Modulus of Elasticity and Impact Resistance of Chopped Worn- Out Tires Concrete

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الخـــــلاصــــــة :

يتضمن هذا البحث دراسة بعض خواص خرسانة مفـــروم الإطـــــارات المطاطية المـــستهلكة، والـــتي تتميز بإضافة مفروم الإطارات المطاطية المستهلكة إلى الخلطات كجزء مستبدل مـــن حجـــم الركـــام (الرمل والحصى بنسب متساوية)، تم اختيار ثلاث خلطات إضافة إلى الخلطة المصدرية، بنسب استبدال ٣٠% ، ٤٠%، و٥٠%.وقد تم إجراء الفحوصات التالية:فحص مقاومة الانضغاط، معامـــل المرونـــة الـــستاتيكي والديناميكي و مقاومة الصدم واطئ وعالي السرعة.وقد وجد إن إضافة مفروم الإطارات يؤثر بشكل عام على خواص الخرسانة، حيث كانت نسبة النقصان في مقاومة الانضغاط مثلا نسبة إلى الخرســانة المرجعيـــة هـــي ٤.٤%، ١٥.٢% ،و ١٨.٨% للخرسانة المستبدلة بـــ ٣٠%، ٤٠% ،و ٥٠% مـــن مفـــروم الإطـــارات المستهلكة كنسبة حجميه من الركام (الرمل والحصى) على التوالي ولكنة أعطى موشرات جيدة للاســتفادة من خرسانة مفروم الإطارات كمادة إنشائية جديدة تستخدم في مختلف التطبيقات.

Abstract:

This work investigates some properties of chopped worn-out tires concrete (Ch.W.T.conc.). It is a type of concrete characterized by the incorporating of Ch.W.T into the mixes as a partial replacement of volume of aggregate (sand and gravel of equal proportion). Three mixes of Ch.W.T conc. In addition to the reference mixes were selected, using Partial Replacement Ratio (PRR)of 30%, 40%, and 50%.The tests which were used in this study were: compressive strength, modulus of elasticity (static and dynamic), and impact resistance (low and high velocity). It was found that incorporating Ch.W.T in concrete effect on the properties of concrete, for example the percentage decreases in compressive strength were 41%, 46.7%, and 52.4% for concrete with 30, 40, and 50% Ch.W.T. PRR by volume of aggregate (50%

sand, 50% gravel) respectively. However, it gave good indicator to be utilized as a new construction material in many applications.

1. Introduction:

As a result of the wide progress that was achieved in the transport and the wide use of vehicles, this gave birth to various problems one of them is the environmental pollution. The combustion of large quantities of worn-out tires got accumulated, thus facing very serious problems of safe disposal, either by the wide land, which was needed to store or by the incineration of the large quantities [1]. Many researchers have endeavored to make use of enormous quantity of waste rubber tires and decrease environmental pollution resulting from them. The idea of using a material of chopped worn-out tires in construction material industry emerged as it enjoys several favorable characteristics such as high resistance to weather conditions, temperature and humidity, low water absorption and light weight in comparison with other materials that are usually used. It is also characterize by high-insulation capacity.

The use of chopped worn-out tires has several economic benefits such as:

1. Reducing environmental pollution and preventing the accumulation of worn-out tires without having to burn them.
2. Manufacturing a high insulating lightweight concrete [this cannot be locally manufactured for lack of natural and manufactured lightweight aggregate].
3. Lightweight masonry of this type of concrete has a positive economic effect on total cost of the construction, it reduces the dead weight loading, giving smaller supporting sections and foundations as well as saving in transport and construction costs [2].

Chopped worn-out tires concrete (Ch.W.T.Conc.) consist of cement, aggregate, chopped worn-out tires and water at various proportions, since the chopped worn-out tires are of low density, the product has the property of being lightweight. The cost is relatively low especially when the constituents of such concrete are available near site.

The chopped worn-out tires are a waste material and are available wherever worn-out tires are available. In addition, the chopping of worn-out tires is very simple; it depends on friction of sharp cutters moving cyclic at a high speed. If the disposal cost is taken into account, the use of this material becomes very attractive.

