A Comparative Study on the Mechanical Properties of Normal and Rubberized Green Concrete

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Abstract The concrete industry is one of the main consumers of natural resources. On the other hand, one of today’s major environmental problems is non-decaying waste tires left in the environment. This study utilizes the waste tires in C-25 concrete grade and investigates its behavior with rebar. An experimental study was carried out on the basic mechanical properties of concrete. A modified concrete was prepared by replacing sand in concrete with rubber aggregate by varying the replacement proportion from 4% to 16% with an increment of 4% by volume. After having the mechanical property, an effective finite element model was developed in ANSYS workbench. The stress-strain diagram from the experiment was described by command and used as input data in ANSYS simulation to analyze and determine the impact of resistance and deformation of rubberized concrete. From the experiment, it was found that the optimal rubber improves the strain capacity and its stress-strain curve shows more nonlinear behavior than normal concrete (NC). From all percentages, 8% crumb rubber concrete (CRC8) shows best relative performance it improves impact resistance, energy absorption and ductility of concrete by decreasing the weight of the structure. At failure, crumb rubber concrete (CRC) exhibited more ductility with large ultimate deflection and more uniform crack distribution. The bond behavior of CRC8 with the deformed bar is only slightly lower than NC. ANSYS output result shows that the structural behavior like maximum stress is comparable except the reduction in compressive strength. The results of FEA positively verified that rubberized concrete could absorb more impact energy before failure.

Keywords: crumb rubber, rubberized concrete, structural behavior

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1. Introduction

The utilization of concrete is growing in the industry of construction and concrete production requires a significant amount of limited natural resources like sand. The demand for building materials has risen to meet the demand for construction companies and suitable virgin materials will become increasingly scarce [1]. As concrete is the most widely used material in the world, there is an environmentally friendly alternative that is green concrete. Green concrete has nothing to do with color. It is concrete made with waste material or recycled material and uses less energy in its production and reduce environmental impact. The use of recycled tire rubber as partial aggregate in concrete may have great potential to positively affect the property of concrete in a wide [2]. Due to its remarkable properties of dumping, rubber concrete can be used in several places where the durability or deformation has importance [3]. Scrap tires are usually considered in concrete mixtures in three main categories, such as chipped, crumb and ground rubber [4]. Then again, the brittle nature of concrete and its low loading toughness contrasted with different materials has provoked the utilization of waste tire particles as solid total for conceivable cure or diminish these negative properties because elastic and deformable tire rubber particles could improve concrete properties [5]. The substitution of various solid components of the solid waste stream for virgin materials such as sand is a task of high priority in making concrete more environmentally friendly. Therefore, it is better to utilize our natural resources at a rate no greater than at which they can be generated [6].

In this study, waste tire crumb rubber was used partially for sand to investigate the possibility of using local crumb rubber concrete for the structural application using experimental test and modeling its structural behavior in finite element method, because the composite action of a structural element of modified concrete requires bond behavior analysis. In addition to this most numerical nonlinear analysis of bond-slip is typically neglected and a perfect connection between concrete and reinforcement is assumed. Its negligence is conducted with a poor structural response. To maintain composite action transfer of load between the steel and concrete is required. The
2. Materials and Methods

2.1. Materials Used

Materials used for this study were a beam, standard cube and cylindrical mold of concrete, crumb waste rubber, natural aggregate, washed sand, ordinary Portland cement, water, mixing and placing equipment. Also, mixer, vibrator, tensile and compressive strength machine have been used. The rubber percentage, size, source, pre-treatment, and others are factors that affect the rubberized concrete strength. The recycled crumb rubber from waste tire production was supplied by Horizon Addis and Ethiopian waste tire saving plant. The crumb rubber creates in the area of the steel-concrete interface [7].

Crumb rubber is ground tire rubber from which the fabric and steel belts have been removed. It has granular texture and range in size from very fine powder to sand-sized particles. It is recovered from scrap tires using both thermal and or mechanical processing techniques. The crumb rubber utilized in this research obtained from both companies.

