IJST, Transactions of Civil Engineering, Vol. 38, No. C1$^{+}$, pp 251-259
Printed in The Islamic Republic of Iran, 2014


# EXPERIMENTAL BEHAVIOUR OF WASTE TYRE RUBBER AGGREGATE CONCRETE UNDER IMPACT LOADING*

T. SENTHIL VADIVEL[1],** R. THENMOZHI[2] AND M. DODDURANI[3]

[1]Dept. of Civil Eng., Dr. N.G.P. Institute of Technology, Coimbatore – 641 048, Tamilnadu, India
Email: tsnsenthu@rediffmail.com
[2]Dept. of Civil Eng., Government College of Technology, Coimbatore – 641 013, Tamilnadu, India
[3]PWD/WRO, Cauvery Basin, Salem – 636 007, Tamilnadu, India

**Abstract–** In reinforced concrete design an important consideration that can be added to the requirements of strength and serviceability is ductility. This consideration is of importance to determine the amount of redistribution of moment that is possible in limited state design. Also, it is of importance in seismic design because to survive a severe earthquake, a structure should be capable of absorbing and dissipating energy by post-elastic deformations. To have an idea about the energy dissipation and ductility, it is essential to conduct impact test. An attempt is made in this paper to cast and test the cylindrical specimens made of Plain Cement Concrete (PCC) and Waste Tyre Rubber Aggregate Concrete (WTRAC) for impact loads with a steel ball drop weight. The test results show that the WTRAC with 6% replacement of both fine and coarse aggregate with rubber aggregates considerably improves the impact resistance and ductility characteristics. Regression model has been developed to estimate the impact strength for WTRAC specimen.

**Keywords–** Plain cement concrete, waste tyre rubber aggregate concrete, impact resistance, energy absorption

## 1. INTRODUCTION

Concrete is the most used material in construction liable for the depletion of natural resources and increases the scarcity of the ingredients such as cement, steel and aggregates, consequently there is a demand for these materials in the commercial sector. Further mining of river sand causes severe environmental damage by lowering ground water table and disintegration of rock strata causes landslide and earthquake. Engineers are anxious to overcome this problem with other alternatives; many researches have attempted to identify the subsidiary use of the traditional materials. The authors already suggested the use of waste truck tyre rubber which is abundantly available as aggregate in concrete named Waste Tyre Rubber Aggregate Concrete (WTRAC) in their earlier studies. A detailed experimentation on mechanical properties has been made by the authors with 2% to 10% replacement of rubber crumbs and chips instead of fine and coarse aggregate. The results found that the 6% replacement of waste tyre rubber aggregates prove exceptionally well in compression, tension and flexural strength and follow the curvature of the conventional specimen in all the tests in M20 and M25 grades of concrete [1-3]. However, the mechanical properties of materials are different under impact loading compared with static loading. Due to the complexity of the dynamic response of concrete structures, the traditional computational methods and design tools may not be of much help to understand the behaviour of materials and structural elements under impact loading [4-6]. Several studies have been carried out to understand the behaviour of concrete and concrete composites under impact loading.

*Received by the editors January 21, 2013; Accepted October 10, 2013.
**Corresponding author

Bischoff et al. [7] experimented with the impact properties of concrete incorporating expanded polystyrene beads and reported that this concrete did exhibit similar properties to an ideal energy absorbing material. Concrete containing varying amounts of polystyrene beads were tested using a drop weight device to impact small concrete slabs of varying thicknesses. This investigation showed that the concrete containing the highest percentage of expanded polystyrene beads significantly prolonged the impact period and reduced contact force. Compressive strength of concrete tested ranged from 4 to 16 MPa. The static tests showed that once peak load had been reached, large deformation followed while the load remained constant. Once concrete became compacted under the static load, the load increased until failure, similar to strain hardening effect. Polystyrene aggregate concrete did not fail by cracking which occurs in standard normal weight concrete, but rather localized crushing under the head of impact tup.

