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Impact of Rubber Waste in Rigid Pavement

Mohamed Samir Eisa1, Mostafa Rabah2, Esraa Ahmed3

1 lecture, Civil Department, Faculty of Engineering, Benha University, Benha, Egypt, e-mail: mohamedeisa524 @bhit.bu.edu.eg.

2 Professor of Surveying and Geodesy, Civil Department, Faculty of Engineering, Benha University, Benha, Egypt, e-mail: mrabah@bhit.bu.edu.eg.

3 Demonstrator, Civil Department, Faculty of Engineering, Benha University, Benha, Egypt, email: esraa.soailam@bhit.bu.edu.eg.

**Mohamed Samir Eisa, mohamedeisa524 @bhit.bu.edu.eg,* *DOI: 10.21608/PSERJ.2021.89586.1134*

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ABSTRACT

The production of rubber tires is about tens of millions annually due to the increase in the production and development of cars every year. Rubber tires need hundreds of years to decompose because one of their components is sulfur. This indicates that there is a clear environmental and economic catastrophe. The best solution is recycling rubber in different fields. The most important of which is concrete as the main backbone in the field of engineering and construction. In this study, the effect of rubber is discussed as coarse aggregate in the form of shredded rubber and as fine aggregate in the form of grinded rubber in concrete used for rigid pavement. Samples were prepared to conduct the necessary tests to study the behavior of rubberized concrete in terms of compressive, indirect tensile strength, impact energy absorption and loading. The results showed that using ten percentage of grinded rubber was the optimal amount as the mixture had properties that were very similar to the properties of ordinary concrete regarding compressive strength, indirect tensile strength, and density. five percentage of shredded rubber caused a decrease in compressive strength, indirect tensile strength, and density of sample C by about 85%, 96.5% and 97%, respectively. five percentage of mixture of shredded rubber and grinded rubber caused a decrease in compressive strength, indirect tensile strength, and density of sample C by 69.57%, 59.6% and 93%, respectively.

Keywords: Rubber tires, Recycling, Shredded rubber, Grinded rubber, rigid pavement

1. INTRODUCTION

In several countries, waste tire management and recycling are considered environmental issues. Every year, 1000 million tires are expected to hit the end of their service life. By 2030, the figure could rise to 1200 million tires, or almost 5000 million tires (including stockpiled) to be discarded on daily basis due to the global expansion of the automotive industry and the growing use of vehicles as the primary mode of transportation. At ambient temperatures, scrap tire is made up of materials that are not environmentally friendly. They normally have negative impacts on the climate. Landfilling is hazardous not only because of the possible harmful environmental effects, but also because it creates a fire threat and serves as a breeding ground for rodents, mice, vermin, and mosquitoes. Egypt and other countries have adopted laws in recent years to either allow the use of these waste products or to investigate the viability of such use. Many experiments on rigid pavement have been performed in recent years to improve its performance. In this study, both coarse aggregate and sand will be replaced by 5%, 10 %, 20 %, 30% of shredded tire rubber and grinded tire rubber, on both individual and simultaneous basis. The capacity of a road to satisfy traffic and environmental demands over its construction life is referred to as pavement efficiency. Many tests such as indirect tensile strength, impact resistance, compressive strength, and ultimate load can be used to estimate pavement degradation and efficiency. Deshmukh et al. 2017 studied eco-friendly materials in rigid pavements. They also studied the mechanical and physical properties of recycling aggregate and their effect on the thickness of the concrete slab. Then, they performed a Z test on three plain concrete specimens and on reinforced rebar and fibre reinforced polymer concrete pavement (CFRP). The results for plain concrete for crack load was 48.8 kN and crack strain was 308.3 μm. For rebar concrete, the crack load was 50 kN and crack strain was 289.3 μm. For fibre reinforced polymer concrete pavement (CFRP), the crack load was 53.2 kN and crack strain was 290 μm.

