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UTILIZATION OF TREATED CRUMB RUBBER STEEL FIBER CONCRETE (TCRSFC) TO IMPROVE DYNAMIC PERFORMANCE OF CONCRETE COLUMNS

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ABSTRACT

This study presents experimental results of the dynamic and related mechanical properties of Treated Crumb Rubber Steel Fiber Concrete (TCRSFC) by partially replacing the fine aggregates in concrete with crumb rubber and steel fiber from waste tires. This aim is to investigate the mechanical properties and dynamic performance of concrete containing 10% of fine crumb rubber and 1 % volume fraction of steel fiber. The concrete cube size of 100 mm x 100 mm x 100 mm was first examined to identify the effective percentage of treated crumb rubber and steel fiber in concrete mix. Based on the results, 10% crumb rubber and 1% steel fiber showing the least reduction in compressive strength. Modification of water cement ratio has been made for concrete contains 10% crumb rubber and 1% steel fiber in order to get approximate strength as Normal Concrete (NC). Based on analysis, dynamic modulus, damping ratio and natural frequency of TCRSFC has improved considerably by 5.18%, 109% and 10.94% when compared with NC. The TCRSFC producing concrete with the desired properties as well as to introduce the huge potential as dynamic resistance structure from severe damage especially prevention of catastrophic failure.

1. Introduction

In general the normal concrete properties are by quasi-brittle failure where, the nearly complete loss of loading capacity, once failure is initiated. Concrete properties can be modified to perform in a more ductile manner by replacing fine aggregates using crumb rubber and the addition of randomly distributed discrete fibers in the concrete matrix, which prevent and limit initiation, propagation and integrate of cracks. The introduction of steel reinforcement in concrete structure has proved its improvement in tensile strength, but when exposing to dynamic loading such as earthquake event, it is cause severe damage due to less energy dissipation (Xue and Shinozuka. 2013). Previous research has shown that the utilization of crumb rubber has improved its damping ratio, which is low in seismic response, but give a reduction in compressive strength and elastic modulus (Xue and Shinozuka. 2013); (Youssf *et al*. .2014). It is suggested that the replacement of crumb rubber in the range of 0%-20% by aggregate replacement (Khatib and Bayomi. 1999); (Tareq *et al*. 2015);.The reduction in compressive strength can be tackled by modification in water cement ratio (Alawode and Idowu. 2011; Zivica. 2009; Rahmani *et al.* 2012. Therefore, the problematic reduction in strength with the inclusion of crumb rubber can be improved by modification in water cement ratio. Besides, the addition of steel fiber from waste tire will helps in improving the concrete properties. Based on past studies, the inclusion of steel fiber in concrete mixtures improves the tensile capacity, toughness and reduce surface cracking and it is suggested that the addition is in the range of 0.5%-2.5% (Atis and Karahan. 2009). Meanwhile, production of waste tire is one of the main problem faced by most of the country all over the world (Eldin and Senouci. 1993; Zheng *et al.* 2008). These

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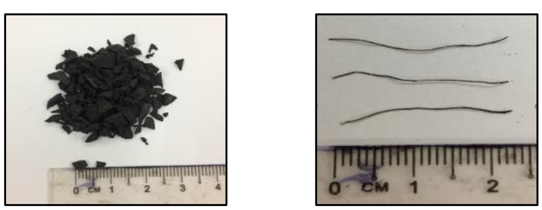
production cause a lot of environmental pollution, especially when stored in landfills or stockpile Herman and Bisesi. 2002). Besides, burning activities of waste tires causes a health hazard from excessive smoke and toxic during the burning process (Issa and Salem. 2013; Moustafa and Elgawady. 2015). In this research, the mechanical and dynamic property of concrete has been investigated and compared with those derived given TCRSFC and NC. The optimum replacement of crumb rubber and of steel fiber was examined. The effect of combination between crumb rubber with steel fiber with at the replacement ratios obtained, modified water cement ratio of the mechanical and dynamic properties of concrete column is determined as well.

