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Energy Absorption Capacity and Impact Energy of Rubberized Concrete

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Abstract: Disposal of used tires is a critical environmental issue in Sri Lanka. Rubberized concrete is one of the solutions introduced by the researchers to minimize the quantity of waste rubber. These studies discovered that rubberized concrete is an ideal alternative for lightweight concrete. However, they further revealed that the compressive strength of concrete degrades with the addition of rubber. Further, the durability of rubberized concrete is still questionable. However, due to the energy absorption capacity of rubber, rubberized concrete have the potential of possessing higher energy absorption capacity.This property of rubberized concrete along with the lightweight will make rubberized concrete an ideal alternative for road barriers. Hence, this study focuses on exploring the static and dynamic energy absorption characteristics of rubberized concrete. Mix designs for grade 25 concrete was done while partially replacing fine aggregate by rubber crumbs at proportions of 5%, 10% and 15%. . The energy absorption due to static loads were measured from plate test and impact energy, energy absorption and shock absorption due to impact loads were calculated from artificial athlete test. The experimental results show that the compressive strength and density of rubberized concrete reduces as the percentage of rubber increase. The low density quality can be used to make lightweight concrete. But significant improvement in shock absorption, Static energy absorption capacity, impact energy and energy absorption capacity can be seen. Due to high energy absorption against dynamic loads, the rebound force get decreased. Therefore rubberized concrete can be used in structures which are prone to impacts to create less impact on the object which collides with the structure. This characteristics make rubber concrete ideal for rigid roadside barriers, foundation pad for machinery, railway buffers and bunkers where the energy and shock absorption more important than the strength.

Keywords: concrete, rubber, fine aggregates, absorption capacity

Introduction

Current studies have shown that approximately 10 billion tires are discarded in one year globally. Further, about 1 billion crumb rubber waste is generated from the tire manufacturing factories annually (Polgar *et al.*, 2018). Contribution of Sri Lanka to that quantity of waste is about 3.2 million (Resources, 2005) per year from imported and manufactured tire waste. Only a small portion of this rubber waste is used for such as rail foundations and highway embankments, energetic purposes in cement kilns, electricity production process, additive for pc mortar or concrete and as a lightweight filler.A major portion is dumped as landfills which inturn creates several environmental issues.

Among several solutions suggested by researches to re-use this rubber waste, rubberized concrete has also been identified as a viable solution(Sukontasukkul and Wiwatpattanapong, 2009). Several studies have revealed that rubberized concrete is lightweight. Compared to the cost of conventional lightweight concrete made with the help of lightweight aggregate, rubberized concrete possess higher economical benefits. However, it has also been discovered that the addition of rubber crumbs cause reduction of compressive strength compared to the conventional concrete of the same grade(Gerges, Issa and Fawaz, 2018). Further, the durability concerns of rubberized concrete is also still at a questionable state. Therefore, use of rubberized concrete has still been limited to applications such as in highway constructions as a shock absorber, in sound barrires as a sound absorber and in buildings as an earthquake shock-wave absorber.

Rubberized concrete has the potential of having higher energy absorption capacity owing to the high energy absorption capacity of rubber. This feature may be helpful in case of structures where energy absorption and impact energy is important such as road barriers, shooting houses and firing ranges. Therefore, this study focuses on exploring static and dynamic energy absorption characteristics of rubberized concrete.

Methodology

The study was purely based on the experimental approach. Fine aggregate was replaced by rubber crumbs at proportions of 5%, 10% and 15% to identify the variation of properties as the rubber percentage increases. The average particle size of rubber crumbs that was taken to this study is within the range of 0.2-0.5mm. The rubber particles were soaked in 10% diluted sodium hydroxide (NaOH). This process is expected to avoid rubber particles from floating in the water. Further, this process has also been proven to improve the bond between cement and rubber as well(Khitab *et al.*, 2017)(Specification, no date). After soaked in NaOH, rubber crumbs were drained and soaked and rinsed three times with fresh water to again neutralize the pH value.

