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Experimental Study on Enhanced Crumb Rubber Concrete

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Abstract— It's very important for environmental issue to use disposal of waste tires. Rubber from waste tires used for partial replacement of fine aggregate in traditional concrete, the resulting product called crumb rubber concrete (CRC). Concrete mixes containing waste crumb rubber untreated/treated with replacement percentages (3% and 6%) of fine aggregate were studied and those mixes were compared with traditional concrete mix to investigate the behavior of untreated CRC and optimized treated CRC. It's worth to be mention that, chemical agent succeeded to treat and increase the bonding chain between crumb rubber and concrete. On the other hand, reinforced concrete beams were cast with the same percentages of fine aggregate replacement (3% and 6% treated crumb rubber). Furthermore, two reinforced concrete beams were cast with three layers, the lower concrete layer cast with traditional concrete but the middle and upper layers were cast with treated CRC to studying flexural strength and bond efficiency, also, control RC beam with traditional concrete was cast for comparison. It was concluded that, compressive strength effected by positive value by increasing treated crumb rubber percentage. CRC shows reduction in the density of concrete in comparison to traditional concrete. By increasing rubber percentage, slump values decreased.

Index Terms— Rubber Concrete, Multi-Layers Concrete, Green Concrete, Sustainability and Recycling

1 Introduction

Here, Green concrete can be define as concrete cast with wasted materials, such as crumb rubber which is manufactured from useless tyres. Useless tyres may be recycled again in many countries as a local production and can explode causing accident and life end for car driver and destroy family mixture. By the way, sometimes different countries decide to get rid of tyres with fire and this may be effect the environmental and cause pollution. The idea of using this useless tyres to decrease the uses of natural sand (as fine aggregate) and may enhance the mechanical properties of green concrete, such as compressive strength and ductility improvement. Hence, chemical agents were used to enhance bond between crumb rubber and concrete to increase compressive strength of concrete. On the other hand, small replacement of rubber was used to maintain compressive strength of concrete and can be noted as follow:

Selvakumar, et al. (2015) [1] discussed concrete mixes with various percentage of replacement of fine aggregate with crumb rubber (5%,10%,15% &20%). The main conclusion was that compressive strength of crumb rubber concrete with 5% replacement was 386.6 kg/cm² which was higher than the strength of normal concrete (367.3kg/cm²) on 28th day. **M. Mavroulidou, et al. (2010) [2]** studied the influence of factors, such as rubber aggregate content and size in addition to curing time. The results showed a great loss in strength, this type of concrete was acceptable for various applications requiring medium to low compressive strength.

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Eldhose C., et al. (2014) [3] investigated wide range of physical and mechanical properties of concrete containing waste tyre aggregates. Waste tyres were powdered into fine particles of various sizes and used to replace the fine aggregate in concrete. The results showed that, not much increase in slump value with the addition of rubber aggregates occurred. Gradual reduction in compressive strength and tensile strength was observed with the addition of used rubber tyre aggregate.

G. Nagesh Kumar., et al. (2014) [4] aimed at arriving to the optimum quantity of the replacement material for the aggregates in concrete for different engineering applications. Coarse aggregate has been replaced with tyre rubber powder and chipped rubber and also cement has been replaced with silica fume with the same water content. Portland slag cement has been used along with super plasticizer less than 1% by weight of cement to achieve required workability of the resulting concrete. Furthermore, durability studies have been conducted. Coarse aggregate was replaced with rubber of 2.5% which was found to be optimum. Also, it was observed that the 40% of compression strength was reduced with increase of replacement of fine aggregate with tyre rubber powder by 40%. Also 36% reduction of strength was observed when both coarse aggregate and fine aggregate was replaced with chipped rubber 2.5% and rubber powder 20%. In addition to this, 34% reduction of compressive strength was observed when both cement was replaced with silica fume 15% and fine aggregate was replaced with rubber powder 10%.

Study on waste tyre rubber as concrete aggregates was investigated by **Kotresh K.M, et al. (2014) [5]**. Three concrete mixes were made by replacing the coarse aggregate with 10%, 20% and 30% of discarded tyre rubber by weight. Compressive strength decreased by 37% when concrete aggregate was replaced by 30%. Three volumetric substitutions: 5%, 1% and

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15% of aggregate (8/16 mm) by rubber aggregate of sizes ranging between 10 and 12 mm were replaced either the fine or coarse aggregates in the concrete mixes partially or wholly by a volume of rubber aggregate. Using crumb rubber in RC beams was studied before by **Erhan Guneyisi, et al. (2014) [6].** The researchers investigate the durability related properties of rubberized concrete and two types of waste scrap tire rubber were used as fine and coarse aggregate, respectively. The rubber was replaced with aggregate by three crumb rubber and tire chips levels of 5, 15, and 25% for the rubberized concrete productions. Silica Fume was replaced with cement at 10% replacement level by weight of total binder content. The results indicated that the utilization of silica fume in the rubberized concrete production enhanced the corrosion behavior and decreased corrosion current density values.