2.2. Experimental Procedure

To avoid the tendency towards segregation or bleeding as well as to increase the adhesion between the cement matrix and crumb rubber particles pre-treatment was required. In this research, the 50% concentrated Hydrogen peroxide (H2O2) solution was used to soak the recycled rubber up to 40 minutes and constant stirring was required to ensure the rubber particles were completely soaked in the solution. The pre-treated crumb rubber was washed and rinsed thoroughly with tap water until the water showed neutral with the pH indicator [8]. After that, it was air-dried and then placed in the oven to remove adhering moisture content.

According to ASTM 136, ASTM C 29/C 29M, ASTM C 29/C 29M, ASTM C 29/C 29M and BS standard procedure the test conducted on fine aggregate were sieve analysis or gradation, water absorption, specific gravity, moisture content, unit weight and silt content [9].

| Table 1. Summarized Test Results for Fine Aggregates |
|-----------------------------------------------|
| No   | Physical Test for Fine Aggregates | Results |
| 1    | Silt Content | Before Washing | 5.5% |
|      |              | After Washing  | 4.25% |
| 2    | Fineness Modulus |          | 3.06 |
| 3    | Unit Weight | Compacted Unit Weight | 1428.25 kg/m³ |
|      |              | Loose Unit Weight | 1223.02 kg/m³ |
| 4    | Specific Gravity | Bulk Specific Gravity | 2.45 |
|      |              | Bulk Specific Gravity(SSD) | 2.49 |
|      |              | Apparent Specific Gravity | 2.49 |
| 5    | Absorption Capacity |                       | 0.61% |
| 6    | Moisture Content |                           | 1.01% |

Coarse aggregate of a normal weight and with a maximum diameter of 20 mm were used. For coarse aggregate, the following physical tests based on ASTM 136, ASTM C 127, ASTM C 29/C 29M, ASTM C-131 and BS Standard procedures; (Sieve analysis, water absorption, specific gravity, moisture content and unit weight) are performed on the properties of aggregate [9].

| Table 2. Summarized Test Results for Coarse Aggregate |
|-----------------------------------------------|
| No   | Physical Test for Coarse Aggregates | Results |
| 1    | Unit Weight | Compacted Unit Weight | 1615.35 kg/m³ |
|      |              | Loose Unit Weight | 1499.75 kg/m³ |
| 2    | Specific Gravity | Bulk Specific Gravity | 2.78 |
|      |              | Bulk Specific Gravity(SSD) | 2.96 |
|      |              | Apparent Specific Gravity | 3.37 |
| 3    | Absorption Capacity |                       | 6.25% |
| 4    | Moisture Content |                           | 1.06% |

The minimum desired strength is 25 MPa with a ratio of proportion (cement, sand and aggregate 1:2.2:2.7). The maximum water-cement ratio is 0.5 and the concrete is non-air entrained as per ACI code for 20mm aggregate size and also the total density of water is 185 kg/m³. Based on the dry weight basis the mass of ingredients per cubic meter of concrete is (cement: 370 kg, water: 185 kg, coarse aggregate: 993.6 kg and sand: 806.4 kg). The average density of crumb rubber varies according to the size of the shreds but can be expected to between 390 kg/m³ to 535 kg/m³. The mean value of the density is 462.5 kg/m³. The absolute volume mix constituents per cubic meter of concrete based on volume is; cement 0.1175 m³, water 0.185 m³, coarse aggregate 0.3301 m³, air 0.02 m³ and fine aggregate 0.3474 m³. The dry mass of sand can be obtained by multiplying the volume of sand and specific gravity. The specific gravity of crumb rubber is 1.15 and the rubber replaced instead of sand in volume is as shown below.

| Table 3. Amount of Crumb Rubber with Sand in Volume |
|-----------------------------------------------|
| Percentages | 0% | 4% | 8% | 12% | 16% |
| Crumb rubber(m³) | 0 | 0.0139 | 0.0278 | 0.0417 | 0.0556 |
| Crumb rubber(m³) | 0 | 15.98 | 31.97 | 47.96 | 63.94 |
| Sand (m³) | 0.3474 | 0.3335 | 0.3196 | 0.3057 | 0.2918 |