The size of Chopped worn-out tires particles varies, usually most of the particles pass through the (6.35 mm) sieve. The chopped worn-out tires have absolute density around (0.92-0.95) gr./cm^3 and bulk density about (0.45) gr./cm^3 [2].

4. Experimental Work:

4.1 Materials:

4.1.1 Cement:

Ordinary Portland cement produced by Kubaysia cement plant was used throughout this work. It was stored in large air tight plastic containers to avoid exposure to atmospheric conditions and at maintain uniform quality. The physical test results of the used cement are given in Tables (1). It conforms to the Iraqi specification No.45/1984 [3].

4.1.2 Fine Aggregate:

Sand of 4.75-mm maximum size was used for concrete mixes of this investigation. The sieve analysis of the used sand is given in Table (2). It conforms to the limits of Iraqi specification No.45/1984[4]. The specific gravity, absorption, sulfate content and material finer than sieve No.200 (75µm) of the used fine aggregate were (2.65, 0.75%, 0.15% and 0.8 %) respectively.

4.1.3 Course Aggregate:

The washed coarse aggregate used was crushed aggregate of 10mm maximum size. The sieve analysis of this aggregate is given in Table (3). It conforms to the Iraqi specification No, 45/1984[4]. The specific gravity, absorption, sulfate content and material finer than No, 200(75µm) sieve of the used coarse aggregate were (2.68, 1.07%, 0.07%, and 0.2%) respectively.

4.1.4. Steel Reinforcement:

Deformed steel bars of 10mm diameter with yield strength of (350 MPa) were used throughout the present research.

4.1.4 Mixing Water:

Potable water was used for mixing and curing purposes.

4.1.5 Chopped Worn-Out tires:

A copped worn-out tire produced by Babel factory in Al-Najaf was used throughout the study, the maximum size of copped worn-out tires particles was 6.35 mm. The sieve analysis, the chemical composition and some properties of the copped worn-out tires are shown in Tables (4), (5) and (6) respectively.

4.1.6. Superplasticizer:

High Range Water Reducing Agent (HRWRA), which is known commercially as Melment L10, was used throughout this work as a (HRWRA).While maintaining equal workability to the reference mixture. The technical description of this type is given in Table (7).

Table (1): Physical properties of cement

Physical properties	Test result	Limits of Iraqi spec. No.5/1984
Specific surface area Blaine Method,m^2/kg	379	$\geq$ 230m^2/kg
Setting time, Vicat's method: Initial setting hrs:min. Final setting hrs:min.	 3:17 4:45	 $\geq$ 1 hour $\leq$ 10 hours
Soundness	0.2%	$\leq$ 0.8%
Compressive strength of mortar, N/mm^2: 3 – day 7 – day	 15.8 27.5	 $\geq$ 15 N/mm^2 $\geq$ 23 N/mm^2

Table (2): Grading of fine aggregate

Sieve size (mm)	Accumulated percentage passing %	Limit of Iraqi specification No.45/1984,Zone(3)
4.75	100	90-100
2.36	95	85-100
1.18	90	75-100
0.60	75	60-79
0.30	38	12-40
0.015	7.5	0-10

Table (3): Grading of coarse aggregate

Sieve size (mm)	Accumulated percentage passing %	Limit of Iraqi specification No.45/1984
12.5	100	100
9.5	99	85-100
4.75	15	10-30
2.36	3	0-10
1.18	0	0-5

Table (4): Grading of Ch.W.T granular.

Sieve size (mm)	% by weight passing
6.35	100
4.75	91
2.36	30
1.18	7
0.60	2
0.30	o.5
0.015	0
0.0075	0

Table (5): Chemical composition of Ch.W.T granular*.

