4th International Conference on Advances in Civil Engineering 2018 (ICACE 2018)
*19 –21 December 2018*
*CUET, Chittagong, Bangladesh*
*www.cuet.ac.bd*

# MECHANICAL PROPERTIES OF RUBBERIZED NORMAL WEIGHT AGGREGATE CONCRETE - AN EXPERIMENTAL STUDY

M. M. Kamal[1], S. K. Adhikary[2]& M. A. Islam[2*]

[1]*Department of Civil Engineering, Dhaka International University, Dhaka-1212, Bangladesh.*
*E-mail: mkrabbi13@gmail.com*
[2]*Departmentof Civil Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh.E-mail: sajal@ce.kuet.ac.bd;ashiq.civil13@gmail.com*[*]

**Corresponding Author*

**ABSTRACT**
In this study, an attempt is made to investigate mechanical properties of rubberized normal weight aggregate concrete, wherein rubber content is used as a volumetric replacement of coarse aggregate. The mechanical properties including compressive strength, splitting tensile strength, flexural strength and flexural toughness are tested in order to study the effect of rubber content on concrete strength. For experimental investigation, five batches of concrete specimens are prepared with 0%, 25%, 50%, 75% and 100% rubber contents. Cylindrical specimens are casted to investigate the compressive strength and the splitting tensile strength properties whereas beam specimens are prepared to study the flexural strength and the flexural toughness properties. Test results indicate that there is a significant reduction in the compressive, splitting tensile and flexural strengths of concrete with increasing rubber content. It is found that the compressive strength is reduced by 87% of initial strength with 100% rubber content whereas with the same rubber content, the splitting tensile and flexural strengths are decreased by 82% and 70% of initial strength, respectively. However, the flexural toughness of concrete is increased by 86% with 100% rubber content, which indicates such concrete could be adopted in special construction where vibration mitigation is a major concern.

Keywords: Rubberized normal weight aggregate concrete; Rubber content; Splitting tensile strength; Tire derived aggregated; Toughness.

## INTRODUCTION

Globally, the waste tires have been increasing with an alarming rate and nowadays is a major concern to the researchers and environmentalists. According to the Environmental Protection Agency (EPA), the annual production of scrap tires in the United States is about 289 Million (Miller and Tehrani, 2017). Recycling of rubber materials from waste tires has become a vital concern across the world. The closed loop recycling technique is regarded as the most appropriate practice for recycling waste materials. However, the closed loop technique of waste rubber cannot be applied in recycling process because of high cost associated with this processes of waste rubber materials (Taha and Nounu, 2009). So, waste rubber could be a suitable option to be used as the coarse aggregate in concrete.

Concrete is the single most widely used artificial material on the earth owing to its remarkable versatility as a construction material (Crow, 2008). Accordingly, the annual production of concrete exceeds about 2 Billion metric tons per year across the world. A major weakness of the concrete as a construction material is the harmful effects on the environment posed by the production of its components (Roskos et al., 2015). In Bangladesh, the generation of rubber waste has been substantially increased due to increase of use of rubber materials. Therefore, it is important to devise viable options in order to convert rubber wastes into resources for the sustainable development of the country.

The objective of this study was to investigate the mechanical properties of rubberized normal weight concrete. Rubberized normal weight aggregate concrete is a concrete prepared by using rubber (waste rubber material) as aggregate in the concrete mix. Numerous researches have been conducted since the early 1990s to study the rubberized normal weight aggregate concrete. Some studies have shown that an increase in rubber content enhances durability, while some investigations have found that compression strength is decreased with the increasing rubber content (Topçu, 1994; Ganjian et al, 2008; Zheng et al, 2008; Xue et al, 2013). Other common properties of concrete such as the splitting tensile strength (Li et al, 2004) and static flexural strength (Khatib et al, 1999) have also been found to decrease with the increased rubber content in the concrete. However, no studies have been found in the past to investigate several mechanical properties of the rubberized normal weight aggregate concrete including compressive strength, splitting tensile strength, flexural strength and flexural toughness. Therefore, an attempt has been made in this study to study the aforementioned mechanical properties of the rubberized normal weight aggregate concrete.

## MATERIALS AND METHODS

In this study, several mechanical properties of the rubberized normal weight aggregate concrete were investigated. This includes compressive, splitting tensile and flexural strengths, and flexural toughness properties. Test setup was developed according to the ASTM specifications for each of the aforementioned tests. Five batches of concrete mix were used, which contains 0%, 25%, 50%, 75%, and 100% of tire derived aggregate (TDA) as a volumetric replacement of coarse aggregate.

