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Effect of crumbed rubber Treatment method on the Flexural Behavior of High Strength Rubberized Concrete Slabs

A A Bashandy ¹, F M Eid^{2,*}, M A Mazyad ³ and M A Arab ^{4,*}

1 Alaa Ali Bashandy, Associated prof., Civil Engineering Department, Minoufiya University, Egypt (E-mail: eng_alb@yahoo.com)

2 Fatma M. Eid, Associated prof., Civil Engineering Department, Minoufiya University, Egypt (E-mail: dr.fatmaelzahraa@gmail.com)

3 Mohammed Ahmed Mazyad, Assistant lecturer, Civil Engineering Department, Thebes academy, Egypt (E-mail: mohammedmazayd79@gmail.com)

4 Mohammed Abd El-Salam Arab, Assistant prof., Civil Engineering Department, Beni-Suef University, Egypt (Corresponding Author; E-mail: emarab@eng.bsu.edu.eg)

*Correspondence: dr.fatmaelzahraa@gmail.com , fatma_elzahraa2002@yahoo.com

The most important research trends that the world is currently interested in are those that have a positive impact on the environment. The burning of the waste tyres is one of the most used means to get rid of these tyres, which causes a lot of gases to the air. The use of crumbed tyre rubber in concrete is considered one of the methods with a positive environmental impact. Using crumbed rubber as a partial replacement material of concrete aggregate is found to possess many engineering applications and holds promise within the future. Replacing 5% of the sand volume by crumbed tyre rubber was used. Flexural behaviour of treated and untreated rubberized concrete slabs was investigated. Experimental program shows that the behaviour of the high strength rubberized concrete slabs can be improved by the used treatment methods. Beside that the coarser of the rubber particles, the more negative effect on the behaviour of the high strength rubberized concrete slabs.

1. Introduction

Across the world, one billion tyres wasted every year and 0.5 billion more are expected to be discarded annually by 2030. Waste tyres need a bigger space for storing than other waste due to their large volume and fixed shape, this creates a serious problem[1,2]. To control the undesirable effects of disposal tyres, such as fire hazard and environmental problems. Many researchers have many trials in recycling and reusing end-of-life tyres by partial replacement of the concrete aggregates with crumb or scrap tyre rubber[3-5].

Siddique and Naik (2004)[4], El-Sherbini et al., (2010)[6], Nor et al., (2015)[7], More et al., (2015) [8], Selvakumar, et al., (2015) [1], Sofi, A., (2016)[9], Pardeshi et al., (2017)[10], Hassanli, et al., (2017)[3], and Al-Nasra et al., (2013)[11]researches shown that there was a significant increase in crumbed rubber concrete's density than normal concrete and that normal strength concrete containing crumbed tyre rubber exhibited a ductile failure.



Gerges et al., (2018)[12] described that softness of the surface of the rubber particles reduced the concrete strength because the rubber particles behaves like voids within the cement and aggregate matrix. Initiation of cracks quickly around the rubber accelerates the failure while loading.

More et al., (2015) [8] investigated the concrete tensile strength for 0, 3, 6, 9 and 12% fine aggregate replacement percentage with crumbed rubber. Their results showed that 3% replacement ratio of sand decreased split tensile strength of concrete by about 30% and the weak bond between cement and rubber particles was the reason of this reduction.

Al-Tayeb, et al., (2012)[13] replaced the volume of sand with 5 %, 10 % and 20% waste crumb rubber. Their study concluded that the impact and bending loads increased with the increase in the percentage of sand replacement by crumb rubber. Beside that the compressive and tensile stresses of concrete by the partial replacement of sand by crumb rubber, reduce by 5–20 %, and 11–17 % respectively.

Sallam, et al., (2008)[14] reported that 10% of fine rubber in the concrete mix was suitable for having an acceptable decrease in compressive strength. In addition, the presence of crumb rubber of small size in concrete increased the resistance of concrete to crack initiation under impact load.

Hassanli, et al., (2017) [3] studied the behavior of rubberized concrete at the structural application level and introduced a numerical prediction of the behavior of rubberized concrete beams and columns. It could be observed that the deflection capacity of the rubberized concrete beam was increased by 7.7% to 27.9% compared to that has no rubber content. Beside that the reduction in flexural strength due to rubber content is not as much as the reduction in compressive strength. Recommendation to use rubberized concrete in flexural members with ductile response was introduced.

