Challenge Journal of Concrete Research Letters

Research Article

Mechanical behavior investigation of rubberized concrete barriers in impact load

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ABSTRACT

Approximately 1.5 million waste tires are produced annually. Waste tires in landfills and stocks cause toxic chemicals to pollute the soil and cause major fires. Waste tires are a global environmental problem. This problem gave an idea of recycling of waste tires instead of landfills and stocks. In this paper, an experimental study is conducted to review the behavior under impact load of rubberized concrete with conventional concrete. Three different mixes were made by adding crumb rubber (0%, 5% and 10%) by volume to the concrete. Nine cantilever column specimens of three type cross section (10x10, 15x15 and 20x20 cm2) were used to investigate the behavior under impact load. The specimens with higher rubberized concrete have longer impact load duration at the initial peak point. Specimens with rubber content become much flexible than normal specimens. Furthermore, the damage level of columns is greater with increasing rubber content. Therefore, the specimens with higher rubberized concrete absorb more impact energy. The barriers with higher rubber content minimize injury and demise when an accidental impact happens. Using concrete with rubber content reduces costs and produces an environmentally sustainable solution.

ARTICLE INFO

Article history:
Received 27 May 2022
Revised 25 June 2022
Accepted 13 July 2022

Keywords:
Waste tire
Impact load
Rubberized concrete
Reinforced barrier

1. Introduction

Parallel to the quickly increasing traffic opportunities and traffic demand global in the last hundred years; because of traffic accidents, financial and health losses are rapidly increasing day by day, so, leading scientists to take some preventions to resolve the issue. One of these preventions is the roadside concrete barrier, which is expressed as a wayside security (Apak et al. 2021). Wayside security is one of the significant topic of highway systems due to its important ratio of high-seriousness accident. Roadside rigid barriers have an important role in decreasing the collision severity and rescuing more people on highway but prefer an unsuitable roadside barrier could reduce roadside barriers' performance (Molan et al. 2018). Therefore, researchers are researching for barriers that will reduce the impact load in accidents.

Collection of waste tire is later increased to dangerous grades. Tire waste is one of them that create significant ecological issues because of the increment and many variations of modern universal. Therefore, recycling waste tire rubber in the form of aggregates as complementary structure material is beneficial (Siddika 2019). In addition, waste tires cause important health and ecological pollution if not recycled. More and more, recycling waste tires into structure engineering utilizations, especially into concrete, has been wining interests (Shu 2013). Thus, this problem gave an idea of recycling of waste tires instead of landfills and stocks.

Behavior under static load of rubberized concrete with conventional concrete has been tested by many researchers. According to Youssf et al. (2015) crumbed rubber in the concrete beam improved the hysteretic damping ratio and energy dissipation by 13% and 150%. On the other hand, it reduced the column viscous damping ratio by 49% checked to a normal concrete column. Alasmari et al. 2019 investigated the mechanical properties of conventional beams with rubberized hybrid beams. The experimental results determined develop-

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ISSN: 2548-0928 / DOI: https://doi.org/10.20528/cjcrl.2022.03.002

ments when the hybrid concrete beams were used in most cases such as collapse pattern, capacity load, ductility, stiffness and stress. The deflection capacity of rubberized concrete beams with conventional concrete beams have been researched by Hassanli et al. (2017). The experimental result found that an increment from 7.7% to 27.9% was determined in the deflection capacity of the rubberized concrete beam checked with the beam with conventional concrete beam. According to Vadivel et al. (2010) the flexural strength comparison in both the grades (M20 and M25) indicate that 2%, 4% and 6% replacements behave exceptionally well and show higher strength than the conventional concrete.

