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# Mechanical and Dynamical Properties of Structural Rubcrete Mixes

O. M. Makki*, H. M. K. Al-Mutairee

*Department of Civil Engineering, College of Engineering, University of Babylon, Babylon, Iraq*

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ABSTRACT

In most civil constrictions, concrete members need to gain some ductility to resist the dynamic loads which it suffered. For sustainability and economical reasons, scrapped tires rubbers are the most cheap material able to achieves this goal. The bad manner in such replacement is that, the high replacing percentages cause a large drop in concrete mechanical properties till becomes unstructural. This paper offers six structural rubcrete mixes and discuss its properties after replacement. Slump, density, water absorption, compressive strength for cubes and cylinders, impact resistance, flexural strength, splitting, ultrasonic and stress versus strain curves were tested and discussed. It can be concluded that, the sustainable rubcrete mixes still structural in spite of the dropping in strength due to the replacing process. Concrete tensile, compressive and flexural strength minimized for every incrementing in rubber amounts due to the loss of bond between mortar and the rubbers.

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**NOMENCLATURE**

| | | | |
|---|---|---|---|
| RF | Reference conventional concrete | G30 | 30 % gravel – chip replacing percent |
| S10 | 10% sand – crumb replacement | Sp.I | Specimen one |
| S20 | 20% sand – crumb replacement | Sp.II | Specimen two |
| S30 | 30% sand – crumb replacement | Sp.III | Specimen three |
| G10 | 10 % gravel – chip replacing percent | MOR | Modulus of rpture |
| G20 | 20 % gravel – chip replacing percent | | |

## 1. INTRODUCTION

Constructions in usual highly exposed to dynamic loads in addition to monotonic loads. It is well known that, concrete is a brittle material that cannot resist dynamic loads. Enhancing dynamic properties of concrete investigated by researchers using different ways like adding steel fibers or rubbers or even both [1-4]. Since rubber is not a biodegradable material and for its low cost against the high cost of steel fiber and for sustainability, it can be used as a percentage replacement from mix aggregate. The total recovery of scraped tires in civil engineering works reached to 89, 94, 91 and 90% in each of the United States, Europe, Japan and Mexico, respectively [5]. Entering scraped tire rubber into constructions helps the nature to get rid of it as a waste material and avoid the pollution which results in if the factories fired it. Rubber has to be replaced as a volumetric percentage of sand or gravel or even both, somes replaced it from aggregate weight or even as an additives. It is important to expect that, the replacement will deteriorate the mechanical properties of concrete if it is done by a big amounts [3, 6–14]. Weakened bond between cement past and rubber particles is the most effective reason for that deterioration in addition to the low unit weight of the mix after replacement [15–20]. The big difference in elastic modulus between the two replaced materials is also a cause [9].

The energy absorption was proved to be enhanced for 5, 10, 15 and 20 % sand replacement by 138, 185, 300, and 396 % while incrementing equals 150, 204, 326 and 426% for the same percentages of gravel replacing [14]. The dynamic modulus of elasticity found to be minimized after replacement [21, 22]. The damping ratio enhanced by 230% of 15% course weight replacement [21]. This paper investigated the effect of three replacing

*Corresponding Author Institutional Email: sth.ola.ali@student.uobabylon.edu.iq (O. M. Makki)

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percentages for fine aggregate and the same for course aggregate on the mechanical properties of concrete. Workability, unit weight, water absorption, cubes compressive strength, cylinder compressive strength, stress strain curve, tensile strength, flexural strength, ultra-sonic, and impact load of concrete were investigated.

## 2. MATERIALS, MIXES AND SPECIMENS

Normal Portland cement was used, along with natural quartzite sand of specific gravity equals 2.65 and 2.6 for gravel. As a full graded replacement was made for both fine and course aggregates for 14 mm maximum gravel-chip size which are matched with the ASTM C33-78, so as for sand crumb replacement . Physical and chemical properties of sand, gravel and rubber are summarized in Tables 1-3.

Seven mixes were casted to investigate the effect of rubber-aggregate replacing. The first group consist of three mixes of sand- Crumb rubber replacement as 10, 20 and 30% replacement. The second group is of gravel versus chips replacing for the same perivious percentages. While the seventh mix was a normal concrete to be used as a reference. All mixes were prepared with (1:1.4:2) percentages and of w/c ratio equals 0.365. Supperplasticsizer Gelimum G54 also utilized. Figures 1 and 2 show the mixing processes, curing, and specimens before tests. A rotating mixer of 250 kg total capacity was utilized. Specimens was cured by sinking into water for 28 days. Mixes percentages per one cubic meter were listed in Table 4. The following section investigated the properties of the seven mixes.