Sabaa and Sri Ravindrarajah [8] reported impact resistance of polystyrene concrete, having densities ranging from 1600 to 2100 kg/m$^3$, with and without polypropylene fibers. They concluded that the impact resistance of concrete is improved by the incorporation of expanded polystyrene aggregate. The energy absorption capacity of concrete is increased via the increasing level of polystyrene aggregate content and the amount of energy required to cause damage and energy dissipation increased with an increased polystyrene aggregate content. The addition of polypropylene fibers of 0.9% by weight of cement increased the impact strength of polystyrene aggregate concrete to produce first crack by 13 to 40% and to cause ultimate failure by 36% to 119%. Lakshmanan et al. [9] studied the behaviour of fiber reinforced beams under repeated impact loading and reported that the stiffness of the beam reduces with increase in number of blows, and also pulse shape and energy distribution have been critically modeled.

Zhang et al. [10] presented the flexural toughness and impact resistance of steel fiber-reinforced light-weight concrete, and the results indicate that the high compressive strength and density are desirable for good impact resistance of plain concrete, and also reported that the incorporation of steel fibers improved the impact resistance substantially.

Tantala et al. [11] investigated the toughness (toughness is also known as energy absorption capacity and is generally defined as the area under load deflection curve of a flexural specimen) of a control concrete mixture and WTRAC mixtures with 5% and 10% buff rubber by volume of coarse aggregate. They reported that toughness of both WTRAC mixtures was higher than the control concrete mixture. However, the toughness of WTRAC mixture with 10% buff rubber (2 to 6 mm) was lower than that of WTRAC with 5% buff rubber because of the decrease in compressive strength.

Raghavan et al. [12] reported that mortar specimens with rubber shreds were able to withstand additional load after peak load. The specimens were not separated into two pieces under the failure flexural load because of bridging of cracks by rubber shreds, but specimens made with granular rubber particles broke into two pieces at the failure load. This indicates that post-crack strength seemed to be enhanced when rubber shreds are used instead of granular rubber.

Goulias and Ali [13] found that the dynamic modulus of elasticity and rigidity decreased with an increase in the rubber content, indicating a less stiff and less brittle material. They further reported that dampening capacity of concrete (a measure of the ability of the material to decrease the amplitude of free vibrations in its body) seemed to decrease with an increase in rubber content. However, Topcu and Avcular [14] recommended the use of rubberized concrete in circumstances where vibration damping is required. Similar observations were also made by Fattuhi and Clark [15], and Topcu and Avcular [16] reported that the impact resistance of concrete increased when rubber aggregates were incorporated into the concrete mixtures. The increase in resistance was derived from the enhanced ability of the material to absorb energy. Eldin and Senouci [17], and Topcu [18] also reported similar results.

The review of literature reveals that there has been little work carried out on WTRAC under impact loading. Hence in the present investigation an attempt is made to find out the behaviour of WTRAC cylindrical specimen under drop-weight impact testing method.

## 2. MATERIAL INVESTIGATION

An elaborative material study was carried out and is discussed below.

***a) Cement***

Cement is a basic requisite for any construction work and also provides a binding medium for the discrete ingredients. In the present study Ordinary Portland Cement of grade 53, confirming to IS: 12269–1987 was used for preparing the concrete. The specific gravity of cement was 3.14.

***b) Fine aggregate***

Natural River sand passing through 4.75mm IS sieve is used for making concrete. As per IS: 383–1970 natural river sand was categorized under grading zone II. The specific gravity and fineness modulus of sand is found to be 2.63 and 4.91.

***c) Coarse aggregate***

Coarse aggregate was passed through 20 mm sieve and retained on 12 mm sieve confirming IS: 383–1970 was used for concreting. The specific gravity and fineness modulus of coarse aggregate is found to be 2.61 and 7.42.

***d) Water***

Clean portable water free from suspended particles, chemical substances, biological elements etc., is used both for mixing of concrete and curing.