In the case of rubber-concrete mixing, the crumb rubber particles were uniformly pre-mixed with the cement to form a rubber-cement dry mix. This helps to improve the interface bond strength between the cement matrix and the rubber particles in the mixing and after mixing. The density or unit weight property of the fresh concrete was investigated by using a cylindrical mold with a constant weight of 4.66kg and volume 0.00687m³. During the cast of concrete, compaction was executed in three layers with 25 blows for each layer. For each percentage of mix, six cube molds having a size (150 mm x 150 mm x 150 mm), six cylinders of 100 mm diameter and 200 mm height and six beam molds having a size (100 mm x 100 mm x 500 mm) were cast for compressive, tensile and flexural strength test. The specimens were detached from the molds and cured in a water bath at a temperature of 23±1°C until the testing age was reached 7 days and
28 days. The cube was centrally placed between the plates of a compression-testing machine loading rate for 150 mm cube was 140 kg/cm² per minute until the specimen fails. For the tensile test, apply the load continuously and without shock, at a constant rate within the range 690 to 1380 KN/m²/min splitting tensile stress until failure of the specimen [10].

3. Finite Element Modeling of Reinforced Rubberized Beam Element

Finite element analysis is used for predicting how a structure reacts to the real external force. It shows whether a structure will deform, crack, or fail. It works by meshing the structure in too many finite elements; add up all the individual behaviors to predict the behavior of the actual object. That is based on the idea of dividing a complex object into manageable pieces (element with the node) [11]. In the analysis of structural members or simple geometries, the development of a refined model that can describe more complex phenomena is essential. Such complex phenomena including various kinds of non-linearity are arising either from the material properties or geometry. CRC stands for crumb rubber concrete and NC stands for Normal concrete.

3.1. Theoretical Bond Stress-Slip Models

The bond behaviors of reinforced concrete members have a great impact on the performance of structural response because they have unequal mechanical and physical features. Understanding of the load transfer, damage patterns, and deformation associated with bond response is included in the mechanism of the bond. The Eligehausen equation that replaces peak bond strength by pull-out test results can effectively predict the local bond stress-slip relationship between rebar and concrete [12]. Therefore, bond interaction between steel and concrete (which is also the property of the cohesive element) is simulated through accepted Eligehausen empirical equations [12].

\[
\tau_1 = 2.5 f'_c^{1/2} \quad (3.1)
\]

\[
\tau = \tau_1 \left( \frac{s}{s_1} \right) \text{ when } 0 \leq s \leq s_1 \quad (3.2)
\]

\[
\tau = \tau_1 \text{ when } s_1 \leq s \leq s_2 \quad (3.3)
\]

\[
\tau = \frac{\tau_3 - \tau_1}{s_3 - s_2} s + \frac{\tau_1 s_1 - \tau_3 s_2}{s_3 - s_2} \text{ when } s_2 \leq s \leq s_3 \quad (3.4)
\]

\[
\tau = \tau_3 \text{ when } s \geq s_3 \quad (3.5)
\]

Where \( f'_c \) is concrete compressive strength in MPa, \( \alpha \) is experimental constant, \( s \) is slip value, \( \tau \) is Bond stress in MPa and \( \tau_1 \) is the maximum bond stress in MPa. For confined concrete with ribbed bars and under good bond condition, the coefficient \( \alpha = 0.4 \) and \( \tau_1 = 0.4 f'_c \). The slip value in the above equation are \( S_1 = 1 \text{mm}, S_2 = 3 \text{mm} \) and the clear rib spacing of the 16mm diameter deformed bar \( S_3 = 8 \text{mm} \). It should be noted that the local bond stress-slip relationship is strongly nonlinear.

