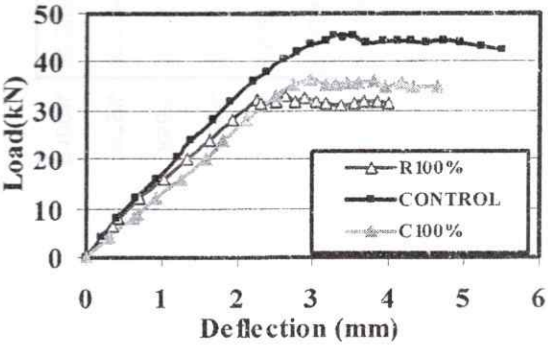


Figure (26.d)

**Figure (26)** Load -Deflection for Test Beams.

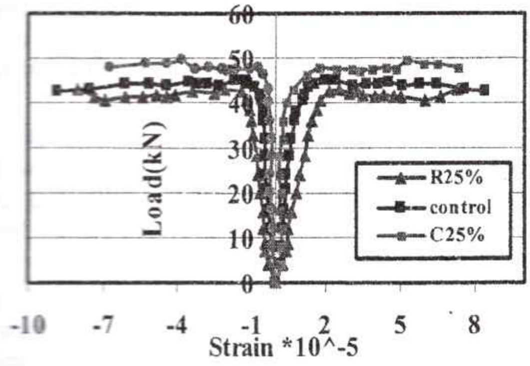


Figure (27.a)

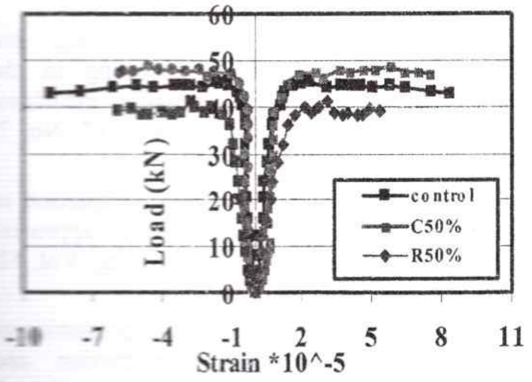


Figure (27.b)

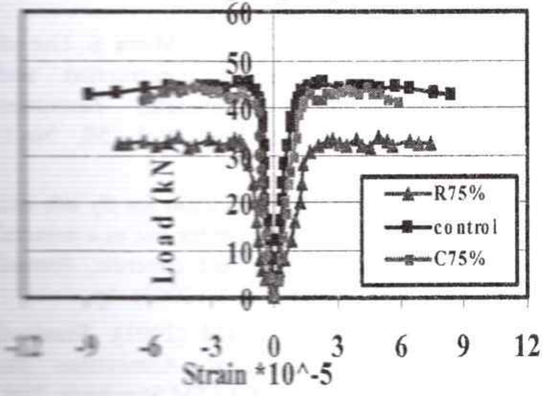


Figure (27.c)

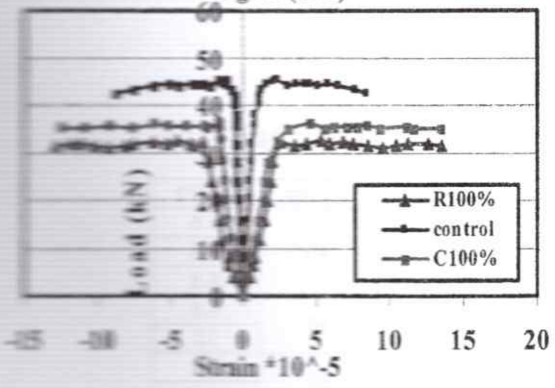


Figure (27.d)

**Figure (27)** Relation between Load and Strain for the Tested Beams.

## 4. Conclusions:-

Based on the available test results, the following conclusions can be drawn:

