

Mechanical Properties of Normal Strength Concrete Containing Different Types of Waste Material as Coarse Aggregate Replacement

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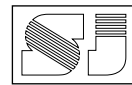
Abstract

In this study, the effect of different types of waste materials on the mechanical properties of normal strength concrete was investigated. Three types of waste material crumbed rubber, granular plastic, and crushed brick with different percentage up to 15% (by weight of coarse aggregate) were used. The effect of waste material on the compressive strength, splitting tensile strength, and static elastic modulus of hardened concrete for 28 days of curing with constant w/c= 0.45 were studied. The maximum loss in concrete compressive strength was recorded to be 54.95%, 50.31%, and 20.41% for concrete mix with 15% crumbed rubber and plastic aggregate and 5% crushed brick particles. Maximum reduction in splitting tensile strength noticed to be 65%, 43.15%, and 13.59% for 15% replacement of crumbed rubber, granular plastic, and crushed brick respectively. The maximum loss in static elastic modulus was found to be 48.29%, 27.14, and 11.23% for concrete mix with 15% crumbed rubber, granular plastic, and 5% crushed brick. From test results it is concluded that up to 15% waste material can be safely used to produce this type of recycled concrete.

1. Introduction

Waste materials specifically plastic and rubber wastes represent a main environmental issue of increasing significance. Nowadays huge quantities of tyres are already stored in the form of whole tyre or as land filled (shredded tyre) ^[1]. Even though waste-tyres are relatively difficult to be ignite, but this hazard is always exist. When tyres start to burn up due to occasional reasons

toxic fumes and high temperature take place^[2]. Comparable considerations can be made for Plastic waste materials, in 2007 the world's annual utilization represented 250,000 million terephthalate bottles (10 million tons of waste) with a growth increase of 15%. Since PET (Polyethylene terphthalate) waste is not biodegradable it can remain in nature for hundreds of years. Previous investigations have already confirmed the potential of different type



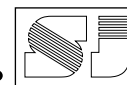
of plastic waste in replacing aggregates in concrete^[3]. The same concept can be taken in to consideration for using bricks as recycled material. Growing the construction sector and demolition of buildings during the last decades lead to huge quantities of waste causing a serious environmental issue. The use of crushed bricks can considerably solve the problem of waste storage and at the same time helps to maintain natural aggregate resources. The first record of using crushed brick in concrete was in Germany (1860), though some difficulty was present due to codes limitation on the presence of impurities, water absorption problem and the lack of information on using crushed bricks in producing concrete^[4]. Vieira et al. ^[5] examined the compressive strength of three different sizes of rubber waste with three different by volume percentages (2.5%, 5%, 7.5%). They found that compressive strength above 20 MPa was obtained using 2.5% of tyre rubber of 2.4 mm. Albano et al. ^[6] examined concrete- scrap rubber composites already been processed with NaOH aqueous solution and saline to improve the adherence characteristic between cement paste and rubber particles. It was concluded that no radical changes were observed when compared with untreated rubber particles. Aiello and Leuzzi ^[7] utilized tyre shreds to replace both fine and coarse aggregates, they found out that the dimensions of the rubber particles have a major role in the strength of concrete. Compressive strength falls much more when replacing coarse aggregates by the shredded tyre particles compared with compressive strength loss of concretes when fine aggregates were replaced by rubber waste. They also found that when (50% or 75%) by volume of fine aggregate replaced with rubber wastes the reduction in the tensile strength was only 5.8% and 7.30%. On the other hand, when the same percentages were used as coarse aggregate replacement a 28.2% strength reduction took place. Ganjian et al. ^[8] noticed different behavior revealing that tensile strength of concrete containing chipped rubber as coarse aggregate replacement is lower than that with

powdered rubber. A reduction of (30%-60%) in tensile strength of concrete took place when a replacement percentage of (5%-10%) used, while in the case of the powdered rubber the reduction was between 15% to 30%. This tendency may be due to the low adherence between the cement and the chipped rubber. The logical reason behind this fact is that the rubber chip was processed in laboratory with a scissor a procedure which is quite different from the one when rubber waste particles are shredded by grinding process resulting in a harsher surface. This behavior was also noticed by Pierce and Williams ^[9] the decrease in tensile strength may be due to the fact that rubber particles prohibit crack opening. The tensile strength of rubber waste concrete composite is affected by the properties of rubber aggregate particles. Because of the low compressive strength of concrete composite containing rubber waste and a direct correlation between compressive strength and modulus of elasticity it is expected that concrete-rubber waste composite has lower modulus of elasticity. Nevertheless, Skripkiunas et al. ^[10] made a comparison between reference one with zero percentage of rubber waste replacement and another specimen containing 3.3 % crumbed rubber. They reported different elastic modulus, 29.6 GPa compared to 33.2 GPa for the reference concrete recording only 11% reduction in the modulus of elasticity. This is attributed to the low elastic modulus of rubber waste. Turatsinze et al. ^[11] noticed a reduction of 40% in the modulus of elasticity when the same percentage of reduction took place in compressive strength. Turatsinze and Garros ^[12] reported that in self-compacting concrete the elastic modulus is increased when rubber particles of (4-1mm) size were used. These authors also confirmed the hazard of intense segregation due to high concentration of rubber aggregates at the surface of the specimen which reveals the necessity of appropriate integration between air-entraining and viscosity agents to prevent segregation. Rahmani et al. ^[13] studied the effect of partial replacement of fine aggregate with PET particles at different percentages (5%,