Before preparing the samples, Sieve Analysis was done as per ASTM C 136-05 (ASTM 2016) for all the three proportions of rubber crumbs in fine aggregate to see whether the partical size distribution is acceptable. Upon conforming the accuracy of partical size distribution, mix design were prepared for grade 25 with water cement ratio of 0.5. Once the concrete mixes were prepared slump readings were obtained for different mixes. Samples required for three tests namely; compression test, Static energy absorption test and shock absorption test were prepared.

1) Compression Test: Twelve samples from four mixes (i.e 0%, 5%, 10% and 15% of rubber) were prepred for the compression test. The test was done as per the standard of American Society for Testing and Materials (ASTM). Cubes were tested after 28 days of curing.

2) Static Energy Absorption Test: Test was done as per EFNARC plate test method(Pham *et al.*, 2019). A test specimen of 600 x 600 x 100mm supported on its four ends and a center point load applied through 100 x 100mm contact surface. The rough side of the specimen out in the bottom during the test because the load is applied opposite to the laying direction. The deformation rate of the midpoint fixed as 1.5mm per minute.

Two cuboids were prepared from the mixes with 0 and 10% rubber crumbs to obtain static energy absorption capacity from the energy absorption test. These cuboids were tested after 7 days of curing. The arranged specimen stored under the water for at least three days before the testing and kept moist during testing.The load-deformation curve recorded and the test continued until a deflection of 25mm is achieved at the center point of the cuboid.

3) Shock Absorption Test: This test was done as per the European Standard, EN 14808:2005 (Demker, 2009). A free weight was allowed to fall on to a spring that placed on the test piece and the maximum force applied was recorded. Then the free weight was allowed to fall on to a hard surface and maximum forced measured. The difference between the maximum forces in test piece and hard surface is reported as the reduction of force.

The falling weight have 20kg (±0.1) mass with hardened striking surface. The weight is allowed to fall vertically and smoothly and minimum friction. The gap between test piece and the free weight was setup as 250(±2.5) mm. The peak impact force applied to the surface is recorded. After peak force was recorded, the procedure was repeated at least 10 times for both conventional and 10% replacing rubber samples and get mean value. The size of the test specimen was 100 × 200 × 80 mm .Then the force reduction (shock absorption) was calculated using equation 2. This procedure was done further until the 1st crack occur and the number of blows applied to test piece was noted. Then the Impact energy was calculated using equation 1.

$$IE = N\, m\, g\, h \qquad (1)$$

Where:
IE = Impact energy (N m)

N = Number of blows to 1st visible crack
m = Mass of the drop weight (kg)
g = Gravitational acceleration=9.81 m/sec^2
h = Height of drop weight (m)

$$R = (1-P/Q) \times 100 \qquad (2)$$

R = Force Reduction [shock absorption (as a percentage)]
P = Maximum Peak Force for test piece (in rubberized concrete sample)
Q= Maximum Peak Force for concrete (in conventional concrete sample)

Results and Discussion

A. Slump

The results of the slump test are shown in Figure 1. It can be seen from the figure that the slump value and hence the workability of concrete decreases with the increase of rubber percentage. The drop of slump value of the concrete with 15% rubber is about 33.3% compared to the control samples which has no rubber.

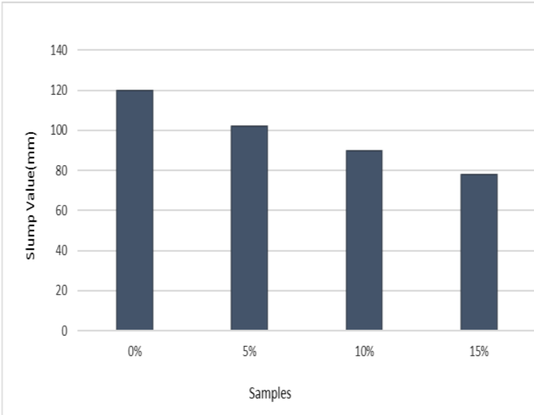

Figure 1. Change of Slump

B. Density

The density of the rubberized concrete was found significantly lesser than conventional concrete. The results are summarized in figure 4. It can be seen that when 15% of fine aggregate is replaced with rubber crumbs, reduction of density is approximately 10% of the conventional concrete of the same grade. This quality of rubberized concrete is beneficial for some applications of concrete.