2 Experimental Program

Untreated and treated crumb waste rubber with 3mm rounded diameter size was used as a partial replacement of fine aggregate (sand) with percentages 0%, 3% and 6%. Seven mixes were cast and **Table 1.** Shows the details of mixes including mix quantities for each mix according to **BS:5328 [7].** Forty two cubes, thirty cylinders and thirty prisms were cast (multi-layers mixes were excluded in cylinders and prisms due to casting difficulty). Cubes were tested for compressive strength, cylinders for indirect tensile strength and prisms for flexural strength after seven days and twenty eight days. Five reinforced concrete beams were cast with control, treated CRC (3% and 6%) and treated multi-layers CRC (3% and 6%) mixes and were tested after twenty eight days. Concrete dimensions for reinforced concrete beams are 100x150x1200mm. The main lower and secondary upper steel reinforcement are two bars of ten mm diameter (high grade steel, B400B-R). The stirrups are having diameter of eight mm and spacing 200 mm (mild steel, B240B-P). Steel Grades are according to **ES:262/2015 [8].**

Multi-layers concrete was cast with three layers, lower layer was cast with traditional concrete then middle and upper layers were cast with treated crumb rubber concrete (3% and 6%), each layer with 50mm height and finally, were tested perpendicular to layers thickness (toward cast direction) in order to studying over layers reinforced concrete beam and measure the effectiveness of using multi-layers generally in structural elements. Cast reinforced concrete beams were tested under the effect of double line loads (pure bending moment), hence, max stresses at top and bottom and neutral axis at almost the middle third of height, so that, using treated CRC in the top and middle third of total height of the beam (this choice depended on obtained results) gave the proper choice of filling maximum compressive stress zone with suitable material to resist but tension zone was filled with traditional concrete having low compressive strength in comparison to treated CRC (as obtained from results). The specimens surfaces were properly cured daily after the removal of the forms with up to seven days after casting.

Table 1. Quantities for Studied Concrete Mixes

Mix	Type	C_C kg/m³	Sand kg/m³	Crumb Rubber kg/m³	Dol. kg/m³	W_c kg/m³
Control	-		600	-		
CRC (3%)	Untreated		582	18		
CRC (3%)	Treated		582	18		
CRC (6%)	Untreated	300	564	36	1200	150
CRC (6%)	Treated		564	36		
CRC (3%)/Multi-Layers	Treated		582	18		
CRC (6%)/Multi-Layers	Treated		564	36		

Note:
C_C: Cement Content, W_C: Water Content.
The materials which are used to produce control and crumb rubber concrete mixes can be written as follow: CEM I 42.5N, "Portland Cement", tested according to **ES:4756-1/2009 [9],** Crushed Stone (Dolomite), (Size One), tested according to **ES:1109/2002 [10],** Siliceous Sand, tested according to **ES:1109/2002 [10],** Crumb Waste Rubber was tested experimentally. **Tables from 2 to 6** show the test results for the used materials.

Table 2. Properties of Used Cement (CEM I 42.5N)

Properties		Measured Values	Limits of the E.S.S*
Fineness (cm²/gm)		3250	-
Specific Gravity		3.15	-
Expansion (mm)		1.3	Not more than 10
Initial Setting Time (min)		175	Not less than 60 min
Final Setting Time (min)		220	-
Compressive Strength (N/mm²)	2 days	24.5	Not less than 10
	7 days	36.8	-
	28 days	58.9	Not less than 42.5 and not more than 62.5
Chemical Compositions	SiO_2	21.86 %	-
	Al_2O_3	5.31 %	-
	Fe_2O_3	3.88 %	-
	CaO	63.88 %	-
	MgO	1.17 %	-
	SO_3	2.73 %	-
	Loss Ignition %	1.31 %	-

*Egyptian Standard No. 4756-1/2009 [9].

