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DETERMINING MECHANICAL PROPERTIES OF CONCRETE WITH PARTIAL REPLACEMENT OF FINE AGGREGATE BY TIRE RUBBER CRUMB

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Abstract: The environment will be critically polluted if the enormous amount of rubber tyres is not adequately reprocessed and disposed of. One of the feasible solutions to the reduction of wastes is using recycled crumb rubber particles in concrete. In this research waste tire rubber were used to study the effectiveness of concrete with replacement of tire rubber crumb in conventional concrete. The rubber crumb were prepared and replacing by 11%, 13%, 15% and 17% of fine aggregate in terms of the density. The concrete cubes were prepared in size of 150 x 150 x 150 (mm) and tested for compressive strength test. The ductility of the concrete were studied by getting the deformation of the cube through dial gauge and plotted the stress strain curve. It was found that the workability of the concrete mix reached its highest slump value in sample with 11% of rubber crumb replacement which was 97mm, and the slump value decreased when the percentage of rubber crumb replacement increased. Overall, the results obtained for compressive strength of the concrete cubes with rubber crumb replacement achieved a lower compressive strength than the control sample. As well, all of the concrete cube samples with rubber crumb replacement obtained a higher strain than that of the control sample.

Keywords: Concrete properties; Compressive strength; Stress-strain; Tire crumb

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INTRODUCTION

Due to the rapid development of construction industry, the usage of concrete is increasing from time to time. The scope of concrete as a structural material, has widened with innovations in science and technology in construction industry but not sustainable for numerous reasons. Rubberized Concrete and "Fiber Reinforced Concrete are some of the technological advances in improving the quality and properties of concrete. According to Kumar (2013), Malaysia had generated an estimation of 8.2 million waste tyres throughout the years and the total wastes produced in this country could go up to approximately 57,000 tonnes annually. Consequently, sustainable methods on recycling and managing this vast amount of wastes are absolutely essential to prevent any serious pollution from occurring.

The environment will be critically polluted if the enormous amount of rubber tyres is not adequately reprocessed and disposed of. Therefore, a few solutions such as reusing tyres from second-hand market and rethreading, recovery of material from chopped, shredded, whole and micronized tyres and recovering of energy can be adopted worldwide (Thomas *et al*., 2015). One of the feasible solutions to the reduction of wastes is using recycled crumb rubber particles in concrete. It helps in the improvement of concrete properties, transforming it to become more flexible as a material (Batayneh *et al*., 2008). Besides that, using recycled tyres in construction components is a green alternative for saving the environment and reusing waste (Aiello and Leuzzi, 2010). Scrap tires are introduced to the cracker mill process which produces irregularly shaped torn particles having large surface area and these particles are commonly known as crumb rubber. Some research has already been conducted on the use of waste tire as aggregate replacement in concrete showing some improvement. The enhanced toughness and sound insulation properties can be achieved when waste tire replaced the aggregate inside the concrete. The partial replacement of sand with crumb rubber results in strength reduction. The greater the rubber content, the more the strength is reduced. River sand is a natural resources which is also a slow generative one. There were many researcher have been researching the properties of using rubber crumb to partially replace the fine aggregates in order to utilize the waste tire, reducing the usage of natural aggregate and also increase the concrete mechanism which can be used to benefits existing concrete construction. In this research, tire rubber crumb is used as a replacement for fine aggregate in order to solve the brittle failure mode, shrinkage and cracking which is not favored by the civil construction application. Thus, to determine the optimum percentage of fine aggregate replacement in the concrete production which will not make a significance decreases in compressive strength of concrete, at the same time to improve the ductility and other properties of the concrete.

METHODOLOGY

Mix Design Method (DOE Method)

The calculation to get the volume that required for concrete mixing in this research was done according to DOE method. In concrete mixing process, the raw materials that required is cement, coarse aggregate, fine aggregate, water and rubber crumb. Concrete mixer was required to provide an evenly mixed concrete which was able to obtain a consistent result. In order to reduce the possibility of human error which affect the consistency of the results, each batch of concrete was required to mix in one shot. Theoretically, the grade of the control mix was M30 which can achieve 30N/mm^2 of compressive strength in 28 days. The outcome of DOE mix design method was illustrated in **Table 1**.