Rubber Hydrocarbon (SBR)	48 %
Carbon black	31 %
Acetone extract	15 %
Ash	2 %
Residue chemical balance	4 %

*Based on the results of Babylon tires factory laboratory

Table (6): Some properties of Ch.W.T. **

Specific gravity	0.92 – 0.95
Apparent density (gm/cm^3)	0.45
Tensile strength (MPa)	4.2 – 21
Speed of combustion	Very slow
Impact effect	Nil
Sunlight effect	Nil
Water absorption	Negligible
Weak acids and bases effect	Nile

**B- Raymond Seymon "Polymeric composites", Alden Press, Oxford 1990

Table (7): Technical data of Superplasticizer (Melment L10)

Property	Result
Density	1.1 gm/cm^3
Solid content	20 %
Appearance	clear to slightly milky
Sugar content	none
PH value	7 – 9
Storage life	at least two year
Chloride content	less than 0.005 %

Frost resistance	it should be thawed before use

4. Type of Specimens:

4.1. Control Specimens:

Steel molds were used throughout this work. The control specimens used in all tests were as follow:

1. For compressive strength, cubes of (100×100×100) mm are used.
2. For Static modulus of elasticity, cylinder of (150 × 300) mm are used.
3. For dynamic modulus of elasticity, beam of (100×100×400) mm are used.

4.2. Slab Specimens:

For impact strength test (low velocity), square slabs of (٥٠٠ ×500×50) mm with minimum reinforcement were used

6. Experimental Program:

The experimental program is planned to investigate the effect of using Ch.W.T. as a partial replacement of sand and gravel with admixtures (HRWRA) on the static and dynamic modulus of elasticity and impact resistance (low and high velocity) of Ch.W.T. concrete. Table (8) shows the details of reference and Ch.W.T. concrete mixes used throughout this work.

Table (8) Details of the experimental program

Mix. Des.	Cemente Content. Kg/m^3	w/c ratio	HRWRA % By weight of cement	Mix. Properties by weight	Ch.W.T Proportion % by volume		Slump mm (±5)	Compressive strength (MPa)at 28 day
					Sand	Gravel		
C_o	450	0.34	5	1:1.38:1.87	0	0	100	61
$C_{15,15}$	450	0.47	5	1:1.38:1.87	15	15	100	36
$C_{20,20}$	450	0.51	5	1:1.38:1.87	20	20	100	32.5
$C_{25,25}$	450	o.56	5	1:1.38:1.87	25	25	100	29

7. Mixing Procedure:

The mixing of concrete is important to obtain the required workability and homogeneity. A mechanical mixer of (0.1) m^3 capacity was used. The interior surface of the mixer was cleaned and moistened before placing the materials.

The raw materials such that gravel, sand, cement, and Ch.W.T were first mixed dry for about one minute concrete then water, or water content of admixture (HRWRA) was added to the mixer. After that mixing continued for about three minuets until the concrete becomes homogenous in consistency. The slump measured immediately after mixing, according to ASTM C- 143-89 [5]

8. Casting Compaction and Curing:

The molds were lightly coated with mineral oil before use, according to ASTM C192-88 [6], concrete casting was carried out in different layer each layer of 50 mm. Each layer was compacted by using a vibrating table for (15-30) second until no air bubbles emerged from the surface of the concrete, and the concrete is level off smoothly to the top of the molds. Then the specimens were kept covered with polyethylene sheet in the laboratory for about (24±2) hrs. After that the specimens remolded carefully, marked and immersed in water until the age of test. The specimens were tested at age of 7 and 28days for control specimens and (56 and 90) days for impact test.

9. Testing of Hardened Concrete:

9.1 Compressive Strength Test:

The compressive strength was determined according to B.S.1881.part 4, 1970 [7]. The average of compressive strength of three cubes was recorded for each testing age (7 and 28days).

9.2. Static and Dynamic Modulus of Elasticity (Ec and Ed):

The static modulus of elasticity was calculated by using the following formula and the average of three specimen results of age 90 days was adopted.

$$E_s= [(S_2-S_1)/ (e_2-0.000050)] \times 10^{-3} \qquad (1)$$

Where:

E_s = Static modulus of elasticity, GPa

S_2 = Stress corresponding to 40% of ultimate load, MPa.

S_1 = Stress corresponding to a longitudinal strain, e_1, of 50 Millionths, MPa.

e_2 = longitudinal Strain produced by stress S_2.