Table 3. Physical Properties of the Used Crushed Stone

Test	Results	Acceptable Limit
Specific Gravity	2.65	-
Unit Weight (t/m³)	1.65	-
Materials Finer than No 200 Sieve	2.05	Less than 3%
Absorption %	1.15	Less than 2.5%
Abrasion (Los Anglos)	18.85	Less than 30%
Crushing Factor	19.50	Less than 30%
Impact	15.05	Less than 45%

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Table 4. Physical Properties of the Used Sand

Test	Results	Acceptable Limit
Specific Gravity	2.70	-
Unit Weight (t/m^3)	1.75	-
Materials Finer than No 200 Sieve	1.50	Less than 3%
Absorption %	1.35	Less than 2.5%

Table 5. Physical Properties of Crumb Rubber

Properties	Measured Values
Crumb Waste Rubber Diameter	3mm rounded
Specific Weight	1.05
Unit Weight (t/m^3)	0.6 t/m^3

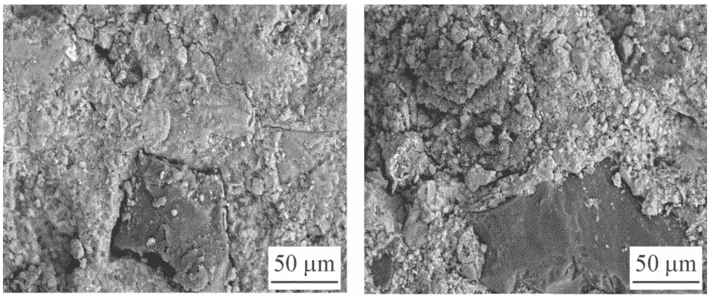
Table 6. Testing of Steel Reinforcement

Properties	Measured Values		Minimum Specification Limit*	
	High Grade Steel B400B-R Y10mm	Mild Steel B240B-P R8mm	High Grade Steel B400B-R	Mild Steel B240B-P
Yield/Proof Stress	539N/mm^2	377N/mm^2	400N/mm^2	240N/mm^2
R_m/R_{eH}	1.25	1.26	1.08	1.08
% of Elongation	20.3%	29.7%	14%	20%

*ES:262/2015, Egyptian Standards for Steel Reinforcement [8].

3 Treatment of Crumb Waste Rubber

Crumb waste rubber having smooth surface, chemical agents can overcome this undesirable behavior. **Liang-Hisng Chou, et al. (2009) [11]** stated that crumb tyres were treated with waste organic sulfur compounds (carbon di sulphide) from a petroleum refining factory improve the bonding between rubber particles and cement hydration products (C–S–H) with the hope of creating a product with an improvement in mechanical strength. **Figure 1.** shows SEM (scanning electron microscope) for concrete sample before and after treatment and illustrate a difference between weak/good bond between untreated/treated crumb rubber and mortar. In this research carbon disulphide (CS_2) chemical agent was used to treat crumb rubber to confirm bond between rubber particles and mortar. The treatment process was started by submerging crumb rubber in carbon disulphide (each 1kg of crumb rubber needs 1litre of carbon disulphate) then leaved to air dries at room temperature (25^{o}c). Carbon disulphide changes the surface tension of crumb rubber (became treated). Finally, Acetone was added to crumb waste rubber to clean it from any chemicals or any dusty particle could be found. After that, crumb waste rubber was washed with distilled water to rinse away the chemicals and leave a surface free from impurities through distillation. It is the preferable choice for cleaning rather than tap water because its more pure.



a) Untreated b) Treated
Figure 1. Untreated/Treated Crumb Rubber
Haibo, et al. (2014) [12]

4 Results and Analysis

4.1 Fresh Concrete Properties

From **Figure 2.**, it's clarify that, the consistency of treated CRC more dry than control mix. However, By increasing percentage of treated crumb rubber in concrete mix the slump decreased, so that, the workability decreased. The reduction recorded as 8% and 17% for treated CRC (3% and 6%), respectively. On the other hand, slump decreased by increasing treated crumb rubber percentage from 3% to 6% by 9%. Decreasing in workability due to increasing friction between treated crumb rubber and mortar which lead to less flow of particles, so that, it's recommended to add superplasticizers (by increasing crumb rubber percentage) to help in terms of ease mixing, placing and finishing of CRC. Untreated CRC recorded the maximum values in comparison to control and treated CRC mixes because the water covered the surface of crumb rubber particles which lead to decreasing the friction between concrete mixture. The increasing in slump values are 3% and 7% in comparison to control mix. The chemical agent treated the crumb rubber surface and decreased the slump values by 11% and 22% for treated CRC (3% and 6%), respectively.