Chaddha et al. 2017 studied rigid pavements and the different kinds of cracks that were formed in them. There are many reasons for cracks occurrence such as concrete mix not matching, unsuitable curing, improper filler material, uncompact subgrade soil, insufficient pavement thickness and rise of soft aggregate. The cracks were fatigue and shrinkage cracks. Also, pumping, spalling and punch out were observed. Khan et al. 2018 studied the effect of replacing soft sand with crumb rubber. The replacement percentages were 0 to 15%. Its effect on compressive and tensile stresses were evaluated. It was noticed that compressive strength decreased from 26.67 kN to 22.62 kN. Also, it was noticed that tensile strength decreased by 43% at 15% crumb rubber. It was recommended that crumb rubber be used in concrete lightweight walls and architectural uses.

Bekhiti et al. 2014 tested the chemical and physical properties of waste tire rubber powder. In the studying the size of particles of rubber powder was about 1.0 mm and the density of rubber powder was 0.83. The percentage of absorption of water was less than 3%. The chemical constituents of the rubber powder were elastomers, polyisoprene, polybutadiene, and styrene-butadiene. With analysing the main components, it was found that rubber represented 54% of the total mass. While carbon black represented 29%, textile represented 2%, oxidize zinc represented 1%, sulphur represented 1% and additives represented 13%. The cohesion varied values between 6.5 and 50 kPa. The friction angle varied values between 8° and 25° based on the size of rubber particle.

Khope et al. 2015 reviewed many different recycled materials used in concrete pavement as a replacement of natural coarse aggregate. The main problem in India, is that it produces several tons of tires, and it is difficult disposing them in a healthy and environmentally sound manner, and under the supervision of the competent authorities. Consequently, the solution was recycling waste tires in the highway construction industry.

Hernandez-Olivares et al. 2006 investigated fatigue bending on rubberized concrete specimens using different percentages of rubber (0%, 3.5%, 5%). It was tested in bending for three categories of concrete specimens with regular rubber tires 0%, 3.5% and 5%. Also, the fatigue strain and Young's Modulus for each specimen was measured every 10 load cycles. The control specimen resisted 106 cycles and gave a flexural stress 4.2 MPa with Young's Modulus of 25.1 GPa and the value of strain was 169 μdef. Also, for 3.5% recycled tire rubber in the specimen of concrete resisted a number of loading cycles estimated to be 106 a value of flexural stress of 3.8 MPa, a Young's Modulus of 27.4 GPa, and the value of strain of 146 μdef.

Reshma et al. 2015 investigated the effect of using waste tires as coarse aggregates in the road construction. The specimens with waste rubber were subjected to both crushing test and impact test and it was found that as waste rubber content increased the value of impact decreased. The abrasion was reduced due to the inclusion of waste rubber. With different percentages of waste rubber, it was found that using 15% and more of rubber content affected all properties. Using waste rubber in the road saves up to 1550 tons approximately of natural aggregate if used in the subbase layer for 1 kilometre.

2. EXPERIMENTAL PROGRAM

In this research, specimens were cast and tested to investigate the behaviour of waste rubber on rigid pavement. The tested specimens in this study were:

1. Thirteen slabs with dimensions (1000 × 1000 × 20 mm). For all slabs, strain, cracking load, and the ultimate load were recorded.
2. Thirty-nine cylinders with dimensions (150 × 150 × 300 mm) were tested for compressive strength.
3. Thirty-nine cylinders with dimensions (150 × 150 × 300 mm) were tested to obtain indirect tensile strength.
4. Thirty-nine specimens with dimensions (10 × 10 × 55 mm) were tested for impact resistance.

The thirteen tested specimens were divided into three groups and a reference group. The reference group included one specimen (C) without rubber as a control specimen. The first Group contained four specimens (C1, C2, C3 and C4) with (5%, 10%, 20% and 30%) shredded rubber as a replacement to coarse aggregate, respectively.

