

Investigations of the Effect of High Percentage of Waste Fine Crumb Rubber on Rubberized Concrete Beam Subject to Impact Load

Ali I. Tayeh*

University of Palestine, Engineering Faculty, PO box 1219, Gaza City, Palestine.

- E-mail of the corresponding author: dr.m.abudaya@hotmail.com

Abstract

In this study, rubberized concrete samples were prepared by substitution (10%, 20% and 30% replacements by volume) of sand by waste fine crumb rubber, and tested under impact three-point bending load, as well as static load. Three types of specimens (size 1000 mm × 100 mm × 500mm) namely, plain concrete and rubberized concrete were loaded to failure in a drop-weight impact machine by subjecting to 30 N weight from a height of 400mm, and another three similar specimens were used for the static load test. In both the tests, the load-displacement of each specimen was investigated. The dynamic beam behaviour was analyzed numerically using the finite-element method (FEM) based LUSAS V.14 software.

In general, the results reveal that the impact bending load in the hybrid beam increases with increase in the percentage of sand replacement by fine crumb rubber, while the static peak bending load always decreases.

Keywords: Impact behavior; Finite element analysis (FEA); Mechanical testing.

1. Introduction

Concrete is the most commonly used as construction material, but some of its properties, such as high flexibility, toughness, energy observation and impact resistance some time need to be improved [I.B. Topcu, (1995)]. On another side, the waste rubber is considered as one of the major environmental problems faced by every country due to their health hazards and difficulty for land filling. Due to the high cost of disposal and the requirement of large landfill area for waste rubber, the issue of random and illegal dumping is alarming [R. Siddique, T.R.Naik. (2004)]. As a promising solution to the aforementioned problems, the idea of adding waste crumb rubber to concrete as sand replacement has recently gained attraction, as it improves the flexibility and ductility of concrete [I.B. Topcu, (1997), M.M. Al-Tayeb, (2012)]. Substantial works were reported on the use of polymers such as tire rubber as a replacement for cement, sand or aggregates in concrete mixtures [I.B. Topcu, (1997), M.M. Al-Tayeb, (2012), A.R. Khaloo, (2008), M.M. Al-Tayeb, V. Corinaldesi, A. Mazzoli, (2011), A. Tortum, (2005), E. Ganjian, (2005), A. Turatsinze, (2005), I.B. Topcu, (2009), I.B. Topcu, (2009), Z.K. Khatib (1999)], these studies revealed that the addition of rubber to concrete enhanced the elastic behavior, while reducing the compressive strength.

A.R. Khaloo, M. Dehestani (2008) studied the toughness of concrete specimens containing tire chips, crumb rubber, and a combination of tire chips and crumb rubber, which replaced 12.5%, 25%, 37.5%, and 50% of the total volume of mineral aggregates. Toughness was enhanced by the additions of all the aforementioned types of rubber, and the maximum toughness index was found with 25% replacement beyond which the toughness decreased. M.M. Al-Tayeb observed that the replacement of cement and sand with rubber powder or crumb rubber in concrete enhanced impact resistance. In this study the effect of high percentage of sand replacement by 10%, 20% and 30% of waste fine rubber on the load-displacement behavior and fracture energy of plain concrete and rubberized concrete subjected to impact load were investigated experimentally. As far as the authors are aware, the analysis of rubberized concrete (with 10%, 20% and 30% of waste fine crumb rubber 0.4–0.8 mm particle size) has not been reported so far. In this case the percentages of rubber are different than paper made by Tayeh 2013. For each case, three beams of size 100 mm × 100 mm × 500mm were loaded to failure in a drop-weight impact machine which facilitated dropping 30N weight from 400mm height, and similar specimens were tested under static load. The top and bending load histories, and load-displacement behavior were analyzed for the normal and hybrid concrete beams. The results were compared with those under static load and those obtained by numerical simulations using Lusas program.

2. Materials and methods

2.1. Materials

Concrete with 50MPa compressive strength was prepared as the control mix. The maximum coarse aggregate

size was 10 mm, and natural sand was used as fine aggregate. The specific gravities of coarse aggregates and sand were 2.65 and 2.66 respectively. Concrete mix was prepared with replacements of sand volume by 10%, 20% and 30% (designated as Fr 10%, Fr 20%, and Fr 30% respectively) with waste fine crumb rubber of particle size 0.2–0.8 mm. Figure 1 shows the images of fine crumb rubber sample (relative density, 0.53) used in the present study.