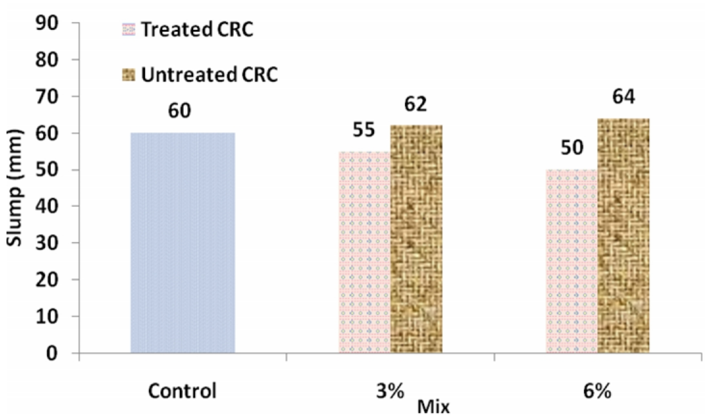


Figure 2. The Effect of Crumb Rubber on Slump Test Results

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4.2 Hardened Concrete Properties

Hardened concrete properties, such as compressive strength, indirect tensile strength and flexural strength and the effect of adopted parameters on its results were studied. Testing of specimens were carried out according to **BS:12390 [13]**. One of the most important properties is density. The density of crumb rubber equal to 0.6 t/m^3 and this value almost less than density of fine aggregate by three times.

Treated and untreated CRC in different percentages are almost the same density values and from **Figure 3.**, it's seems that, control mix recorded the maximum value due to higher density but CRC recorded the lowest values. This is because the density of crumb rubber less than fine aggregate density by three times. By increasing crumb rubber percentage the density decreased by 2% and 4% for CRC (3% and 6%), respectively. Otherwise density of CRC (6%) less than CRC (3%) by 2%. The obtained results doesn't gave a good achievement because crumb rubber replacement percentages less than to gave significant effective.

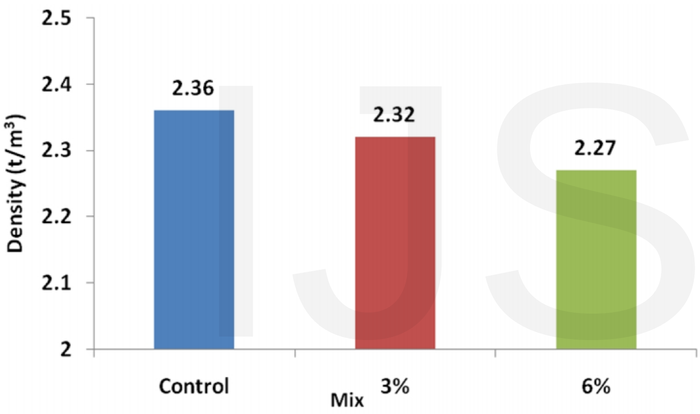

Figure 3. The Effect of Crumb Rubber on Density of Concrete
(as an average of untreated/treated CRC)

Compressive strength, indirect tensile strength and flexural strength were studied and the results at seven and twenty eight days were observed. The Following Table 7. shows the test results for compressive, indirect tensile and flexural strengths. It's seem that, control mix achieved a good hardened properties in comparison to untreated mixes in all ages but treated CRC gave a competitive results.

Figure 4. shows that, compressive strength decreased by 4%, 4% and 2%,1% for untreated CRC after seven days and twenty eight days, respectively, in comparison to control mix. Increasing untreated crumb rubber percentage decreased the loss of concrete strength. On the other hand, after seven days, by increasing treated crumb rubber percentage compressive strength increased by 9% and 22% for treated CRC (3% and 6%), respectively. Otherwise, after twenty eight days, compressive strength increased by 10% and 21% for treated CRC (3% and 6%), respectively in comparison to control mix. Also, increasing treated crumb rubber percentage from (3% to 6%) enhanced compressive strength by 13% and 10% after seven and twenty eight days, respectively. Multi-Layers mixes are almost the same behavior (as 3% and 6%) and this confirm truest of using bonding material **Addibond 65 [14]** which is used to join layers to working together. These results are compatible (variation in values located at 3% defects as a maximum) and gave a good achievement to use CRC with traditional concrete to obtain the benefits of them.

Cubes were tested and it's noted from crushed cubes that, treated crumb rubber (3%) achieved an increase in compressive strength by 13% and 15% after seven and twenty eight days in comparison to untreated crumb rubber, respectively. In case of treated CRC (6%), the compressive strength increased by 24% and 22% after seven and twenty eight days in comparison to untreated crumb rubber, respectively. The failure happened in mortar (no crumb rubber appeared) as shown in **Figure 5.**, so that, the chemical agent optimized the bond between crumb rubber and mortar. Otherwise, crumb rubber particles appeared widely in untreated CRC failure mechanism. The increase in compressive strength of CRC is due to many factors, such as chemical agents which enhanced bond, capability of crumb rubber to absorb more energy and shows some ductile behavior before failure. By the way, crumb rubber occupied volume in concrete mixture which lead to increase water availability (acting like curing process) and this reason enhanced hydration reactions between cement and water to get strong mortar.