Specimen groups	Specimen codes	Shredded rubber %	Grinded rubber %
Control	C	0	0
First group	C1	5	0
	C2	10	0
	C3	20	0
	C4	30	0
Second group	C5	0	5
	C6	0	10
	C7	0	20
	C8	0	30
Third group	C9	5	5
	C10	10	10
	C11	20	20
	C12	30	30

Table 1: Specimen groups and percentages of coarse and fine rubber aggregates

The second group included four specimens (C5, C6, C7 and C8) with (5%, 10%, 20% and 30%) grinded rubber as an alternative to fine aggregate, respectively. The third group contained four specimens (C9, C10, C11 and C12) with a mixture of shredded rubber and grinded rubber at percentages (5%, 10%, 20% and 30%) as an alternative to each of the coarse aggregate and fine aggregate, respectively as illustrated in table 1.

2.1.Materials Properties

2.1.1 Concrete

Trial mixes were carried out in the reinforced concrete laboratory at Benha Faculty Engineering. After 28 days, a suitable combination was chosen to achieve the target compressive strength of 350 Kg/cm^2. The following sections describe the properties of the materials used to prepare the concrete mix, including fine aggregate, coarse aggregate, cement, and mixing water.

2.1.2 Fine Aggregate

Natural siliceous sand was used as fine aggregate. It was clean and almost impurity-free. In the laboratory, fine aggregate sieve analysis was performed. To exclude all particles larger than 4.75 mm, the sand was first sieved through 4.75 mm sieve. The Fineness modulus (FM) of the used sand was found to be 2.75. Table 2 shows the physical, chemical, and mechanical properties of fine aggregates used.

Property	Test result
Specific gravity	2.66
Volumetric weight (t/m3)	1.62
Void ratio	35%
Fineness modulus	2.75
Clay, silt, and fine dust (by weight)	1.85%
Chloride % (by weight)	0.02

Table 2: Physical, chemical, and mechanical properties of fine aggregates used

2.1.3 Coarse Aggregate

Crushed graded dolomite (locally available) with a maximum size of 10 mm was used in the concrete mix. The overall shape was circular and sub-angular, with a smooth uniform surface texture, free of any unwanted impurities. The aggregates were cleaned to remove dust and dirt. The properties of coarse aggregate are shown in Table 3.

Property	Test result
Type	Crushed
Specific gravity	2.66
Volumetric weight (t/m3)	1.31
Total Water Absorption	1%

Table 1: Physical and mechanical properties of coarse aggregates used

2.1.4 Shredded Rubber

Rubber that has been shredded or chipped to be used in place of coarse aggregate. It was necessary to shred the tire twice to use it as rubber. The rubber was 300 - 430 mm long and 100–230 mm thick by the end of stage one. Cutting reduced the size to 100 - 150 mm in the second step. Table 4 shows the Chemical composition of shredded tire rubber used and figure 1 shows the shredded rubber.

Ash content	5.11%
Carbon black content	28.43%
Acetone extract	9.85%
Volatile matter	0.56%
Hydrocarbon content	56.05%
Polymer analysis	SBR

Table 4: The chemical composition of shredded tire rubber used

2.1.5. Grinded Rubber

Grinded rubber, which replaced fine aggregate, was produced in special mills where large rubbers were broken down into smaller torn pieces. Depending on the type of mills used and the temperature, various sizes of rubber particles can be formed during this process. Particles with high irregularity in the range of 0.425 - 4.75 mm were obtained using a simple technique. Figure 1 shows the grinded rubber.