Sivakumar, et al., (2013) [1] studied the replacement of coarse aggregate in reinforced concrete beams. According to their study the cracks have been occurred slightly near to the support of the beam, also recycled coarse aggregate replacement up to 30% in concrete has shown good improvement in flexural strength.

The present work focused on studying the effect of using different treating methods for crumbed rubber using different chemicals and techniques on the flexural behavior of treated and untreated high strength rubberized concrete slabs.

2. Materials and Methods

2.1. Materials

Cement: The used cement was ordinary Portland cement CEM I N 52.5 conforming to (E.S.S. 4756-1/2009)[15].

Coarse aggregate: The coarse aggregate was a natural dolomite with a maximum nominal size of 12.5mm. The coarse aggregate has a specific gravity 2.65.

Fine aggregate: The fine aggregate was natural siliceous sand with a specific gravity 2.65.

Crumb tyre rubber: Two grades of rubber were used. The first grade was the finer and mixes contain this type has a symbol started with F. The second grade was the coarser and mixes contain this type has a symbol started with C. Grade F has a grain size less than 0.6mm and larger than 0.15mm. Grade C has a grain size less than 2.36 mm and larger than 0.6mm.

Silica fume: The density and fineness of the used silica fume were 2210 kg/m^3 and $23.52 \text{ m}^2/\text{gm}$ respectively conforming to ASTM C 1240[16].

Super-plasticizer: Sika Viscocrete 3425 was used according to ASTM-C-494, types G and F[17].

Sodium hydroxide (NaOH): Sodium hydroxide is a strong caustic alkali (known as caustic soda). It is highly soluble in water liberating intense heat. It is an odorless white crystalline solid.

Potassium permanganate (KMnO₄): Potassium permanganate is a strong oxidizing agent. It is purplish crystalline solid. It is soluble in water giving an intensely purple or pink solution.

Sodium bisulfite (NaHSO₃): Sodium bisulfite is a compound with a chemical formula NaHSO₃. This salt of bisulfate is prepared by bubbling sulfur dioxide in a solution of sodium carbonate in water.

Steel Reinforcement: Mild steel of 8 mm diameter was used as the main reinforcement for the concrete slabs. The yield and ultimate strength of the steel bars are 2950 Kg/cm² and 3990 Kg/cm² respectively.

2.2. Mix Proportions

A high strength concrete mix was used in this research. As indicated from the literature review, 5% rubber replacement as a percentage of fine aggregates volume was chosen. Mix proportions used in this test program for control mix concrete are summarized in Table (1).

Table 1. Concrete mix proportions in kg/m³.

Cement	Silica fume	Water	Super-Plasticizer	Coarse Aggregate	Fine Aggregate
550	27.5	184.8	4.91	850	670

2.3. Slabs Dimensions and Reinforcement

The tested slabs were with dimensions of 1100×450×50 mm. 11 reinforced high strength concrete slabs were cast. The slab reinforced with 4 steel bars of 8mm diameter were in the longitudinal direction and 7 steel bars of 8mm diameter were in the short direction.

2.4. Testing Procedures and Equipment

Impact test: Impact test was carried out on 100x100x500mm prisms. A 1.150 kg metallic ball was dropped from 1.12 m height at the center of the prisms and this for all prisms. For each prism, the number of blows was recorded for the failure crack then impact energy was calculated. Impact test procedure and apparatus was set according to (CSTB/ MELTM (1989) and ISO 7892 (1988))[18].

IE (Impact energy) (J) = No. of blow at the Final crack × M × H × g

Where M: the weight of ball= 1.15 Kg.

N: No. of blow at the final crack

H: is the drop height of the body (1.12 m)

g: is the acceleration of gravity (9.81 m/s²).

Slab Flexural Test: Three points load flexural test were executed on the reinforced high strength concrete slabs to investigate the load deflection behavior and study the different factors affecting this behavior. Slabs were tested on a steel frame with two support. The load was applied by a hydraulic cylinder acting with 150 ton capacity and 150 mm maximum Stroke which was connected to a hydraulic electric oil pump for feeding the hydraulic jack. The applied load was measured by a load cell of 225 ton capacity. A strain gauge for measuring displacements up to at least 100 mm was placed under each slab at the center of its span to measure deflections were used for deflection measurements within the region of pure bending. Figure (1) shows the machinery used in the slabs testing.



Figure 1. Three Point Load Flexural Test.