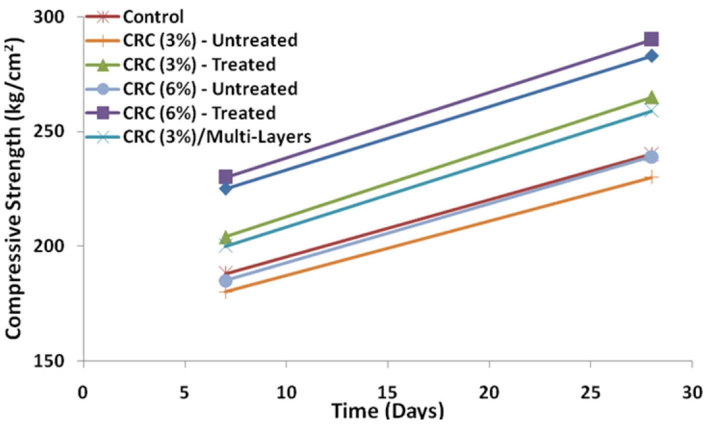

Figure 4. Relationship between Compressive Strength and Time (Days) for different Mixes

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Figure 5. Failure Mechanism of Treated CRC Cube

Figure 6. shows that, control mix recorded the maximum indirect tensile strength value in comparison to CRC. Generally, untreated CRC (3% and 6%) recorded loss in indirect tensile strength by 17%, 33% and 19%, 33% in comparison to control mix after seven and twenty eight days, respectively. By the way, treated CRC (3% and 6%) loss the strength by 4%, 7% and 13%, 15% in comparison to control mix after seven and twenty eight days, respectively. On the other hand, Indirect tensile strength for treated CRC (3%) and (6%) increased by 15%, 14% and 31%, 28% after seven and twenty eight days in comparison to untreated CRC, respectively. Crushed cylinder shows that, bonding of crumb rubber by chemical agent can't overcome the splitting force and failure happened between mortar and crumb rubber particles as shown in **Figure 7.** (significant appearance of wide volume of crumb rubber particles and appeared with huge quantities in untreated CRC). This problem happened with a wide range by increasing crumb rubber percentage as stated in previous researches.

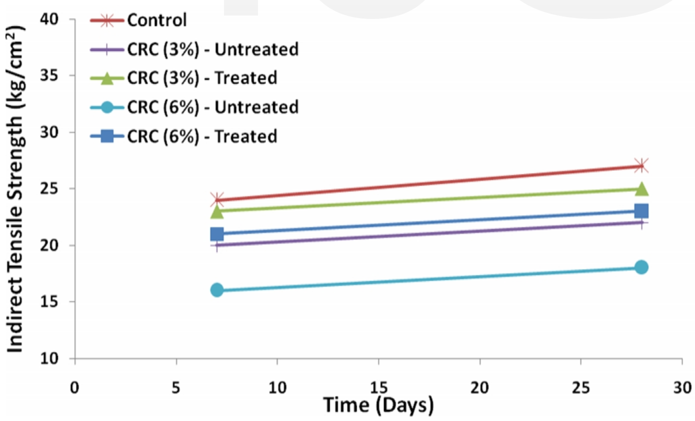

Figure 6. Relationship between Indirect Tensile Strength and Time (Days) for different Mixes

Figure 7. Crack Pattern for Treated Cylinder

Figure 8. shows that, control mix gave a good behavior and recorded the optimum values in case of flexural strength. By increasing crumb rubber percentage, flexural strength decreased by 13%, 10% and 21%, 19%, respectively for treated CRC (3% and 6%) after seven and twenty eight days in comparison to control mix. Flexural strength decreased by 26%, 25% and 39%, 35% for untreated CRC (3% and 6%) after seven and twenty eight days, respectively. Treated CRC (3%) and (6%) achieved an increase in flexure strength by 18% and 19%, 30% and 24% after seven and twenty eight days in comparison to untreated CRC, respectively. Crumb rubber creates a weakness points in concrete and these points increased in untreated CRC. These points observed and authorized by inspection of crushed prism. These points can't overcome the splitting force and finally lead to failure as shown in **Figure 9.**.