**TABLE 1.** Chemical and physical properties of rubber

| Composition | Value |
|---|---|
| Chip density | 650 kg/m$^3$ |
| Crumb density | 720 kg/m$^3$ |
| Carbon black | 20% |
| steel | 4 % |
| Water absorption | 0.01 |
| Specific gravity | 1.09 |

**TABLE 2.** Chemical and physical properties of fine aggregate

| Properties Test results Limits of | Magnitude |
|---|---|
| Sulfate content ($SO_3$) | 0.01 % |
| Specific gravity | 2.65 |
| Fineness modulus | 3.19 |
| absorption | 0.1 |

**TABLE 3.** Chemical and physical properties of course aggregates

| Properties | Magnitude |
|---|---|
| Sulfate content ($SO_3$) | 0.08 % |
| Specific gravity | 2.6 |
| absorption | 0.15 |

**TABLE 4.** Mixes weights (kg/m$^3$)

| Mix | Cement | Sand | Gravel | Rubber | Water | G54 |
|---|---|---|---|---|---|---|
| RF | 475 | 760 | 1119 | 0 | 124 | 2.33 |
| S10 | 475 | 684 | 1119 | 34 | 124 | 2.33 |
| S20 | 475 | 608 | 1119 | 68 | 124 | 2.33 |
| S30 | 475 | 532 | 1119 | 103 | 124 | 2.33 |
| G10 | 475 | 760 | 1008 | 44 | 124 | 2.33 |
| G20 | 475 | 760 | 896 | 88 | 124 | 2.33 |
| G30 | 475 | 760 | 784 | 132 | 124 | 2.33 |

**Figure 1.** Casting and curing process

**Figure 2.** Specimens before test

## 3. PROPERTIES RESULTS AND DISCUSSIONS

The average of three specimens' values at 28 day of curing was investigated for each single mix of the following.

**3. 1. Workability** The workability of concrete mixes were investigated using slump test in accordance to ASTM 143M-12 [23]. It can be concluded from Figures 3 and 4, which are shown in the results of slump test that, the replacement working on decreasing concrete workability in amounts depend on replacement percentages. It can be also noting that, the mix has an excellent workability for civil engineering works. The unrounded rubber particles (in comparing with the aggregate) will bound the water particles into their irregular shapes, that what causes the low slumps for rubcrete. From Figure 4 it can be concluded that and in accordance to UNI EN 12350-2 [24] the form of all rubcrete mixes was true slump.

**3. 2. Unit Weight** The unit weight of rubcrete is lower than concrete due to replacing the heavier aggregate by the lighter rubber, and that what proved in Table 5. The results based on the mean of three samples for each single mix. The unit weight of rubcrete decreases for each incrementing in rubber percentages for either sand or gravel replacement. Sand replacement specimens lighter than the gravel for the same replacing percents. It is due to that, the crumb in denser than chip for the same cubic meter as explain in Table 5. But, for such replacements, it impossible to consider rubcrete as a light weight material.

**3. 3. Water Absorption** It is the ability of material to absorb water. It can be stated that, replacement increases water absorption of concrete mixes since rubber is a hydrophobic material. All obtained results are summarized in Table 6. and such results were confirmed with the reported data in literature [18, 25, 26].