To obtain the maximum bond stress the experimental result on mechanical behavior such as compression, tensile and flexural tests was taken as input material properties. The Stiffness value in the shear direction (calculated from the initial slope of the bond-slip curve) for NC and CRC8 is 64.27MPa/mm and 56.24 MPa/mm respectively. The initial tangent modules indicate the elastic rigidity of a concrete material. The maximum bond strength for NC \( (\tau_{\text{max}} = 14.14\text{MPa}) \) and CRC8 \( (\tau_{\text{max}} = 13.22\text{MPa}) \). CRC 8 stands for crumb rubber concrete with 8% replacement.

The analytical prediction of deformed bars embedded in an optimized mix of CRC8 has less bond performance compare to NC. One reason for decreasing bond performance is problems with the bond between cement matrix and rubber particles.

Figure 1. Comparison of Bond Stress-slip Relationship Between NC and CRC8

3.2. Rubberized Concrete Stress-Strain Curve

A complete stress-strain influences the accuracy of the analytical results of the ultimate stress distribution in ductility and load-carrying capacity [13]. The stress-strain result of CRC varied due to different rubber particle sizes, rubber source, and percentage. The focus of this study was the effect of rubber content on the compressive behavior of crumb rubber concrete subjected to uniaxial compression load. Both strain and the axial load was measured from the stress-strain experimental test. From the experiment, it was found that the crumb rubber improves the post ultimate stress-strain curve and strain capacity which have a positive effect on post ultimate ductility capacity.

Figure 2. Stress-strain Behavior of Rubberized Concrete for 7 days

The descending shape of the curve and its part of the area represents the plastic deformation ability of concrete, it also indicates the residual strength of material after the
peak stresses. With consideration of rubber effect, the best fit model is useful in the analysis and designing of crumb rubber concrete as input for the finite element model.

The bond behavior and stress-strain relationship of both NC and CRC8 were used as input parameters using the command in this simulation. Then again, mesh refinement is a key step in validating any finite element model and gaining confidence in the model and the result. To describe the deformation and stress gradients the mesh size should be small enough to describe more accurately [14]. The reinforced concrete beam material was modeled by 8 nodes solid element (SOLD65) with three degrees of freedom and translation in x, y and z direction. The modeling of steel reinforcement bar was as a line body rod element by taking the discrete engineering models Spar Link Element (LINK8 for flexural behavior analysis and LINK180 for impact resistance analysis) a line reinforcement bar. LINK8 and LINK180 are can deform plastically and have two points with three degree of freedom at a point in the x, y and z direction. Instead of considering perfect bond and rebar as axial rod element; it was assumed to have the analytical bond stress slip graph between concrete and rebar as input in the FE model.

### 3.3. Flexural Behavior of Reinforced NC and CRC Beam Element

Two-point loading flexural tests were conducted experimentally for both NC and CRC8 beams. For this analysis, a model is developed in Finite element software ANSYS workbench to characterize the response of a volume of bond zone material with rebar subjected to loading.

### 3.4. Impact Resistance of Reinforced NC and CRC Beam Element

Explicit Dynamics simulate the response of structures to loadings, material deformation, and failure. It is a high-speed analysis solver used to calculate the state of a given system at a different time; it is not a slow compression test of the beam like the implicit (static) rather accidental impact of the reinforced concrete beam with instant velocity. The time step for this solver is extremely small due to material sound speed and it is also a function of characteristic element length and material sound speed [14]. In this research, a numerical example was carried out to investigate and compare the impact resistance of both NC and modified concrete with rebar.

To study the impact behavior of reinforced CRC8 a model was developed in ANSYS workbench; A fixed supported beam of rectangular cross section 0.25m x 0.4m and having 1m span length was subjected to 12.52kg impact load and hit the concrete block with 8m/s at the mid span. The concrete was modeled as 3D solid element.