TDA was extracted from the auto-mobile's tyre and crumbled for using it as the coarse aggregate. It was found that TDA had specific gravity of 1.74 and unit weight of 652 kg/m$^3$. According to the ASTM C150 specification for using binding materials, Ordinary Portland Cement (OPC) was used in the current study. Black stone was used as the coarse aggregate with a specific gravity of 2.70 whereas Kushtia sand was used as the fine aggregate having a specific gravity of 2.52. The concrete mix was designed for a slump value of 100 mm, maximum aggregate size of 19 mm for 21 MPa of concrete with **a** water-cement (w/c) ratio of 0.48. The mixing ratio of concrete was 1:1.7:2.7 by weight whereas the ratio was 1:2:3 by volume.

Experimental set up to test mechanical properties of the rubberized normal weight aggregate concrete is shown in Fig 1. As can be seen from the figure, four tests (e.g., compressive, splitting tensile and flexural strength tests, and flexural toughness test) were undertaken in this study. The compressive strength test was performed according to the ASTM C39 standard test procedure. A total of 15 cylindrical samples (4" diameter x 8" height) were prepared with the aforementioned five different rubber contents (RC). Samples were kept in curing for 28 days before carrying out the test. The experimental set up for this test is shown in Fig 1a. For the splitting tensile strength test, the ASTM C496 standard test procedure was followed. Fig 1b shows the experimental set up for this test. A total of 15 cylindrical samples (4" diameter x 8" height) were made in this test with five different RC like the compressive strength test procedure. The specimens were also kept under curing for 28 days before performing the test.

In order to undertake the flexural strength test, 5 beam specimens (6" width x 6" height x 24" length) were casted for 5 different concrete mixes with different RC as indicated above starting from 0% to 100%. In this test, the ASTM C78 specifications were used. Samples were kept in curing for 28 days before undertaking the test. Samples were tested using the Universal Testing Machine (UTM). The experimental set up is shown in Fig 1c. In this test, 5 beam specimens were casted with the same specifications detailed in the flexural strength test. To perform this test, the ASTM C1018-97 standard test procedure was adopted. It is important to mention that this test calculation is based on an experiment for which deflection against load data are necessary. Accordingly, the same setup of the flexural strength test with dial gauge deflections were used in this test. The experimental set up for this test is shown in Fig 1d**.**


Figure 1. Experimental set up for (a) compressive strength test, (b) splitting tensile strength test, (c) flexural strength test, and (d) flexural toughness computation.

## RESULTS AND DISCUSSIONS

### *Compressive Strength Properties of Rubberized Normal Weight Aggregate Concrete*

The compressive strength test results indicate that there is a reduction in the compressive strength with the increasing rubber content, which is shown in Fig 2. It is seen from the figure that the strength reduction takes an exponential pattern for the rubberized normal weight aggregate concrete in the current study. The control mix (standard case with 0% rubber content) strength was found as 19.4 MPa, which is less than the estimated 21 MPa, decreased to 2.5 MPa for 100% replacement of coarse aggregate by the rubber content. The reason behind this could be the fact that the surfaces of the rubber aggregate were not rough enough to create proper bonding with the binding materials.

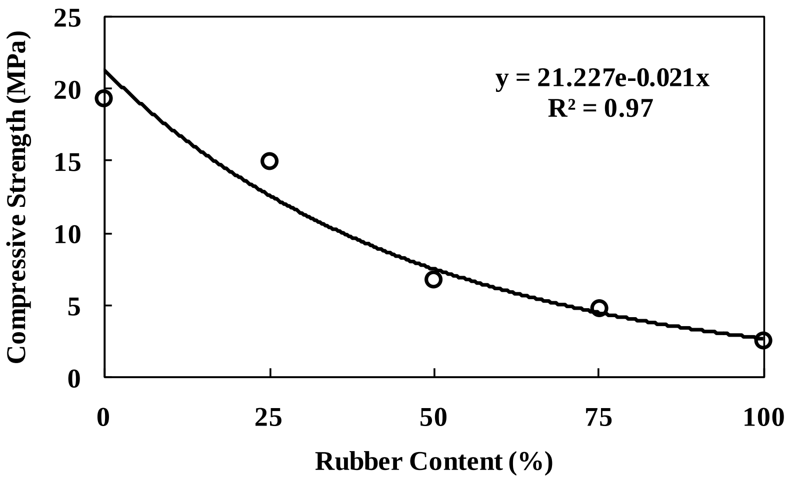


Figure 2. The compressive strength of rubberized normal weight aggregate concrete at 28 days

Failure mode of the test specimens was also investigated for all the replaced quantity of rubber. Three different types of failure patterns were observed following the ASTM C 39 specification to identify the failures. The observed failure patterns were shear, cone and shear, and columnar. For the control mix, failure occurred with taking sufficient time. However, failure occurred with less time compared to the control mix with the increasing rubber content in the concrete mix.