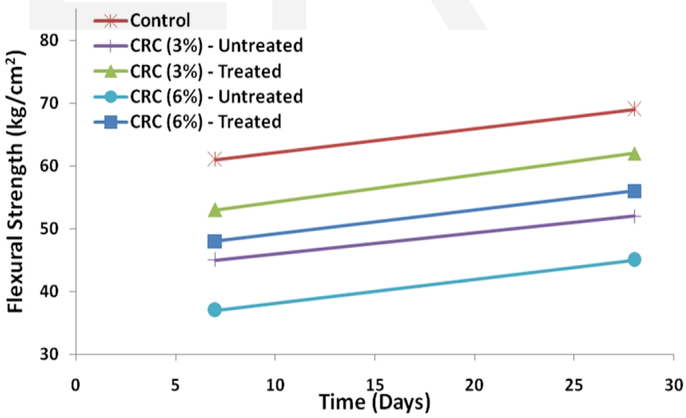

Figure 8. Relationship between Flexural Strength and Time (Days) for different Mixes

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Figure 9. Crack Pattern for Treated Prism

4.3 Analysis of RC Beams

Analysis of reinforced concrete (RC) beams are carried out to study the behavior of CRC and multi-layers concrete beams to get a general view about using multi-layers concrete in construction. Definitely, the ultimate load recorded, propagation of cracks observed and finally crack pattern classified. Five RC beams were tested to investigate the compatibility of using multi-layers concrete (CRC with traditional concrete) and gain the advantage of using treated CRC in compression zone due to high resistance to compression and use traditional concrete in tension zone (low compressive strength mixture) because the main steel reinforcement is the responsible to carry tension. The investigation, also, included the efficiency of using crumb rubber in concrete to enhance its mechanical properties (more ductility noted in crack pattern as state below). The following Table 8. shows the test results (as obtained from data logger) under the effect of pure bending moment.

From **Figure 10** and **Figure 11.**, its noted that, beam (B-1)/control mix gave the lowest value for ultimate load. (B-1) crushed at load 5.52 ton, the recorded vertical deflection at mid span was 4.00 mm. The (B-1) ductility ended at deflection 4.00mm with brittle failure.

Beam (B-2)/CRC 3% recorded ultimate load was 6.19 ton. The maximum vertical deflection was 12.54 mm, also Beam (B-4)/CRC 3%/Multi-Layers recorded ultimate load was 6.03 ton. The maximum vertical deflection was 13.06 mm. These values of vertical deflection gave a good proof for beam ductility in comparison to Beam (B-1)/control. Both of them, almost the same value of ultimate load and the small variation of ultimate load (about 2%) due to change in concrete homogeneity in case of multi-layers. This change, changed young's modulus for beam (B-4) and this appeared in relationship between load and deflection (low slope compared to beam (B-2), so that, beam (B-4) was recorded the smallest value in ultimate load but achieved the maximum deflection. This confirmed by the form of cracks and propagation of it in beam (B-4) (more weak than beam (B-2)).

Beam (B-3)/CRC 6% recorded ultimate load was 6.65 ton. The maximum vertical deflection was 13.33 mm also Beam (B-5)/CRC 6%/Multi-Layers recorded ultimate load was 6.62 ton. The maximum vertical deflection was 14.30 mm. These values of vertical deflection gave a good proof for beam ductility in comparison to Beam (B-1)/control. Both of them, almost the same value of ultimate load and the small variation of ultimate load (about 0.5% gain) due to change in concrete homogeneity in case of multi-layers. This change, changed young's modulus for beam (B-5) and this appeared in relationship between load and deflection (low slope compared to beam (B-3), so that, beam (B-5) was recorded the smallest value in ultimate load but achieved the maximum deflection. This confirmed by the form of cracks and propagation of it in beam (B-5) (more weak than beam (B-3)).

From **Figure 12**, its seem that, at the same certain failure load of control specimen (B-1), beam (B-1)/control mix gave vertical deflection less than (B-4) and (B-5)/multi-layers CRC beams (3% and 6%) by 9% and 2%, respectively due to change in layers homogeneity but (B-2) and (B-3)/CRC beams (3% and 6%) recorded less values by 9% and 12% in comparison to (B-1)/control beam. Although, multi-layers beams recorded more deflection at the same certain load but it's finally gain stiffness and recorded high ductility in comparison to (B-1)/control mix.