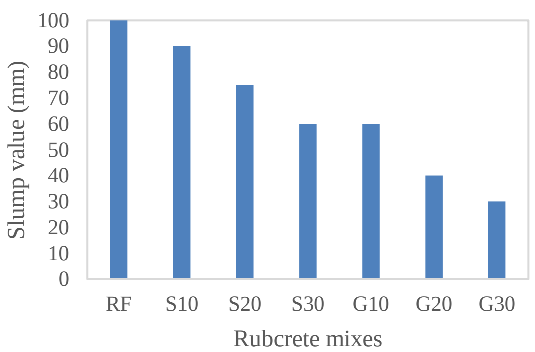


**Figure 3.** Slump test values

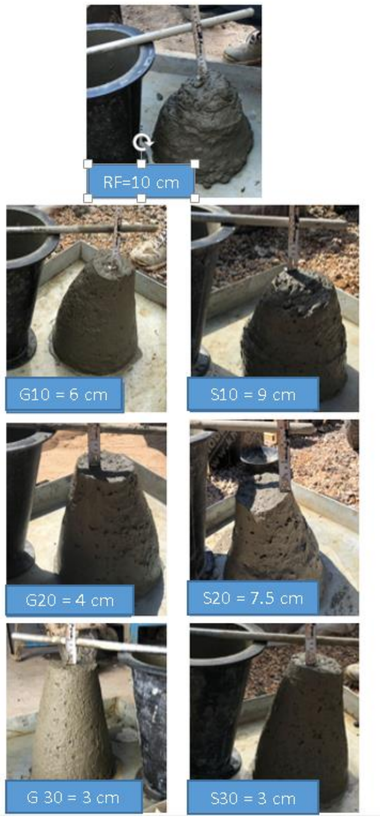


**Figure 4.** Workability test

**TABLE 5.** Rubcrete unit weight (All weight in kg)

| Mix | SP.I | Sp.II | SP.III | mean | Redaction % |
|---|---|---|---|---|---|
| RF | 8.03 | 8.025 | 8.034 | 8.03 | |
| S10 | 7.67 | 7.665 | 7.625 | 7.653 | 4.69 |
| S20 | 7.445 | 7.393 | 7.375 | 7.403 | 7.8 |
| S30 | 7.09 | 7.065 | 7.16 | 7.105 | 11.5 |
| G10 | 7.905 | 7.87 | 7.85 | 7.875 | 1.93 |
| G20 | 7.705 | 7.705 | 7.66 | 7.69 | 4.23 |
| G30 | 7.325 | 7.31 | 7.345 | 7.327 | 8.76 |

**TABLE 6.** Water absorption details

| Mix | Water absorption (%) | Increment (%) |
|---|---|---|
| RF | 0.024 | |
| S10 | 0.027 | 11.41 |
| S20 | 0.037 | 53.45 |
| S30 | 0.041 | 69.44 |
| G10 | 0.027 | 12.96 |
| G20 | 0.030 | 24.25 |
| G30 | 0.03 | 37.85 |

**3. 4. Compressive Strength** The average of three cubes in accordance to BS 1881 -116 [27] to get the British compressive strength $F_{cu}$. Furthermore, the average of three cylinders of 150*300 mm$^2$ (diameter * height) was also tested to get the American compressive strength $f'c$. The converting factor from British to American compressive strength was also checked out for rubcrete. Table 7 shows the results of the three cubes specimens, the means of them, the difference in accordance to reference mix and the converting factor from cylinder to cube. It can be noting that, compressive strength drops for each incrementing in rubber percents but still structural for this suggested rubcrete mix. Also, since the replacement was from the volume of aggregates, the weight of rubber in cubic meter is more than the gravel, that which made the gravel replacement specimens stronger than the sand replacing. The failure of the RF mix was as a fully sudden explosion due to its strength in contrast to other rubcrete mixes.

Relenting on the results, the converting factor from cubes to cylinders was found to be ranged from 0.8 to 0.83 which is matched with the normal converting factor.

To discuss the converting factor from 100*200 mm cylinder into a 150*300 mm specimen, an average of 3 specimens were tested and compared with the bigger cylinders results. All details are listed in Table 8. It can be concluded that, the reconverting factor from bigger to smaller cylinder is ranged from 0.08 to 0.88 for rubcrete mixes.

**TABLE 7.** Cubes compressive strength

| Mix | SP.I (MPa) | SP.II (MPa) | SP.III (MPa) | Mean (MPa) | Redaction (%) | Convert to f'c |
|---|---|---|---|---|---|---|
| RF | 52.92 | 53.28 | 52.9 | 53.06 | | 0.814139 |
| S10 | 34.27 | 34.34 | 34.42 | 34.35 | 35.27 | 0.8297 |
| S20 | 26.49 | 25.05 | 26.34 | 25.97 | 51.06 | 0.808692 |
| S30 | 22.74 | 22.64 | 22.8 | 22.74 | 57.14 | 0.835396 |
| G10 | 37.93 | 37.67 | 38.16 | 37.92 | 28.53 | 0.804221 |
| G20 | 34.39 | 34.2 | 34.23 | 34.3 | 35.36 | 0.810464 |
| G30 | 27.54 | 27.4 | 27.41 | 27.48 | 48.22 | 0.800703 |