Trial Mix

The purpose of trial mix was to reduce and determine the possibility of failure for the actual concrete mix. We found out the mechanical properties of the design mix can be achieved in theoretical waybyusing lab equipment. In this trial mix, 3 plain concrete cubes were casted and cured for 7 days to test their compressive strength. According to BS 8110-1:1997, the M30 concretes compressivestrength is required to achieve 65% of the total characteristic compressive strength which is between 19–20N/mm^2.

Raw Material

Raw material which will be use in this research is Portland Composite Cement, Natural Coarse and Fine Aggregates, Rubber Crumb and Water.

Cement

The cement used in this research was Portland Composite Cement which is produced in Malaysia. The chemical compound of the Portland Composite Cement was stated in **Table 2**.

Table 1. Mix design

Samples	Cement (kg)	Water (litre)	Coarse Aggregate (kg)	Fine Aggregate (kg)	Rubber Crumb (kg)
Per m3	420	210	1050.2	729.8	
Control	15.31	7.66	38.28	26.60	0
11%	15.31	7.66	38.28	23.68	2.10
13%	15.31	7.66	38.28	23.14	2.49
15%	15.31	7.66	38.28	22.61	2.87
17%	15.31	7.66	38.28	22.08	3.25

Table 2. Chemical composition (Cement)

Chemical Compound	Mass (%)
Lime, CaO	62-63
Silica, SiO2	20-21
Alumina, Al2O3	5.2-5.6
Iron Oxide, Fe2O3	4.4-4.8
Magnesia, MgO	0.5-0.7
Sulphur Trioxide, SO3	2.4-2.8
Soda or Potash, Na2O+K2O	1.5-2.5

Aggregate

Aggregates contribute most of the strength of the concrete hence it was necessary to ensure the quality of the aggregates. The purpose of aggregates in concrete was to maintain the dimension stability and reduced the cost of construction at the same time. Besides, the workability of the concrete mix is also depends on the size of the aggregates. In this research, the coarse aggregate was seized in the lab to get the desired size between 10-20 mm and then dried out to reach the SSD condition. River sand was used as the fines aggregates in this research. The moisture content of the river sand is also a quality concern so that the targeted mean strength can be achieved.

Rubber Crumb

Waste tires rubber is usually categorized into 3 broad categories which are chipped rubber, crumb rubber and ground rubber. Chipped rubber is used to replace gravel and the size of the chipped rubber is between 75-130mm. Ground rubber that may use to replace cement and have a range of size between 0.075-0.475 mm. Rubber crumb is manufactured by special mills and have a range of size between 0.425-4.75mm. Rubber crumb was used in this research to replace the fine aggregate.

Water

Water used in concrete has to be free from sewage, oil, acid, strong alkaline or vegetable matter, clay and loam to ensure the quality of concrete mix. Clean potable water was used for mixing and curing during the research.

Preparation of Concrete Cube

45 (forty five) concrete cubes with dimension of (150mm×150mm×150mm) were prepared. The number of test specimen was to ensure the results can be obtained in a more consistent and accurate way hence decrease the factor caused by practical or human error. First of all, the materials required was prepare according to the mix proportion. The concrete mixer was then clean and dry before the mixing process in order to ensure the quality of concrete mix. Then, 60% of the total amount of the water was first mix with all the coarse aggregate, fineaggregate, and cement in the concrete mixer. Then, the mixtures were requireto stir for 3 minutes to make sure the materials mix evenly. After that, the remaining 40% of the water was added afterwards. After all the materials were pour into the mixer, another 3 minutes time of stirring time was require to ensure that the concrete mix produce was mixed evenly and have a uniform strength-distribution. The ready mix concrete was then pour into the mould as soon as possible to ensure that there is no occurrence of evaporation of water from the wet concrete to the surrounding. The concrete was then tamp manually by using the tamping rod for compaction purpose. It is important to make the surface of the concrete smooth after the compaction so that the result of the compressive strength test is consistent and accurate.

Curing

Once the concrete cubes were set, it were removed from the mould and submerged into the water tank for curing purpose. The concrete cube were place inside the water tank for certain days until they were taken out to do the compressive strength test. The period of curing before the compressive strength test were 7 days, 14 days and 28 days.

Laboratory Test

The laboratory test is also known as the concrete test. The tests included are the slump test and compressive strength test. Slump test is to test the workability of the fresh concrete while the compressive strength test is to test the total load that can be taken by the hardened concrete cube.