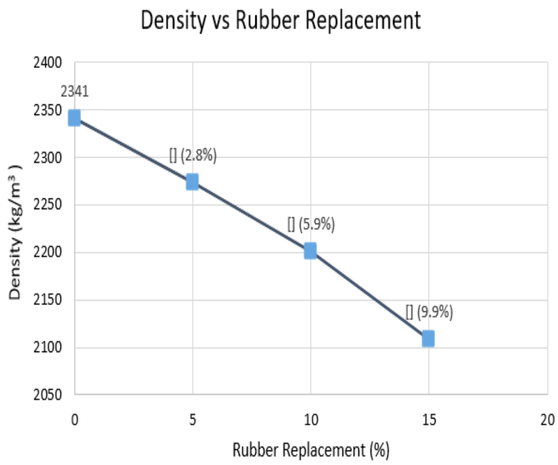

Figure 2. Change of Density

C. Compressive Strength

Variation of compressive strength with the variation of rubber content in concrete is shown in Figure 3. It is obvious from the figure that there is a significant decrease in compressive strength as the percentage of rubber increases in the concrete. When the percentage of rubber crumbs is 15% of the fine aggregate, the reduction of compressive strength is approximately 66% compared to the compressive strength of the conventional concrete of the same grade. Similar observations are reported under the "study on waste tyre rubber as concrete aggregate" This is the biggest disadvantage of rubberized concrete which limits the applications of it.

When observing the failure patterns, inclined shear cracks were observed in conventional concrete samples, while in the rubberized concrete samples, horizontal cracks were observed. This is due to the low compressive strength of rubberized concrete.

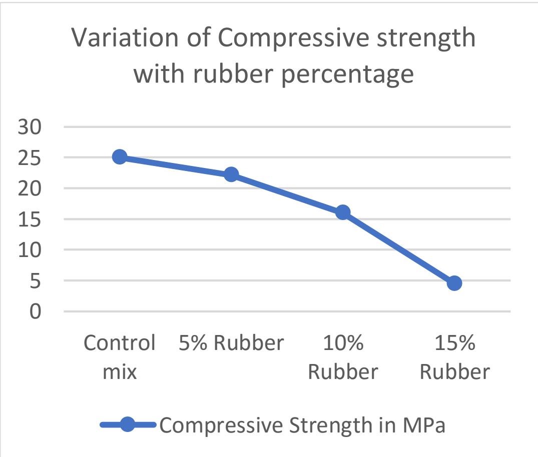

Figure 3. Variation of compressive strength

D. Static Energy Absorption

Static energy absorption capacity (toughness) is the area under the stress strain curve of a compressive test or load deflection curve of a flexural test and the units of toughness is taken as Joule per cubic meter. Here the flexural test was done and hence the area of the load deflection curve was taken in calculating the toughness. The results of the test are given in Table 1. It was noticed that the maximum load of rubberized concrete is about 50% of the maximum load of conventional concrete. However, the displacement at failure of rubberized concrete is about double the value of the same for conventional concrete. Hence, the energy calculated by taking the area under the load deflection curve is approximately 12% higher for rubberized concrete. Therefore, it is evident that despite the reduction in strength, the toughness which is a measure of energy absorption capacity under static loading is higher for rubberized concrete compared to conventional concrete.