2.5. Rubber Treatment Methods

2.5.1. Using NaOH alone:

In this method, 20%NaOH solution was used. Crumb rubber was soaked in the solution for 24 h after that the rubber was rinsed in distilled water to remove excess NaOH. Sample with this treatment method abbreviated by N.

2.5.2. Using NaOH, KMnO₄, and NaHSO₃:

In this method, two samples were used. The first sample treated by soaking in 20% NaOH concentration for 24h and then treated crumbed rubber was soaked in the solution of 10% KMnO₄ for 24h then treated by 5% NaHSO₃ for 24h. The second sample was soaked in 5% NaOH and then soaked in5% KMnO₄ by stirring for 2h with heating and treated by 5% NaHSO₃ stirring for 0.5h with heating respectively. The two samples rinsed in distilled water. The first sample abbreviated by NKS24 and the second sample abbreviated by NKS.

2.5.3. Subjected the treated and untreated rubber to 200°C temperature:

This technique aimed to investigate the effect of high temperature on rubber surface modification. In this method, untreated crumbed rubber was placed in tightly closed containers and heated at 200°C for 0.5h. Samples with this treatment were abbreviated as CF and FF for grade C and F respectively.

2.6. Mechanical Properties of the Tested Concrete Mixes

Table 2 shows the mechanical properties results of the treated and un treated rubberized concrete mixes.

Table 2. Mechanical Properties of the used mixes.

	Compressive Strength Mpa	Tensile Strength Mpa	Flexural Strength Mpa	IE J
Control	73	8.4	10.95	2095
C	63	7.2	9.92	3900
CN	74	8.53	11.4	3421
CNKS	78.5	8.75	10.96	3320
CNKS24	79.5	8.99	11.54	3446
CF	77	8.5	11.25	1994
F	71	8.16	11.36	2287
FN	63.5	7.1	10.4	2338
FNKS24	65.5	7.6	9.2	2148
FNKS	57.5	6.2	8.1	1971
FF	80	9.1	11.7	2146

3. Slab Results and Discussion

3.1. Load deflection curve

The comparison of load deflection curves for tested slabs containing treated crumb rubber and control slab compared in figure 2 and figure 3. The reasons for the difference between the curves will be addressed in the following items.

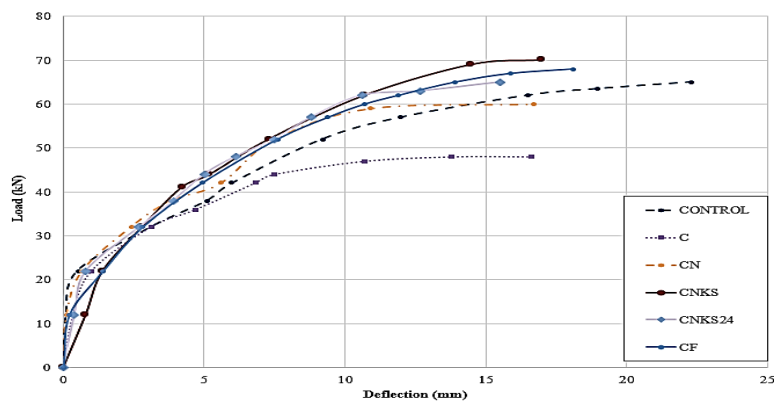


Figure 2. Load deflection curves for slabs containing grade C rubber.

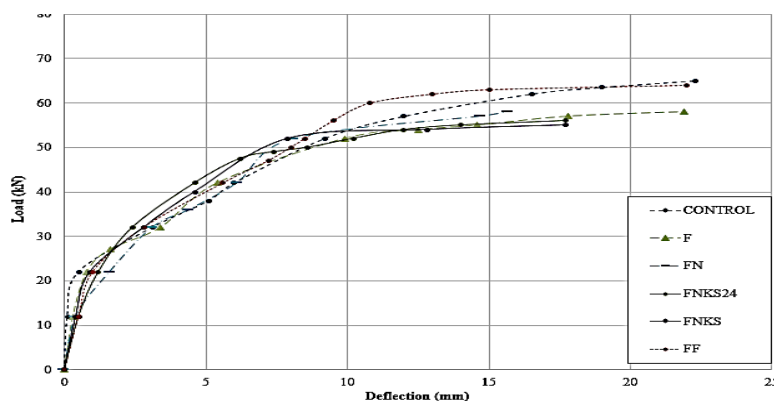


Figure 3. Load deflection curves for slabs containing grade F rubber.