**TABLE 8.** Small cylinders compressive strength

| Mix | SP.I (MPa) | SP.II (MPa) | SP.III (MPa) | Aver. (MPa) | Redaction (%) | Convert factor |
|---|---|---|---|---|---|---|
| RF | 34.47 | 34.73 | 35.08 | 34.76 | ---- | 0.80 |
| S10 | 23.1 | 22.6 | 22.96 | 22.88 | 34.1 | 0.803 |
| S20 | 18.04 | 18.27 | 18.57 | 18.29 | 47.3 | 0.871 |
| S30 | 15.48 | 15.39 | 16.26 | 15.7 | 54.8 | 0.82 |
| G10 | 25.59 | 26.14 | 26.52 | 26.08 | 24.9 | 0.85 |
| G20 | 24.27 | 24.56 | 24.79 | 24.53 | 29.40 | 0.88 |
| G30 | 18.17 | 18.71 | 19.17 | 18.6 | 46.24 | 0.84 |

**3. 5. Stress Strain Curve** Stress versus strain curves are one of the best behavior viewers to the concrete mixes. It shows the linear, and nonlinear stages under loading conditions. It was tested through evaluating the average of three cylinders of 100*200 mm (diameter * height) for all seven mixes. From Figure 5, one may conclude that, rubcrete mixes have a strain values much more than the conventional concrete mixes due to its elasticity under loading with lower compressive strengths. The intensity of this behavior becomes more visible at high replacement rates. The brittle exploded failure of the reference mix was less gradually after every incrementing in rubber percentages and becomes as a ductile failure. All cylinders failed within the standard expected failure types listed in ASTM VC39/C39M- 15a [28] specification for type 3 (i.e. columnar vertical cracks from both ends) as shown in Figure 6 which illustrated the failure mode of three different mixes.

**3. 6. Tensile Strength** Three samples of 100*200 mm cylinders were tested to investigate the splitting tensile strength of the seven mixes in accordance to the ASTM C496 specifications [29]. Table 9 listed the tensile strengths at 28 day age in which deduced that, the tensile strength of rubcrete decreases for every rising in replacement amount due to loss of bonding, less density

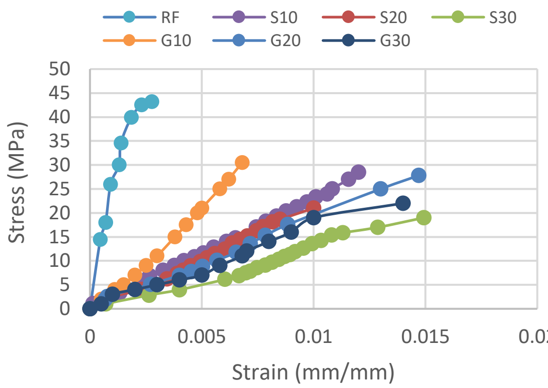


**Figure 5.** Stress vs strain curves for all mixes

**Figure 6.** Failure mode of cylinders

of rubcrete or due to the micro cracks of mortar which will multiple due to the difference between the rubber elastic modulus and the morter. Specimens after failure can be seen at Figure 7.

**3. 7. Rupture Strength** A prisms of (100*100*300 mm) dimensions were casted for the seven mixes to test the modulus of rupture at 28 days in accordance to the ASTM C133-97 [30]. The tested specimens results' were clarified at Figure 8, andaccordingly the rupture strength of rubcrete reduced due to the reduction in bending strength. It possible to conclude that, a dropping in MOR noted since the flexural strength effected in the first degree on compressive strength. Results also showed that, the flexural strengths of sand replacement are slightly higher than the gravel replacement, which is due to the sand provides higher ductility than gravel. Rupture test for rubcrete also investigated widely by Mohammed and Breesem [31]. Failure shape of all specimens was similar so one specimen was considered as shown the failure (Figure 9).