### Table 4. Material properties for the numerical analysis

| Properties of Reinforcement Bar | Properties of Concrete | NC | CRC8 |
|---------------------------------|------------------------|----|------|
| Modulus of Elasticity           | 200 GPa                | 32MPa | 28MPa |
| Yield Strength                  | 460 MPa                | 3.2MPa | 2.8MPa |
| Steel Poisson’s Coef.           | 0.3                    | Flexural strength |
| Thermal Expansion Coef.         | 10x10^-6/°C            | Modulus of Elasticity | 32.5GPa | 29GPa |
| Density                         | 7850 kg/m^3            | Poissons Coefficient | 0.2 | 0.2 |
| Bar Diameter                    | 12mm                   | |

Figure 3. Fixed and simply supported schematic of boundary condition, uniform and concentrated load
The size of the mesh used for the analysis of impact resistance in the concrete block was 15mm. In the analysis setting of erosion control, the required input to ANSYS was to delete the elements when they fail. The total deformation and damage of elements are also the required outputs. In the output control, the resulting number of points was changed from 20 to 50 to get a bit higher quality number of result points at the end. The reinforced CRC8 and NC have 6-12mm longitudinal reinforcement and 6mm diameter transverse stirrups as shown in the figure below. The reinforcement bar was modeled using a line body inside the modified concrete.

4. Results and Discussions

4.1. Physical Properties of Aggregate

The grading curve for the coarse aggregate falls within the upper and lower limit of the grading requirement.
The result of the particle size distribution for natural sand and artificial sand (crumb rubber) is illustrated below. From the experimental work conducted the crumb rubber sizes are closer to the lower limit of the standard as compared to fine aggregate. The fineness modulus of natural fine aggregate and crumb rubber was 3.06 and 3.35 respectively. Depending on their size the samples can be classified as coarse and medium sand.

![Figure 7. Fine aggregate and crumb rubber gradation chart](image)

### 4.2. Workability Test of Fresh Rubberized Concrete

During the fresh or plastic state of concrete mix, a slump test was executed to measure the workability of concrete. In the compaction factor test, it was shown that the addition of crumb rubber reduced the workability of fresh concrete. The workability and consistency of fresh crumb rubber concrete decrease with increasing rubber replacement percentage. The possible reason for decreased workability and consistency is the incorporation of crumb rubber has changed the aggregate gradation which influences the cement and water requirement. Because the shape and surface characteristics of aggregate particles and its grading are factors that affect workability and consistency.

### 4.3. Mechanical Tests on Hardened Concrete

The density of all specimens was calculated based on the average weight of the 7 days and 28 days the age of curing. The weight strength reduction percentage rate was from 2.05% to 6.7%.

![Figure 8. Effect of crumb rubber on workability using compaction factor](image)

![Figure 9. Unit weight versus crumb rubber percentage](image)
It was shown that rubberized concrete reduces a dead load of concrete structure, this results in significant benefit in terms of the load-bearing element of small cross-section and also the total mass of materials to be handled is reduced. This allows the structural designer to reduce the size of the beam, column, and other load-bearing structural members because of the reduction of overall weight results in saving structural frames. Therefore, using optimal crumb rubber concrete is advantageous than NC when less weight is required.

The compressive test was conducted for all mixes at the age of 7th and 28th day of curing after the concrete specimens were cast.

At the age of 28 days compressive strength, starting from CRC4 to CRC16 the strength reduction rate increased from 6.08% to 35.16%. Among the different percentages of rubber, the compressive strength of CRC8 was about 18.25% and 13.07% lower than NC at the age of 7th and 28th day respectively. From this particular research, no matter what rubber grading was used gradual reduction of compressive strength for rubberized concrete was observed with the rubber percentage increase and also the optimal rubberized concrete has been CRC8. Besides other parameters, the possible reason for strength reduction was, the flexible nature of tire rubber can cause a problem in the mixture as a result stress concentration is more severe in rubberized concrete than ordinary concrete.

The introduction of crumb rubber makes concrete more non-homogeneous material; as a result, stress distribution will not be uniform like NC. In addition to this compressive strength is highly dependent on water-cement ratio and quality of ingredients. During the failure stage, NC exhibited brittle failure while the CRC specimens remained intact (did not shatter) after failure compares to a conventional concrete mix. Rubberized concrete showed a more ductile failure mode under uniaxial compression loading.