On the other hand, other studies focused on the mechanical properties of rubberized concrete with conventional concrete in impact load. A study by Al-Tayeb et al. (2013) investigated mechanical behavior of rubberized concrete in static, dynamic and impact load by compare. The bending load-flexibility attitude was examined for the conventional and hybrid beams (double layer beam with rubberized (10% and 20% replacements by volume) top and normal bottom), under static and impact loads. Specimens (size 50 mm _ 100 mm _ 400 mm) were loaded to collapse in a drop-mass impact vehicle by dropping a 20 N mass from elevation 300 mm to the center of a simply supported specimen, and the static load test were performed with same beams. The using of crumbed rubber in concrete beam increases flexural impact feature of the specimen while dynamic loading crosschecked to the static loading. In addition the adding of crumbed rubber increased the toughness and flexibility capability of the conventional beam. The effect of maximum impact force and impact duration of rubberized concrete with conventional concrete in accident, have been researched by Pham et al. (2018). The outcome of experiment have shown that rubberized concrete quite decreased the capacity impact force of up to 50% and increased the impact time. These features make crumbed rubber in concrete an encouraging materiel for safety construction and especially for future structures of inflexible roadside barriers. Crumbed rubber in concrete decreased the capacity impact force so that it delivered a lower force to roadside barriers as well as a lower rebound force, which is desirable for conservation of voyagers in an accident. According to Abdelmonem et al. (2019) an obvious decrease of approximately up to 50% in compressive, tensile, and flexural strength was detected with increasing the crumbed rubber up to 30%. The crumbed rubber in concrete beam mixes displayed great attitude in salt water. The rubberized concrete also had up to 83% higher impact durability checked to the conventional concrete.

The above studies concluded that rubberized concrete has higher energy absorption, hysteretic damping ratio, impact duration, toughness, deformation ability, and good behavior in seawater but lower compressive, tensile and flexural strength, maximum impact force viscous damping ratio than the corresponding conventional concrete.

The review of literature reveals that there has been no work carried out on rubberized cantilever concrete under impact loading. Therefore, in this paper an experimental study is conducted to review the behavior under impact load of rubberized concrete cantilever column with conventional concrete.

2. Experimental Study

2.1. Materials

Three types of rubberized concrete mixed (%0, %5 and %10) were used in casting concrete barrier specimens. The conventional concrete had the compressive strength of 30 MPa. The crumb rubber was manufactured by waste tire. Crumb rubber added to the concrete mix are shown in Fig 1. Rubber at 5% and 10% were added to mix of the rubberized concrete. All the collected experimental result were gained with the help of LabView SignalExpress program by National Instruments throughout the experimental study. Moreover all the collected data refined with the help of DIAdem program by National Instruments.

Fig. 1. 2-3 mm diameter crumbed rubber.

2.2. Method and tests

2.2.1. Test specimens

Table 1 shows the test specimens and their properties used in this study. A total of 9 specimens with three types of cross-section area (10x10, 15x15 and 20x20 cm^2) were produced. 0.5% percentage reinforcement was placed in the tension zone of the cantilever specimen. Three concrete mixes (conventional concrete, 5% rubber concrete and 10% rubber concrete) were planned to investigate the effects of the amount of rubberized concrete. Fig. 2 shows the production of specimens in the laboratory.

2.2.2. Experimental setup and procedure

Fig. 3 displays the drop weight machine, which was produced to examine the impact load test of specimen. After the weight used for the impact test is released, it moves on the rails and falls on the specimen. In this study, experiments were carried out for all samples with 84 kg impact load and 40 cm drop height. Fig. 3 shows the accelerometers and load cell. Two accelerometers were placed on the right and left side surfaces of the cantilever specimen. The load cell with plates was placed on the upper surface of the cantilever sample. Fig. 3 shows the support assembly of the experimental setup. The specimen was supported from two points using plates and anchors. These two supports caused the reinforced concrete specimen to act as a cantilever.