The strain was measured using compressmeter according to ASTM C469-87a [8].

The dynamic modulus of elasticity was determined on the laboratory specimens subjected to longitudinal vibration on their natural frequency; according to B.S.1881.1970 [9].

The dynamic modulus of elasticity was estimated by using the following equation:

$$Ed = 4\rho n^2 L^2 \times 10^{-12} \quad \text{------------------------ (2)}$$

:Where

E_d = dynamic modulus of elasticity, GPa.

n = Fundamental longitudinal frequency, Hz

ρ = Density, kg/m^3

L = length of specimens, mm

The average result of three specimens for each testing age 7,28, and 90days) was adopted

9.3 Impact Test:

Four (500×500×50) mm, slab specimens for each group were tested under low velocity impact load. The impact was calculated using (1020 gm) ball dropping freely from a height of 2.5 and 1.2 m. Two specimens were tested for each height at 90 days. The test rig used for low velocity impact test was illustrated in reference [10]

After curing time of 90days, the specimens were white painted and placed in its position in the testing frame with the finished face up. The falling mass dropped repeatedly and the number of blows required to case first crack (usually observed) is recorded. In addition, the crack pattern and crack propagation were observed and recorded. The number of blows required for failure (no rebound) was also recorded.

10. Results and discussion:

10.1. Compressive strength:

The compressive strength was determined at age of (7,28) days for moist cured concrete specimens. The test results of compressive strength are summarized in Table (10).

Fig. (1) and Table (10), shows that the compressive strength for concrete decreases with addition of Ch.W.T. in general. However, this reduction in compressive strength was depended on the partial replacement ratio (PRR) of aggregate (gravel and sand). The reduction in compressive strength was depended on the effect of Ch.W.T. on the microstructure of concrete matrices and the transition zone between the aggregate and the cement past [2]. Hence, in general the addition of Ch.W.T. reduces the compressive strength, this reduction can be explained by the following:

1. The Ch.W.T. partials are weak materials and compressible with flexibility, hence the compressive strength of concrete will be reduced because it is affected by the strength of its components.
2. The Ch.W.T. concrete required higher W/C ratio to achieve the suitable workability. This property results in the lower strength.
3. The number of voids increases in the mixes containing Ch.W.T., which would affect the compressive strength negatively.

From Table (10), it can be seen that the percentage decreases in compressive strength at 7 days were 45%, 52%, and 57% for concrete with 30, 40, and 50% Ch.W.T. PRR by volume of aggregate (50% sand, 50% gravel) respectively. At 28 day the percentage decreases in compressive strength were 41%, 46.7%, and 52.4% for concrete with 30, 40, and 5 0% Ch.W.T. PRR by volume of aggregate (50% sand, 50% gravel) respectively.

Table (9): Average compressive strength of Ch.W.T. concrete

Mix. Des.	Cemente Content. Kg/m^3	w/c ratio	HRWRA % By weight of cement	Mix. Properties by weight	Ch.W.T Proportion % by volume		Slump mm (±5)	Compressive strength (MPa)	
					Sand	Gravel		7 days	28 day
C_o	450	0.34	5	1:1.38:1.87	0	0	100	50	61
$C_{15,15}$	450	0.47	5	1:1.38:1.87	15	15	100	27.5	36
$C_{20,20}$	450	0.51	5	1:1.38:1.87	20	20	100	24	32.5
$C_{25,25}$	450	o.56	5	1:1.38:1.87	25	25	100	21.5	29