1. Using crushed ceramic as a recycled aggregate improved the flowability of the recycled self-compacted concrete mixtures compared to use red brick as a recycled aggregate.
2. The compressive strength for the dolomite mix was 36 Mpa at 28 days.
3. At 28 days, the compressive strength was reduced by 19.4, 37.5, 33.33 and 45 percent when the coarse aggregate was replaced by crushed red brick at 25, 50, 75 and 100%, respectively compared to counterpart control mixes. The corresponding ratios when crushed ceramic was used were 21.4, 31.4, 27.8 and 24.2 percent.
4. The strength loss refers to either intrinsic weakness of the coarse aggregate in case of crushed red brick and partial reduction in the bonding strength between the coarse aggregate or the matrix in case of the crushed ceramic.
5. Compared to the counterpart control mixes, the fracture modules was reduced by an average of 43 and 27 percent when red brick and crushed ceramic was used as coarse aggregate.
6. Compared to the counterpart control mixes, the splitting tensile was reduced by an average of 52 and 32 percent when red brick and crushed ceramic was used as coarse aggregate.
7. The reduction in splitting tensile and fracture modules for mixes with crushed ceramic was lower than of the mixes with crushed red brick by 28% and 32% respectively.
8. Increase of the percentage of recycled aggregate decreases the density of RSCC. Replace 100% of crushed red brick decreased the density by 14%.
9. Using ceramic as a coarse aggregate; the ultimate load for the tested beams with 25 and 50% recycled materials increased by 9.3 % and 7.5 % and decreased by 2.4 % and 19.4 % at 75 and 100% recycled materials compared to the control beams.
10. Using red brick as a coarse aggregate; the ultimate load for the tested beams with 25, 50, 75 and 100% recycled materials decreased by 4.6%, 11.7%, 26% and 27.6% compared to the control beams.
11. The post cracking stiffness of the tested beams cast with RSCC mixes was significantly less than control beam. Exception case of using 25 and 50 % crushed ceramic as a coarse aggregate was effective in increasing the post-cracking stiffness, increased to 9 and 7.5% respectively.

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**Table [1]** concrete mix proportions for trial self-compacted concrete mixes (kg/m$^3$).

| Mix code | Cement | Water | Sand | Dolomite | Fly ash | BVF1 |
|---|---|---|---|---|---|---|
| E | 400 | ٢٠٠ | 1011 | 674 | 40 | 6.6 |
| F | | | 1008 | 672 | | 8.8 |
| G | | | 1008 | 672 | | 8.8 |
| I | | | 980 | 653 | 40 | 6.6 |
| L | | 220 | 974 | 663 | | 11 |
| J | | | 962 | 641 | 60 | 9.2 |
| K | | | 959 | 639 | | 11.5 |
| H | | | 944 | 629 | 80 | 12 |

**Table [2]** Rheological properties of trial self- compacted concrete mixes.

| Mix No. | Slump test |  |  |  |  | V-funnel test |  |  |  |  | J-ring test |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | $D_{av.}$ (mm) |  | $T_{50cm}$ (sec) |  | $T_f$ (sec) | T (sec) |  | $T_{5min}$ (sec) |  | Velocity (m/sec) | T (sec) | $D_{av.}$ (mm) | $H_2$-$H_1$ (mm) |  |
| E | 440 | (600 mm)* | None |  | 1.5 | None |  |  |  |  |  |  |  |  |
| F | 390 |  |  |  | 1.2 |  |  |  |  |  |  |  |  |  |
| G | 410 |  |  |  | 1.25 |  |  |  |  |  |  |  |  |  |
| H | 690 |  | 1.5 | (2-5 sec)* | 13 | 2 | (6-12 sec)* | 3.55 | (9-15 sec)* | 0.32 | 2 | 540 | 5 | (0-10 mm)* |
| I | 650 |  | 2.5 |  | 9.1 | 6.5 |  | 6.9 |  | 0.1 | 7 | 600 | 10 |  |
| J | 580 |  | 1.3 |  | 5.1 | 5.06 |  | 8.21 |  | 0.12 | 3 | 520 | 10 |  |
| K | 630 |  | 1 |  | 6.2 | 3.19 |  | 4.96 |  | 0.2 | 6 | 545 | 10 |  |
| L | 705 |  | 2 |  | 7 | 7.86 |  | 9.85 |  | 0.1 | 6 | 590 | 5 |  |

$D_{av.}$ : The average of the flow diameter for the slump test and the j- ring test (mm).
$T_{50cm}$: Time at diameter of concrete equal 50 cm (sec).
$T_f$: The time which the concrete stop spreading in the slump test (sec)
* Requirements of technical specification of self-compacted concrete [4]