2. Materials and Test Methods

2.1 Materials

All concrete mixtures are using a same binder materials which is Ordinary Portland Cement (OPC). Fine aggregates and crumb rubber used in concrete mixture is passing through 4.75 mm while maximum size of coarse aggregates is 10 mm. Crumb rubber was treated with Sodium Hydroxide (NaOH) solution for 20 minutes for removing unnecessary impurities on crumb rubber surface. Then, crumb rubber was rinsed with water and drying for 24 hours at ambient temperature. Meanwhile, the average length of steel fiber is 2.35 cm with diameter of 0.30 mm. Figure 1 shows the (a) crumb rubber and (b) steel fiber used in concrete mixtures.



(a) (b)

Figure 1: (a) Crumb rubber and (b) Steel fiber

2.2 Mix design

There are eight types of concrete mixtures that have been used in this research with different mix proportions. Normal Concrete (NC), Treated Crumb Rubber Steel Fiber Concrete 1 (TCRSFC1) (10% treated crumb rubber, 0.5% steel fiber), Treated Crumb Rubber Steel Fiber Concrete 2 (TCRSFC2) (10% treated crumb rubber, 1.0% steel fiber) , Treated Crumb Rubber Steel Fiber Concrete 3 (TCRSFC3) (20% treated crumb rubber, 0.5% steel fiber), Treated Crumb Rubber Steel Fiber Concrete 4 (TCRSFC4) (20% treated crumb rubber, 1.0% steel fiber), Treated Crumb Rubber Steel Fiber Concrete 5 (TCRSFC5) (25% treated crumb rubber, 0.5% steel fiber), Treated Crumb Rubber Steel Fiber Concrete6 (TCRSFC 6) (25% treated crumb rubber, 1.0% steel fiber) are using the same water cement ratio (0.55) while water cement ratio of Treated Crumb Rubber Steel Fiber Concrete 7 (TCRSFC7) (10% treated crumb rubber, 1.0% steel fiber) has been modified from 0.55 to 0.50. Besides, 0.3% of superplasticizer was added to TCRSFC1, TCRSFC3, and TCRSFC5 while 0.6% was added to TCRSFC2, TCRSFC4, TCRSFC6 and 1.0% to TCRSFC 7. The addition of superplasticizer is to improve the workability of fresh concrete.

3. Sample preparation

Each concrete mixture consist of three cubes (100 mm × 100 mm × 100 mm) to be tested for compressive strength test and to be used as a preliminary result as an indication which specimen has similar or approximately NC before being tested for compressive strength (cylinder), modulus of elasticity, free vibration and seismic shaking table. Compressive strength and modulus of elasticity test are determined according to British standard BS 1881-116 (1983) and BS 1881-121 (1983). After preliminary testing, NC and TCRSFC7 mixture were cast for six cylinders with 100 mm diameter and 200 mm height (compressive strength and modulus of elasticity) and small scale column with two reinforcing (3mm diameter) which is designed by 1:6 ratio according to Malaysian Standard MS1064: Part 10 (2001). There are three parts for the small scale column which is lump mass (12 cm × 12 cm × 19 cm), column (4 cm × 4 cm × 50 cm) and foundation (27.5 cm × 27.5 cm × 8 cm). Small scale column was fixed with bolts and nuts on shaking table and accelerometer was glued on lump mass, column and shaking table before being tested under free vibration and seismic shaking table. For free vibration test, an impact load was applied at lump mass by a hammer to induce the vibration, and the vibration was recorded by accelerometer. After free vibration test, column specimen was tested by exiting the shaking table test with modified north-south Ranau earthquake ground motion which is 1.0g. The ground motion was scale up from 0.126g (6.1 magnitude) to 1.0g in order to examine the effectiveness of combination 10% crumb rubber and 1% steel fiber in concrete column (during earthquake event).

4. Results and Discussion

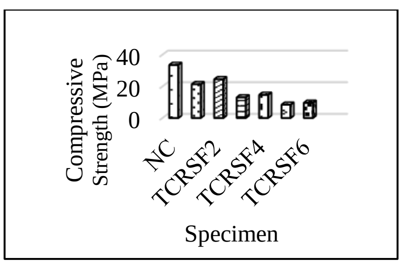
4.1 Compressive Strength

The compressive strength of concrete was reduced as the percentage of crumb rubber replacement increased as shown in Table 1.