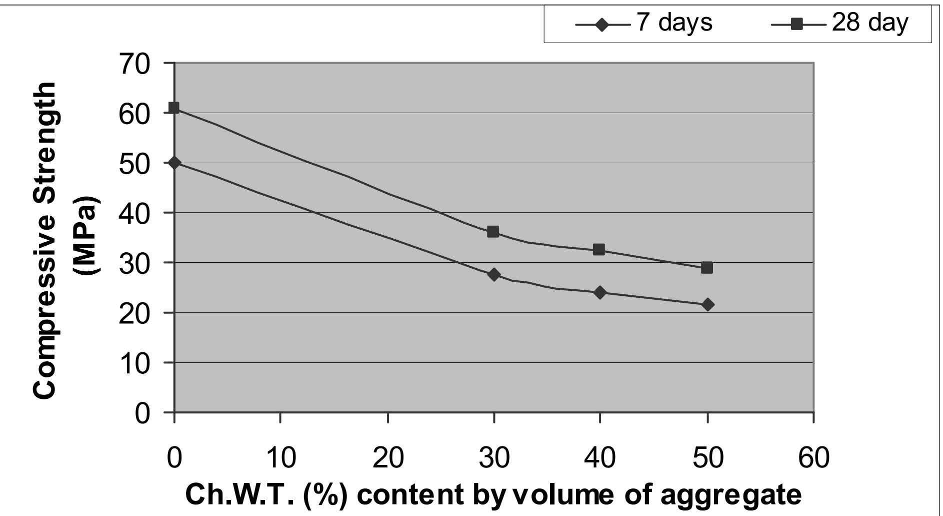

Fig. (1):Relationship betwen the compressive strength and Ch.W.T. PRR by volume of aggregate

10.2. Static and Dynamic Modulus of Elasticity (Ec and Ed):

The results of secant static modulus of elasticity Ec are shown in Table (11). The Ec values of Ch.W.T. concrete range between (32.8 to 26.7) GPa. Fig.(2) Illustrated that the Ec decreases with increases of Ch.W.T. content, the percentage decreases relative to reference concrete were 19%, 30.8%, and 34% for Ch.W.T. concrete with 30% ,40%, and 50% Ch.W.T by volume of aggregate respectively.

The test results of dynamic modulus of elasticity Ed are summarized in Table (11), from this Table it can be seen that the Ed decreases with increases of

Ch.W.T. content. At 7 days, the percentage decreases relative to reference concrete were 9.7%, 17.2%, and 25.1% for Ch.W.T. concrete with 30%, 40%, and 50% Ch.W.T by volume of aggregate respectively. For 28 day the percentage decreases relative to reference concrete were 4.4%, 15.2%, and 18.8% for Ch.W.T. concrete with 30%, 40%, and 50% Ch.W.T by volume of aggregate respectively.

The Ec and Ed results indicated that the weakness of Ch.W.T. has pronounced influence on lowering the value of Ec and Ed, but from Table (11), it can be noted that the percentage decreases for Ed less than the percentage decreases of Ec at same age, this may be attributed to the damping effect of Ch.W.T..

Generally, The content of Ch.W.T. in concrete is the principle factor that affects the value of Ec and Ed, which is shown in Fig.(2), this is attributed to the Ec of the Ch.W.T. itself which affect the Ec and Ed of the concrete. It is known that the factors which influence the strength of concrete generally influence the Ec in the similar tend, or a little to a lesser degree [2].

The relationship between Ec and compressive strength of the Ch.W.T. concrete is shown in Fig. (3).

The following empirical formula can be derived to predict the Ec for Ch.W.T. concrete.

$$Ec = 0.416 f_{cu} + 15.517 \qquad \text{correlation factor (R)} = 0.96 \quad \text{-------} (3)$$

Where:

Ec = Static modulus of elasticity, (GPa)

f_{cu} = 28-day compressive strength of 100 mm concrete cube, (MPa)

And for Ed empirical formula can be derive:-

$$Ed = 0.2525 f_{cu} + 31.518 \qquad (R) = 0.98 \quad \text{-------} (4)$$

Where:

Ed = Dynamic modulus of elasticity, (GPa)

f_{cu} = 28-day compressive strength of 100 mm concrete cube, (MPa).