**Table [3]** Proportions of recycled self-compacted concrete mixes (kg/m$^3$).

| Mix code | Cement | Water | Sand | Dolomite | Recycled aggregate | Fly ash | BVF1 |
|---|---|---|---|---|---|---|---|
| Control mix (L) | 400 | 220 | 974 | 663 | 0 | 40 | 11 |
| C25% |  |  |  | 534 | 134 |  |  |
| C50% |  |  |  | 440 | 220 |  |  |
| C75% |  |  |  | 380 | 285 |  |  |
| C100% |  |  |  | 0 | 668 |  |  |
| R25% |  |  |  | 465 | 116 |  |  |
| R50% |  |  |  | 364 | 182 |  |  |
| R75% |  |  |  | 294 | 221 |  |  |
| R100% |  |  |  | 0 | 250 |  |  |

**Table [4]** Rheological properties of recycled self-compacted concrete mixes.

| Mix No. | Slump test |  |  |  |  | V-funnel test |  |  |  |  | J-ring test |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | $D_{av.}$ (mm) |  | $T_{50cm}$ (sec) |  | $T_f$ (sec) | T (sec) |  | $T_{5min}$ (sec) |  | Velocity (m/sec) | T (sec) | $D_{av.}$ (mm) | $H_2$-$H_1$ (mm) |  |
| Control mix (L) | 705 | (600 mm)* | 2 | (2-5 sec)* | 7 | 7.86 | (6-12 sec)* | 9.85 | (9-15 sec)* | 0.1 | 6 | 590 | 5 | (0-10 mm)* |
| C25% | 710 |  | 2 |  | 4 | 6.8 |  | 8.7 |  | 0.09 | 4.36 | 625 | 10 |  |
| C50% | 815 |  | 2.3 |  | 5.9 | 5.1 |  | 6.9 |  | 0.12 | 5.5 | 665 | 8 |  |
| C75 % | 1000 |  | 2.6 |  | 6 | 4.8 |  | 6.65 |  | 0.13 | 5.8 | 660 | 5 |  |
| C100% | 1020 |  | 3 |  | 6.7 | 4.3 |  | 6.33 |  | 0.15 | 5.2 | 660 | 3 |  |
| R25% | 705 |  | 2.5 |  | 6 | 6.07 |  | 7.07 |  | 0.1 | 5.2 | 640 | 8 |  |
| R50% | 740 |  | 2.8 |  | 5.48 | 6.25 |  | 7.17 |  | 0.1 | 5.5 | 620 | 7 |  |
| R75% | 745 |  | 3.25 |  | 6.91 | 6.89 |  | 5.25 |  | 0.09 | 6.5 | 575 | 5 |  |
| R100% | 800 |  | 3.6 |  | 5.48 | 7.26 |  | 5.42 |  | 0.09 | 7 | 565 | 5 |  |

**Table (5)** Experimental Test Results for Beam Specimens.

| Beam code | Initial Cracking load (kN) | Ultimate load (kN) | Deflection (mm) |  | Ductility index | Number of cracks |
|---|---|---|---|---|---|---|
|  |  |  | $\Delta y^{**}$ | $\Delta u^{**}$ |  |  |
| control | 12.0 (1.00)$^{*}$ | 45.3 (1.00)$^{*}$ | 2.62 | 3.52 | 1.34 | 33 |
| C25% | 8.0 (0.67) | 49.5 (1.09) | 3.18 | 6.0 | 1.89 | 44 |
| C50% | 9.7 (0.81) | 48.7 (1.08 ) | 3.04 | 4.49 | 1.48 | 25 |
| C75% | 8.6 (0.72) | 44.3 (0.98) | 3.17 | 4.85 | 1.53 | 24 |
| C100% | 8.6 (0.72) | 36.5 (0.81) | 2.74 | 2.96 | 1.08 | 32 |
| R25% | 7.0 (0.58) | 43.2 (0.95) | 3.46 | 5.6 | 1.62 | 47 |
| R50% | 4.6 (0.38) | 41.0 (0.91) | 2.82 | 3.28 | 1.16 | 39 |
| R75% | 5.9 (0.49) | 33.7 (0.74) | 4.03 | 4.77 | 1.18 | 37 |
| R100% | 6.5 (0.54) | 32.8 (0.72) | 2.25 | 2.64 | 1.17 | 45 |

* ( ): load as a fraction of that of the control beam.
** Δy, Δu: mid-span deflection at yield and ultimate load, respectively