10%, and 15%). Results showed that the compressive strength of prepared concrete increased by 8.86% and 11.97% for water to binder ratio of 0.42 and 0.52 respectively. On the contrary, additional increase in PET particles up to 10% and 15% the compressive strength of concrete falls because of weak cohesion between the concrete mixture and the PET particles. Since PET particles act as a barrier and prohibit the cement paste from involvement in the natural aggregates. As a result, concrete strength decreases progressively. They also emphasized that due to the adversely effect of smooth surface texture of PET particles on the bond strength between plastic pieces and cement paste and the increased surface area of PET particles as compared with natural sand the tensile strength decreases. Prahallada and Parkash^[14] noticed that when plastic fiber with an aspect ratio of 50 used to replace fine aggregate an increase in compressive strength occurs. The percentage of the compressive strength increase was 11%. Further increase in the aspect ratio beyond the ratio of 50, a decrease in the compressive strength took place. Cordoba et al.^[15] confirmed that optimal size of PET plastic flakes wastes to be used in concrete is 1.5 mm when 2.5% of the fine aggregates are replaced. The PET plastic flake sizes used in this study were 0.5 mm, 1.5 mm, and 3 mm, with percentages of replacement of (1%, 2.5%, and 5%) by volume. It was also emphasized that the compressive strength value of concrete made with PET depends on the concentration of PET flakes, the PET flakes, and the curing time. Scanning electron microscopy results indicated improvement in the compressive strength of concrete when smaller sizes of PET particle were used with lower concentrations. However, few researchers (Rahmani et al.^[13]; Prahallada and Parkash^[14]; Malagaveli^[16]; Ramadevi and Manju^[17]) mentioned that the addition of HDPE and PET fibers in small quantities slightly improves the compressive strength but addition of large amount of PET particles decrease the strength. Nibudey et al.^[18] studied the effect of adding plastic fibers on the

tensile strength of concrete with controlled strength of 3.48 MPa. They emphasized that the tensile strength increased when plastic fibers were added at 1% and strengths of 3.87 MPa and 4.13 MPa were observed after the addition of fiber at aspect ratios of 35 and 50 respectively. An experiment conducted by Malagaveli^[16] showed that, the split tensile strength generally increased by 14% when the plastic fibers content was 3.5% and began gradually to decrease when the HDPE (High-density polyethylene) fiber content was increased from 3.5 to 6%. Mathew et al.^[19] observed the modulus of elasticity of the plastic coarse aggregate decreased by 22.12% relative to the natural coarse aggregates concrete. The aggregate in concrete play main role for quantifying the mechanical properties of concrete. Majority of researches shows a decrease of modulus of elasticity of concrete in the presence of any form of plastic. This is because of modulus of elasticity of plastic. Debieb and Kenai^[20] performed a study at which natural fine aggregate, coarse aggregate, or both were partially replaced with crushed brick at different percentages (25%, 50%, 75%, 100%). Results indicated that the compressive strength of concrete containing crushed brick aggregate was lower than that made of natural aggregate. At the age of 28 days, the compressive strength decreased by about 10-35 % for recycled coarse aggregate while the decrease was about 30% for recycled fine aggregate and about 40% when both fine and coarse aggregate were replaced by crushed bricks aggregate. Darshita and Anoop^[21] studied the strength of concrete with partial replacement of fine aggregate by crushed bricked, bricks aggregate particles passed through sieve 4.75 mm and retained on 0.075mm sieve with different percentage of replacement (10%, 20%, and 30%). Results showed decrease in compressive strength at 10% replacement of natural aggregate however as the percentage of replacement increased higher compressive strength is obtained. Padminin et al.^[22] investigated the use of two different types of bricks (high strength low water absorption and