Table (11): Average Ec and Ed of Ch.W.T. concrete

Mix Designation.	Modulus of elasticity (GPa)		
	Ec	Ed	
	28 day	7 days	28 day
C_o	40.5	43	46.6
$C_{15,15}$	32.8	38.8	42.2
$C_{20,20}$	28.0	35.6	39.5
$C_{25,25}$	26.7	32.2	37.8

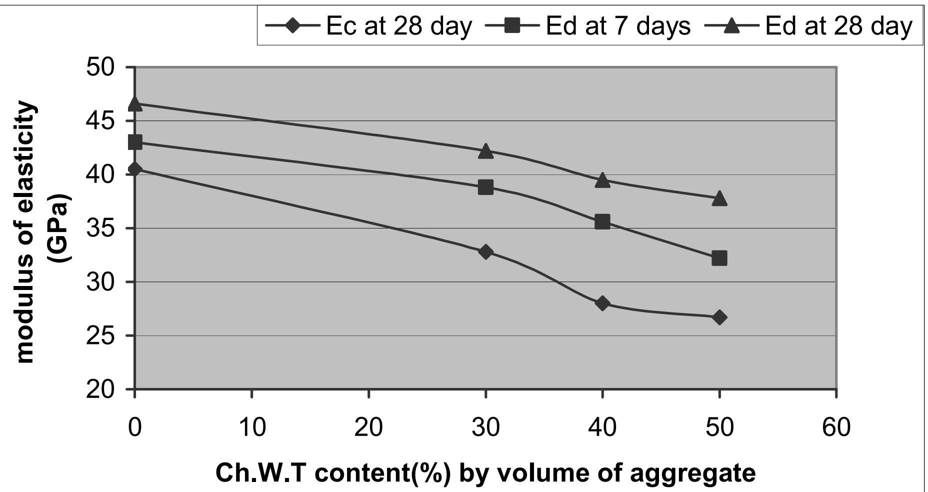

Fig.(2):Relationship between (Ec and Ed) with Ch.W.T content(%) by volume of aggregate

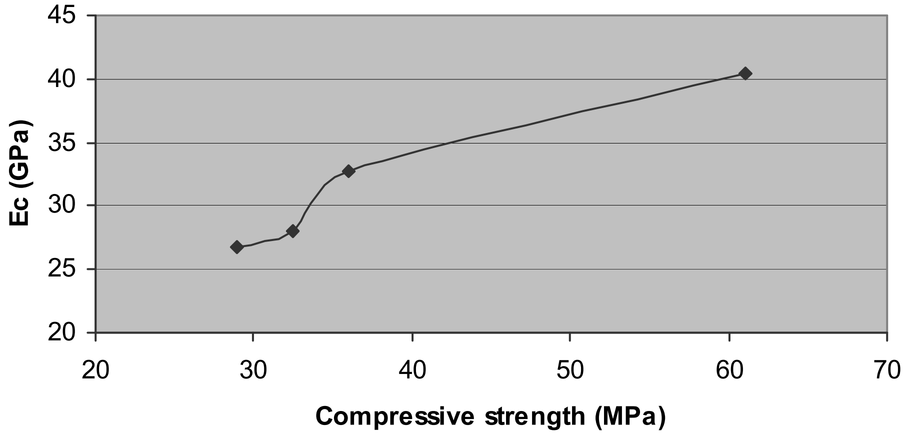

Fig.(3): Relationship between compressive strength and Ec

10.3 Impact Resistance:

10.3.1. Low Velocity Impact:

The impact resistance results in terms of number of blows are shown in Table (12). The relationship between Ch.W.T. content and number of blows to first crack and failure (no rebound) are shown in Figs. (4) and (5) respectively. The relationship between compressive strength and number of blows, which cause failure, is show in Fig. (6).

From test results, it can be seen that the presence of Ch.W.T. reduced that first crack impact resistance; this may be related to the fact that both aggregate-matrix bond and the relative stiffness of aggregate and matrix have a role to play in impact resistance. So replacing the aggregate with Ch.W.T. reduces the first crack impact resistance of mixes, Fig(4). The percentage degreases of number of blows from 1.2 m height, which is caused first crack relative to reference concrete at 90 day were 20%, 36%, and 52% for Ch.W.T. concrete with 30%, 40%, and 50% Ch.W.T by volume of aggregate respectively. From 2.5 m height the percentage degreases of number of blows, which is caused first crack relative to reference concrete at 90 day were 40%, 60%, and 87% for Ch.W.T. concrete with 30%, 40%, and 50% Ch.W.T by volume of aggregate respectively.