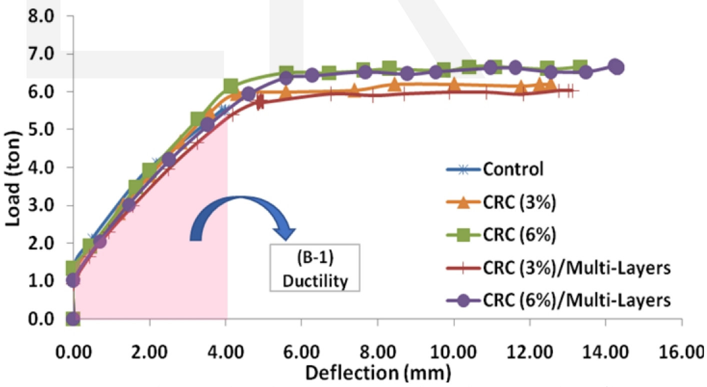

Figure 10. Relationship between Load and Vertical Deflection for Tested RC Beams

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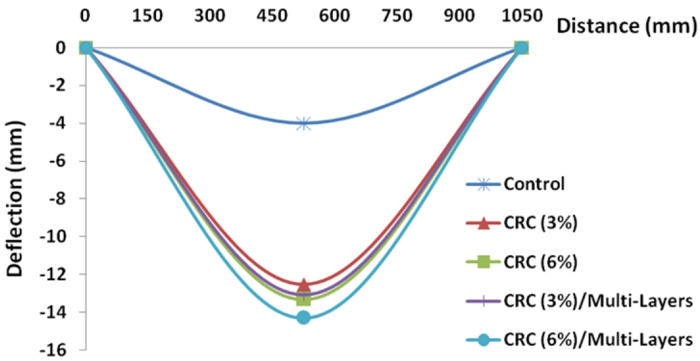

Figure 11. Profile Shape of Vertical Deflection (Elastic Line) for Tested Beams

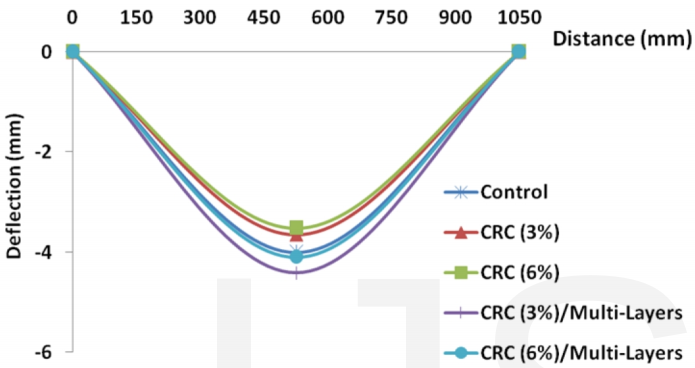

Figure 12. Profile Shape of Vertical Deflection (Elastic Line) for Tested Beams at Failure Load of Control Beam (B-1)- 5.52 ton

Strain in main steel reinforcement measured by strain gauge connected with strain meter. The relationship between load and strain almost elastic. Main reinforcement doesn't reach the yield stress value (4000kg/cm² according to **ES:262/2015 [8]**) for all RC beams. Supposedly that, by increasing applied load, the recorded strain increased. Control RC beam failed at almost level of stress in main steel bar equal to 2400kg/cm² but CRC (3% and 6%) RC beams recorded almost level of stresses 2800kg/cm² and 3100kg/cm², respectively. Multi-layers RC beams recorded almost level of stress in main steel bars 3300kg/cm² and 3400kg/cm². Ductility of CRC played a large role in strain values. More ductility in concrete, more energy absorbed and finally lead to more strain values due to capability to carry applied load. For multi-layers RC beams, strain values more than non layers because middle deflection in multi-layers RC beams more than non layers RC beams due to low young's modulus in case of multi-layers (consist of different materials as stated above). The following **Figure 13.** shows the relationship between Load and strain in main steel for tested RC beams.

For all CRC tested RC beams, By Increasing load, the deflection increased and the first crack started to occur at almost (35% of ultimate load) at middle of beam (pure bending moment/tension zone). However cracks started from right and left supports with angle equal to 45° up to compression zone (points of loading) then tested RC beam started to lose it is stiffness due to decreasing of young's modulus (E) and cracked beam behavior activated. Increasing effective load transform beam behavior to failure state and middle cracks got more wide and appeared with large dispersion. The crack pattern classified as flexure failure due to pure bending moment followed by crushing failure at upper middle compression area (between two point loads). There are observed that no difference in cracking mechanism between control and CRC beams. The same happened in case of control RC beam but it's failed suddenly without any ductility observed and less energy absorbed. The following **Figure 14.** shows typical crack pattern for one of tested beams (loads in KN).

