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Research Article

Enhanced Properties of Crumb Rubber and Its Application in Rubberized Concrete

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Abstract

This paper evaluates the mechanical properties of rubberized concrete mixes containing rubber treated in sodium hydroxide solution and similar mixes containing untreated rubber the test results are compared to those control mixes without rubber. The aim of the present work is treating rubber to increase the bond between the rubber particles and concrete. Crumb rubber was utilized as partial replacement of sand in concrete. The replacement ratios were 5, 10 and 15% by volume of sand. Silica fume was used as an addition to increase the compressive strength. The water to cement ratio used in all concrete mixes was 0.42. The concentrations of the NaOH solution were 15%, 20% and 30%. It was found that using 20% concentration of NaOH for crumb rubber treatment was the most effective resulting in favourable hardened concrete characteristics. Experimental results showed higher compressive and flexural strengths, modulus of elasticity and tensile strength of rubberized concrete containing treated rubber compared to untreated rubber mixes. Although, there was a remarkable reduction in the strength and modulus of elasticity values with the increase in rubber content, using of fine rubber in building construction could help save energy, reduce costs and solve the solid waste disposal problem posed by this type of waste instead of negative effects on society and environment.

***Keywords**: Recycling, Tire rubber, Concrete, NaOH treatment*.

1. Introduction

Scrap tires are being generated and accumulated in large volumes. Accumulation of hazardous waste materials in vast quantities such as chemicals, toxic or non-decaying material causes an increasing threat to the environment because of the highly complex configuration of the ingredient materials. In order to eliminate the negative effect of these depositions and in terms of sustainable development, there is a great interest in the recycling of these non-hazardous solid wastes in applications where tires can be used and where the addition of tire rubber has proven to be effective in protecting the environment.

In the last 20 years, a lot of work had been done in various civil engineering projects by using these waste materials. Several studies had been conducted to facilitate using of this waste material into concrete which provides a strong recommendation for using of this waste as a partial replacement of coarse or fine aggregate by scrap tire rubber in concrete production.

Rubberized concrete is an affordable construction material that withstands more pressure and impact when compared to conventional concrete. Rubberized concrete can be therefore used in buildings as an earthquake shock-wave absorber, foundation pad of machinery, construction of highway pavement, airport runways and crash barriers. Also, rubberized concrete would be very suitable to be used in architectural applications such as nailing concrete where high strength is not necessary, in wall panels which require low unit weight, jersey barriers in which high strength is not necessary.

(Benazzouk *et al*, 2003) observed a sharp reduction in compressive strength of concrete on inclusion of rubber particles in cementitious matrix citing two possible reasons: (i) presence of less stiff rubber particles than the surrounding cement paste and (ii) cracks around the rubber particles, which accelerate the failure in the matrix.

Studies have indicated that if the rubber particles have a rougher surface, better and improved bonding may develop with the surrounding matrix which results in higher compressive strength.

Pre-treatments may vary from washing rubber particles with water to acid etching, plasma pretreatment and various coupling agents (Naik *et al*, 1991). (Dong, 2013) employed a new approach to improve the performance of rubberized concrete by developing a cementitious coating layer around rubber particles with silane coupling agent.

(Li *et al*, 2016) has investigated the influence of surface treatment by using silane coupling agent (SCA) and carboxylate styrene-butadiene rubber (CSBR) on

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the mechanical strength. It was observed that, the hydrophobic nature and lower density of waste rubbers lead to the poor interfacial bond and heterogeneous distribution of rubbers within concrete. Also the surface modification of waste rubber by the combination of carboxylate styrene butadiene rubber (CSBR) and silane coupling agent (SCA) improved the interfacial adhesive behavior of rubber to cement hydrates and improved the microstructure of concrete. (Chou, 2010) also reported that the pre-treatment of waste tire rubber with sulfur compounds improved the compressive, tensile and flexural strengths of rubberized concrete.

It is evident from the work reported above that although a number of studies have been undertaken on the properties of rubberized concrete; most of the studies are limited to a single w/c ratio. Further, there are very few studies available for the combined effect of inclusion of waste rubber tire fiber and silica fume in concrete. It may be noted that waste tire fibers were found to perform better than the waste rubber chips as replacement of aggregates (Pelisser, Fernando *et al*, 2011). Similarly, (Gupta *et al*, 2014) observed better performance of rubber fibers as compared to rubber ash.