3.2. Absorbed energy

The ductility is a structural property that is governed by the fracture and depends on the structure element's size. It could be calculated by considering the area below the load-deflection curve. The more increase in absorbed energy values refers to more slab ductile behavior.

Figure 4 shows the absorbed energy values for the tested slabs. As shown in Figure 4 it could be noticed that the control slab was more ductile than others and the CNKS gave the best result which decreased by 1.81% compared with the control mix.

3.3. Ultimate and cracking load

Figure 5 and Figure 6 show the ultimate and cracking load for the tested slabs respectively. It is clear that the results are close in the initial cracking load, and the difference was in the ultimate load. Beside that using treatment methods improved the ultimate load results compared to the control slab. The ultimate load decreased by 26.15% and 7.69% for used C and CN. While, the ultimate load increased by 7.69%, 10.76% and 4.61 % for CNKS, CNKS24 and CF, respectively. However for grade F the ultimate load decreased by 10.76%, 10.76%, 13.84 %, 15.38% and 1.5% for mixes F, FN, FNKS, FNKS24 and FF, respectively.

FNKS24, FNKS and FF respectively. The pervious results is a good indication of the effectiveness of the used chemical treatment methods. Chemical modification methods modify the surface of rubber to introduce strong polarity groups such as polar carbonyl(C=O), hydroxyl (O–H) and sulfonate (SO₃) groups on the rubber surface. Bonded groups made a hydrogen bond and ionic bond with large numbers. The bond between the cement matrix and rubber greatly improved which leads to improving the mechanical properties of the rubberized concrete. The results of CF and FF slabs in ultimate loading is an indication for the improvement happened to the rubber by Subjecting the untreated rubber to 200°C temperature.

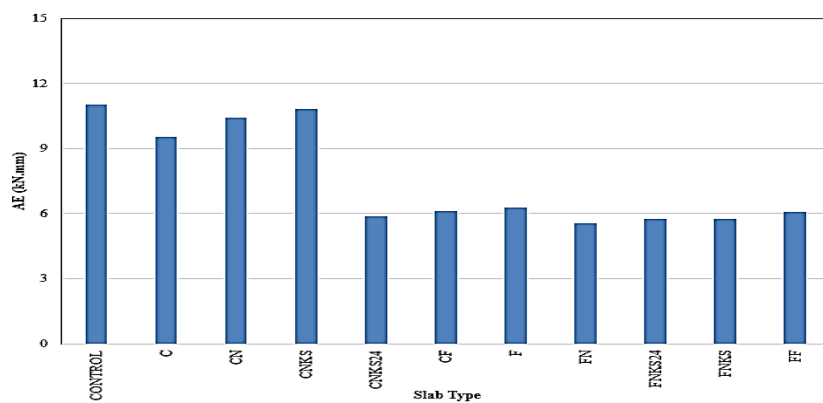


Figure 4. Absorbed energy for high strength rubberized concrete slabs.

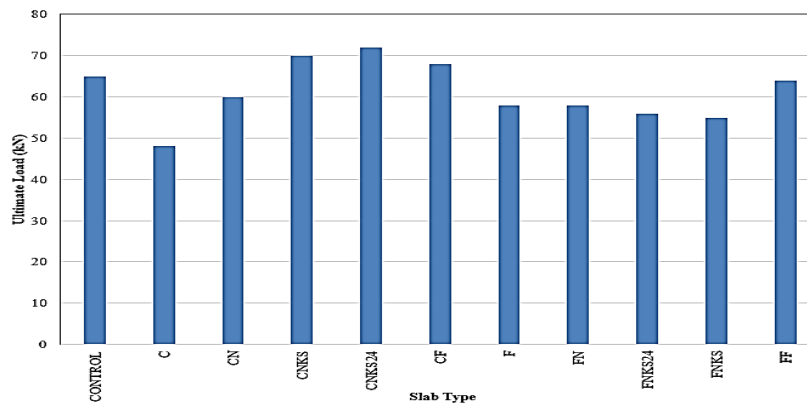


Figure 5. Ultimate load for high strength rubberized concrete slabs.