Slump Test

The workability of the fresh concrete was test by using slump test immediately after the mixing of the concrete. In order to check the uniform quality of each batch of concrete, this test was required to carry out for every batch of fresh concrete. The slump test procedures were following the BS EN 12350-2. The slump cone was filled with 3 layers of compacted fresh concrete. Every layer was required to tamp for 25 times each by using tamping rod to make sure it was fully compacted. After the tamping for last layer, the slump cone was removed to check the condition of the slump. The slump values was measured by putting the slump mould beside the concrete and measured the difference in height between the concrete and slump cone.

Concrete Compressive Strength Test

According to BS EN 12390 part 3, the concrete compressive strength test was carried out by using the compression test machine in the laboratory. During the test, the load applied keep increasing until the concrete fail and cracks of concrete was observe. The peak load was recorded when the test machined stopped applying the load. The compression strength of the cube was obtained by using the load apply divide by the effective area of the concrete cubes which is the surface of concrete cube contact with the machine. Since it was a cube, the area of contact will be (150mm×150mm).

Ductility

The deformation of the concrete cube was record by putting the dial gauge on the compressive strength machine and recorded in video. Further calculation was make to study the ductility ratio of the concrete cube. When a brittle failure occurred, the load applied by the compressive strength test machine tend to drop vigorously after the failure. While a ductile failure occur when the load applied by the machine remain constant and dropped slightly even after the cracked.

RESULTS AND DISCUSSION

Slump Test

The slump test which following BS EN 12350-2 were carried out throughout the concrete casting, where a total of 5 slump test was carried out in order to determine whether the increasing of the percentage of rubber crumb in volume would affect the workability of concrete. The measurement of slump test was showed in **Table 3**.

From the data obtained, it was shown that the control sample achieved 53mm of slump value. The slump of the sample reached the required slump value which is in the range of 30-60mm, this indicated that the concrete batch was properly mixed. The workability of the concrete mix reached its highest slump value in sample with 11% of rubber crumb replacement which was 97mm, and the slump value decreased when the percentage of rubber crumb replacement increased. It clearly shown that the present of rubber crumb in concrete mix will increase the workability but, the percentage of replacement reached its optimum value for workability at 11% of replacement. Further increase in the percentage of rubber crumb replacement will decrease the workability but still provide greater workability than the control sample.

In the literature, most of the studies showed that increasing in the percentage of rubber crumb in concrete mix will improve the workability and the result tested was tally with the previous research. While according to Murugan and Natarajan (2015), the workability of concrete increases when rubber crumb is used to replace fine aggregate in concrete mixing. This may be due to the less absorption capacity when compared with natural fine aggregate such as river sand, so the workability of the concrete is increasing as the percentage of rubber crumb increases. But the percentage of the replacement need to be control in order to achieve high workability. The reason behind is because the replacement of river sand with rubber crumb reduce the water absorption hence more water are available to lubricate the mix and increase the workability. But, when the percentage of rubber crumb in a concrete mix reach an optimum level, further increase in the percentage of rubber crumb will tend to restrict the movement between aggregates and reduce the lubricating effect of the cement even when more water were left in the mix.

Table 3. Slump test result

Sample	Measurement obtained (mm)
Control	53
11%	97
13%	92
15%	88
17%	69

Compressive Strength

According to BS 1881 - Part 116, 2009, the compressive strength test had been carried out to test the compressive strength of the samples. The tests were carried out after 7 days, 14 days and 28 days of curing to check whether to concrete cube achieve the desired strength. The data collected were shown in **Figs. 1–3** below. The results of compressive strength test of the concrete cube after 7 days of curing. Theoretically, the cube will reached 65% of their design strength after 7 days of curing. The control sample achieved an average of 19.98MPa which satisfied the targeted mean strength for the design of grade M30 concrete. The concrete cube with rubber crumb replacement get an average of 17.64MPa, 15.76MPa, 15.53Mpa and 13.15Mpa for 11%, 13%, 15%, and 17% respectively. All of the concrete cube with rubber crumb replacement did not reached the required target strength on 7 days which is 19.5MPa. The results shown that concrete cubes with rubber crumb replacement achieved a lower compressive strength compared with the control sample after 7 days of curing.