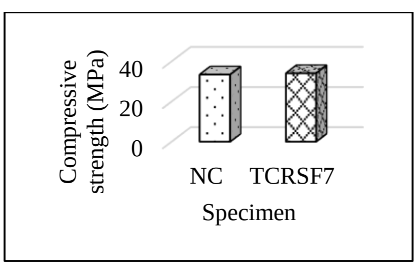
Table 1: Compressive strength of concrete specimens

Specimen	Water cement ratio	Treated Crumb Rubber (%)	Steel Fiber (%)	Compressive Strength (MPa)	Percentage different (%)
NC	0.55	-	-	33.46	-
TCRSFC1	0.55	10	0.5	21.33	-36.25
TCRSFC2	0.55	10	1.0	24.47	-26.87
TCRSFC3	0.55	20	0.5	13.01	-61.11
TCRSFC4	0.55	20	1.0	14.61	-56.34
TCRSFC5	0.55	25	0.5	8.39	-74.93
TCRSFC6	0.55	25	1.0	9.59	-71.34
TCRSFC7	0.50	10	1.0	34.15	+2.06

The inclusion of 25% crumb rubber and 0.5% steel fiber (TCRSFC5) shows the highest reduction (74.93%) in strength followed by TCRSFC6 (71.34%),TCRSFC3 (61.11%) TCRSFC4 (56.34%), TCRSFC1 (35.25%) and TCRSFC2 (26.87%) with respect to NC. The modification in water cement ratio from 0.55 to 0.50 for 10% crumb rubber and 1% steel fiber (TCRSFC7) approximately improve the concrete strength by 2.06%. From the analysis, it is showing that the modification in water cement ratio give an improvement in compressive strength which is agreed by past researcher (Alawode and Idowu. 2011). Figure 2(a) illustrates the compressive strength of concrete specimen (0.50 water cement ratio) while (b) shows the comparison of NC (0.55 water cement ratio) and TCRSFC7 (0.50 water cement ratio) at age of 28 days which is all of concrete specimen were compared to NC.



(a)

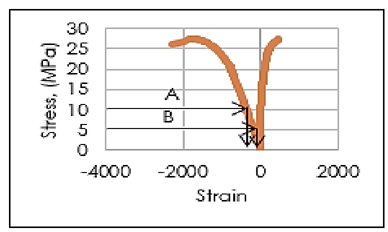


(b)

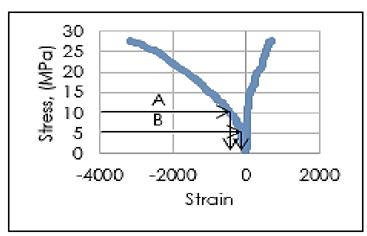
Figure 2: Compressive strength of concrete specimen (a) 0.55 water cement ratio and (b) comparison for 0.55 water cement ratio (NC) and 0.50 water cement ratio (TCRSFC7)

4.1 Modulus of Elasticity

The modulus of elasticity for both NC and TCRSF7 was tested and determined by using British Standards 1881-Part 121 which is defined as secant modulus (A) at one-third of compressive strength cube at age 28 days. Meanwhile the dynamic modulus (B) is defined as small instantaneous strain. Generally, the dynamic modulus is 20%-40% higher than secant modulus. Besides, dynamic modulus are more suitable for stress analysis of structure that subjected to earthquake or impact loading (Metha and Monteiroar. 2006). Figure 3 illustrates the stress-strain curve from tested specimen. Determination of elastic modulus was calculated according to British Standards 1881-Part 121.



(a)



(b)

Figure 3: Stress-strain curve of (a) NC and (b) Stress-strain of TCRSFC7, A is secant modulus and B is dynamic modulus.