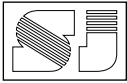
medium strength with higher water absorption) as natural coarse aggregate replacement with maximum size of 25 mm. Results revealed split tensile strength increase for a given compressive strength with w/c ratio reduction, this increment in strength is due to higher bond between aggregate and mortar phase. Rani et al. [23] utilized different replacement levels of natural aggregate with crushed brick aggregate (15,20, and 25)%. Results implied that the tensile strength of concrete increased initially at 15% and 20% replacement on the contrary when the replacement percentage increased to 25% the strength diminished. Zhang and Zong [24] cited that concrete modulus of elasticity decreased as the replacement levels increased up to 50% due to the lower modulus of elasticity of crushed brick aggregate as compared with natural aggregate. Cahim [25] emphasized that crushed brick aggregate can be used as aggregate in concrete mixtures without effect on the properties of hardened concrete up to 15% while increasing the percentage of replacement up to 30% leads to a decrement in the modulus of elasticity about 20%. Lonh et al. [26] indicated that the deformation of brick chips aggregate is significantly higher than that of natural aggregate which negatively affected the modulus of elasticity of concrete specimens, higher reduction in modulus of elasticity was observed to be 40% when 100% of natural aggregate is replaced with brick chips particles. The main objective of this research proposal was to evaluate the possibility of using different types of waste material (crumbed rubber, granular plastic, and crushed brick) as partial replacement for the coarse aggregate in concrete mixture. The behavior of hardened state of concrete containing waste materials was investigated in this study. Novelty related to this work is that all previous studies deal with replacement of fine aggregate with rubber particles and use plastic close in the shape of the natural aggregate instead of plastic fibers. The results of this study are interesting and will clear the way for the production of concrete containing different types of waste materials, and to use this

type of concrete in produce structural elements to be used in different structural applications.

2. Materials and Methods

2.1. Materials

Cement, sand, gravel, water, crumbed rubber, granular plastic, and crushed brick were used in this investigation. The cement used in this investigation was ordinary Portland cement locally available (Type I ASTM) produced by Tasluja factory- Al-sulaimanaya/ Iraq. The chemical composition and physical properties of used cement are shown in Tables 1 and 2, respectively. Fine aggregate used in this study was clean natural river sand. Properties of sand used for mix design are shown in Table 3. Crushed gravel with maximum size of 10 mm was used for all mixes as coarse aggregate. For the coarse aggregate, specific gravity was 2.65, water absorption was 1.2%, loss bulk density was 1453.8 kg/m³, and compacted bulk density was 1628.8 kg/m³. Size distribution of fine and coarse aggregate based on sieve analysis test according to ASTM C33 [27] are given in Fig. 1 and Fig. 2, respectively. Drinking water was used for washing the materials, mix preparation, and curing of specimens. Old rubber sheets were collected from cement factory where the plates were used as a conveyor belt for cement bags. After washing the rubber sheets with water to remove cement residues and dirt in order to increase the adhesion between rubber aggregate and cement paste. The sheets were cut into longitudinal strips then cut into small pieces of different sizes by the mean of cutter as shown in Fig. 3. The grading of rubber particles is given in Fig. 4. Plastic garbage containers were collected from different dump sites in al- Sulaimaniya and subjected to crushing process by the mean of chipping machines in plastic factories (Emart-plastic) in order to obtain the same shape and size of coarse aggregate as shown in Fig. 5. The plastic aggregate was washed with water to remove the impurities and loose materials to avoid their side effects on the concrete mix. The



grading of plastic particles is given in Fig. 6. New clay bricks of 235x111x74 mm working size with average compressive strength of 35.8 MPa were used as an alternative for coarse aggregate. The bricks were crushed in to small pieces of different sizes by the mean of hammer, so that the brick particles are close to the shape and size of the natural aggregate as shown in Fig. 7. Before using crushed brick in concrete mix it was delivered into the saturated surface dry state (SSD) by immersing the crushed bricks particles in water for 24 hours and then surface dried them from extra water. The grading of brick particles is shown in Fig. 8.

2.2. Concrete mix proportion and specimen's preparation

Mix design is the process of choosing appropriate components and determining accurate proportions of concrete ingredients. All tests were carried out on normal strength concrete with compressive strength of (35MPa). Mix proportion for this concrete was (465: 698:930)(cement: fine aggregate: coarse aggregate) and water/cement was 0.45. For each mixing coarse aggregate in SSD state, fine aggregate in SSD state, and cement was mixed, after that waste materials particles were sprayed on the mix continuously till homogeneous mix was obtained then clean water was added and mixing continued until the mix became homogeneous. Beside control mix, three different waste material (crumbed rubber, plastic waste, and crushed brick) with three different percentages for each type of waste (5%, 10%, 15%) as coarse aggregate replacement was used for producing different concrete mixes. Table 4 shows materials content per one cubic meter of concrete mixes. Designation of concrete mixes given in Table.4 is as follows. M is for mix, R is for crumbed rubber, P is for granular plastic, and B is for crushed brick, and the number given is the percentage of coarse aggregate replacement with waste material aggregate.