Figure 2 shown the results of compressive strength test of the concrete cube after 14 days of curing. Theoretically, the cube will reach 90% of their design strength after 14 days of curing which mean the control sample should achieved 27 MPa or more during the testing. Unfortunately, all of the control sample and the sample with rubber crumb replacement did not reach the required target strength for 14 days which is 27MPa. The control sample achieved an average of 21.67 MPa which did not satisfy the targeted mean strength for the design of grade M30 concrete. The concrete cube with rubber crumb replacement gets an average of 18.94MPa, 17.55MPa, 17.27Mpa and 15.29Mpa for 11%, 13%, 15%, and 17% respectively.

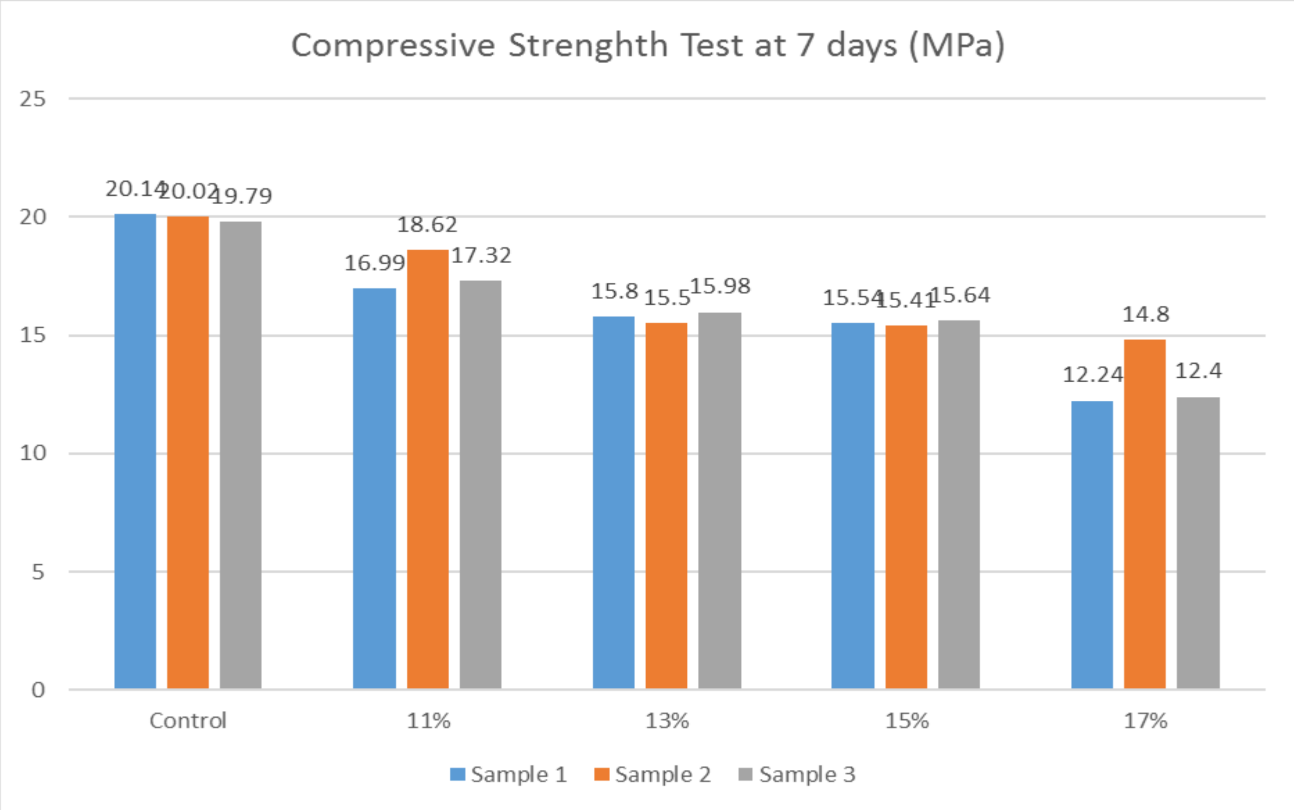

Fig. 1 Compressive Strength Test Result at 7 days

The results show that concrete cubes with rubber crumb replacement achieved a lower compressive strength compared with the control sample after 14 days of curing. **Figure 3** shows the results of compressive strength test of the concrete cube after 28 days of curing. Theoretically, the cube will reach 99% of their design strength after 28 days of curing which means the control sample should achieve at least 30 MPa or more during the testing. Unfortunately, all control samples and the concrete cube with rubber crumb replacement did not achieve the target strength for 28 days which is 30MPa. The control sample achieved an average of 24.32MPa which did not satisfy the targeted mean strength for the design of grade M30 concrete. The concrete cube with rubber crumb replacement get an average of 20.97MPa, 19.15MPa, 18.87 Mpa and 16.87Mpa for 11%, 13%, 15%, and 17% respectively. The results shown that concrete cubes with rubber crumb replacement achieved a lower compressive strength compared with the control sample. The reason for such decrease is due to the lack of proper bonding between cement paste and crumb rubber particles, as compared to natural aggregate (sand) and cement paste. As a result, the non-uniform distribution of stresses applied could lead to the formation of cracks (Sofi, 2018).