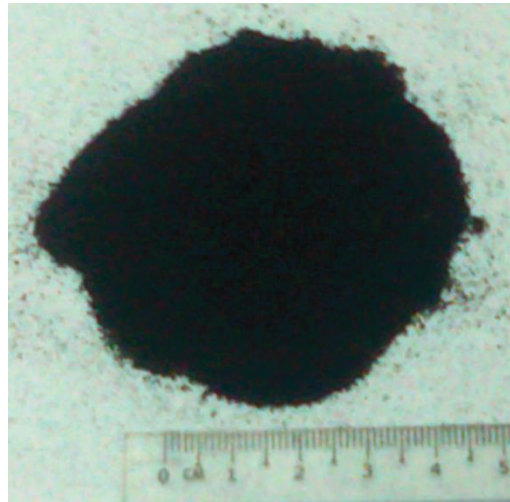


Figure 1: Image of the rubber powder sample.

For the compression and modulus of elasticity tests, three cylinders of height 300mm and diameter 150 mm were used for each type, according to ASTM C 39 [American Society for Testing and Materials (2001)] and ASTM C 469 [American Society for Testing and Materials (1994)], and three cylinders of height 160mm and diameter 100 mm were used for split-tensile, according to ASTM C 496 (1996). The specimens for three-point static and impact flexural loading tests were 100 mm wide, 100 mm deep and 500 mm long, with a loaded span of 400 mm. All specimens were cured in water for 28 days in accordance with ASTM C 192 (2006).

2.2. Experimental set-up and procedure

The three-point static flexural strength tests were performed according to ASTM C78 (1994). Impact tests were conducted on an instrumented falling-weight impact machine as in Figure 2; the machine facilitated dropping 4 kg hammer from 400mm drop heights. The impact load history during the test was measured using piezo-electric load cell of 50 kN capacity. The specimens were supported by two steel cylinders of 10 mm diameter. The specimen acceleration during impact was recorded by accelerometer with a range of $\pm 2500g$ (g is gravitational acceleration) and Sensitivity 2.5 mV/g. Data from the load cell and the accelerometer were recorded at 0.2ms intervals using a PC-based data acquisition system.



Figure 2: The experimental impact flexural test rig.

The top load, P_t at the mid-span of the beam recorded by the load cell is the sum of inertial load (P_i) and bending load (P_b) acting at the center

[N. Banthia, (1987), (1987) (1989) (1999)] So:

$$P_b = P_t - P_i \quad (1)$$

where P_i for linear distribution of accelerations along the beam is uniform, and expressed by:

$$P_i = \rho A a \left[\frac{L}{3} + \frac{8}{3} \times \frac{ov^3}{L^2} \right] \quad (2)$$

where ρ : mass density of concrete; A : area of cross-section of the beam; a : acceleration at the center; L : span of the test beam; and ov : length of the overhang.

The displacement histories at the load-point can be obtained by double integrating the acceleration history $a(t)$:

$$d(t) = \int_0^t \int_0^t a(t) dt \quad (3)$$

The fracture energy was calculated as the area under impact bending load versus displacement curve [N. Banthia, Impact resistance of concrete. (1987). (1987) (1989) (1999)].

2.3 Finite element model

In order to simulate the behavior of rubberized concrete beams subjected to the impact load, LUSAS V.14 was used. The concrete beam was assumed to be built up with hexahedron elements [Oñate E., (2009)].

The top load curve obtained from experiment was used to define the load at the location P_t ($x=250\text{mm}$, $y=100\text{mm}$, $z=50\text{mm}$), and each beam was supported widthwise with cylindrical supports at locations $x=50\text{mm}$ (support 1) and $x=350\text{mm}$ (support 2). Elasto-plastic material was used to model both plain and rubberized concrete structures. To choose the appropriate number of elements and mesh size, a number of trials were made.