***Splitting Tensile Strength Properties of Rubberized Normal Weight Aggregate Concrete***

In this test procedure, load was applied at the perimeter of concrete cylinder block. It was found from the test results that the splitting tensile strength value for the control mix (standard case with 0% rubber content) was 2.60 MPa. However, the strength values were decreased exponentially with the increasing rubber content. Fig 3 shows the variation of splitting tensile strength for the rubberized normal weight concrete for different rubber contents. As can be seen from the figure, the strength reduction is exponential with the increasing rubber content. It is important to note that the characteristic splitting-tensile mode of failure was observed for all specimens in this test, which was followed by a single crack formed down the centre of the cylinder prior to failure. It is worth mentioning that with the reduction in splitting tensile strength, failures were more rapid compared to the control mix but the failure was occurred similarly at the middle of the cylindrical specimens.

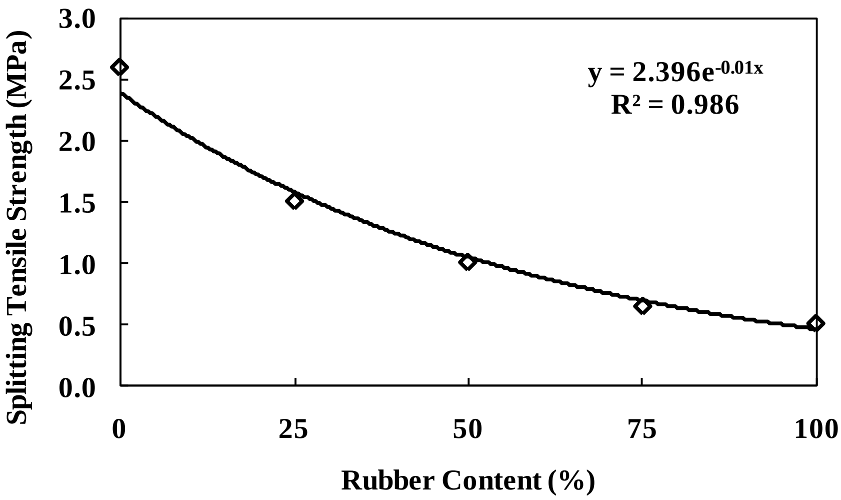


Figure 3. The splitting tensile strength of rubberized normal weight aggregate concrete at 28 days

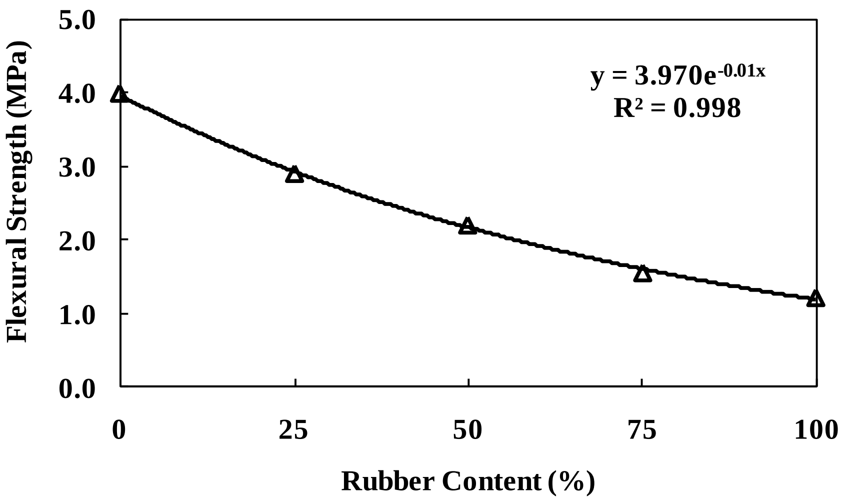


Figure 4. The flexural strength of rubberized normal weight aggregate concrete at 28 days

***Flexural Strength Properties of Rubberized Normal Weight Aggregate Concrete***

In order to investigate the flexural strength behaviour of the rubberized normal weight concrete, the specimens were tested under a simply supported loading orientation. The test results indicated that the flexural strength for the control mix was 4 MPa. The flexural strength obtained for the rubberized normal weight concrete with different rubber contents is shown in Fig 4. The figure reveals that the flexural strength also decreases with the increasing rubber content in the rubberized normal weight concrete and the strength reduction follows an exponential pattern. The reason could be the loose bonding between the aggregates due to inadequate roughness of the aggregates.