Figure 4 below shows the average compressive strength for all concrete samples. The reason why the control sample did not achieve the required strength at 14 days and 28 days was due to the problem of the testing machine. The control sample reached the required target strength on 7 days indicated that the control mix was mixed properly before casting. Other reason of the failure of the control sample is because of lack of maintenance of the machine and the human error when compacting the cube. When a concrete cube is not compacted properly, it will not achieved it target strength because many voids were formed due to poor compaction. The void in the cube will lead to a drop in the compressive strength of the concrete cube.

Overall, the compressive strength of the concrete cubes with rubber crumb replacement achieved a lower compressive strength compared with the control sample. When the percentage of rubber crumb replacement increase, the compressive strength of the concrete cube will decrease. The reason behind was due to the poor water absorption mechanism of the rubber crumb compare to sand caused excess water in the concrete mix hence affect the water cement ratio of the mix. After the water evaporated, the pore left behind made the cube weaker. The drop of compressive strength for concrete cube with rubber crumb replacement was because of the increase of porosity in the concrete cube.

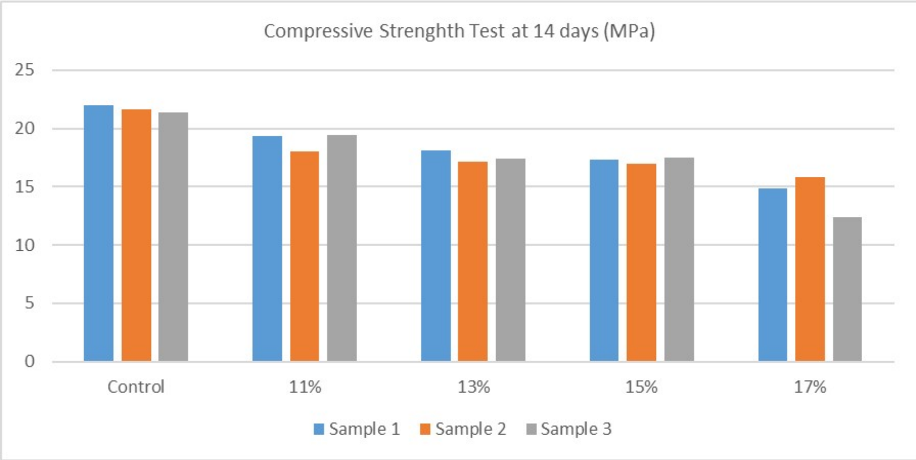

Fig. 2 Compressive Strength Test Result at 14 Days.

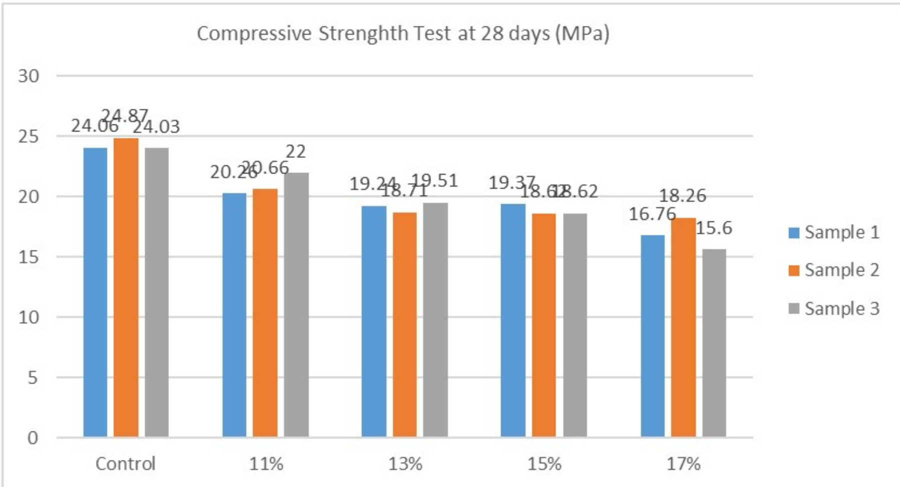

Fig. 3 Compressive Strength Test Result at 28 Days.