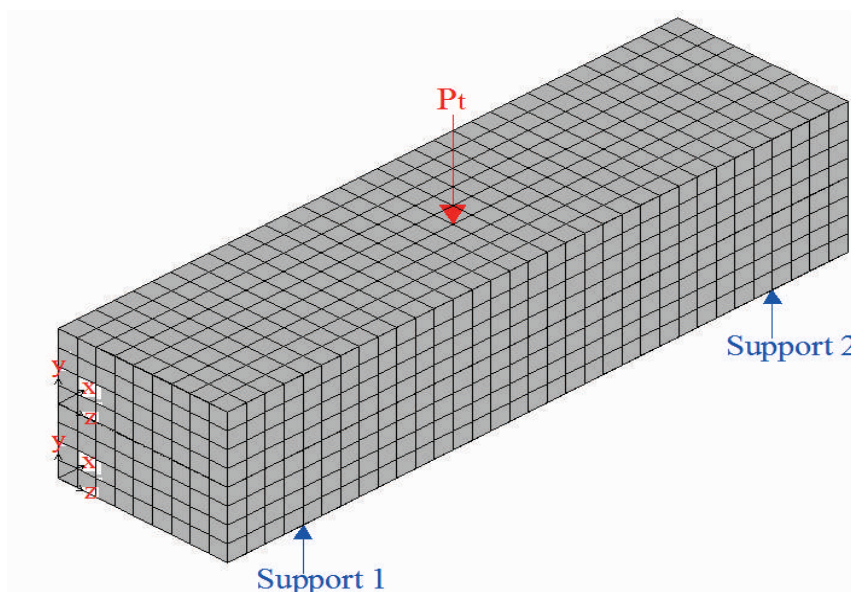


Fig.3: Finite element model for the beam.

Explicit (central difference) nonlinear dynamic scheme was used to determine the acceleration and thus the velocity and displacement increments for each time step

[Chopra, A. K(2007)].

The damping ratio for first circular and second circular frequencies is assumed as 5% [LUSAS 14. (2006)].

3.0 Results and discussion

3.1 Experimental results

The results of compressive stress and modulus of elasticity are given in Table 1. It is observed that, the average compressive stress of the plain concrete in 28 days is 46MPa. As the cement volume is decreased with proportional addition of rubber powder, the compressive stress reduces significantly by 35, 43 and 57% with 2.5%, 5% and 7.5% of volumes respectively. The elastic modulus was also found to decrease by 17, 24 and 38% respectively compared with the plain concrete. Similar observations were also reported by Khaloo et al. [A.R. Khaloo(2008)].

Table 1: Compressive strength and modulus of elasticity

Concrete type	Average compressive stress (MPa)	Average elastic modulus (kN/mm ²)
Plain	46	29
Fr10%	30	24
Fr 20%	26	22
Fr 30%	20	18

The normal and rubberized concrete beams fail in bending mode and there was no delamination of the material during the hybrid beam test. Figure 4 depicts the histories of top load, inertial load and bending load for plain concrete and the three types of rubberized concrete beam. The results show that both the inertial load and bending load increase significantly with high percentage increasing of sand replacement by fine crumb rubber. The inertial load increases because addition of rubber increases the flexibility of the composite mix. The increase in top and bending loads is due to the fact that as the rubberized concrete has enhanced ability to absorb impact energy[M.M. Al-Tayeb].

Thus the rubberized concrete with high percentage of rubber content exploits the important positive features of normal concrete beams, thereby maximizing its performance under impact load.

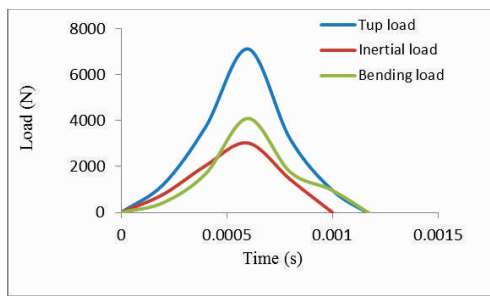


Figure 4a: Plain concrete.

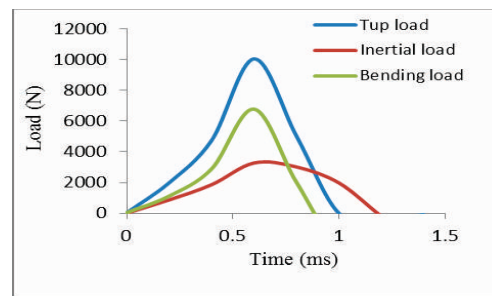


Figure 4b: Fr 10%.

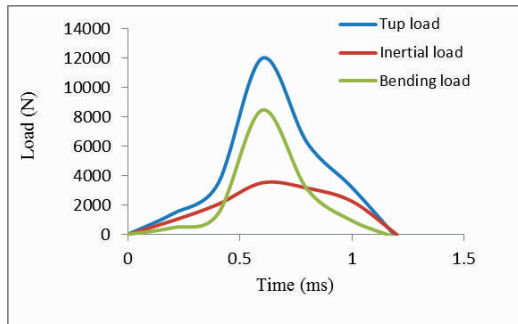


Figure 4c: Fr 20%.