Table 1. Static Energy Absorption Results

Rubber Replacement (%)	Maximum load (KN)	Displacement (mm)	Energy (J)
0%	40.15	7	72
10%	19.84	15	81.5

E. Impact energy and energy absorption due to impact loads

The Impact energy was measured in eight samples from four mixes (i.e 0%, 5%, 10% and 15%). The results are given in Figure 4 and it can be seen that as the percentage of rubber crumbs increases to 5% and 10%, the impact energy also increases. Significant increment of 47.6% is observed when the percentage of rubber is 10%. However, at 15% of rubber content, a slight reduction of impact energy compared to the 10% rubber content can be seen. This could be due to the considerable reduction of compressive strength (66% compared to conventional concrete) observed in this sample of rubberized concrete. However, the value of impact energy in this sample is also still higher than the impact energy of conventional concrete. Therefore, it is evident from the results that addition of rubber crumbs can provide significant improvement to impact energy of concrete.

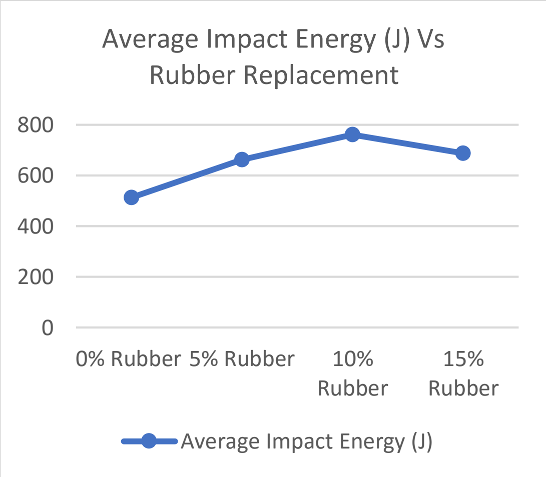

Figure 4. Variation of Energy with Rubber Replacement

F. Shock Abosrption

Shock absorption is calculated by considering percentage reduction in the maximum peak force compared to the conventional concrete sample. The results are shown in Table 2 from the results that shock absorption also increases as the rubber content increases. Maximum increment of shock absorbent is noticed as 8.75% which occurs for the samples with 15% rubber content.

Table 2. Shock absorption results

Rubber Preparations (%)	Maximum peak force in conventional concrete (Q(N))	Maximum peak force in test piece (P(N))	Shock absorption (%)
5	9424.919	8908.1715	5.45
10	9424.919	8734.088	7.3
15	9424.919	8604.653	8.75

Conclusions

Being in an agreement with the previous studies reported in the literature, density and also the compressive strength of concrete were found to decrease as the rubber content of concrete increases. Although, the density reduction is beneficial for some applications, the reduction in compressive strength is a major weakness in rubberized concrete. It was noticed that when 15% of fine aggregate was replaced by rubber crumbs, the reduction of compressive strength is approximately 66%. Further, the reduction in density is also not as significant as the lightweight concrete produced using the lightweight aggregate. The lowest density observed in this study was 2109 kg/m^3 where as the lightweight concrete can have densities as low as 1400 kg/m^3. However, the cost of rubberized concrete may considerably be lesser than the lightweight concrete. Further, the slump also found to decrease with the addition of rubber. However, this issue may be solved with the use of admixtures and additives.

Despite the above mentioned disadvantages, the results of this study revealed that rubberized concrete has better impact and energy absorption properties compared to the conventional concrete. The maximum increment of toughness reported in this study was 12%. Meanwhile, a significant increment of 47.6 was observed in impact energy. Also, the increment in shock absorption is observed as 8.75%. Therefore, it is clear that rubberized concrete is beneficial for structures where low strength but high impact and energy absorption properties are important such as road barriers. However, concrete mixes have to be carefully designed to achieve the optimum combination of properties to suit the applications. It is also important to pay attention to the cost factor as well. As rubber crumbs is a waste product, there is a high possibility of producing low cost structures using rubberized concrete. In addition, the environmental benefits achieved through the use of waste rubber must also be considered as an added advantage to the use of rubberized concrete.

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