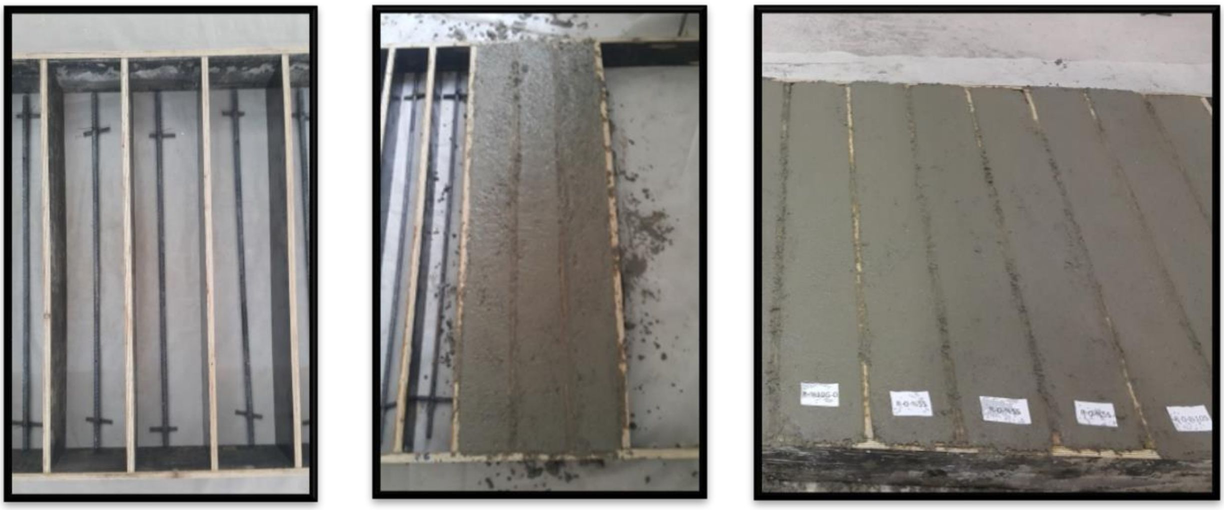

Fig. 2. Production of specimens in the laboratory.

Fig. 3. Experimental setup.

Table 1. Test specimens.

Specimen	Cross-section	Length	Rubber ratio	Concrete	Percentage
C10x10x110R-0G	10X10 cm²	110 cm	0%	C30	%0.5
C10x10x110R-5G	10X10 cm²	110 cm	5%	C30	%0.5
C10x10x110R-10G	10X10 cm²	110 cm	10%	C30	%0.5
C15x15x110R-0G	15X15 cm²	110 cm	0%	C30	%0.5
C15x15x110R-5G	15X15 cm²	110 cm	5%	C30	%0.5
C15x15x110R-10G	15X15 cm²	110 cm	10%	C30	%0.5
C20x20x110R-0G	20X20 cm²	110 cm	0%	C30	%0.5
C20x20x110R-5G	20X20 cm²	110 cm	5%	C30	%0.5
C20x20x110R-10G	20X20 cm²	110 cm	10%	C30	%0.5

3. Discussion

3.1. Time-impact force histories

The time impact load histories read by the load cell on the concrete column surface is shown in Fig. 2. All the charts of concrete specimens show a parallel pattern with the first maximum point. First maximum impact force was quite more than next peaks. There is a space between the initial and next impact force with negative impact force. The meaning of this gap is the separation of the connection between the column and the impactor. First peak impact force time is shown in Fig. 4.