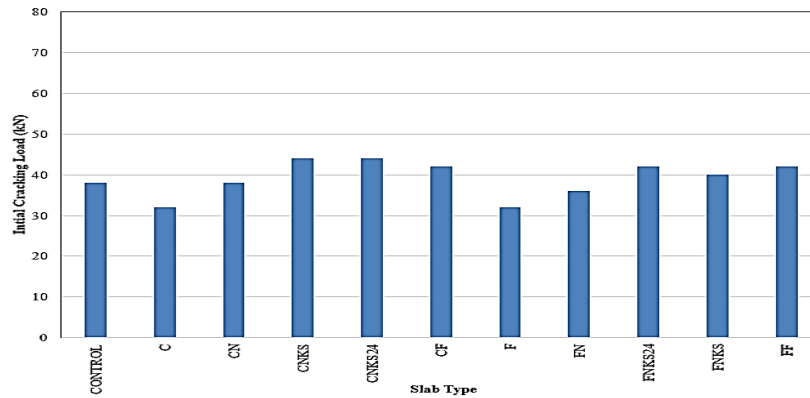


Figure 6.Initial cracking load for high strength rubberized concrete.

3.4. Cracks pattern and failure

The cracks' patterns were recorded at each load increment; all the tested slabs were failed shear. Figure 7 shows examples of 9 types of tested slabs after failure. For control slab, the flexural cracks were initiated at the bottom of the slab but stopped at a certain distance before penetrating compression zone and with load increasing; shear crack appeared at both sides of the slabs to form with the load increasing the same shape and direction of the inclined compression strut till sudden failure. All slabs were initiated by flexure cracks and propagated vertically upward, but did not meet the inclined compression strut. As the applied load increased, diagonal shear cracks appeared through the inclined compression strut. With increasing load, other shear cracks develop to the lower area near the support and the slab reached sudden failure through the inclined compression strut.

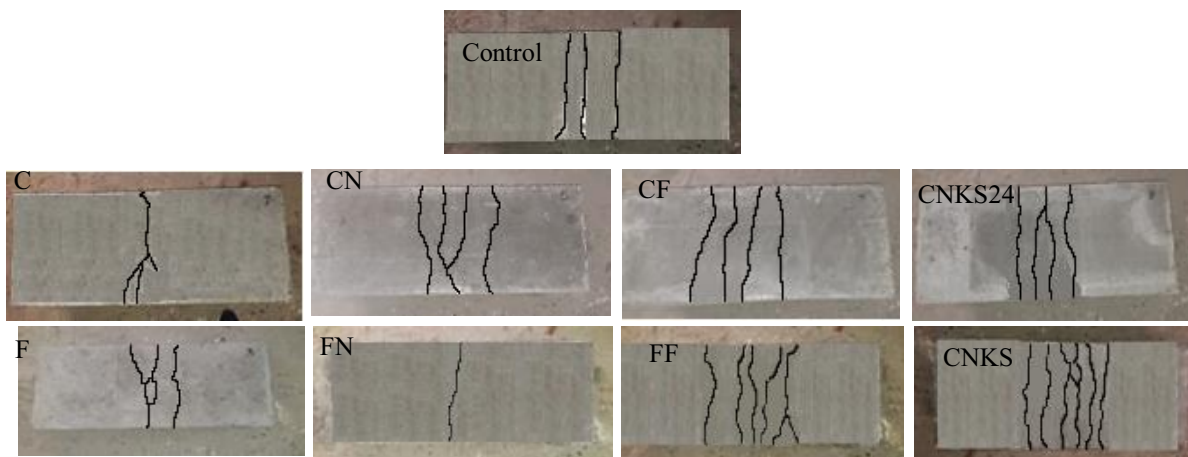


Figure 7.Crack pattern of tested slabs.

4. Conclusions

Based on the results obtained from the current research, the following conclusions could be obtained:

- 1- Partially replacing of fine aggregate with untreated crumbed rubber has a negative effect on the behavior of high strength concrete slabs.
- 2- The coarser of the rubber particles, the more negative effect on the behavior of the high strength rubberized concrete slabs.
- 3- The behavior of the high strength rubberized concrete slabs can be improved by the used treatment methods.
- 4- For the same grade of crumbed rubber, the used treatment method has a slightly effect on the initial cracking load of the high strength concrete slabs and a significant effect on the ultimate load.
- 5- The ultimate load decreased by 26.15% and 1.5% when used grade C and grade F on the concrete mix respectively.
- 6- CNKS24 gave the best results on the ultimate and cracking loads than other treatment methods.

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