Based on analysis, secant modulus, Es and dynamic modulus, Ed of TCRSFC7 cylinder shows an increment by 5.60% (27.82 GPa) and 5.18% (31.05 GPa) higher NC cylinder which is 26.28 GPa and

29.52 GPa. From observation, it is show that the modulus of elasticity is directly proportional to compressive strength of concrete which is the modulus of elasticity increase as the compressive strength increase. Figure 4 shows the mode of failure for concrete specimen under modulus of elasticity. Based on observation, NC exhibited a brittle failure which is small pieces of concrete are shattered meanwhile TCRSC7 are more ductile and less brittle because it was confined by 1% of steel fiber in concrete specimen thus improve the modulus of elasticity.

(a) (b)

Figure 4: Mode of failure for (a) NC and (b) TCRSFC7

4.1 Free Vibration Test

Damping ratio is defined as energy dissipation, which can be measured by a free vibration test. Four concrete columns consisting of two NC and two columns of TCRSFC7 were tested under a free vibration test. The damping ratio was computed by using logarithmic decrement, Equation (4.1), in which A1 denotes the first amplitude of acceleration, An is the amplitude after the next cycle and n is next cycle of oscillation

$$\text{Damping, } \zeta = {}^{1}/_{2n\pi} \text{ x In } {}^{A1}/_{An} \qquad (1)$$

Based on the analysis, the damping ratio for TCRSFC7 is 9.6% and that for NC is4.6%. According to past studies, the range of damping ratios for concrete vary from 4%-7% (Adams and Askenazi. 1999; Xue and Shinozuka. 2013). Moreover, the natural frequency of TCRSFC7 has increased by 10.96% (11.14 Hz) compared with NC (10.04 Hz). According to the resonance method, the natural frequency is directly proportional to the dynamic modulus, (E_D Inman. 1999; Rao 1995).

4.1 Seismic Shaking Table Test

After the free vibration test, the same column specimen was subjected to the seismic shaking table test. Figure 5 shows the crack on the column specimen surface after excitation with North-South Ranau earthquake 1.0g ground motion. Based on observation, crack lines appear in the connection between the foundation and column and on the column surface on both the Normal NC and TCRSFC7, but the cracks on TCRSFC7 are relatively smaller than on the NC.

(a) (b)

Figure 5: Damage of column specimen after seismic shaking table test. (a) NC (b) TCRSFC7

The acceleration response was recorded by the accelerometer and the result was plotted as a Time-History graph. Based on the analysis, the seismic response of the TCRSFC7 column demonstrated a smaller acceleration response, which is 1.21g as compared to that of the NC column (1.91g). The smaller acceleration response on TCRSFC7 is due to inclusion of 10% crumb rubber and 1% of steel fibre, because crumb rubber itself has high resistance in impact loading, while the steel fibre improved the concrete's stiffness (Xue and Shinozuka. 2013; Minnetyan and Batson. 1984), which is demonstrated by an improvement in the dynamic modulus and damping ratio.

5. Conclusions

This research focused on investigation of the mechanical properties of concrete with replacement of crumb rubber with fine aggregate ranging from 0%-25% and addition of steel fiber (0%-1.0%) and dynamic performance of concrete with inclusion of 10% crumb rubber as sand replacement and 1% of steel fiber as addition in concrete volume with modification of water cement ratio. The conclusion are presumed:

(a) Replacement of crumb rubber causing reduction in compressive strength up to 74.93% however modification of water cement ratio from 0.55 to 0.50 for TCRSFC7 (10% crumb rubber and 1% steel fiber) showing an improvement in compressive strength up to 2.06%.

(b) Dynamic modulus for TCRSFC7 has increased by 5.18% with respect to NC. This increment consistent with increment of natural frequency from free vibration test.

(c) Based on free vibration analysis, damping ratio and natural frequency of TCRSFC7 column is 9.6% and 11.14 Hz NC column is

4.6% and 10.04 Hz. Inclusion of crumb rubber and steel fiber has improve 109% of damping ratio and 10.96% of natural frequency.

(d) The peak response acceleration of TCRSFC7 column (1.21g) is reduce by 37% which is less than NC column (1.91g). This is showing that the presence of crumb rubber and steel fiber in concrete mixture helps in reducing seismic force due to an increment in damping ratio.

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