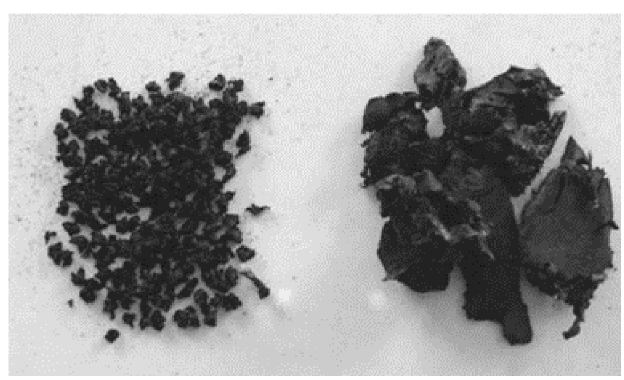

Figure 1: Grinded rubber and shredded rubber

2.2.Test Setup and Testing Procedures

The test set-up used in this study consisted of rigid steel frame supported on the laboratory rigid floor, as shown in Figure 2.

Figure 1: rigid steel frame supported on the laboratory rigid floor

2.1.1 Test Setup

The load was applied using a hydraulic jack of 100-ton capacity, connected to an electrical pump that provides oil pressure. The load was applied and measured using a load cell connected to a data acquisition system. The readings were recorded and saved in an excel sheet on the computer. The specimens were prepared for testing resting on soil in a steel container with dimensions of (1.5 × 1.5 × 0.75 m). The soil was compacted by a hammer weighing 10 kg on a three-layer depth of 25 cm. The soil layers served as subbase course layers for the pavement concrete slab as shown in Figure 3 .The specimens were placed over the subbase layers in the middle of the container then, the load was applied using a hydraulic jack on a steel plate with dimensions of 30*30*5 cm to ensure distribution of the load over an area greater than the area of the load cell, which has a diameter of 10 cm to avoid penetration of the specimens, as shown in Figure 4. A special arrangement was designed for each dial gauge to fix it in its exact position and to ensure proper readings. Propagation of cracks was marked after each load increment up to failure. The strain gauge was installed in the middle of the bottom of each slab. The strain gauge was used to measure the incident strain corresponding to each load in each slab individually.

Figure 3: The steel container filled with subbase layers.

Figure 2: The specimen was placed in the middle of container and the steel plate was placed in its center.

2.1.2 The properties of the strain gauge were as follows:

Gauge length: 6 mm.
Gauge factor: 2.12 ± 1%.
Gauge resistance: 120.3 ± 0.5 Ω.
Transverse sensitivity: 0.1%.

2.1.3 Test procedures

For each test, the specimen was aligned inside the testing frame and the strain gauge was connected to the data acquisition system. The data acquisition system starts to gather data before the application of load. The load was applied at a steel plate with dimensions of (30 × 30 × 5cm) in a vertical direction and was increased monotonically using an electric hydraulic jack of 100-ton capacity until failure of the specimen. Both faces of the specimen were observed to follow the propagation of cracks. The load was applied at a regular interval (1 ton) before the formation of the first crack. After the formation of first crack, the load was applied in a regular interval (0.5 ton), the load was kept constant while cracks were marked. During the test, the initiation and propagation of cracks were marked after each load increment up to failure to understand the behaviour of the tested specimens. Crack loads, ultimate failure load, and strain were recorded simultaneously.

3. RESULTS AND DISCUSSION

3.1.Compressive Strength Test

Compressive strength tests were conducted on three standard cylinders of 150x150x300 mm for each mixture at 28 days. The test was carried out in a 200-ton compression testing machine. The results were monitored for each cylinder on a single bound, and the average of the three cylinders was taken to know the compressive strength of each mixture. The values of compressive strength for samples C1, C2, C3, and C4 were 85%, 70.4%, 50.6% and 35.5% respectively were compared to sample C. The values of compressive strength for samples C5, C6, C7, and C8 were 99.01%, 96.36%, 69.28% and 41.86% of the value of sample C. The values of compressive strength for samples C9, C10, C11, and C12 were 69.57%, 50.58%, 32.44% and 14.02% respectively of the value of sample C as shown in Figures 5,6 and 7. This is because the strength of waste rubber is less than that of aggregate. Consequently, as waste rubber increases compressive strength decreases. Also, the surface area of waste rubber is not smooth and less than that of aggregate, so it needs more cement content.