2. Mechanism of NaOH Treatment for Rubber

When sodium hydroxide (NaOH) is dissolved into water, thermal energy is generated. During treatment, zinc stearate turns to sodium stearate, which is more soluble in water and would be removed from the surface during the rinsing of the rubber after the treatment. This removal causes significant changes in the surface chemistry of the treated rubber by increasing the contact surface between rubber and the cement paste and making the bond between them stronger. This observation can lead the way to further research on the best treatment to eliminate zinc stearate from the rubber surface in order to optimize the incorporation of tires into cementitious materials (Ling, Tung-Chai, 2011).

Rubber particles are composed of organic components (such as isoprene, styrene, butadiene, etc.). The reaction of a base with organic materials produces a rough surface that can trap air inside producing bubbles which will increase the air-entrained in concrete.

These bubbles will increase the deficiencies of concrete and further reduce the concrete strength [9]. However, the immersion of rubber in NAOH aqueous solution is used for increasing the adhesion of rubber to the surrounding cement paste. This increase in adhesion enhances the strength of concrete containing rubber particles through a microscopic increase in the surface texture of the rubber particles.

So, the roughness level of rubber particles should be balanced and optimized. The alkali solution cannot have significant effect on rubber particles if the time of treatment in NaOH solution is not sufficient, or the alkali solution is not strong enough. On the other hand, extended immersion can damage the rubber particles and make their surfaces rougher (Khorrami Morteza *et al*, 2010).

The level of improvement achieved by this method has not been consistent between different studies. Hence, it is worthwhile to study the application of this treatment method. This study is aimed to investigate the optimization of NaOH solution for rubber treatment. The produced rubberized concrete is expected to have enhanced strength, while providing means of saving natural resources.

3. The Experimental Work

3.1. Materials

The cement used was ordinary Portland cement (CEM I 42.5N) conforming to (ESS 4756-1/2009) [10] with specific weight 3.15. The physical properties of cement are shown in Table. (1). The coarse aggregate was natural dolomite from Suez. The coarse aggregate size was 10-25 mm with a specific gravity of 2.65. The grading of coarse aggregates is illustrated in Figure.(1) according to ASTM C127 [11]. The fine aggregate was natural siliceous sand from El-khatatba with a specific gravity 2.60 and fineness modulus of 2.60. The grading of fine aggregates is illustrated in Figure.(2) according to ASTM C128 [12]. Micro silica is a product resulting from industry of ferro silicon alloys. The product is a rich silicon dioxide powder with average particles size f 0.1 micrometers. The water reducer admixture was Sika Plastiment- RX/SRB. It meets the requirements for super-plasticizers according to ASTM C-494 type A, B and D [13]. Its color is brawn and its density is 1.185 kg/L. Tap water was conditioned to the temperature of (23 ± 2°C) was used for mixing and curing procedures. Recycled tire rubber is obtained from Marco Misr International for producing rubber products in 10th of Ramadan City-Cairo-Egypt. The grading of rubber is illustrated below as shown in Figure. (2). Rubber is classified as crumb rubber with 2 mm nominal size as shown in Figures. (2 and 3). The specific gravity of crumb rubber was 1.12. Sodium hydroxide is a composite baseline. It dissolves in water easily producing intense heat. The concentrations of the NaOH solution used are given in Table.(2).

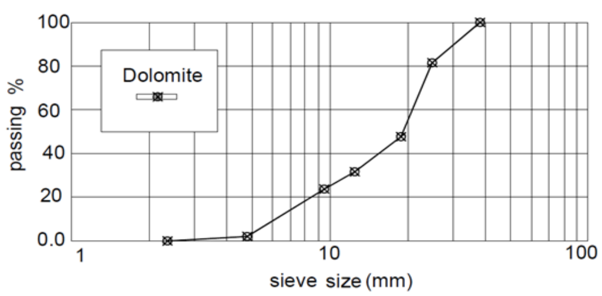

Fig.1 Sieve Analysis of Dolomite Aggregates

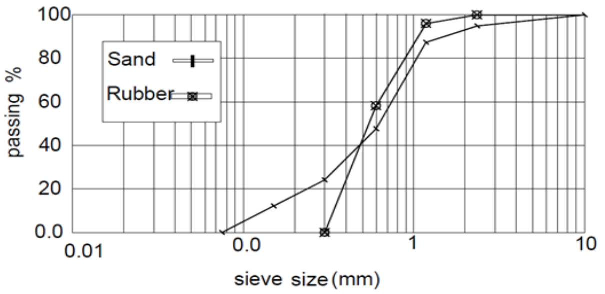

Fig.2 Sieve Analysis of Sand and Rubber Aggregates

Fig.3 The Sizes of Rubber Particles

Table 1 Portland Cement Properties

Property	Test results	ESS 4756-1/2009 LIMITS
Setting time (min)	150	Not less than 60 min
Initial Final	195	–
Soundness (mm)	1	Not more than 10
Compressive	23.5	Not less than 20
strength (MPa) 2 days 28 days	55.2	Not less than 52.5