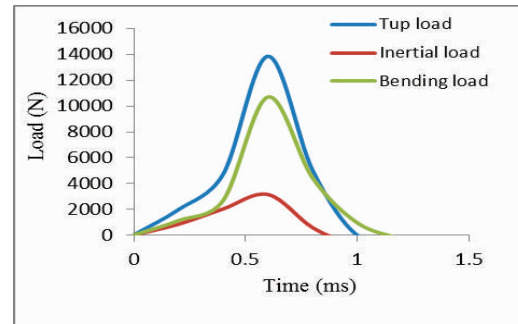


Figure 4d: Fr 30%.

Fig.4: Variations in Tup, inertial, and binding loads with time.

Figure 5 shows the calculated impact bending load against deflection for the plain and the hybrid rubberized-normal concrete structure. In this article, the fracture energy is defined as the area under impact bending load vs. displacement curve [N. Bantia, Impact resistance of concrete. (1987). (1987) (1989) (1999)] .

Table 2 summarizes the fracture energies for the plain and hybrid concrete beams. The dynamic fracture energy is higher than static fracture energy as also observed in the previous studies [N. Bantia, Impact resistance of concrete, (1987), (1987), (1989), (1999), D.M. Jerome, (1997)]. The fracture energy of the plain concrete under impact load is 1.35 Nm. As the sand is replaced by 30% volume of fine crumb rubber, the fracture energy is increased by 190%.

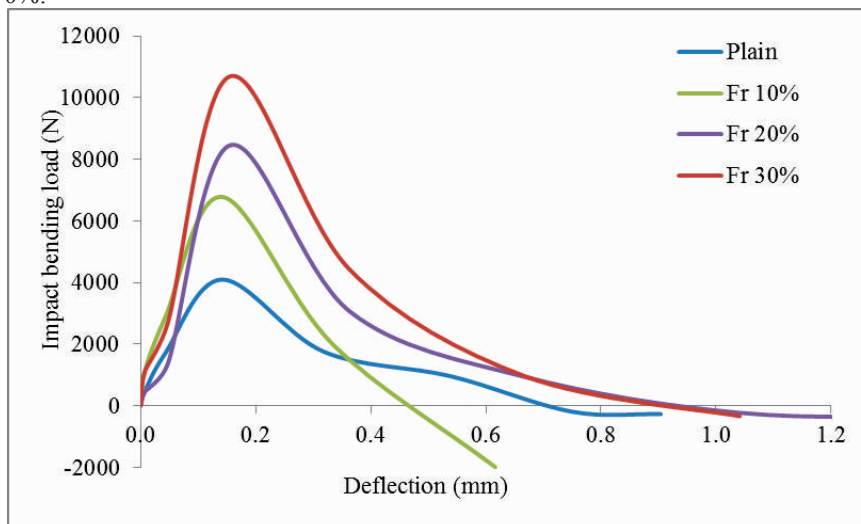


Figure5: Impact bending load against deflection

3.2 Comparison of dynamic and static test results

Table 2 shows the comparison between the plain concrete and three type of rubberized concrete under static bending and impact bending tests. Generally the static peak bending load is less than the impact peak bending load and it decrease with increase the percentage of rubber replacement; this is consistent with the published works [N. Bantia, Impact resistance of concrete (1987), (1987), (1989), (1999), D.M. Jerome, (1997)]. It is also observed that, the impact peak bending increase significantly with increase the percentage of rubber replacement and the ratio between dynamic and static peak bending loads increases in the rubberized concrete beam. This is

because the addition of rubber to concrete decreases its strength under static load but the ability of rubber to absorb dynamic energy enhances the strength of concrete under impact load.

Table 2: Comparison of experimental static and impact bending

Concrete mixes	Static test		Impact test	
	Peak bending load (N)	Fracture energy (Nm)	Peak bending load (N)	Fracture energy (Nm)
Plain	3944	0.53	3931	1.35
Fr10%	3021	0.61	6782	2.10
Fr 20%	2730	0.64	8463	2.95
Fr 30%	2296	0.68	1070	3.24

3.3 Validation of FE simulation

The predicted impact load vs. displacement behaviors for plain concrete and hybrid structure beams were compared with the respective experimental results, as illustrated in figure 8 which demonstrate the strength of the proposed model in handling the problem.