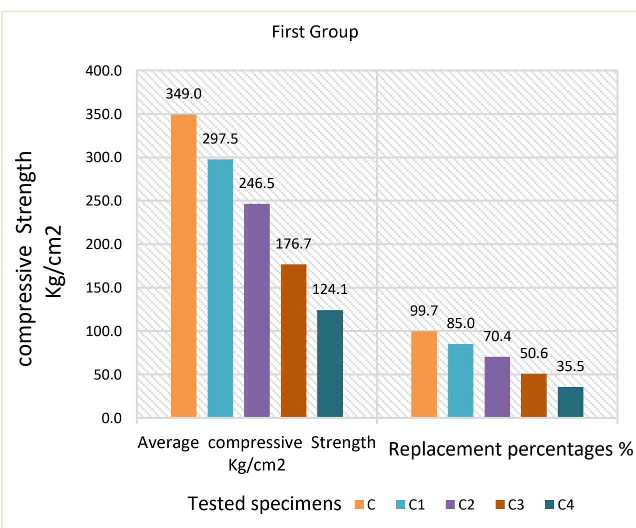

Figure 5: Compression strength at different replacement percentages of rubber as coarse aggregate.

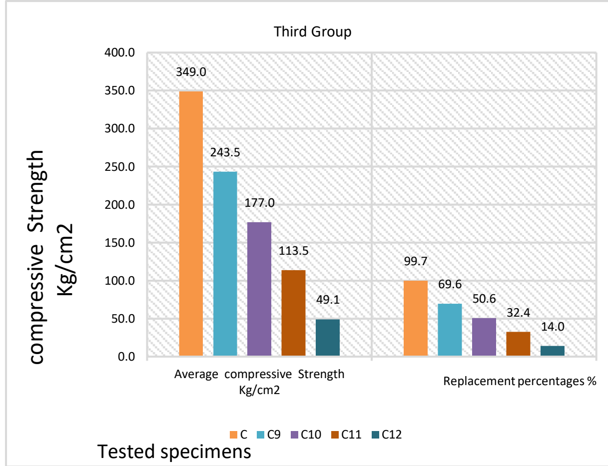

Figure 6: Compression strength at different replacement percentages of rubber as fine aggregates.

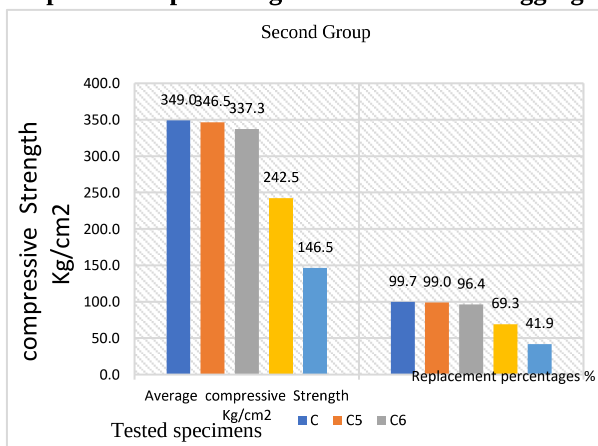

Figure 7: Average compression strength at different replacement percentages of rubber as both coarse and fine aggregates.

3.2.Indirect Tensile Strength Test

The indirect tensile strength tests were conducted on three standard cylinders of 150x150x300 mm for each mixture at 28 days. The load was applied continuously at a constant rate up to failure using testing machine of capacity 50 ton. The failure load was reported to calculate the indirect tensile strength and the three specimens were used to calculate the average strength for each mixture. The values of indirect tensile strength for samples C1, C2, C3, and C4 were 97.5%, 96%, 71%, and 42% respectively when compared to the value of sample C. The values of indirect tensile strength for samples C5, C6, C7, and C8 were 96.55%, 96.03%, 83.45%, and 46.79% respectively of the value of sample C. The values of indirect tensile strength for samples C9, C10, C11, and C12 were 59.63%, 52.40%, 46.79%, and 35.43% in comparison to the value of sample C. This is because nonhomogeneous content of waste rubber caused a decrease in the indirect tensile strength as shown in Figure 8.