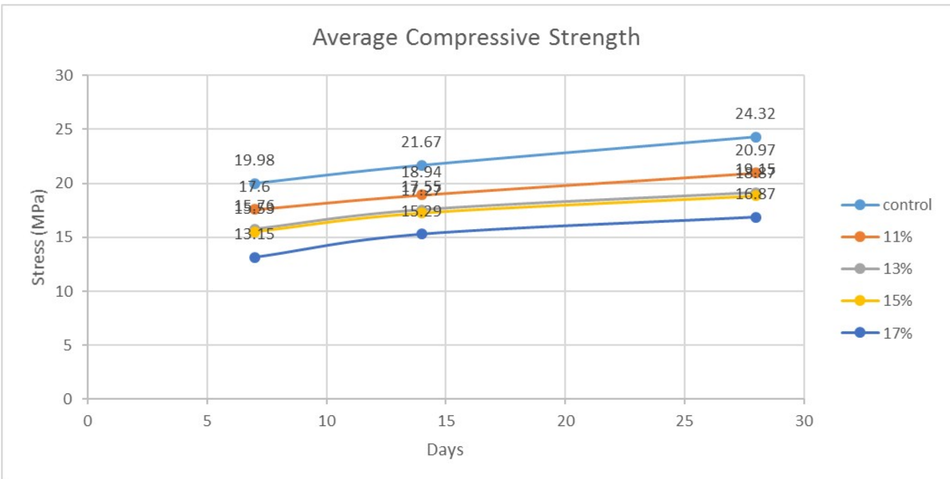

Fig. 4 Average compressive strength results.

Besides, rubber particles generally contain relatively low strength and as the proportion of crumb rubber increases, the properties of rubber eventually dominate the properties of concrete which results in the loss of strength (Pelisser *et al.*, 2011). The smooth surface of the rubber crumb compared to the rougher surface of sand will weaken the bond between the aggregate and the cement hence reduce the strength of the cube. The bond between the cement and the aggregates distributed most of the compressive strength of the concrete cube. When the bond between the cement pastes and aggregates was not strong enough, the concrete cube will not achieve the target compressive strength. This proved that the replacement of fine aggregates with rubber crumb will decrease the compressive strength of the concrete cube (Falak *et al*, 2015).

Ductility

The deformation of the concrete cube was recorded and analysed to fulfil the objective of this study. A dial gauge was clamped by a retort stand and setup at the bottom of the compressive strength test machined to record the deformation of the concrete cube. All the result of deformation of the concrete cube obtained were used to plot a stress stain curve to study the ductility of the concrete cube. Among the 3 samples, the concrete cube with the best stress strain curve were used. The data for the concrete cube with the best result were tabulated in **Table 4** to calculate the ductility ratio of the cube over the control sample to plot the ductility ratio graph. The stress strain curve for all concrete cube tested 28 days after the curing was plotted in the **Fig. 5**.

By using the data obtained, a stress strain curve of the concrete cube were plotted. The graph showed that the concrete cube with higher percentage of rubber crumb replacement had higher strain compared to the concrete cube with lower percentage of rubber crumb replacement. All of the concrete cube with rubber crumb replacement obtained a higher strain than the control sample. The increase in strain of the concrete cube were due to the natural properties of rubber which is elastic. According to Khaldoon A. Bani-Hani and Ahmed Senouci, (2015), considerable loss of strength was observed when the rubber crumb content in the mix was increased. Losses up to 90% of the compressive strength was measured, depending on the percentage of crumb rubber in the mix. When the cube was being compressed by the testing machine, the cube tend to

Table 4. Stress Strain results

Control		11%		13%		15%		17%	
Stress (MPa)	Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)
0	0	0	0	0	0	0	0	0	0
5	0.0007	5	0.0009	5	0.0010	5	0.0012	5	0.0014
10	0.0015	10	0.0017	10	0.0018	10	0.0021	10	0.0023
15	0.0021	15	0.0023	15	0.0027	15	0.0030	15	0.0031
20	0.0025	20	0.0029	19.51	0.0032	18.62	0.0035	18.26	0.0037
23.82	0.0028	22	0.0039	19.51	0.0053	18.62	0.0063	18.26	0.0071
23.82	0.0050	22	0.0052						