***Flexural Toughness Properties of Rubberized Normal Weight Aggregate Concrete***

Toughness usually refers to the ability to absorb energy comes from the external sources. Toughness is often represented by an index named Toughness Index. Toughness Index can be defined as the ratio of area under load-deflection curve up to 3.0 times first crack deflection to the area under load-deflection curve up to first crack deflection, which is often noted as $I_5$ (Miller and Tehrani, 2017). Fig 5 shows the variation of Toughness Index for different rubber contents. As can be seen from the figure, initially after an unexpected slight decrease in index value from 7.41 for 0% to 7.31 for 25%, the values are increasing with the increasing rubber content in the rubberized normal weight concrete. The noticeable fact is that the index value is the highest for 100% coarse aggregate replacement by the rubber content in rubberized normal weight concrete. The toughness index value for 100% rubber content was found as 13.8. This gives an important insight regarding the potential utilization of the rubberized normal weight concrete for the cases where shock absorption is more important rather than the concrete strength.

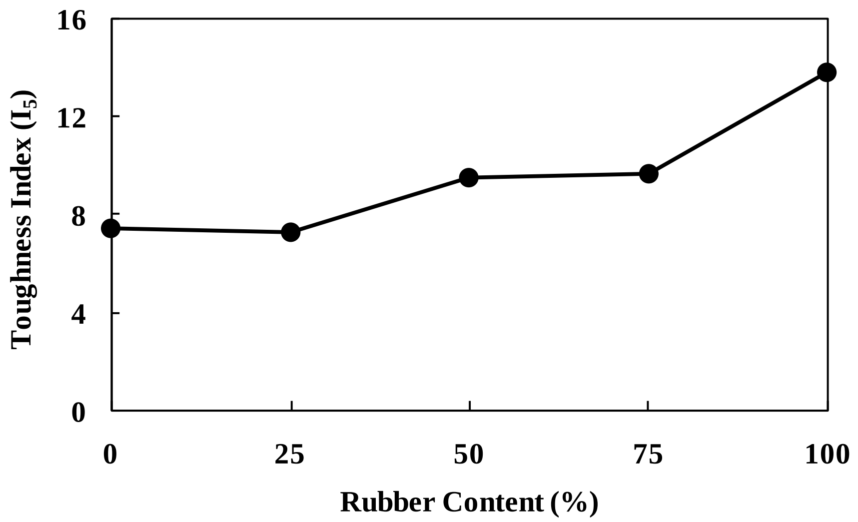


Figure 5. The flexural toughness of rubberized normal weight aggregate concrete at 28 days.

**CONCLUSIONS**

The conclusions and specific findings of the research are summarized as follows:

- Rubber reduces the compressive strength, splitting tensile strength and flexural strength up to 87%, 81.7% and 70%, respectively for 100% rubber content with respect to normal concrete (standard case with 0% rubber content as a volumetric replacement of coarse aggregate).
- Most impressive part of this study is that there is an increase in the flexural toughness with increasing rubber content in the concrete mix. It was found that rubber increases the flexural toughness by 28.9%, 31%, and 86% for a rubber content of 50%, 75%, and 100%, respectively. Increased flexural toughness demonstrates that the energy absorbing capacity of concrete increases with increasing rubber content.
- The results of the current study suggest that the rubberized normal weight aggregate concrete could be used for applications where absorption of excessive energy or mitigation of vibration is a key concern at high rubber replacement values rather than achieving higher strength.

**REFERENCES**

Crow, JM. 2008. The concrete conundrum. *Chem. World*, 5(3): 62–66.

Ganjian, E; Khorami, M and Maghsoudi, AA. 2008. Scrap-tyre-rubber replacement for aggregate and filler in concrete. *Constr. Build. Mater.*, 23(5): 1828–1836.

Khatib, ZK and Bayomy, FM. 1999. Rubberized Portland cement concrete. *J. Mater. Civ. Eng.*, 11(3): 206–213.

Li, G; Garrick, G; Eggers, J; Abadie, C; Stubblefield, MA and Pang, SS. 2004. Waste tire fiber modified concrete. *J. Compos. Part B: Eng.*, 35(4): 305–312.

Miller, N. M and Tehrani, F. M. 2017. Mechanical properties of rubberized lightweight aggregate concrete. *Constr. Build. Mater.*, 147: 264–271.

Roskos, C; White, T and Berry, M. 2015. Structural performance of self-cementitious fly ash concrete with glass aggregates. *J. Struct. Eng.*, 141(3): B4014010-1-10.

Taha, B and Nounu, G. 2009. Utilizing waste recycled glass as sand/ cement replacement in concrete. *J. Mater. Civ. Eng.*, 21(12): 709-721. DOI: 10.1061/(ASCE)0899-1561 (2009)21:12(709).

Topçu, IB. 1994. The properties of rubberized concretes. *Cement Conc.. Res.*, 25(2): 304–310.

Xue, J and Shinozuka, M. 2013. Rubberized concrete: a green structural material with enhanced energy-dissipation capability. *Constr. Build. Mater.*, 42: 196–204.

Zheng, L; Huo, XS and Yuan, Y. 2008. Strength, modulus of elasticity, and brittleness index of rubberized concrete. *J. Mater. Civ. Eng.*, 20(11): 692–699.