***e) Rubber aggregate***

Finely grounded tyre rubber from which the fabric and steel belts have been removed has a granular texture and ranges in size from very fine powder to sand-sized particles were used as fine rubber aggregate. The truck tyre rubber which was chiseled into regular coarse aggregate size was used as coarse rubber aggregate. Both of the above two categories are shown in Fig. 1. The grading of rubber aggregates for IS: 383 – 1970 were compared with conventional fine and coarse aggregates. The rubber aggregates behaved quite similar to the normal aggregates which are shown in Fig. 2. The specific gravity of rubber crumbs and chips was 1.14 and 1.16. Fineness modulus of rubber crumbs and chips was 5.35 and 7.68.


Fig. 1. Waste tyre rubber aggregates

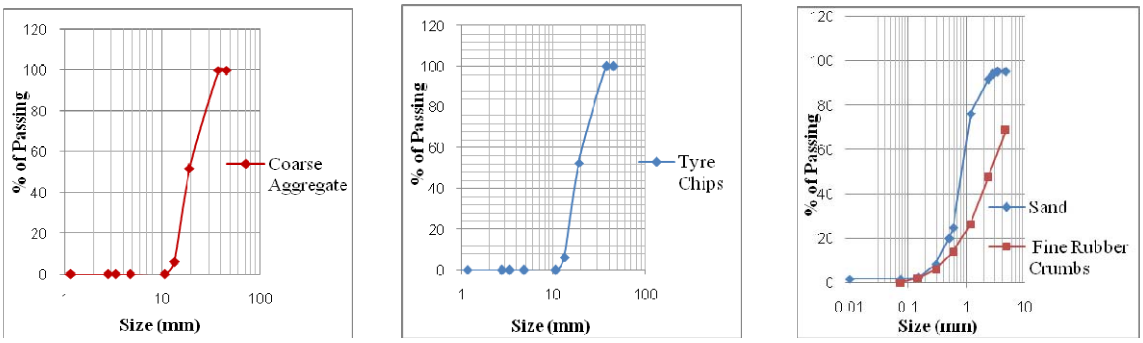


Fig. 2. Grading of aggregates

## 3. TEST SPECIMENS

A series of tests were conducted to study the impact strength and ductility index of WTRAC. A total of twelve specimens categorized into four groups were tested in this programme. Each group was composed of three identical specimens. R0 specimens with conventional concrete are referred to as control specimens, the other three groups were made of concrete with partial replacement of rubber aggregates named WTRAC. R1 specimens were cast with 6% rubber crumbs as FA replacement, whereas R2 specimens were designed with 6% rubber chips as replacement for CA. In R3 series, both FA and CA were partially replaced with fine rubber crumbs and rubber chips.

All the specimens in this series were 150 mm diameter and 64 mm height. Mix was prepared to get M20 grade concrete as per IS: 10262 – 2009. The concrete mixes CA, FA and cement were fed in this order and mixed for 2 minutes. 75% of the water was initially added after the dry mixing. The remaining water was then added and mixed properly. For each mix, slump of the concrete was measured and the value is given in Table 1. Hollow tubular mould of 150 mm ϕ with a height of 64 mm was made from commercially available PVC pipes. The moulds were placed over a hardened platform and it was filled in the mould with proper compaction. After 24 hours, the cylindrical specimens were demoulded and they were kept in a curing tank for 28 days. After 28 days curing, the specimens were air dried and they were white washed before testing. The geometrical details of the cast specimens are given in Table 2. Along with the cylindrical specimens, 12 control cubes (150 mm x 150 mm x 150 mm) and 12 cylinders (150 mm x 300 mm) were also cast and tested for its mechanical properties and are presented in Table 3.