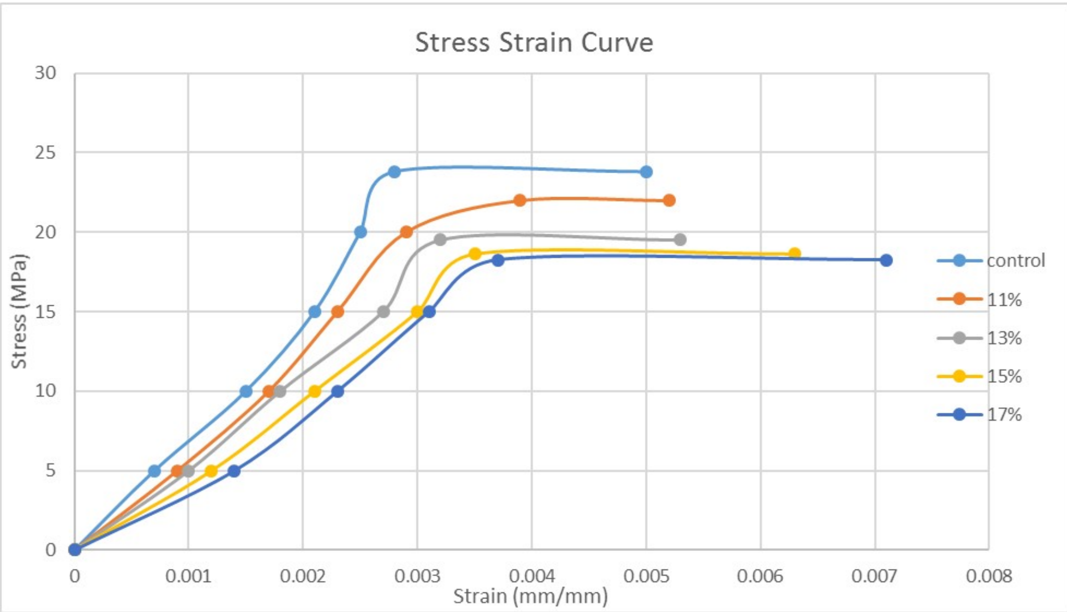

Fig. 5 Stress Strain Curve.

break when the stress reached its maximum, the bond between the cement and aggregates was very strong but brittle make the concrete fail very quickly after it reached its maximum stress. On the other hand, the bond between the cement, aggregate and rubber crumb were not as strong as the bond between cement and aggregates only but it was more ductile. These can be proved by the stress strain curve where the concrete cube can last longer and deform more even after the cube reached its maximum stress compared with the cube with rubber crumb. The elastic nature of the rubber allows the concrete cube to deform more before failure occurs.

Figure 6 showed the ductility ratio of the rubberized concrete was plotted by using the percentage of rubber crumb replacement against the strain of rubberized concrete cube at 85% of ultimate stress over the strain of the control concrete cube at 85% of ultimate stress. A curve line with equation was formed. The equation for this curves line can be used for predicting the value of ultimate stress with desired percentage of rubber crumb replacement.

$$y = (5.375 \times 10^{-3})\, x^2 - 0.103b + 1.5716 \qquad (1)$$

Mode of Failure

From Fig.7 - Fig.11, the mode of failure of the concrete cube with different percentage of replacement can be seen. The control sample failed in rather brittle way that it cracked into half. The cube with rubber crumb replacement has shown less cracking behaviour compared to the control sample. The compressive strength reduced when the use of rubber crumb in concrete mixing higher in percentage (Yogender *et al*., 2012). But the concrete cube with 11% and 13% of rubber crumb replacement still showed a rather brittle failure mode. Whereas the concrete cube with 15% and 17% of rubber crumb replacement showed less cracking behavior. The cracking behavior on cube with 15% and 17% of rubber crumb replacements were less severe compared with the control cube and cube with lower percentage of replacement.