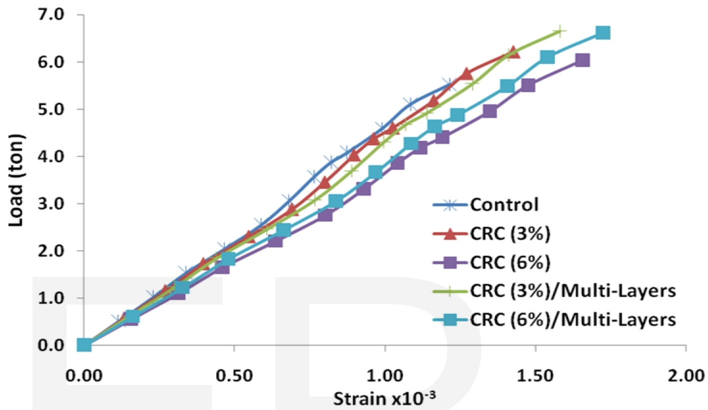

Figure 13. Relationship between Load and Strain in Main Steel for Tested RC Beams

Figure 14. Crack Pattern for One of Tested RC Beams (as an Example)

5 Conclusions

This study showed an alternative way of recycling tires by incorporating them into concrete construction. Through this study, crumb rubber from waste tires was used as a partial replacement of the natural fine aggregates. This will help other

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countries which miss the availability of natural materials. Based on the experimental study of using waste rubber in concrete (CRC). The results showed a powerful and ambition conclusions in the field of sustainability and recycling of waste and can be summarized in specific points as follow:

1. Consistency of treated CRC more dry than traditional concrete and by increasing percentage of treated crumb rubber in concrete mix, the slump decreased, hence, the workability decreased. The reduction recorded as 8% and 17% for treated CRC (3% and 6%), respectively. On the other hand, slump decreased by increasing crumb rubber percentage from 3% to 6% by 9%.
2. Untreated CRC recorded the maximum values in comparison to control mix. The increasing in slump values are 3% and 7% in comparison to control mix. The chemical agent treated the crumb rubber surface and decreased the slump values by 11% and 22% for treated CRC (3% and 6%), respectively.
3. The density of traditional concrete more than CRC and by increasing crumb rubber percentage the density decreased by 2% and 4% for CRC (3% and 6%), respectively. Otherwise density of CRC (6%) less than CRC (3%) by 2%. The obtained results doesn't gave a good achievement because crumb rubber replacement percentages less than to gave significant effective. Treated and untreated CRC in different percentages are almost the same density values.
4. Compressive strength decreased by 4%, 4% and 2%,1% for untreated CRC (3% and 6%) after seven days and twenty eight days, respectively, in comparison to control mix. Increasing untreated crumb rubber percentage decreased the loss of concrete strength.
5. Chemical agent (Carbon di Sulphide) succeed to improve compressive strength of CRC and increase bonding chain between crumb rubber and mortar. This significantly confirmed by obtained test results and failure mechanism.
6. Treated crumb rubber (3%) achieved an increase in compressive strength, indirect tensile strength and flexure strength by 13% and 15%, 15% and 14%, 18% and 19% after seven and twenty eight days in comparison to untreated crumb rubber, respectively. In case of treated CRC (6%), the compressive strength, indirect tensile strength and flexure strength increased by 24% and 22%, 31% and 28%, 30% and 24% after seven and twenty eight days in comparison to untreated crumb rubber, respectively. Control mix achieved a good hardened properties in comparison to untreated CRC mixes in all ages.
7. By increasing treated crumb rubber percentage, compressive strength after seven days increased by 9% and 22% for treated CRC (3% and 6%), respectively. Otherwise, after twenty eight days, compressive strength increased by 10% and 21% for treated CRC (3% and 6%), respectively. Also, increasing treated crumb rubber percentage from (3% to 6%) enhanced compressive strength by 13% and 10% after seven and twenty eight days, respectively.
8. Multi-Layers mixes are almost the same behavior (as 3% and 6%) and this confirm truest of using bonding material Addibond 65 which is used to join layers to working together.
9. Control mix recorded the maximum indirect tensile strength value in comparison to CRC. Generally, CRC (3% and 6%) loss the strength by 4%, 7% and 13%, 15% in comparison to control mix after seven and twenty eight days, respectively.
10. Control mix gave a good behavior and recorded the optimum value in case of flexural strength. By increasing crumb rubber percentage, flexural strength decreased by 13%, 10% and 21%, 19%, respectively for CRC (3% and 6%) after seven and twenty eight days.
11. It's highly recommended to add fibers (like steel fiber for an example) to improve weakness of indirect tensile strength and flexural strength.
12. The behavior of RC beams in bending is excellent especially with the increase in the proportion of treated crumb rubber in the concrete mixture. As the percentage of crumb rubber increased, the resistance of bending for RC beams improved from 12% to 20% according to the percentage of crumb rubber (3% to 6%) with a significant improvement in ductility and the ability of the beam to absorb more energy (appeared strongly in the load deflection curve in comparison to control beam).

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