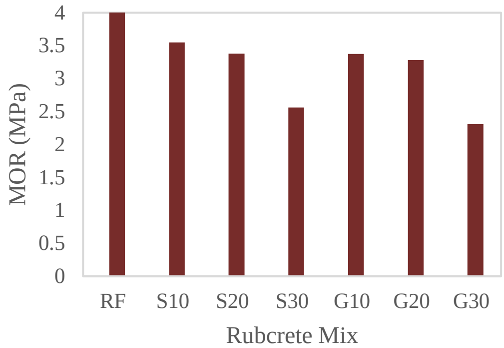


**Figure 8.** Flextural strength

**TABLE 9.** Tensile splitting test details

| Mix | SP.I (kN) | SP.II (kN) | SP.III (kN) | Ft (MPa) | Redaction (%) |
|---|---|---|---|---|---|
| RF | 344.8 | 245 | 341.12 | 4.941 | |
| S10 | 220.86 | 297.14 | 224.78 | 3.942 | 20.210 |
| S20 | 200.24 | 203.68 | 200.88 | 3.210 | 35.032 |
| S30 | 163.78 | 164.52 | 162.74 | 2.606 | 47.252 |
| G10 | 262.3 | 257.6 | 260.94 | 4.144 | 16.121 |
| G20 | 209.7 | 208.6 | 211.6 | 3.343 | 32.335 |
| G30 | 182.55 | 183.94 | 185.08 | 2.927 | 40.75 |

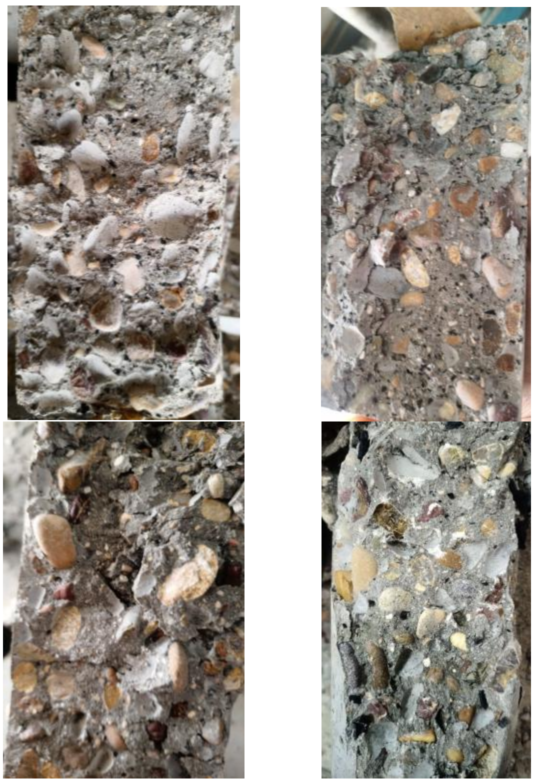

**Figure 7.** Failure splitting

**3. 8. Ultrasonic Test** It is used for investigating the velocity of passing sound waves through concrete mixes to show its deterioration against loads and its cracks. It can also view how the sound wave effected by aggregates-scraped rubbers replacements. A non-destructive test was made for disk specimens (65*152 mm (diameter * length)) for the seven concrete mixes. The specimens' centers were identified in order to achieve the extremely direct wave path passing through them (Figure 10). From the obtained results which are summarized in Table 10; it can be noting that, the replacements slowed down the sound wave which crossed within due to the high energy absorb of rubber. Gravel replacement showed more slowly velocity when compared with the same percent of replacement of sand due to the larger rubber particles.

**3. 9. Impact Test** In accordance to Tonon [32] and ASTM D5607, the impact resistance of concrete may be gotten by casting a cylindrical specimens of 65*152 mm (diameter * length) and applying a drop weight simulated of 4.54 kg. Number of hits which caused the first crack were recorded besides the total number of hits to final failure. The impact test showed that, replacing causes to higher impact resistance for rubcrete mixes comparing with concrete as detailed in Table 11. Gravel replacement mixes shows more impact resistance when comparing with sand replacement. The reason was visible and sensible during the test, it is due to that, the chips particles bigger than sand which will collect the cracks and prevent them to be developed during the test. Failure shapes of the mixes were listed in Figure 11.