Table 1. Mix proportions with ingredients

| Group Name | Specimen ID | Cement (kg/m$^3$) | Fine aggregate (kg/m$^3$) | | Coarse aggregate (kg/m$^3$) | | W/C ratio | Slump (mm) |
|---|---|---|---|---|---|---|---|---|
| | | | Sand | FR | Jelly | CR | | |
| Control | R0 | 50.00 | 71.40 | 0.00 | 151.24 | - | 0.50 | 4.50 |
| WTRAC | R1 | 50.00 | 67.12 | 4.28 | 151.24 | - | 0.50 | 4.20 |
| | R2 | 50.00 | 71.40 | - | 142.17 | 9.07 | 0.50 | 9.00 |
| | R3 | 50.00 | 69.26 | 2.14 | 146.70 | 4.54 | 0.50 | 9.74 |

Table 2. Specimen details

| Specimen ID | Types of specimens | Size (mm) | No. of specimens |
|---|---|---|---|
| R0 | Conventional concrete | 150 mm φ x 64 Ht. | 3 Nos. |
| R1 | Fine aggregate replacement with 6% rubber crumbs | 150 mm φ x 64 Ht. | 3 Nos. |
| R2 | Coarse aggregate replacement with 6% chiseled truck tyre chips | 150 mm φ x 64 Ht. | 3 Nos. |
| R3 | 3% Rubber crumbs & 3% chiseled truck tyre chips replacements with FA & CA | 150 mm φ x 64 Ht. | 3 Nos. |

Table 3. Impact test results for M20 grade WTRAC specimens

| Specimen ID | Mech. properties ($N/mm^2$) | | No. of blows for first crack | No. of blows for ultimate failure | Energy consumed @ first crack (Joul) | | Energy consumed @ ultimate failure (Joul) | | Ductility index | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $f_{ck}$ | $f_t$ | | | $E_1$ | $E_{1Avg}$ | $E_2$ | $E_{2Avg}$ | $(E_2/E_1)$ | $(E_2/E_1)_{Avg}$ |
| R01 | 26.67 | 2.12 | 39 | 43 | 1633.66 | 1577.81 | 1801.21 | 1731.40 | 1.10 | 1.10 |
| R02 | 29.11 | 2.12 | 38 | 41 | 1591.77 | | 1717.44 | | 1.08 | |
| R03 | 24.66 | 1.91 | 36 | 40 | 1507.99 | | 1675.55 | | 1.11 | |
| R11 | 25.92 | 2.2 | 31 | 33 | 1298.55 | 1298.55 | 1382.33 | 1410.25 | 1.06 | 1.09 |
| R12 | 24.98 | 2.15 | 30 | 33 | 1256.66 | | 1382.33 | | 1.10 | |
| R13 | 26.45 | 2.02 | 32 | 35 | 1340.44 | | 1466.11 | | 1.09 | |
| R21 | 29.86 | 2.45 | 22 | 26 | 921.55 | 907.59 | 1089.11 | 1061.18 | 1.18 | 1.17 |
| R22 | 29.64 | 2.38 | 21 | 24 | 879.66 | | 1005.33 | | 1.14 | |
| R23 | 29.84 | 2.4 | 22 | 26 | 921.55 | | 1089.11 | | 1.18 | |
| R31 | 23.29 | 1.78 | 45 | 49 | 1884.99 | 1815.18 | 2052.55 | 2052.55 | 1.09 | 1.13 |
| R32 | 21.96 | 1.69 | 44 | 52 | 1843.10 | | 2178.21 | | 1.18 | |
| R33 | 23.00 | 1.84 | 41 | 46 | 1717.44 | | 1926.88 | | 1.12 | |

## 4. TEST SETUP

The test frame equipment was fabricated in the laboratory as per ACI 544.2R89 committee's recommendations which consist of a standard manually operated 3.5 kg compaction hammer with a 48 inch drop (1.22 m); a 64mm diameter hardened steel ball and a flat base plate with positioning bracket shown in Fig. 3. Thickness of the specimen was ensured to the nearest millimeter at its center and at the ends of a diameter prior to the test. The specimen was placed on the base plate with the finished face up and positioned within four legs of the impact testing equipment. The bracket with the cylindrical sleeve was fixed in place and the hardened steel ball was placed on the top of the specimen within the bracket. The drop hammer was then placed with its base upon the steel ball and held vertically. The hammer was dropped repeatedly, and the number of blows required to form the first visible crack at the top surface of the specimen and at ultimate failure were recorded.