2.3. Testing specimens

The measurement of concrete compressive strength was performed on the standard 100x200 mm cylinders using a digital compression machine of 4000 kN capacity of CONTROLS model-Italy, according to ASTM C39^[31]. Three days before testing, all cylinders were capped using a sulfur- sand mix to give a uniform stress distribution on the specimen's surface during testing. The loading rate was 565 lb/sec (2.5 kN/sec) as per the ASTM C39 specification. The measurement of concrete splitting tensile strength was performed on the 100x200 mm cylinders using the same machine utilized for compression test, according to ASTM C496^[32]. The static elastic modulus test was made on the 100 x 200 mm cylinders in accordance with ASTM C469^[33]. Average result of three tested samples was determined at the age of 28 days for the mentioned three tests.

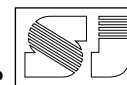
3. Results and discussion

The results obtained in this study are interesting and may clear the way for further experiments on the behavior of normal strength concrete with different types of waste materials. Test results on each property examined in this study are listed in Table. 6 and discussion of results in some detail are given in the sections to follow.

3.1. Mechanical Properties

3.1.1. Compressive strength

Figs. 9 through 11 show variation of concrete compressive strength value with crumbed rubber, granular plastic, crushed brick aggregate percentage at 28 days age, respectively. From test results, it is important to note that, for concrete containing crumbed rubber and granular plastic waste material one can observe significant reduction in compressive strength with increasing waste materials content. On the contrary concrete samples containing crushed brick as coarse aggregate replacement shows increment in

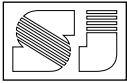


compressive strength value as the replacement percentage increased. This behavior can be attributed to the high compressive strength of virgin brick used which reached 35.8 MPa also the irregular shape and sharp edge of crushed brick particles lead to higher bond between waste aggregate particles and cement paste. Results show that the maximum reduction in the compressive strength for 15% waste content reached 54.95% for crumbed rubber, 50.31% for plastic, and 20.41% for 5% crushed brick content. Results also indicate that the replacement of coarse aggregate with crumbed rubber will lead to higher loss in compressive strength compared with the replacement of plastic and crushed brick for the same replacement level. In general, the strength loss can be attributed to the smooth surface of rubber waste material, low mechanical strength of rubber aggregate, the lack of good interlocking between the cement paste and waste aggregates in addition to high deformation under load because of low elastic modulus of these materials as compared with natural aggregate. The high deformation taking place leads to a failure in a lower stress value compared with that of normal concrete. In concrete samples containing crumbed rubber and granular plastic, the crack does not occur in the waste particles but goes around the waste aggregates. This fact also indicates the poor bond strength between the cement paste and waste aggregates. In the case of control concrete and concrete samples containing crushed brick, the failure took place right through the aggregates, indicating higher bond strength between the cement paste and coarse aggregates. Compressive strength loss obtained in this study as a result of using crumbed rubber are corresponds to the results obtained by Vieira et al. [5] knowing that they obtained compressive strength above 20 MPa using 2.5% by volume tyre rubber. Reduction in compressive strength as a result of using crumbed rubber also matched the results obtained by Albano et al. [6] who improved that treating the rubber particles with NaOH aqueous has no radical effect as compared with un treated particles. On the other hand as a

result of using granular plastic particles in this study as coarse aggregate replacement a reduction in compressive strength took place as compared with results obtained by authors Rahmani et al. [13], Prahallada and Parkash [14], and Cordoba et al. [15] who found out that adding of plastic in different form in small quantity slightly improved the compressive strength but the addition of large amount of plastic decrease the strength. For crushed brick aggregate replacement results obtained in this study confirmed to that obtained by authors Darshita and Anoop [21] where the compressive strength increased as the percentage replacement increased.

3.1.2. Splitting tensile strength

Figs. 12 through 14 show variation of concrete splitting tensile strength value with crumbed rubber, granular plastic, crushed brick percentage at the age of 28 days respectively. From the data presented one can see that the behavior is similar to the compressive strength, where a steady and continues reduction in tensile strength were noticed attributing this behavior to the same reasons such the particle size of waste aggregate, surface nature, low elastic modulus of waste aggregate used as compared with the mechanical properties of natural coarse aggregate, and low adhesive strength between the surface of waste materials and the cement paste leading to low bond. The results indicated that regardless of the type of waste materials used for larger content of each type of waste material the reduction in tensile strength of concrete is increased. According to the test data, the maximum reduction takes place at 15% replacement of crumbed rubber, plastic, and crushed brick which are 65%, 43.15%, and 13.59% respectively. Fig. 15 show the failure modes of cylinders in splitting tensile strength test of concrete containing different types of waste material. From the failure pattern, it can be seen that in the case of concrete containing crumbed rubber and plastic waste aggregates the