Table 2 Concentrations of NaOH

The Concentration of NaOH (by weight) %	15.0	20.0	30.0
The Concentration of NaOH b Mall / liter	4.23	6.09	9.95
NaOH grams / liter	169.3	243.8	398.3
The Density of the Solution g / m3	1160	1219	1328

3.2. Rubber Treatment in Sodium Hydroxide (NaOH) Solution

In order to perform the treatment of rubber particles, a saturated solution of sodium hydroxide was prepared. This was carried out using identical solution concentration and consistent modification of rubber. To keep the consistency, the volume of modifier solution in container was set to be 5 times larger than the volume of rubber. Also, NaOH alkaline is dissolved in 10 L from water by volume and the concentration was different as shown in Table.(2). Then, the rubber in the solution was stirred regularly to guaranty a uniform treatment of rubber particles Figures. (4, 5 and 6) present some samples taken from containers at the end of different treatment concentration. Afterwards, the rubber particles were rinsed to be cleaned from alkali solution. Rinsing with water was continued until the PH of washed rubber particles became at the lowest value.

Fig.4 Shape of Rubber after Treatment with 15% NaOH

Fig.5 Shapes of Rubber after Treatment with 20% NaOH

Fig.6 Shape of Rubber after Treatment with 30% NaOH

3.3. Experimental Test Program

A total of 13 concrete mixes were proportioned Table.(3) shows the weight of the different constituents in kilogram per cubic meter of fresh concrete. The weight of the constituents was calculated by applying the absolute volume role assuming full compaction and zero air voids in the fresh concrete mass. The control mix (mix c) with zero rubber content was proportioned so that the ratio of the coarse aggregate to fine aggregate by weight was 1.50. The twelve mixes were grouped in three groups depending on the sand replacement ratio. The rubber replaced 5%, 10% and 15% of sand by volume in groups 1, 2 and 3, respectively. Each group comprised four mixes.

Table 3 Constituents for Mix Series Prepared for Assessing Rubber Treatment Methods for 1 m3.

GROUP	Mix	Rubber %	Cement (Kg)	Sand (Kg)	Dolomite (Kg)	Rubber (Kg)	Water (Kg)	Silica Fume (Kg)	Water Reducer (Kg)
-	C	0.0	500	637	956	0.0	210	50	4
1	U 5	5	500	605	956	13.7	210	50	4
	T5/15								
	T5/20								
	T5/30								
2	U 10	10	500	573	956	27.4	210	50	4
	T10/15								
	T10/20								
	T10/30								
3	U 15	15	500	541	956	41.1	210	50	4
	T15/15								
	T15/20								
	T15/30								

The concrete mix in a group is donated by a letter T or U (the letter T stands for treated rubber and the letter U stands for untreated rubber) followed by a ratio (5%, 10% or 15%) which refers to the rubber /sand replacement percentage followed by a slash and the percentage of NaOH solution concentration (15%, 20% and 30%) for example: (T10/15) is a mix containing rubber treated in 15% concentration NaOH solution and 10% of sand by volume.

3.4. Test Specimens

The experimental program involved the testing of 100 mm concrete cubes to evaluate the compressive strength, 150 x 300 mm cylinders to evaluate the splitting tensile strength and modulus of elasticity, while 100 x 100 mm x 500 mm prisms were used to determine the modulus of fracture.

3.5. Mixing and Casting

A 30 liter drum mixer was used for mixing the concrete. First, the mixer was changed with the aggregate and the blend of cement and silica fume. The dry constituents were thoroughly mixed for two minutes, the mixing water was added and mixing continued for a minute and finally, the rubber and the water reducer admixture were added. Mixing continued for two minutes to ensure efficient action of the chemical admixture.

3.6. Curing of Concrete Specimens

After casting, all specimens were kept in the moulds for 24 hours. After which, they were removed from the moulds and immersed in water at 20°C until the age of testing. The steel moulds were prepared and casted following the requirements and procedure described in the respective specifications [14, 15 and 16], respectively.