Fig. 3. Drop weight impact test setup

The first crack was identified by visual observation. The surface of the test specimen is painted with white colour for clear visibility of the cracks. Ultimate failure is defined in terms of the number of blows required to open the cracks in the specimen sufficiently to enable fractured pieces to touch three of the four positioning legs on the base plate. The stages of ultimate failure were clearly recognized by the fractured specimen butting against the legs of the base plate. The failure modes of each category of specimens were shown in Fig. 4.

Fig. 4(a). Failure pattern of R0 specimen

Fig. 4(b). Failure pattern of R1 specimen

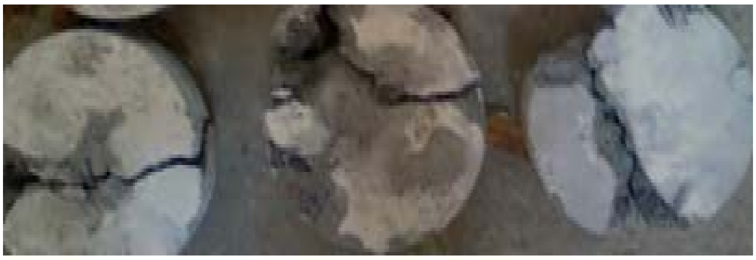

Fig. 4(c). Failure pattern of R2 specimen

Fig. 4(d). Failure pattern of R3 specimen

## 5. EXPERIMENTAL RESULTS

Impact strength test was carried out with normal room temperature on cylindrical specimen of dimensions 150mm x 64mm using a 3.5 kg steel ball fell down from a specific height (1.22m), the readings recorded from the beginning of cracks of concrete samples and also when full damage appears. The energy consumed by the specimen until failure was considered as a measure of its impact resistance.

The energy consumption was evaluated from the following equation:

$$\text{Energy} = \text{Weight (N)} \times \text{Height (m)}$$

Where, the height is equal to the summation of heights to failure and

$$\text{Weight} = \text{Mass (kg)} \times g\ (\text{m/sec}^2)$$

Where 'g' is gravity acceleration.

Table 3 gives the data for the obtained test results. They are analyzed and compared successively by taking into consideration, first, the no. of blows for first crack of each specimen, then by comparing the no. of blows for ultimate failure. The last section concerns the study of failure modes of each category of specimens.

It is found from the test results that the test samples of R1 specimen with FA replacements consumed around 80% energy of conventional concrete itself. The samples containing 6% FA substitution with crumb rubber failed through gradual compression that appeared like a true crushing, resulting in a post failure material that was sponge-like and elastic in nature.

The R2 specimens cast with 6% CA replacements consumed less energy than all the others. They hypothesized that there are two major causes for this energy reduction. First, because rubber is much softer than the surrounding cement paste, loading cracks are initiated around the rubber particles due to this elastic mismatch, which propagate to bring about failure of the rubber-cement matrix. The second possible reason for the reduction in energy is that it depends greatly on the density, size and hardness of the coarse aggregate. As the aggregates are partially replaced with relatively weaker rubber, a reduction in energy is reached.

The R3 specimens which were cast with 3% FA and 3% CA replacements absorbed more energy. Because of the rubber aggregates ability to withstand large deformations, the rubber particles acted as springs, delaying the widening of cracks and preventing early full disintegration of the concrete mass. The continuous application of the impact load will cause generation of more cracks as well as widening of existing ones. During this process, the failing specimen is capable of absorbing significant plastic energy and withstanding large deformations without full disintegration. This process will continue till the stresses overcome the bond between the cement paste and the rubber aggregates.

The test results showed that the impact resistance of the concrete increased when rubber aggregates were partially replaced for CA to the mixture. It can be argued here that this increased resistance was derived from an increased ability of the material to absorb energy and insulate sound during impact.

## 6. DISCUSSION OF TEST RESULTS

### *a) Impact strength*

It is evident from Fig. 5 that the R3 type of WTRAC improved the impact resistance of concrete and the improvement was about 20% that of conventional concrete. R1 concrete specimen performed 83% in impact strength compared to that of conventional specimen and R2 specimen performed only 61% of conventional concrete.