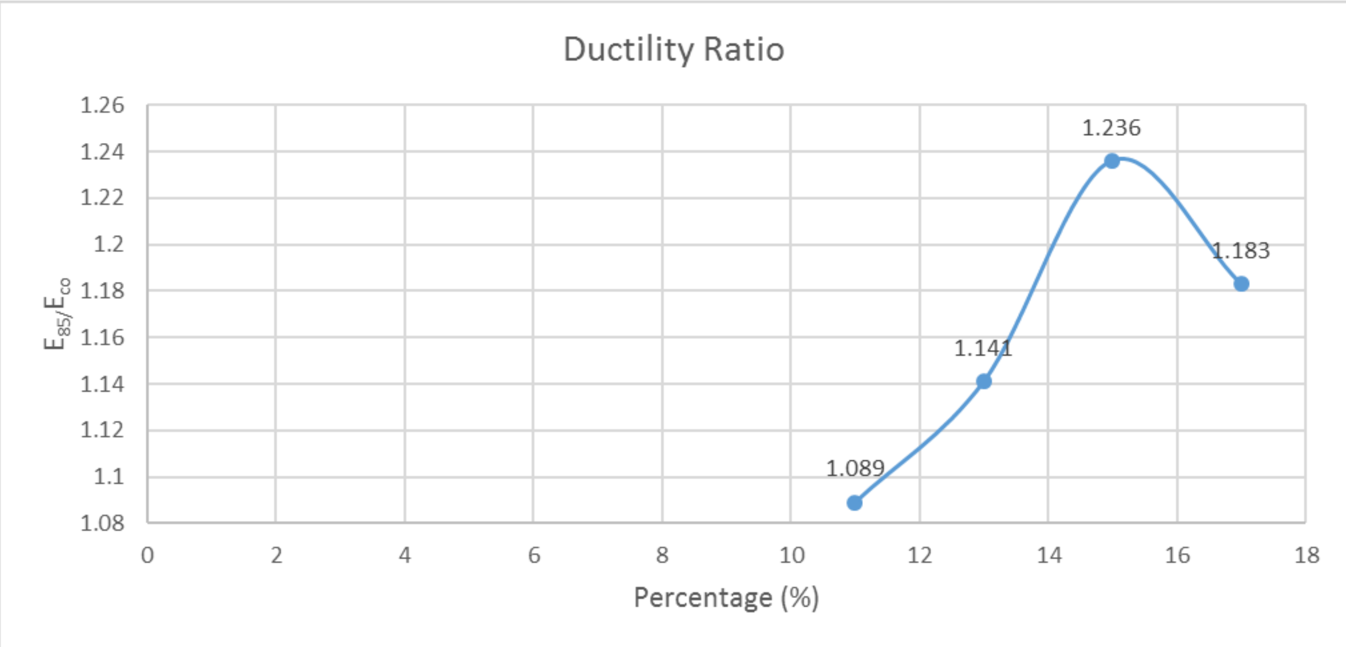

Fig. 6 Ductility ratio.


Fig. 7 Control sample.


Fig. 8 Cube with 11% of replacement.


Fig. 9 Cube with 13% of replacement.


Fig. 10 Cube with 15% of replacement.

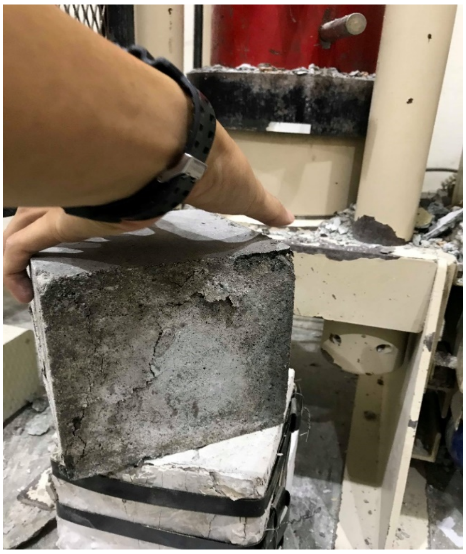
Fig. 11 Cube with 17% of replacement.

CONCLUSION

Based on the results and discussion, this study concluded that compressive strength of the concrete cube decreased when the percentage of the replacement of rubber crumb increased. Concrete cube with 11% of rubber crumb replacement will give the optimal and best replacement with slight decrease in compressive strength. The concrete cube with replacement of tire rubber crumb is more ductile than the concrete cube without replacement.

With regards to the workability of concrete mix, it decreases with increase in percentage or, rubber crumb from 11% onwards. And concrete mix with rubber crumb have greater workability than concrete mix without "rubber crumb". It can be recommended to reduce the water cement ratio for increased compressive strength results. Chemical admixture can be added to increase the bonding strength between the rubber crumb with the cement paste and aggregates.

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