The failure in all the beams predicted by the FE model is of bending mode which is consistent with the experimental results. The predicted impact load vs. displacement behaviors for plain concrete and rubberized concretes were compared with the respective experimental results, as illustrated in Figure 6 which demonstrate the strength of the proposed model in handling the problem. Figure 6a shows that at the end of impact response of the plain concrete, the predicted and experimental displacements are 0.9mm and 0.7mm respectively. The predicted and experimental displacements still closed with sand replacement by high percentage of fine crumb rubber as shown in Fig 6b to Fig 6c. Thus it can be deduced that the proposed FEM model is excellent in handling the problem under investigation.

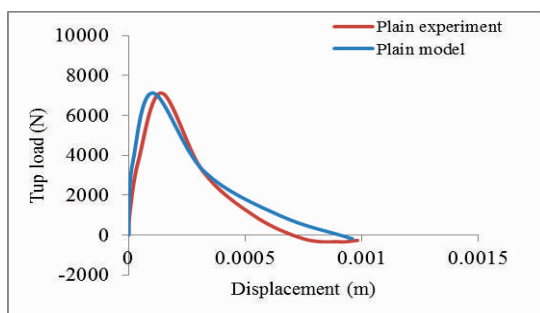


Figure 6a: Plain concrete.

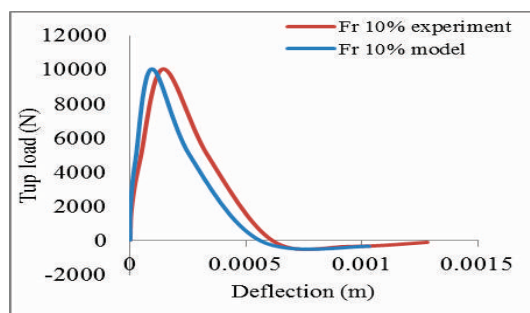


Figure 6b: Fr 10%.

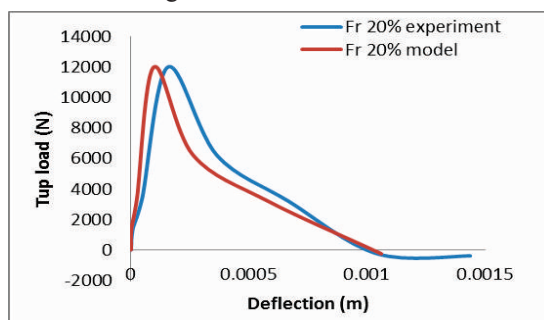


Figure 6c: Fr 20%.

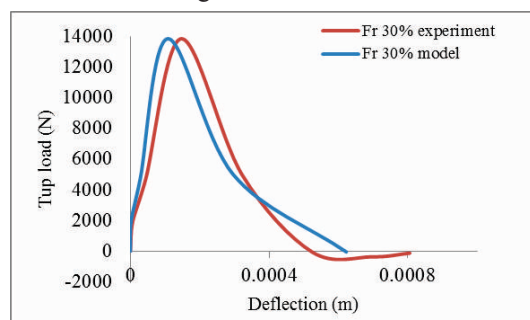


Figure 6d: Fr 30%.

Figure 6: Variations in Tup, inertial, and binding loads with time.

4. Conclusion and Recommendations:

The effect of addition of high percentage of waste fine crumb rubber on the impact load performance of concrete was investigated. Concrete specimens were prepared by adding 10%, 20% and 30 % of rubber powder as sand replacement; all the specimens were tested under impact and static loads. It has been experimentally demonstrated that the impact tup, inertial load and bending load of hybrid structure increased with the increase in the percentage of sand replacement by fine crumb rubber; however the static peak bending load always

decreased. Accelerometer could be used successfully to measure both the displacement and inertial loading effects in the instrumented impact tests. The impact bending energies were larger than the static energies, in all the cases. On the other hand the fracture energy increased with the increase in percentage of sand replacement. The experimental observations of impact load-displacement behavior were well matched with the numerical predictions obtained by the proposed FEM model.