### *b) Ductility index*

Ductility may be quantitatively represented by an index called ductility index, which may be defined as the ratio of energy absorbed at failure to the energy absorbed at first crack. Fig. 6 shows the ductility indices for WTRAC for M20 grade. It was found that the ductility index values were higher for the R2 type of concrete and the value was found to be 6.5% higher than conventional concrete. R3 increases with 2.7% and R2 performs nearly equal to the conventional concrete in ductile behaviour.

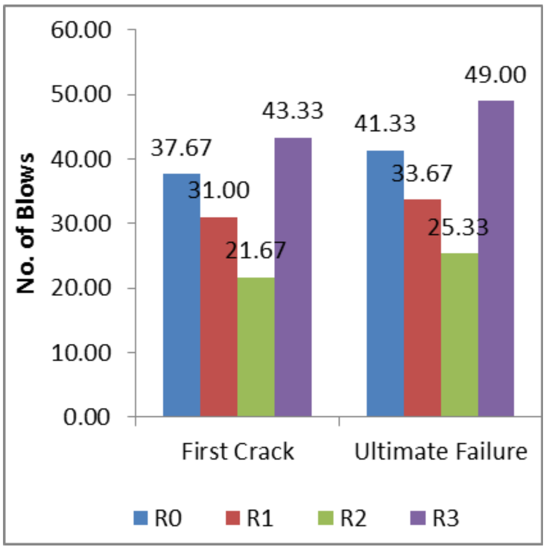


Fig. 5. Average no. of blows Vs WTRAC

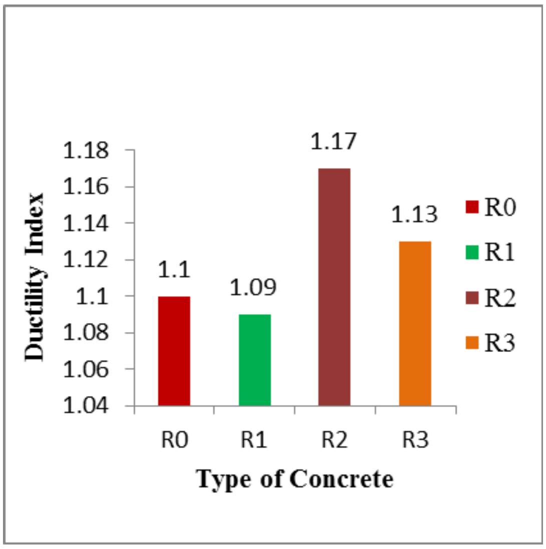


Fig. 6. Ductility index Vs WTRAC

### *c) Energy absorption*

TRAC of both fine and coarse rubber aggregate (R3) absorbed 18.55% more energy compared to conventional concrete. WTRAC of fine rubber aggregate (R1) absorbs nearly 80% of energy from the conventional concrete and WTRAC of coarse rubber aggregate (R2) absorbs only 37% of energy compared with conventional specimen.

## 7. CONCLUSION

Although a WTRAC mixture generally has a reduced $f_{ck}$ that may limit its use in certain structural applications, it possesses a number of desirable properties, such as lower density, higher toughness, higher impact resistance, enhanced ductility and more efficient sound and heat insulation compared to conventional concrete. Such engineering properties are advantageous for various construction applications. Structural applications involving WTRAC are possible if appropriate percentage of rubber aggregates are used. WTRAC absorb significant plastic energy and undergo relatively large deformations without full disintegrations. This property can be utilized in various structural and geotechnical projects in which the deformation at peak load is a primary design concern.

***Acknowledgement:*** We express our gratitude to Dr. R. Sundararajan, Principal Government College of Technology, Coimbatore for graciously granting the permission to pursue the research work in the Structural Engineering laboratory of GCT, Coimbatore. We would like to thank members of our family and friends. A special mention to Mr. Raqib Hussain, Mrs. R. Chitra, Mrs. Sunila George and Mrs. Haseena Begam for their support extended towards the research progress.