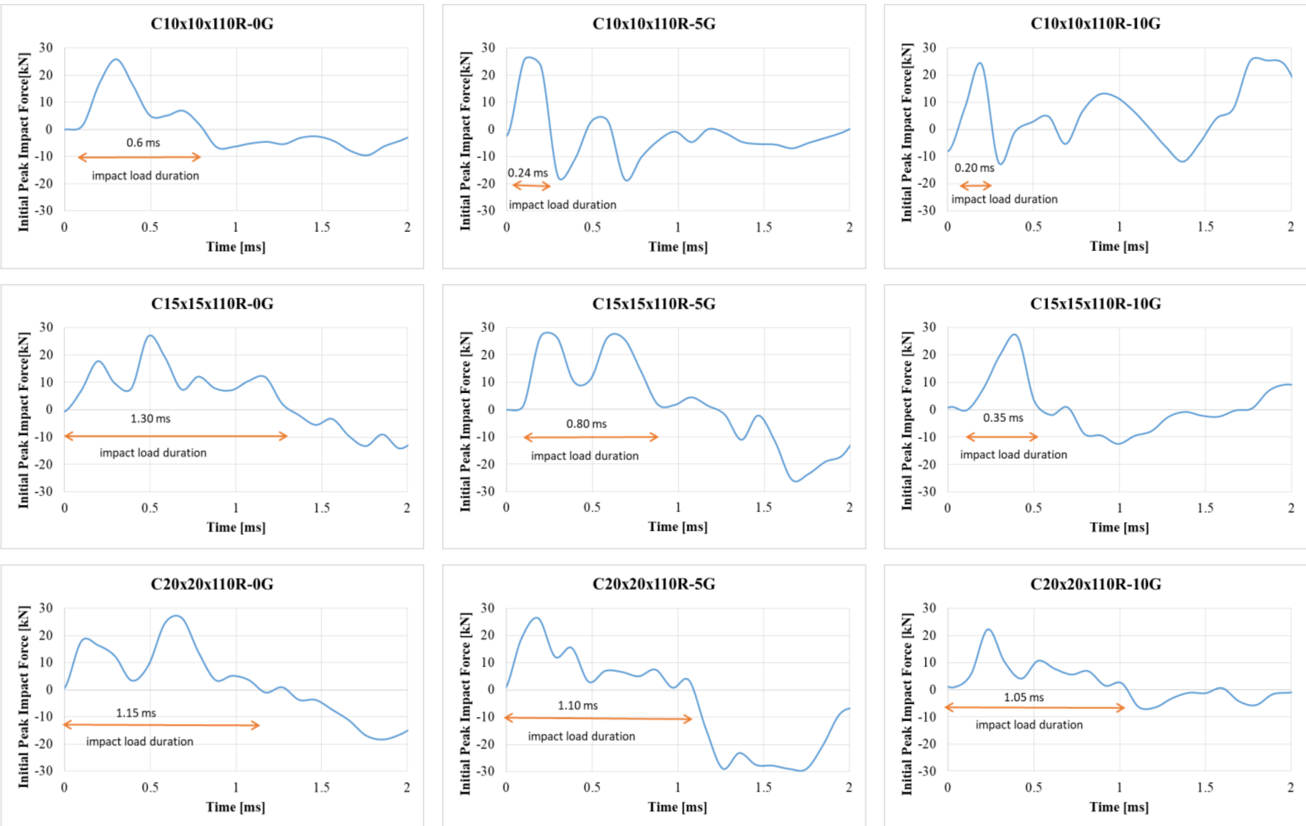

Fig. 4. Initial maximum impact force time.

The impact load time at the initial maximum point is about 0.60 ms for the normal concrete column C10x10x110R-0G, 0.24 ms for the %5 rubberized concrete column C10x10x110R-5G and 0.20 ms for the %10 rubberized concrete column C10x10x110R-10G. %5 and %10 rubberized concrete columns' impact load duration decreased %60 and %67 respectively. As a result, the columns with higher rubber content have longer impact load time at the initial peak point. On the other hand as seen in the graphs, for the other cross sections, the increase in the rubber amount shows a similar effect. It is advantageous to use rubber in concrete barriers due to the shortening of the impact load time at the initial peak point. Therefore, the barriers with higher rubber content minimize injury and demise when an accidental impact happens. Impact load time histories of the analyzed specimens are displayed in Fig. 5.