References

- A.R. Khaloo, M. Dehestani, P. Rahmatabadi, Mechanical properties of concrete containing a high volume of tire-rubber particles, *Waste. Manage.* 28(12)(2008)2472–2482.
- American Society for Testing and Materials (ASTM) C39/C39 M-01, Test Method for Compressive Strength of Cylindrical Concrete Specimens, Annual Book of ASTM Standards, Pennsylvania (2001).
- American Society for Testing and Materials (ASTM) C469-94, Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression, Annual Book of ASTM Standards, Pennsylvania (1994).
- American Society for Testing and Materials (ASTM) C496, Standard test method for splitting tensile strength of cylindrical concrete specimens. Annual book of ASTM Standards, Pennsylvania (1996).
- American Society for Testing and Materials (ASTM) C192/192M-06, Standard practice for making and curing concrete test specimens in the laboratory, vol. 4.02, West Conshohocken, PA, USA(2006).
- American Society for Testing and Materials (ASTM) C78–94. Standard test method for flexural strength of concrete (using simple beam with third-point loading). West Conshohocken, PA: ASTM International (1994).
- A. Tortum, C. Celik, A.C. Aydin, Determination of the optimum conditions for tire rubber in asphalt concrete, *Build. Environ.* 40(11) (2005) 1492–504.
- A. Turatsinze, S. Bonnet, J.L. Granju, Mechanical characterisation of cement based mortar incorporating rubber aggregates from recycled worn tyres, *Build. Environ.* 40(2)(2005)221–226.
- Chopra, A. K. *Dynamics of Structures: Theory and Application to Earthquake Engineering: third edition* Prentice-Hall (2007).
- D.M. Jerome, C.A. Ross, Simulation of the dynamic response of concrete beams externally reinforced with carbon-fiber reinforced plastic, *Comput. Struct.* 64(5-6) (1997) 1129–1153.
- E. Ganjian, M. Khorami, A.A. Maghsoudi, Scrap tyre rubber replacement for aggregate and filler in concrete, *Constr. Build. Mater.* 23(5)(2005)1828–1836.
- I.B. Topcu, The properties of rubberized concretes, *Cement and Concrete Research* 25(2) (1995) 304–310.
- I.B. Topcu, Assessment of the brittleness index of rubberized concretes, *Cem. Concr. Res.* 7(2)(1997)177–183.
- I.B. Topcu, T. Bilir, Analysis of rubberized concrete as a three phase composite material, *J. Compos. Mater.* 43(11)(2009) 1251–1263.
- I.B. Topcu, T. Bili, Experimental investigation of some fresh and hardened properties of rubberized self compacting concrete, *Mater. Des.* 30(8) (2009) 3056–3065.
- LUSAS 14. Theory manual volume 1. FEA Ltd., V.14.0.3. Surrey, UK; (2006).
- M.M. Al-Tayeb, B.H. Abu Bakar, H.M.Akil, H.Ismail, Effect of partial replacements of sand and cement by waste rubber on the fracture characteristics of concrete, *Polym-Plast. Technol. Eng.* 51(6) (2012) 583-589.
- M.M. Al-Tayeb, B.H. Abu Bakar, H. Ismail, H.M. Akil, Impact Resistance of Concrete with Partial Replacements of Sand and Cement by Waste Rubber. *Polym-Plast Technol Eng.* 51(12), 1230-1236.
- N. Banthia, Impact resistance of concrete, PhD thesis, University of British Columbia, Vancouver, B.C. Canada (1987).

N. Banthia, S. Mindess A. Bentur, Impact Behavior of Concrete Beams, *Mater. Struct. (Paris)* 20(119) (1987) 293–302.

N. Banthia, S. Mindess, A. Bentur M. Pigeon, Impact testing of concrete using a drop weight impact machine, *Exp. Mech.* 29(2) (1989) 63–69.

N. Banthia, P. Gupta and C. Yan, Impact resistance of fiber reinforced wet-mix shotcrete. Part 1: beam tests, *Mater. Struct.*32 (1999) 563-570.

Oñate E., *Structural Analysis with the Finite Element Method. Linear Statics, Volume 1: Basis and Solids (Lecture Notes on Numerical Methods in Engineering and Sciences)*, Springer (2009).

R. Siddique, T.R.Naik, Properties of concrete containing scrap-tire rubber -An overview, *Waste. Manage.* 24(6) (2004) 563–569.

Tayeh A.I., Effect of Replacement of Sand by Waste Fine Crumb Rubber on Concrete Beam Subject to Impact Load, (2013), *Journal of Civil and Environment Research*, ISSN (Paper)2224-3216 ISSN. 2225-0948.

V. Corinaldesi, A. Mazzoli, G. Moriconi, Mechanical behaviour and thermal conductivity of mortars containing waste rubber particles, *Mater. Des.* 32(3) (2011) 1646-1650.

Z.K. Khatib, F.M. Bayomy, Rubberized Portland cement concrete, *J. Mater. Civ. Eng.* 11(3)(1999)206–213.