In the tensile strength test, slight strength reduction was shown in CRC4 and CRC8, however, from CRC12 to CRC16 the tensile strength showed a decreasing trend with increasing rubber replacement percentage. From the average tensile strength test results, it indicates that the tensile strength of CRC 8 had better performance than the other percentages. The strength difference from NC was only -2.7%. For the other percentage, the strength difference varies from 9.35% for CRC4 up to 28.48 % for CRC16. The rubberized concrete specimen exhibited higher plastic energy absorbing capacity because no brittle failure was observed in both compressive and tensile tests. There was also a reduction in flexural strength of rubberized concrete. It is not surprising that it follows a similar trend like compressive strength but its reduction rate is different, which is similar to tensile strength. During flexural test failure, compared to the control mix the crumb rubber concrete shows a more ductile mode of failure. Among the different percentage, it shows a relative increment of flexural strength, this might be due to the observed increment of ductility.

Table 5. Average compressive load and the corresponding compressive stress

| Crumb Rubber(%) | W/C Ratio | 7th Day | 28th Day |
|-----------------|-----------|---------|----------|
|                 |           | Failure Load(KN) | Compressive Strength(MPa) | Strength Difference from NC(%) | Failure Load(KN) | Compressive Strength(MPa) | Strength Difference from NC(%) |
| 0               | 0.5       | 559.75 | 24.87 | 728.03 | 32.36 |
| 4               | 0.5       | 545.5 | 24.35 | -2.09 | 683.98 | 30.39 | -6.08 |
| 8               | 0.5       | 457.56 | 20.33 | -18.25 | 632.93 | 28.13 | -13.07 |
| 12              | 0.5       | 412.43 | 18.12 | -27.14 | 535.44 | 23.86 | -26.26 |
| 16              | 0.5       | 366.12 | 16.19 | -33.17 | 471.99 | 20.98 | -35.16 |

Figure 11. Modulus of elasticity with crumb rubber percentage
4.4. Modulus of Elasticity

In consideration of rubber replacement, Aslani (2017) proposed a numerical equation to express the relationship between modulus of elasticity and rubber percentage. The equation of Aslani was obtained from the regression analysis of testing results with uniform size of graded rubber [13].

\[
E_{CRC} = E_C \left( \frac{1}{\alpha e^{\beta r}} \right) \quad 2.5 \leq r \leq 100
\]

Where: \( E_{CRC} \) is the modulus of elasticity of rubberized concrete at rubber percentage of \( r \); \( \beta r \) is rubber content as a percentage and \( E_C \) is the modulus of elasticity of NC.

The modulus of elasticity coefficients taken as \( \alpha = 1.05 \) and \( \beta = 0.0168 \). Figure 11 shows the calculated modulus of elasticity change with crumb rubber percentages, together with Aslani’s (2017) proposed model. The data for Aslani (2016) was also based on a broad range of experimental results gathered from the literature.

4.5. Finite Element Analysis Result: Flexural Behavior of Reinforced NC and CRC8

To illustrate and compare the numerical simulation analysis and performance of rubberized concrete in the structural area; the investigation of flexural behavior of reinforced NC and CRC8 was carried out through ANSYS 3D modeling. Both the reinforcement bar and concrete were modeled as a 3D solid element.

Reinforced CRC8 subjected to concentrated load results in directional deformation and stress distribution in the NC and CRC8 beam at the ultimate deflection point. It can be seen that nearly 35% of the CRC8 beam was deflected more than the NC beam, which also verifies the good ductility of the CRC8 beam. Even if there is a significant difference in deflection, the stress capacity of the NC beam and CRC8 beam are close to each other. This is due to a very small compression zone exists inductile beam under flexure load.