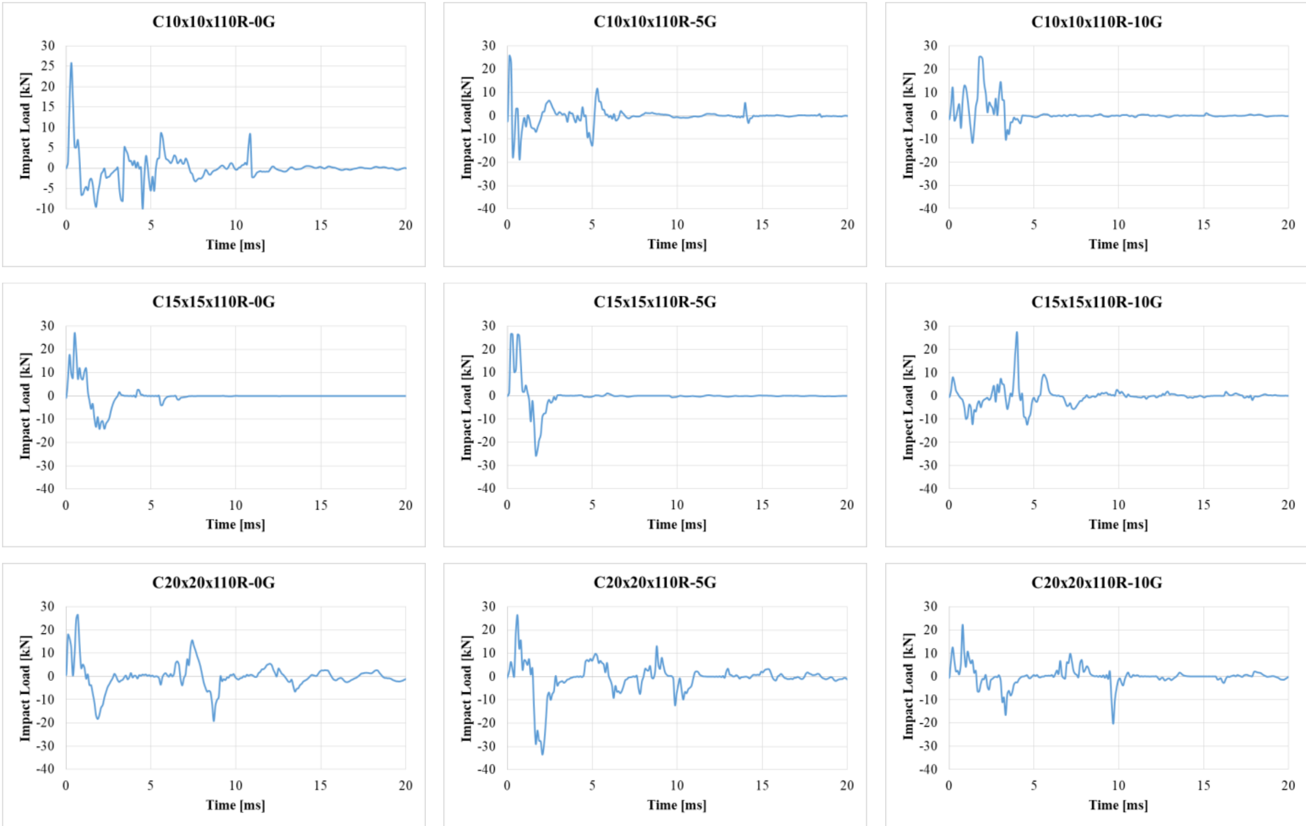

Fig. 5. Impact load-time histories of the tested beams.

3.2. Time-deformation histories

The time deformation histories of the specimens were produced from LVDT at the tracking points from the column end as shown in Fig. 5. In addition, the maximum displacement and residual displacement at the end of the column are presented in Figs. 6 and 7. Maximal deformation of columns of 20x20 cross section under impact load is quite small and most of this deformation is in the elastic region. As the cross section decreased, the maximum displacement and residual displacement increase and most of this deformation is in the plastic region. Maximum deformation - Rubber Ratio of the beams in the impact load are shown in Fig. 6. Residual deformation - rubber ratio of the beams in the impact load are shown in Fig. 7.

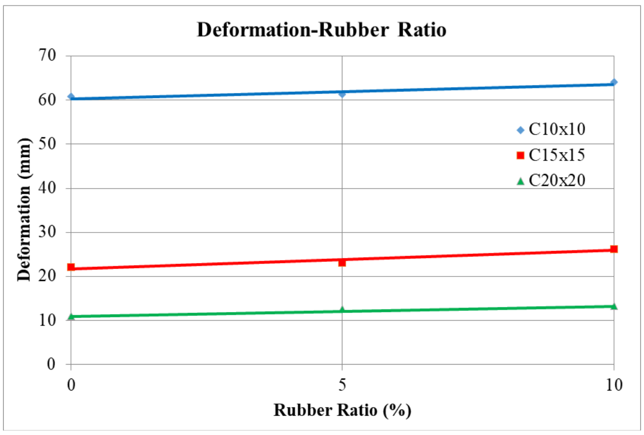

Fig. 6. Maximum deformation - rubber ratio of the beams in the impact load.

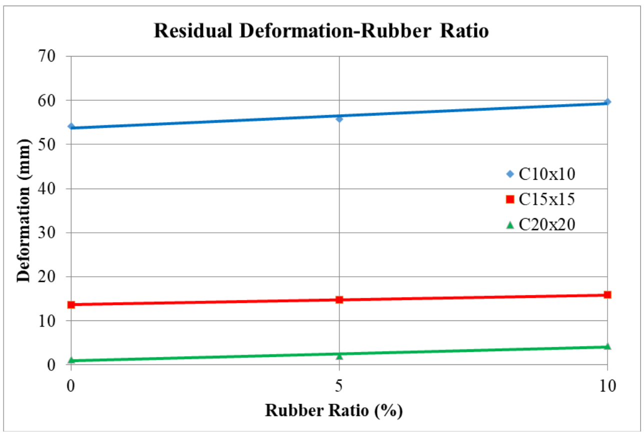

Fig. 7. Residual deformation - rubber ratio of the beams in the impact load.

The maximal deformation at the impact point of conventional columns (for cross sections 10x10,15x15 and 20x20 respectively) was 60.7-22.1-10.8 mm while the corresponding values of the specimens with 5% and 10% rubberized concrete were 61.1-23.1-12.5 mm, and 63.9-26.3-13.1 mm.