4. Results and Discussion

Fresh and hardened concrete were tested to determine the influence of the test parameters including the rubber-sand replacement ratio and the treatment of the rubber particles.

4.1. Slump of Fresh Concrete

As the rubber particles were thoroughly washed after being immersed in NaOH, the water absorbed on the rough surfaces of the rubber particles added to the free water in the concrete mixes and that would explain the gradual increase of the slump as the rubber percentage was increased. On the other hand, the slump decreased as the untreated rubber content increased as the unit weight of the fresh concreted decreased. Also, the results indicated that the concentration of the NaOH solution had no significant influence on the slump.

Table 4 The Results of the Slump Test

Mix	Rubber Percentage	Conc. of NaOH	W/C	Slump[mm]
C	R.0%	--	0.42	50
U5	R.5%	0%		60
T5/15		15%		70
T5/20		20%		60
T5/30		30%		75
U10	R.10%	0%		55
T10/15		15%		75
T10/20		20%		65
T10/30		30%		75
U15	R.15%	0%		45
T15/15		15%		75
T15/20		20%		60
T15/30		30%		60

4.2. Hardened Properties of Concrete

4.2.1 Compressive Strength

The compressive strength for all mixes was evaluated at 28 days. When 5 percent rubber was used, the compressive strength decreased by 24% compared to the control mix in case of untreated rubber. When the rubber was treated in 15, 20 and 30 percent concentration NaOH solution, the corresponding reduction ratios were limited to 11 , 4 and 13 percent as can be seen in Figure.(7).

Similar trend was obtained when the rubber content increased to 10 and 15 percent.

At 10 percent rubber replacement ratio, the compressive strength was reduced by 30.5 percent when untreated rubber was used. While the reduction ratio was limited to 20, 7.5 and 22 percent for 15, 20 and 30 percent NaOH concentration, respectively.

The corresponding ratios at 15% rubber content were 38 percent for untreated rubber and 24, 13.7 and 28 percent for treated rubber as can be seen in Figure (9).The above results show that the compressive strength was gradually reduced as the rubber content increased. However, the reduction was effectively controlled by the treatment of the rubber in 20% NaOH solution.