The flexural behavior of CRC8 mainly depends on the directional deformation and stress distribution of the beam element, when it subjected to distributed load it is more stressed than NC similar to the concentrated loading but its magnitude is less. The figure below shows the directional deformation and stress distribution of reinforced NC and CRC8 beam at the ultimate deflection point. It was seen that almost 29% of the CRC8 beam deflected than that of the NC beam. The reinforced CRC8 beam exhibited more ductile with large deflection. In both cases (concentrated and distributed loading) the result of the beam showed that there is no bond-slip failure occurring along the span of the beam by inspection.

Figure 12. Deflection and Equivalent stress of CRC8 and NC
Figure 13. Directional deformation and Equivalent stress of reinforced CRC8 and NC

Figure below shows the reinforcement bar stress distribution in the rubberized concrete of the CRC8 beam at the ultimate deflection point.

It can be seen that approximately 30% of the steel rebar has yielded, this also verifies the good ductility of the CRC8 beam.

Figure 14. Stress distribution of embedded rebar in CRC8
4.6. Finite Element Analysis Result: Impact Resistance of Reinforced NC and CRC8

The numerical analysis focused on the dynamic advantage of rubberized concrete. As shown in Figure below the elements delete themselves when they fail.

![Figure 15. Total Deformation and damage of NC and CRC8](image)

The Reinforced CRC8 beam improves the impact resistance of structural components because fewer elements are failed in CRC8 than NC. 1 means the element has fail and 0 means completely intact (undamaged).

All of the results positively verified that the addition of crumb rubber in concrete could absorb more impact energy. The impact stresses and damage were reduced in rubberized concrete; this is due to its lesser elastic modulus and higher plastic energy absorption capacity of rubber particles. Due to the flexible nature of rubber with tolerable strength reduction, the rubberized concrete can increase the impact resistance of structural members. The addition of rubber to cement concrete improves the dynamic response and properties of concrete materials.

5. Conclusion and Recommendation

5.1. Conclusion

The results obtained from both laboratory testing and finite element methods are directed to the following conclusions.

The compressive strength gain of CRC from 7 days to 28 days was higher than the control mix, it was around 27.72%, and while for NC, it was 23.15%. From the experiment, it was found that the optimal rubber improved the strain capacity. The reduction rate of modulus of elasticity was lower than the compressive strength. The stress-strain curve of CRC shows more nonlinear behavior than NC. The failure of CRC occurs uniformly and doesn’t cause any separation in the specimen. Crack width and propagation velocity in CRC are lower than those of NC and also it shows the more ductile mode of failure.

From all percentages, CRC8 shows the best relative performance as a result using crumb rubber for the structural purpose up to the optimal percent (8%) may help to find the commercial potential for waste or recycled tire products to be used as an alternative material for sand in the concrete industry. It gives an average compressive strength of 28MPa which is higher than the minimum requirement. Because of the low specific gravity of crumb rubber, the unit weight of rubberized concrete decreases with an increased rubber replacement percentage.

The finite element analysis of Reinforced CRC8 results positively verified that the addition of rubber into concrete could absorb more impact energy before final failure or
damage. The bond behavior of CRC8 with a deformed bar is only slightly lower than that of NC. The ductility and resistance to the crack of CRC could make it suitable in a structure subjected to impact load.

In general, rubberized concrete can possess some superior characteristics. These include higher ductility, lightweight, improved resistance to cracks, improve impact resistance due to its flexible nature and lower modulus of elasticity. All of these findings indicate that there is a great potential for CRC to be used in the structural application at the same time helping to solve environmental problems caused by waste tires.

5.2. Recommendation

Based on this study, the following recommendations have been forwarded:

In this study only uniaxial compression was investigated however during practical application mostly due to boundary conditions from the surrounding, concrete is subjected to a biaxial and triaxial state of stress even to complex loadings like seismic loading. This also requires further investigation.

The interface between the cement concrete and crumb rubber particles is very important as a result microstructure investigation on CRC should be studied. On the other hand, the Eligauison model for bars in concrete with only short embedment length and confined concrete required more study for different reinforcement bars in rubberized concrete.

All these can provide a basis for further research on rubberized concrete and its potential application.

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