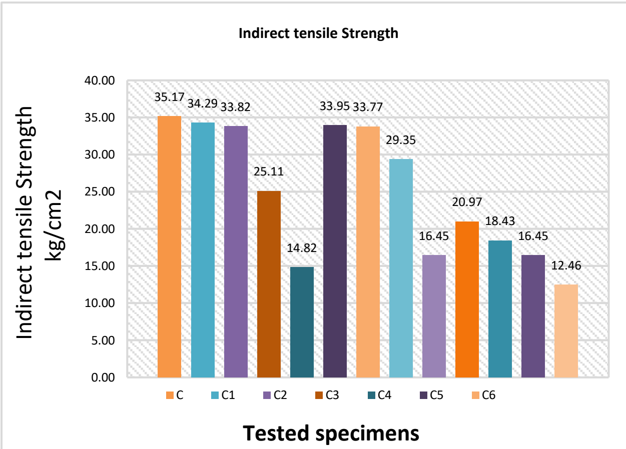

Figure 8: Effect of rubber waste on indirect tensile strength

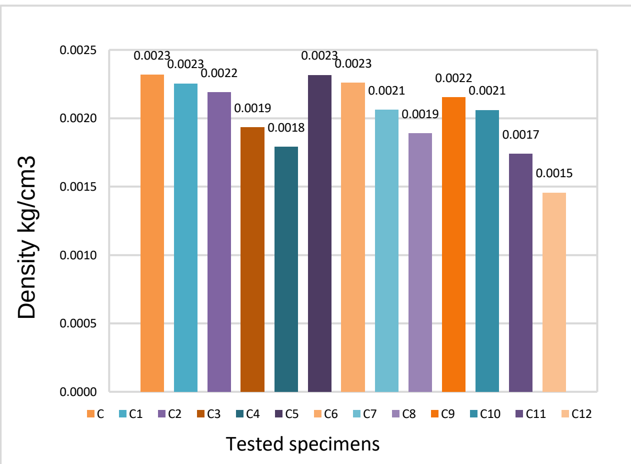

Figure 9: Effect of rubber waste percentages on density

3.3.Density

Each sample was weighed individually and by knowing the sample weight and volume, the density of each mixture was calculated, and a comparison was made between them as shown in Figure 9. The values for C1, C2, C3, and C4 were 97%, 94%, 83% and 77.7% when compared to the density of the control specimen. The values of density for the samples C5, C6, C7, and C8 were 99.9 %, 97.4%, 88.9% and 81.5% of density of sample C. The values of density for the samples C9, C10, C11, and C12 were 93 %, 88.8%, 75% and 62.8% of density of sample C. This is because the weight of rubber is less than that of aggregate so the density in the case of rubber is less than the aggregate.

3.4.Impact Test

To conduct this test, an impact test machine was used from the mechanics of materials lab, due to the lack of an impact test device in the concrete laboratory, bearing in mind that the device used is used only for ductile materials and not for brittle materials such as concrete, but this test was taken to obtain indicative values. This test is called the Charpy test by which the impact energy provides an indication of the toughness of a material. The energy required to fracture the sample was recorded for each mixture. As shown in figure 10. It was observed that the increase in energy absorption for samples C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11 and C12 were 102.40%, 104.79%, 107.94%,109.50%, 99.49 %, 101.60 %, 104.79 % ,106.37 %,104.30 %, 106.37 %, 109.50 % and 111.05 % when compared to the control sample. This is because waste rubber has a great ability to absorb energy more than the aggregates so increasing the waste rubber content increased the ability to absorb the impact load.