crack does not occur in the waste particles but goes around the waste aggregates. This fact also indicates the poor bond strength between the cement paste and waste aggregates. In the case of control concrete and concrete containing crushed brick, the failure took place right through the aggregates, indicating higher bond strength between the cement paste and coarse aggregates. It was also noticed that the control specimens and crushed brick specimens had the brittle type failure, sudden breakage accompanied by sound. On the other hand for the specimens containing waste material aggregates, the failure occurred smoothly without any noise during breakage. It is also indicated that the addition of waste particles will induce ductility into the concrete specimens. Therefore, when added in proper proportion, the concrete can be made ductile with the addition of waste aggregates in concrete. Results obtained in this study are compatible with that obtained by authors Ganjian et al. ^[8], Pierce and Williams ^[9] when a reduction in splitting tensile strength took place as the percentage of crumbed rubber increased. On the other hand results obtained by authors Nibudey et al. ^[18], and Malagaveli ^[16] improved a slight improvement in tensile strength as a result of using a small quantities of different form and types of plastic, while in this research study the splitting tensile strength decreased as the replacement percentage increased.

3.1.3. Static Elastic Modulus

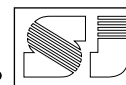
Fig. 16 through 18 show variation of modulus of elasticity value with crumbed rubber, granular plastic, and crushed brick aggregate percentage at 28 days respectively. From presented data, one can observe a continuous decrease of elastic modulus with increasing the percentage of coarse aggregate replacement with both crumbed rubber and plastic waste materials while the elastic modulus value of concrete samples containing crushed brick aggregate increased as the replacement value increased. This behavior can be attributed to the lower elastic modulus of rubber and plastic waste material aggregates as

compared to that of natural and brick aggregate. Replacement percentage of 15% of rubberized concrete and plastic concrete mix showed the highest reduction in modulus of elasticity which is 48.29%, 27.14% for crumbed rubber and plastic respectively and for concrete containing 5% crushed brick was the highest reduction in modulus of elasticity as compared with control specimen which was 11.23%. Also, test results show that the replacement of coarse aggregate with crumbed rubber particles has more effect on the reduction of elastic modulus than plastic for the same percentage. This occurred because of the fact that crumbed rubber particles will suffer from higher deformation under compressive stress due to their bigger size as compared with two other types of waste material also to the hazard of intense segregation due to high concentration of rubber aggregates at the surface of the specimens. Taking care of aggregate particle arrangement is important with regard to the elastic modulus because the deformation of waste particles under stress has a great effect on the elastic modulus. On the other hand concrete elastic modulus of specimens containing crushed brick increase as the replacement percentage increased due to their stronger particles as compared to rubber and plastic waste particles. Results obtained in this study are compatible with that obtained by Skripkiunas et al. ^[10], and Mathew et al. ^[19] where the elastic modulus decreased as the percentage of crumbed rubber and plastic respectively increased. On the contrary, as a result of using crushed brick in this study the elastic modulus increased as the replacement percentage increased, which violates the results obtained by Zhang and Zong ^[24], and Lonth et al. ^[26] those authors revealed a decrease in elastic modulus as the replacement percentage increased.

4. Conclusions

Conclusions were drawn from this extensive study as follows:

- 1- Different types of waste material can be used as



partial replacement of natural coarse aggregate with a percentage up to 15%.

2- Compressive strength of concrete made with rubber and plastic waste materials was found to decrease with increase in the percentage of waste particles. The compressive strength was found to decrease by 54.95%, and 50.31% for crumbed rubber and granular plastic respectively. On the contrary as the percentage replacement of crushed brick increased the compressive strength of concrete increased. Maximum decrease was found to be 20.41 at 5% replacement.

3- For given w/c, the splitting tensile strength of concrete regardless the type of waste materials replacement significantly decreases with increase in the percentage of waste materials contented in the concrete. Reduction in splitting tensile strength was found to be 65.00%, 43.15%, and 13.59% at 15% replacement of crumbed rubber, granular plastic, crushed brick respectively.

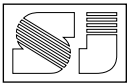
4- Static elastic modulus of concrete made with rubber and plastic waste materials was found to decrease with increase in the percentage of waste particles. The elastic modulus was found to decrease by 48.29%, and 27.14% for crumbed rubber and granular plastic respectively. On the other hand as the percentage replacement of crushed brick increased the compressive strength of concrete increased. Maximum decrease was found to be 11.23 at 5% replacement.

5- Introduction of waste materials in concrete tends to make concrete ductile, hence increasing the ability of concrete to significantly deform before failure. This characteristic makes the concrete useful in situations where it will be subjected to harsh weather such as expansion and contraction, or freeze and thaw.

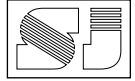
From the above finding, it can be concluded that concrete with waste materials as partial replacement for coarse aggregate can be used in situations which requires concrete with lower strength (light weight reinforced concrete). Also the benefits of using waste materials in concrete as aggregates resulting in reduction in waste and accordingly diminished the pollution.