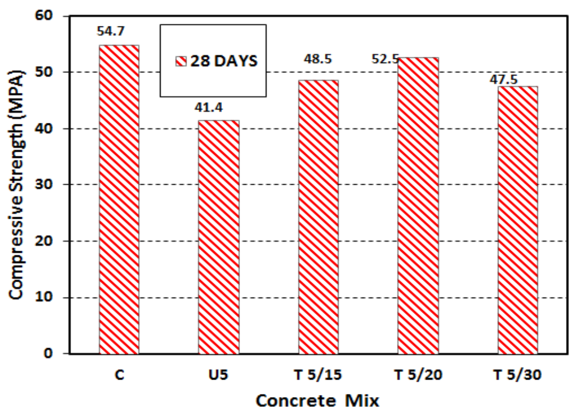

Fig.7 Compressive Strength of the Tested Cubes for 5% Crumb Rubber

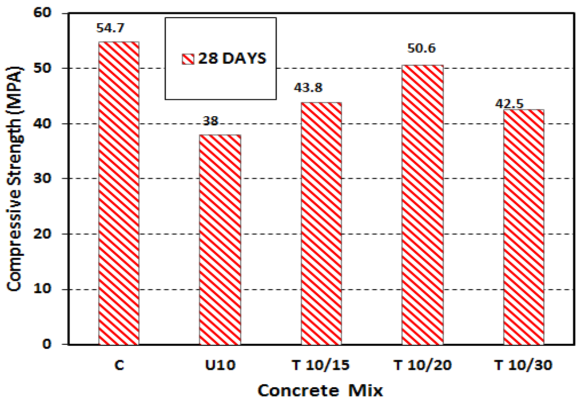

Fig.8 Compressive Strength of the Tested Cubes for 10% Crumb Rubber

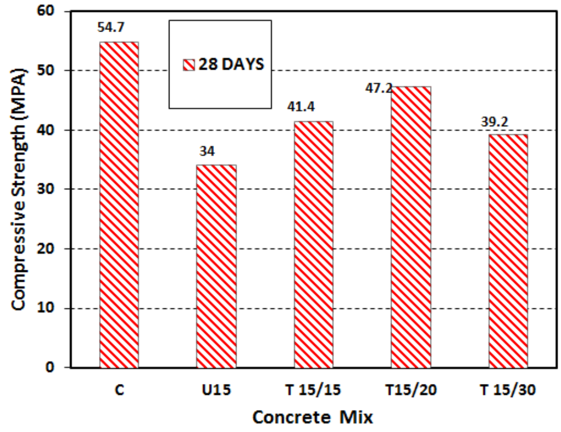

Fig.9 Compressive Strength of the Tested Cubes for 15% Crumb Rubber

4.2.2 Tensile Strength

The tensile strength for all mixes was evaluated at 28 days. When 5 percent rubber was used, the tensile strength decreased by 28.5% compared to the control mix in case of untreated rubber. When the rubber was treated in 15, 20 and 30 percent concentration NaOH solution, the corresponding reduction ratios were limited to 8.7, 5.3 and 18.2 percent as can be seen in Figure.(10).

Similar trend was obtained when the rubber content increased to 10 and 15 percent. At 10 percent rubber replacement ratio, the tensile strength was reduced by 32.8 percent when untreated rubber was used, while the reduction ratio was limited to 17.3, 11.3 and 25.1 percent for 15, 20 and 30 percent NaOH concentration, respectively.

The corresponding ratios at 15% rubber content were 38 percent for untreated rubber and 23.4, 15.6 and 36.3 percent for treated rubber as can be seen in Figure (10).The above results show that the tensile strength was gradually reduced as the rubber content increased. However, the reduction was effectively controlled by the treatment of the rubber in 20% NaOH solution.

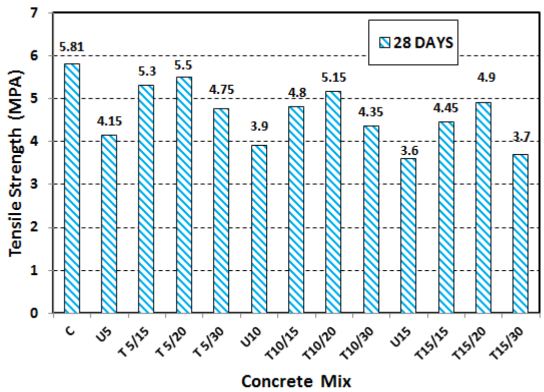

Fig.10 Tensile Strength of the Tested Cylinders after 28 Days

4.2.3 Flexural Strength

The flexural strength for all mixes was evaluated at 28 days. When 5 percent rubber was used, the compressive strength decreased by 31.9% compared to the control mix in case of untreated rubber. When the rubber was treated in 15, 20 and 30 percent concentration NaOH solution, the corresponding reduction ratios were limited to 5.2, 4.2 and 8.1 percent as can be seen in Figure.(11).

Similar trend was obtained when the rubber content increased to 10 and 15 percent. At 10 percent rubber replacement ratio, the flexural strength was reduced by 34.8 percent when untreated rubber was used, while the reduction ratio was limited to 14.1, 6.2 and 16 percent for 15, 20 and 30 percent NaOH concentration, respectively.

The corresponding ratios at 15% rubber content were 40.7 percent for untreated rubber and 23, 7.2 and 25.9 percent for treated rubber as can be seen in Figure (11).The above results show that the flexural strength was gradually reduced as the rubber content increased. However, the reduction was effectively controlled by the treatment of the rubber in 20% NaOH solution.

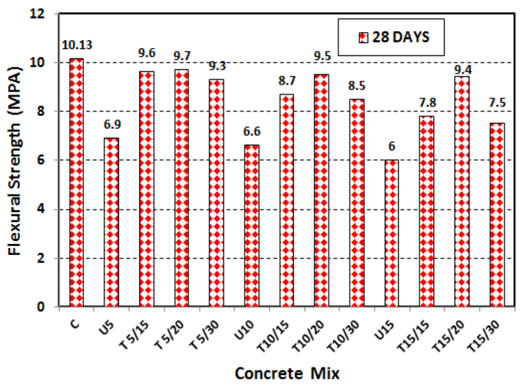

Fig.11 Flexural Strength of the Tested Cylinders after 28 Days

4.2.4 The Modulus of Elasticity

The modulus of elasticity is an important parameter of concrete in the design of structures since it impacts the serviceability and performance of concrete structures. The elastic modulus of concrete is closely related to properties of cement paste and stiffness of concrete aggregates. Test results demonstrated in Figures.(12-15) indicated that different concentrations of the treatment solutions significantly affect the modulus of elasticity of concrete.