These results show that rubberized concrete columns become much more flexible than normal concrete columns. In addition, as the column cross-section gets larger the effect of the rubber on the deformation increases. Displacement time histories of the analyzed specimens are displayed in Fig. 8.

3.3. Time-acceleration histories

Acceleration time histories of the analyzed specimens are displayed in Fig. 9. Maximum average acceleration–rubber ratio of the beams in the impact load are shown in Fig. 10.

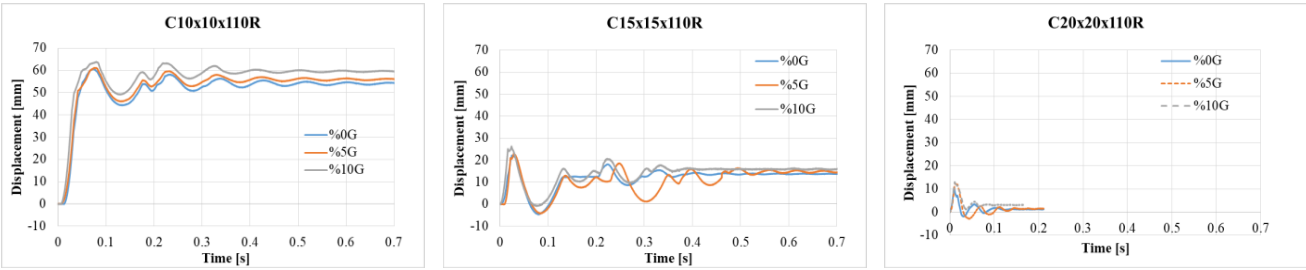

Fig. 8. Displacement-time histories of the tested beams.