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الخصائص الميكانيكية للخرسانة ذات المقاومة الاعتيادية التي تحتوي على انواع مختلفة من النفايات كبديل للركام الخشن

بروين لطيف عزيز¹

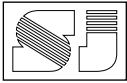
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المستخلص

تم في هذا البحث دراسة تأثير انواع مختلفة من النفايات على الخصائص الميكانيكية للخرسانة ذات مقاومة الانضغاط الاعتيادية. تم استخدام ثلاثة انواع مختلفة من النفايات المطاط، البلاستيك، و الطابوق بنسب مختلفة تصل الى 15% (بالوزن من الركام الخشن). تمت دراسة تأثير النفايات المختلفة على مقاومة الانضغاط، مقاومة الشد، ومعامل المرونة للخرسانة الصلبة بعد 28 يوم من المعالجة في الماء. لوحظ من النتائج ان اعلى خسارة في مقاومة الانضغاط للخرسانة كانت 95,54%، 31,50%، و 41,20% للخلطات الخرسانية التي تحتوي على 15% من المطاط والبلاستيك و5% من الطابوق المكسر. كذلك لوحظ ان الحد الاقصى للانخفاض بمقاومة الشد هو 65%، 15,43%، و 59,13% للخلطات التي تحتوي على 15% من المطاط، البلاستيك، والطابوق المكسر. وتبين ان الحد الاقصى للخسارة في معامل المرونة مساوي الى 29,48%، 14,27%، و 23,1% للخلطات الخرسانية التي تحتوي على 15% من المطاط والبلاستيك و5% من الطابوق المكسر. يمكن الاستنتاج من النتائج التي حصلت عليها امكانية صنع كونكريت يحتوي على 15% من النفايات بطريقه امنه واستعماله في صناعة هذا نوع من الكونكريت .

الكلمات المفتاحية: الطابوق المكسر، المطاط، البلاستيك، الخصائص الميكانيكية، النفايات.

**Table 1: Chemical composition of cement.**

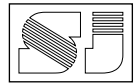
Chemical test	Result	ASTM C150 ^[30]
Magnesium oxide MgO (%)	1.9	≤ 5
Sulfate content SO ₃ (%)	2.5	<2.5 if C ₃ A<5 / <2.8 if C ₃ A<5
Loss on Ignition (%)	3.5	4
Insoluble residue (%)	0.7	1.5

Table 2: Physical properties of cement.

Physical properties	Test results	ASTM C150 specification limits
Blaine (m ² /Kg)	355.8	≥280
Setting time		
1. Initial setting time(minutes)	155	≥ 45 min.
2. Final setting time(hour)	3:15	≤ 10 hour
Compressive strength (MPa)		
1. 3 days compressive strength	27.5	≥ 20
2. 28 days compressive strength	51.2	≥ 42.5
Expansion (mm)	1	≤ 10

Table 3: Properties of fine aggregate

Properties of Fine aggregate	Values	Test method
Finesse modulus (FM)	3	–
SSD Specific gravity	2.518	ASTM C128 ^[28]
Water absorption %	1.7	ASTM C128 ^[28]
Loose bulk density, kg/m ³	1876.7	ASTM C29 ^[29]
Compacted bulk density, kg/m ³	1988.5	ASTM C29 ^[29]

**Table 4: Concrete mix proportions.**

Mix	Waste Material Percentage	Cement (kg)	Coarse Aggregate (kg)	Fine Aggregate (kg)	Water Content (kg)
M0	0	465	930	698	209
MR5	5% Rubber	465	883.5	698	209
MR10	10%Rubber	465	837	698	209
MR15	15%Rubber	465	790.5	698	209
MP5	5%Plastic	465	883.5	698	209
MP10	10%Plastic	465	837	698	209
MP15	15%Plastic	465	790.5	698	209
MB5	5%Brick	465	883.5	698	209
MB10	10%Brick	465	837	698	209
MB15	15%Brick	465	790.5	698	209

Table 5: Mechanical properties results of concrete mixes.