The overall results showed that rubber particles in concrete led to a reduction in the modulus of elasticity of treated and untreated rubberized concrete compared to plain concrete. The reduction of the modulus of elasticity due to the use of rubber aggregates can logically be justified by the well-established fact that the modulus of elasticity of concrete is influenced by on the strength of concrete and the large difference between the elastic modulus of rubber and the elastic modulus of other concrete elements such as aggregates and cement paste.

Rubber treatment in NaOH concentration of 20% for 5% rubber content gave the highest modulus of elasticity among other NaOH concentrations. The improvement in the bond between rubber and cement paste could positively influence and prevent acceleration of the crack propagation in concrete.

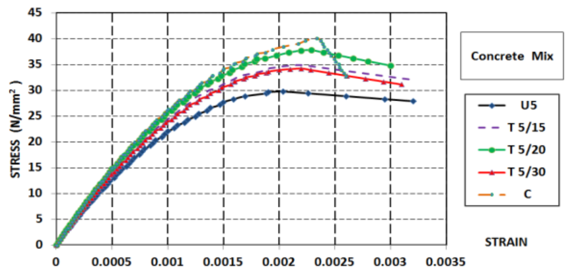

Fig.12 Stress-Strain Curve of the Tested Cylinders after 28 Days for 5% Crumb Rubber

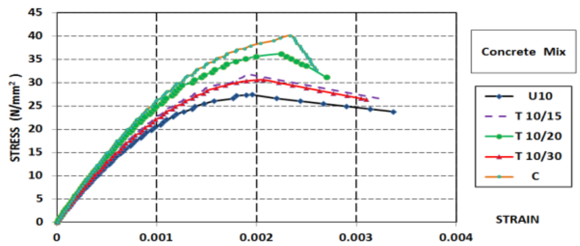

Fig.13 Stress-Strain Curve of the Tested Cylinders after 28 Days for 10%Crumb Rubber

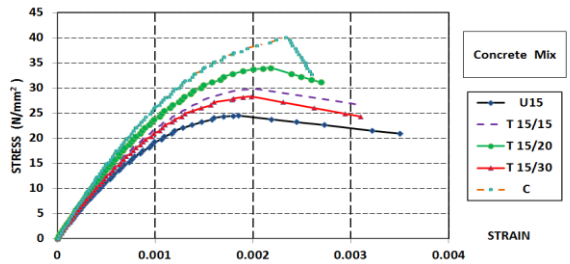

Fig.14 Stress-Strain Curve of the Tested Cylinders after 28 Days for 15% Crumb Rubber

Fig.15 Shape of Failure for Tested Cylinders after the Modulus of Elasticity Test

Conclusions

This study presents the results of partially replacing sand in concrete mixes with treated and untreated tire rubber. Based on the results of the study the following conclusions can be drawn:

1) The slump of fresh concrete tended to be reduced due to the replacement of sand. The unit weight of concrete was low. However, the compatibility of concrete was not affected.
2) The 28-day compressive strength was reduced due to sand replacement with rubber. The reduction ratio was 24% at 5% replacement and increased to 38 percent when the replacement ratio increased to 15%.
3) The percentage of compressive strength reduction was reduced effectively by the treatment of rubber in NaOH solutions. The optimum reduction was recorded at 10% rubber replacement ratio. The reduction was limited to 7.5% in case of treated rubber compared to 30.5% in case of untreated rubber.
4) The 28-day splitting tensile strength was reduced due to sand replacement with rubber. The reduction ratio was 28.5% at 5% replacement and increased to 38 percent when the replacement ratio increased to 15%.
5) The percentage of splitting tensile strength reduction was reduced effectively by the treatment of rubber in NaOH solutions. The optimum reduction was recorded at 10% rubber replacement ratio. The reduction was limited to 11.3% in case of treated rubber compared to 32.8% in case of untreated rubber.
6) The 28-day flexural strength was reduced due to sand replacement with rubber. The reduction ratio was 31.9% at 5% replacement and increased to 40.7 percent when the replacement ratio increased to 15%.
7) The percentage of flexural strength reduction was reduced effectively by the treatment of rubber in NaOH solutions. The optimum reduction was recorded at 10% rubber replacement ratio. The reduction was limited to 6.2% in case of treated rubber compared to 34.8% in case of untreated rubber.

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