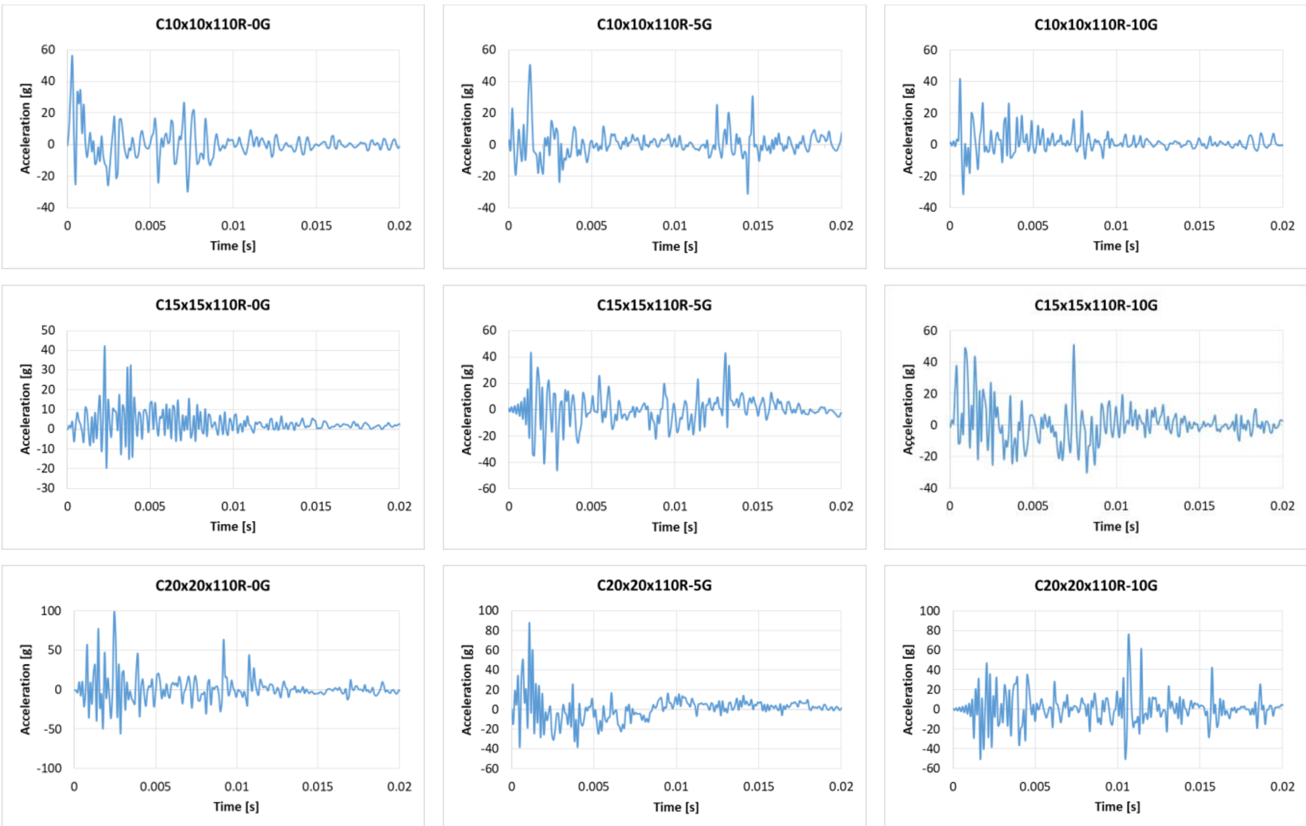

Fig. 9. Acceleration-time histories of the tested beams.

3.4. Deformation and progressive failure

The behavior of columns under impact loading consists of two phase. The first phase is the impact force phase, where the impactor transfers the load to the column. In this study, the first phase consists of about 10ms-20ms. The other phase is the free vibration phase which the impactor has no connection with the column. The second stage consists of about 1s.

Table 1 shows impact failure of cantilever column C10x10x110R-0G, C10x10x110R-5G and C10x10x110R under Impact load. The failure of columns with different rubber content were investigated. The damage level of columns is greater with increasing rubber content therefore, the columns with higher rubber content absorb more impact energy. Impact failure of cantilever column C10x10x110R-0G, C10x10x110R-5G and C10x10x110R in impact load are shown in Fig. 11.

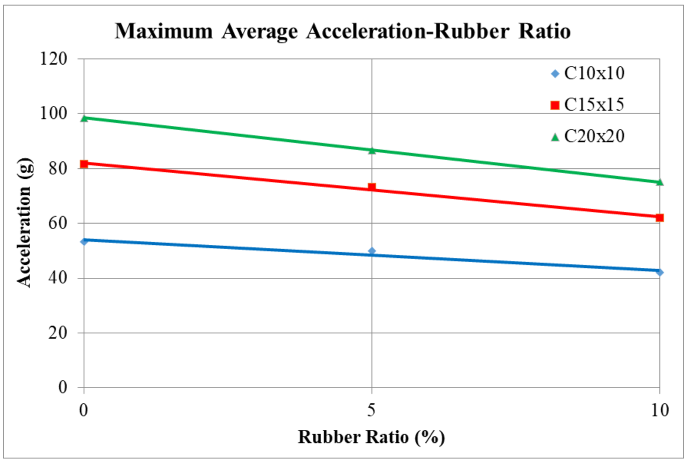

Fig. 10. Maximum average acceleration - rubber ratio of the beams in the impact load.

Fig. 11. Impact failure of cantilever column C10x10x110R-0G, C10x10x110R-5G and C10x10x110R in impact load.

4. Conclusions

In this paper, an experimental study is conducted to review the behavior under impact load of rubberized concrete cantilever column with conventional concrete.

The findings can be summarized as follows:

- The damage level of columns is greater with increasing rubber content therefore, the maximum rubberized concrete column content absorb more impact energy.
- Rubberized concrete columns become much flexible than normal concrete columns.
- The barriers with higher rubber content minimize injury and demise when an accidental impact happens.
- The maximum rubberized concrete columns have longer impact load duration at the initial peak point.
- 5% and 10% rubberized concrete columns' impact load duration decreased 60% and 67% respectively in C10x10x110R.
- Under the impact energy, rubberized concrete has slightly much deformation relative to conventional concrete.
- %5 and %10 rubberized concrete columns' residual deformation increased 64% and 242% respectively in C20x20x110R.
- The use of concrete with rubber content reduces costs and produces an environmentally solution.

Waste tires in landfills and stocks cause toxic chemicals to pollute the soil and cause major fires. Waste tires are a global environmental problem. This experimental study investigated the effect of steel wires recycled waste tire on concrete properties. Rubberized concrete columns become much flexible than normal concrete columns. Therefore, the barriers with higher rubber content minimize injury and demise when an accidental impact happens. As a result, the use of waste tire in reinforced concrete building elements should be expanded. Waste tire recycling is important for a sustainable environment and traffic safety.

Acknowledgements

None declared.

Funding

The authors received no financial support for the research, authorship, and/or publication of this manuscript.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

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