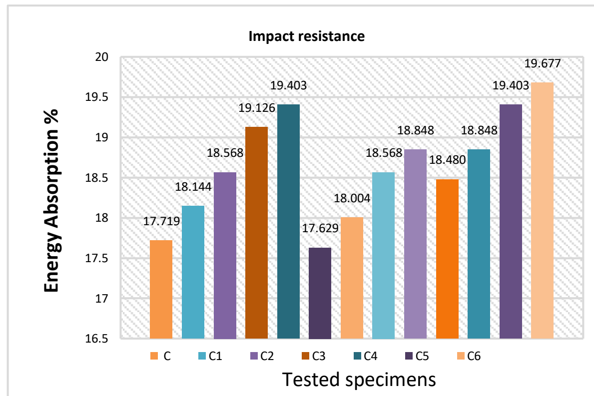

Figure 10: Effect of waste rubber on energy absorption.

3.5.Ultimate Loading Test

As mentioned above at 2.2.1. the test was carried out and had the following results. Regarding both, first crack and failure at ultimate load, there was an increase for all tested specimens except in specimens C5 and C9 (in the second and third group respectively). Specimens C5 and C9 gave slightly lower failure values when compared to the control mix, the increase was pronounced when 20% and 30% of waste rubber was used both individually (in mixes C3, C4, C7 & C8) and simultaneously (in mixes C11 & C12). This may be attributed to the ductility of rubber.

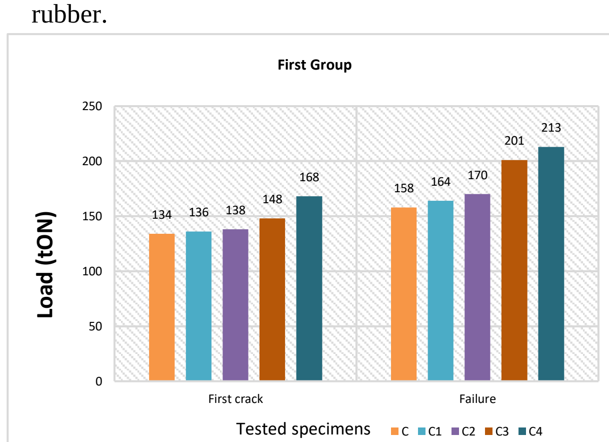

Figure 11: Loading test for first group samples.

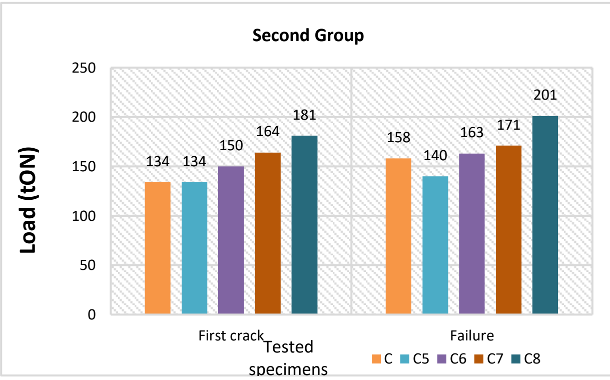

Figure 12: Loading test for second group samples.

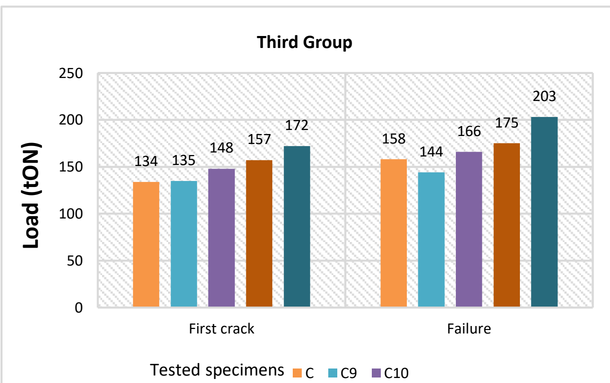

Figure 13: Loading test for third group samples

4. CONCLUSION

Based on the results of this study, the following conclusions can be drawn:

1. The rubber with different shape caused decreasing in the value of the compressive strength, indirect tensile strength, and the density. In the other hand caused increasing in impact resistance, energy absorption, first crack, and ultimate loads.
2. The optimum percentage of using shredded rubber is 5% which caused a decrease in the compressive strength it was 85% of sample C. Indirect tensile strength as similar as sample C approximability. The density was 97% of sample C. In the other hand there is an increase in the impact resistance it was 102.4% of sample C, that because the rubber has the ability to absorb energy, as rubber is compressible material, and the modulus of elasticity is high. And there is an increase in first crack and ultimate loads with 101%, 104%, respectively of Sample C.
3. The optimum percentage of using grinded rubber is 10% the compressive strength was 96.4% of sample C. Indirect tensile strength was 96.03% of sample C. The density decreased to 97.5% of sample C. In the other hand there is an increase in the impact resistance it was 101.3% of Sample C. that because the rubber has the ability to absorb the energy, as rubber is compressible material, and the modulus of elasticity is high. And there is an increase in first crack and ultimate loads with 112%, 103%, respectively of Sample C.
4. Using a mixture of shredded and grinded rubber by 5% caused a significant decrease in compressive strength it was 69.57% of sample C. Indirect tensile strength was 59.63% of sample C. The density decreased to 93%. In the other hand there is an increase in the impact resistance it was 104.3% of Sample C because the rubber has ability to absorb the energy. And there is a slight increase in first crack it was 100.8% of sample C, and there was a decrease in ultimate load it was 91.1% of sample C. Therefore, it is not recommended to use the mixture of shredded and grinded rubber as an alternative for coarse aggregate, and fine aggregate, respectively.

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Credit Authorship Contribution Statement

Mohamed Samir Eisa: Validation, Reviewing, Supervision,
Mostafa Rabah: Reviewing, Editing, Supervision,
Esraa Ahmed: Generating the idea, Collecting data, Methodology preparation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

5. REFERENCES

[1] Deshmukh, A. Rabbani, N.K. DHAPEKAR, Dr. G. Bhatt. "Design of rigid pavement: Hypothesis". International Journal of Civil Engineering and Technology (IJCIET). Volume 8. Article ID: IJCIET_08_06_049, (6 June 2017)

[2] S. CHADDHA, A. SINGH CHAUHAN, B. CHAWLA." A Study On The Rigid Pavement Construction, Joint and Crack Formation". International Journal of Modern Trends in Engineering and Research. Volume 04, Issue 1 ISSN 2349-9745, (January 2017)

[3] S. Khan, A. Singh. "Behaviour of Crumb Rubber Concrete". International Journal of Research in Engineering, IT and Social Sciences. Volume 08 Issue 2. ISSN 2250-0588, (February 2018)

[4] M. BEKHITI, H. TROUZINE, A. ASROUN. "A Review on Application of Waste Tire in Concrete". Engineering, Technology & Applied Science Research Vol. 4, No. 4, 2014, pp.669-672, (August 2014)

[5] R. A. Khope, M. V. Mohod. "A Review paper on Recycled Materials in Concrete Pavement". International Journal of Research in Engineering, Science and Technologies. ISBN 2395-6453, (December 2015).

[6] F. Herna´ndez-Olivares, G. Barluenga, B. Parga-Landa, M. Bollati, B. Witoszek "Fatigue behaviour of recycled tyre rubber filled concrete and its implications in the design of rigid pavements‘ " Construction and Building Materials 21 (2007) ISBN 1918–1927, (June 2006)

[7] Reshma E.K, Dhananjay A.S, Ketki Y., Kundan J., Omkar Thombare, Shreejit Shitole, Subhash K., "Investigations on Replacement of Coarse Aggregates by Waste Tires for Road Construction". IOSR Journal of Mechanical and Civil Engineering. ISSN: 2278-1684.Volume 12, (Mar - Apr. 2015)