Mix	Compressive Strength (MPa)	Splitting Tensile Strength (MPa)	Static Elastic Modulus (GPa)	Density (kg/m ³)
M0	36.83	7.002	34.52	2639.92
MR5	24.28	5.84	22.43	2528.77
MR10	19.20	3.66	20.62	2408.82
MR15	16.59	2.45	17.85	2365.40
MP5	28.28	5.42	30.61	2498.20
MP10	22.55	4.67	28.31	2442.57
MP15	18.30	3.98	25.15	2285.78
MB5	29.31	6.81	30.64	2576.23
MB10	32.61	6.26	32.31	2564.34
MB15	35.13	6.05	33.72	2550.22

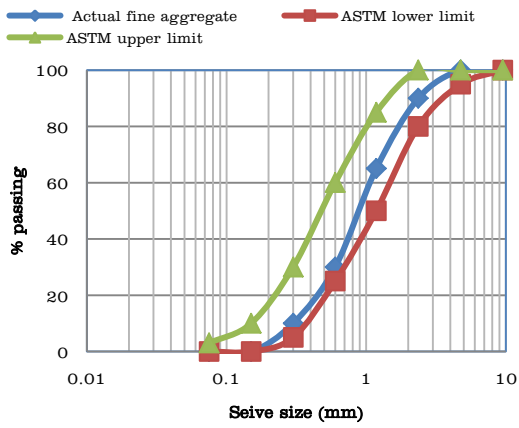
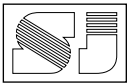


Fig. 1: Grain size distribution of fine aggregate.

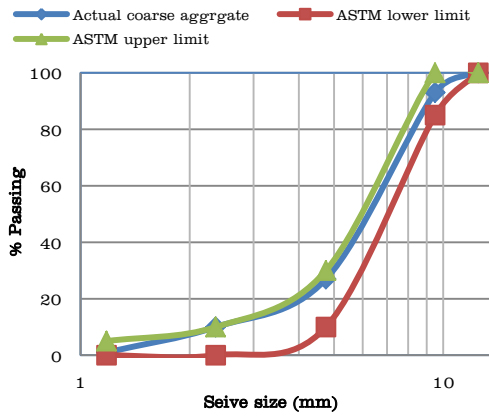


Fig. 2: Grain size distribution of coarse aggregate.



Fig. 3: View of crumbed rubber particles.



Fig. 4: View of granular plastic particles.



Fig. 5: View of crushed brick particles.

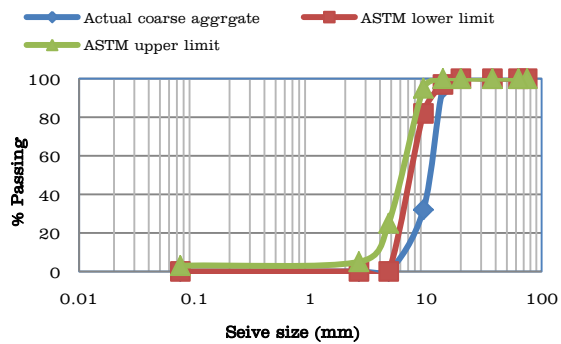


Fig. 6: Grain size distribution of crumbed rubber.

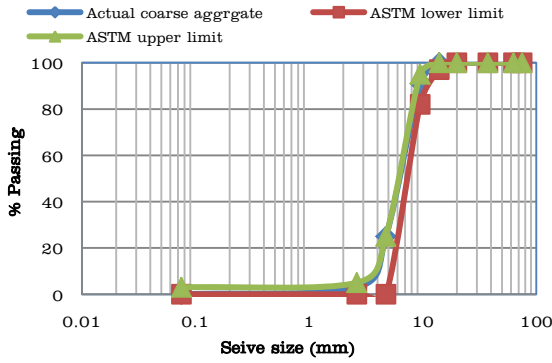
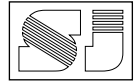


Fig. 7: Grain size distribution of granular plastic.

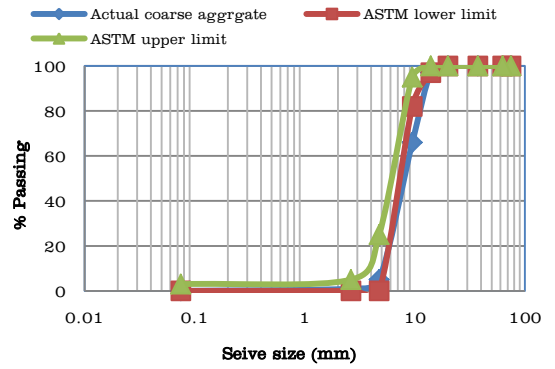


Fig. 8: Grain size distribution of crushed brick.

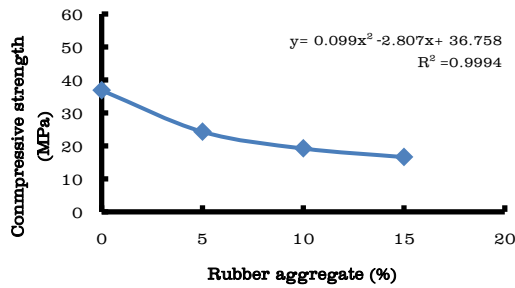


Fig. 9: Variation of compressive strength with rubber.