**Figure 9.** Specimen G10 for example after failure

**Figure 10.** Ultra sonic test

**TABLE 10.** Sound velocities through rubcrete

| Mixes | Velocity (m/s) | Decrement (%) |
|---|---|---|
| RF | 5191 | ------ |
| S10 | 4928 | 5.066 |
| S20 | 4304 | 17.09 |
| S30 | 4224 | 18.63 |
| G10 | 4444 | 14.39 |
| G20 | 4201 | 19.07 |
| G30 | 4172 | 19.63 |

**TABLE 11.** Impact test results

| | Number of hits till 1st crack | Number of hits till failure | Energy at first crack | Energy at failure | Increment due to replacement % |
|---|---|---|---|---|---|
| RF | 6 | 8 | 122.1 | 162.8 | -------- |
| S10 | 4 | 17 | 81.41 | 346.0 | 112.5 |
| S20 | 7 | 35 | 142.4 | 712.3 | 337.5 |
| S30 | 12 | 61 | 244.2 | 1241.5 | 662.5 |
| G10 | 5 | 24 | 101.7 | 488.4 | 200 |
| G20 | 8 | 38 | 162.8 | 773.4 | 375 |
| G30 | 15 | 116 | 305.3 | 2361 | 1350 |

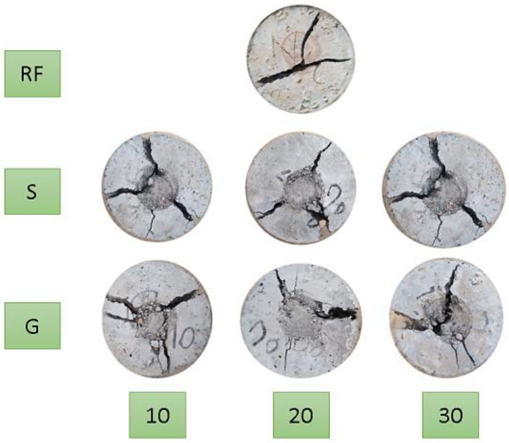


**Figure 11.** Specimens after failure

## 4. CONCLUSIONS

1. Rubcrete workability deteriorated for every increment in replacement percentage.
2. Partial rubber versus aggregate replacement means replacing heavier by lighter material which will make the rubcrete a lighter material than conventional concrete.
3. The capability of sand to absorb free water mix is more than the gravel capacity so that the water absorption of sand replacement becomes larger, especially after knowing that, the weight of crumb in the one cubic meter is larger than the chips.
4. Concrete compressive strength does not matter it was British of American compressive strength-drops after any replacement in amounts depends on the replacement type, percentages and kind.
5. Converting factors from $F_{cu}$ to $f'c$ as well as converting factor from 100*200 cylinder size to 150*300 size are the same of conventional mixes for rubcrete.
6. Mixes percentages offers a sustainable structural rubcrete so suitable for the dynamic constructions.
7. Rubcrete mixes has a high straining rates due to the elastic behaviour of rubber, and that strain depends for the first degree on rubber amounts.
8. Splitting tensile effected by the concrete compressive strength so it is logically drops after any replacement especially it depends on the bond strength between mortar and gravel particles which it weaken for rubbers, so as for flexural property.

9. Involving rubber into concrete mixes deteriorate the velocity of sound wave passing through the mix because the ability of rubber to absorb energy.

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## Persian Abstract

**چکیده**

در اکثر انقباضات عمرانی، اعضای بتنی برای مقاومت در برابر بارهای دینامیکی که متحمل می‌شوند باید مقداری شکل‌پذیری به دست آورند و راه‌های زیادی مانند افزودن الیاف فولادی به مخلوط بتن یا جایگزینی سنگدانه‌ها با لاستیک وجود دارد. به دلایل پایداری و اقتصادی، لاستیک های لاستیک اسقاط شده ارزان ترین مواد برای دستیابی به این هدف هستند. روش بد در چنین جایگزینی این است که درصد جایگزینی بالا باعث افت زیادی در خصوصیات مکانیکی بتن می شود تا اینکه غیر سازه ای شود. این مقاله شش مخلوط روبکریت ساختاری را بررسی می کند و خواص آن را پس از جایگزینی مورد بحث قرار می دهد. اسلامپ، چگالی، جذب آب، مقاومت فشاری برای مکعب ها و سیلندرها، ضریب ضربه، مقاومت خمشی، شکاف، مدول الاستیک و تنش در مقابل منحنی‌های کرنش آزمایش و مورد بحث قرار گرفتند. می توان نتیجه گرفت که اختلاط rubcrete پایدار علیرغم افت استحکام ناشی از فرآیند جایگزینی همچنان ساختاری دارند. استحکام کششی، فشاری و خمشی بتن به دلیل از بین رفتن پیوند بین ملات و لاستیک ها به ازای هر افزایش در مقادیر لاستیک به حداقل می رسد.