## REFERENCES

1. Senthil Vadivel, T. & Thenmozhi, R. (2012). Experimental study on waste tyre rubber replaced concrete - an ecofriendly construction material, *Journal of Applied Sciences Research,* Vol. 8, No. 6, pp. 2966-2973.
2. Senthil Vadivel, T. & Thenmozhi, R. (2011). Experimental behaviour of concrete with waste tyre rubber as coarse aggregate. *International Journal of Nature Environment and Pollution Technology*, Vol. 10, No. 2, pp. 173-178.

3. Senthil Vadivel, T. & Thenmozhi, R. (2011). Characteristic study on rubbercrete - an innovative construction material produced through waste tyre rubber. *i-manager's Journal of Civil Engineering*, Vol. 1, No. 1, pp. 34-39.
4. Sudarsana Rao, H., Vaishali, G., Ghorpade, N. V. & Ramana, K. (2010). Gnaneswar. Response of SIFCON two-way slabs under impact loading. *International Journal of Impact Engineering*, Vol. 37, pp. 452–458.
5. Khaloo, A. R. & Tariverdilu, Asl. (2001). Ductility evaluation of confined high-strength concrete flexural members. *Iranian Journal of Science and Technology, Transaction B, Engineering*, Vol. 25, No. 1, pp. 129-131.
6. Izadifard, R. A., Maheri, M. R. (2011). Ductility effects on the behaviour of steel structures under blast loading. *Iranian Journal of Science and Technology, Transaction B, Engineering*, Vol. 34, No. 1, pp. 49-62.
7. Bischoff, P. H, Yamura, K. & Perry, S. H. (1989). Polystyrene aggregate concrete subjected to hard impact. *Proc. of the Institution of Civil Engineers, London*, Vol. 89, No. 2, pp. 225-239.
8. Sabaa, B. A. & Sri Ravindrarajah, R. (2000). Impact resistance of polystyrene aggregate concrete with and without polypropylene fibres. *Proc.of the Second International Symposium on Structural Lightweight Aggregate Concrete, Norway*, pp. 719-728.
9. Lakshmanan, N., Srinivasulu, P., Muthumani, K., Sivaramasarma, B. & Gopalakrishnan, N. (1991). Behaviour of fibre reinforced concrete under repeated impact loading. *J Struct Eng*, Vol. 18, No. 1, pp. 21–30.
10. Zhang, M. H., Li, L. & Paramasivam, P. (2005). Flexural toughness and impact resistance of steel fibre-reinforced light weight concrete. *Mag Concr Res*, Vol. 56, No. 5, pp. 251–62.
11. Tantala, M. W., Lepore, J. A. & Zandi, I. (1996). Quasi-elastic behaviour of rubber included concrete. *Proceedings, 12th International Conference on Solid Waste Technology and Management.*
12. Raghavan, D., Huynh, H. & Ferraris, C. F. (1998). Workability, mechanical properties and chemical stability of a recycled tyre rubber-filled cementitious composite. *Journal of Materials Science*, Vol. 33, No. 7, pp. 1745-1752.
13. Goulias, D. G. & Ali, A. H. (1997). Non-destructive evaluation of rubber modified concrete. *Proceedings of Special Conference ASCE*, New York, pp. 111-120.
14. Topcu, I. B. & Avcular, N. (1997). Analysis of rubberized concrete as a composite material. *Cement and Concrete Research*, Vol. 27, No. 8, pp. 1135-1139.
15. Fattuhi, N. I. & Clark, N. A. (1996). Cement-based materials containing tire rubber. *Journal of Construction and Building Materials*, Vol. 10, No. 4, pp. 229–236.
16. Topcu, I. B. & Avcular, N. (1997). Collision behaviors of rubberized concrete. *Cement and Concrete Research*, Vol. 27, No. 12, pp. 1893–1898.
17. Eldin, N. N. & Senouci, A. B. (1993). Rubber-tyre particles as concrete aggregate. *Journal of Materials in Civil Engineering*, Vol. 5, No. 2, pp. 478-496.
18. Topcu, I. B. (1995). The properties of rubberised concrete. *Cement and Concrete Research*, Vol. 25, pp. 304-310.