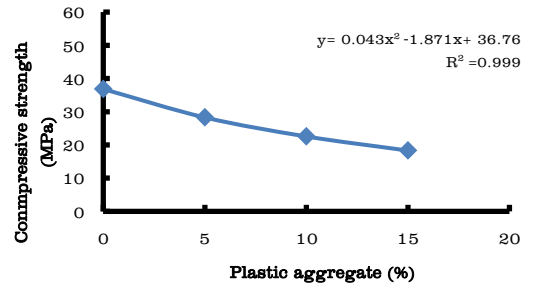


Fig. 10: Variation of compressive strength with plastic.

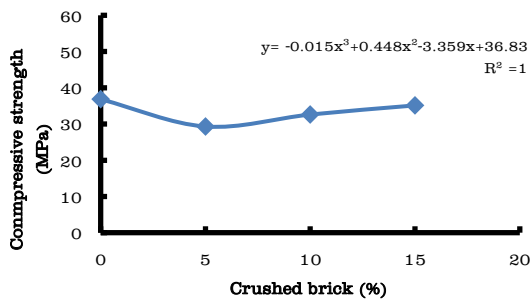


Fig. 11: Variation of compressive strength with brick.

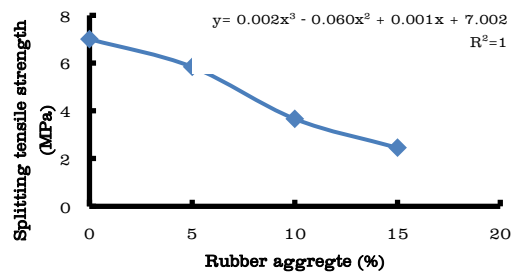


Fig. 12: Variation of splitting tensile strength with rubber.

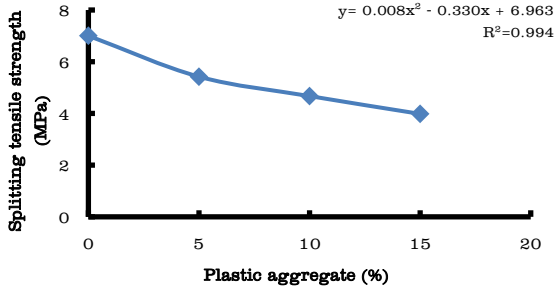
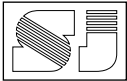


Fig. 13: Variation of splitting tensile strength with Plastic.

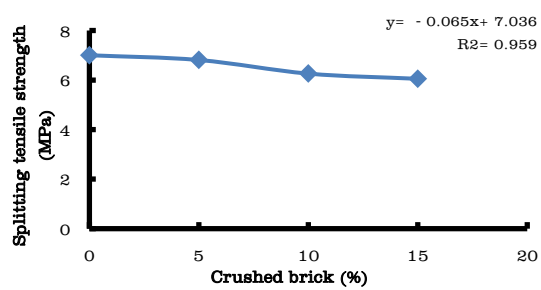


Fig. 14: Variation of splitting tensile strength with brick.



Fig. 15: Failure pattern of concrete containing different type of waste materials in splitting tensile strength.

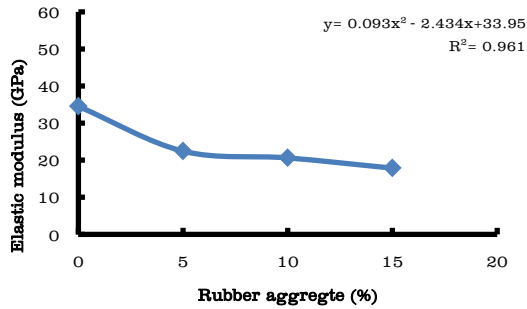


Fig. 16: Variation of elastic modulus with rubber.

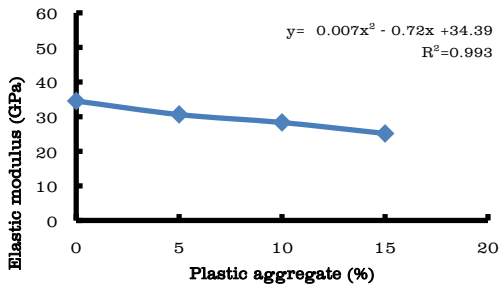


Fig. 17: Variation of elastic modulus with plastic.

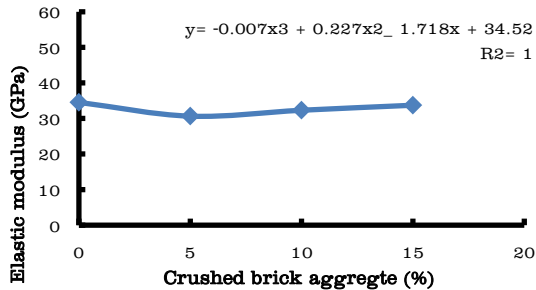


Fig. 18: Variation of elastic modulus with brick.