Fig.(5) illustrated that the impact resistance to failure was degreased with increase of Ch.W.T. content. The percentage degreases of number of blows from 1.2 m height, which caused failure relative to reference concrete at 90 day were 8%, 33.3%, and 44.4% for Ch.W.T. concrete with 30%, 40%, and 50% Ch.W.T by volume of aggregate respectively. From 2.5 m height the percentage degreases of number of blows, which is caused failure relative to reference concrete at 90 day were 28%, 56%, and 76% for Ch.W.T. concrete with 30%, 40%, and 50% Ch.W.T by volume of aggregate respectively.

From Table (12), it can be seen that the percentage degreases in the number of blows, which caused failure is lesser than the percentage degreases in the number of blows required to cause first crack, this behavior attributed to the damping effect of Ch.W.T., which increased the impact energy absorption. However, specimens who appear to possess relatively low impact resistance to first cracking are not necessarily weak, in impact, and to seem to have high impact resistance to failure that is in agreement with previous work [2, 11].

The effect of compressive strength on the impact resistance is plotted in Fig. (6), in general Green [12] found that the higher the static compressive strength of concrete the lower the energy absorbed per blow before cracking, but the impact strength of the concrete increases with its compressive strength (and there for age) at a progressively increasing rate.

Mode of Failure under Impact:

For all specimens the crack started at the center of bottom face of specimens and moved increasingly outward as the number of blows increased. And for specimens failing with more than one major crack (more than two pieces), the crack pattern was that only one major crack appeared at the beginning of the test and with increasing that number of blows up to half of the ultimate number, the second crack appeared. The cracks continued increasing in width and length until the specimen is fractured into separated pieces.

Table (12): Number of blows caused first crack and failure

Mix Designation.	F_{cu} at 28 day	E_c At 28 day	E_d At 28 day	No. of blows to cause (1.2 m)at 90 day		No. of blows to cause (2.5 m)at 90 day	
				First crack	Failure	First crack	Failure
C_o	61	40.5	46.6	25	63	15	25
$C_{15,15}$	36	32.8	42.2	20	58	9	18
$C_{20,20}$	32.5	28.0	39.5	16	42	6	11
$C_{25,25}$	29	26.7	37.8	12	35	2	6

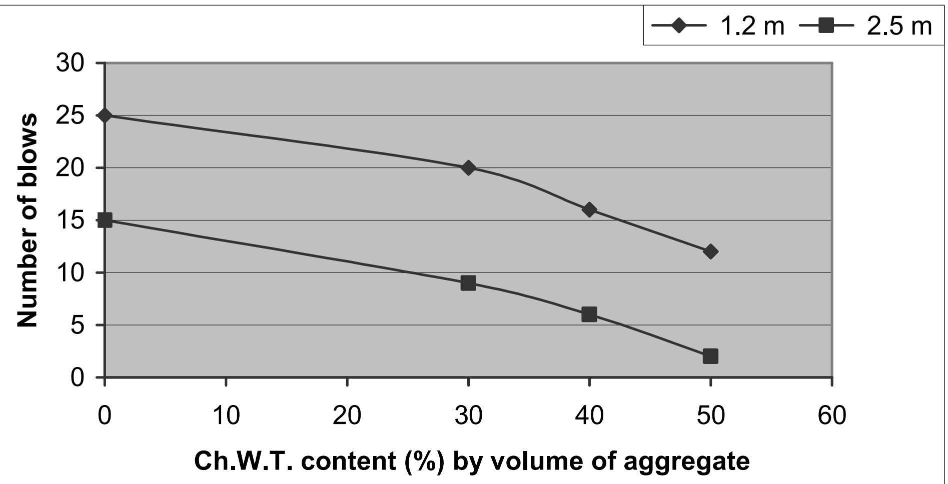

Fig. (4):Effect of Ch.W.T. content on the number of blows to firest crack

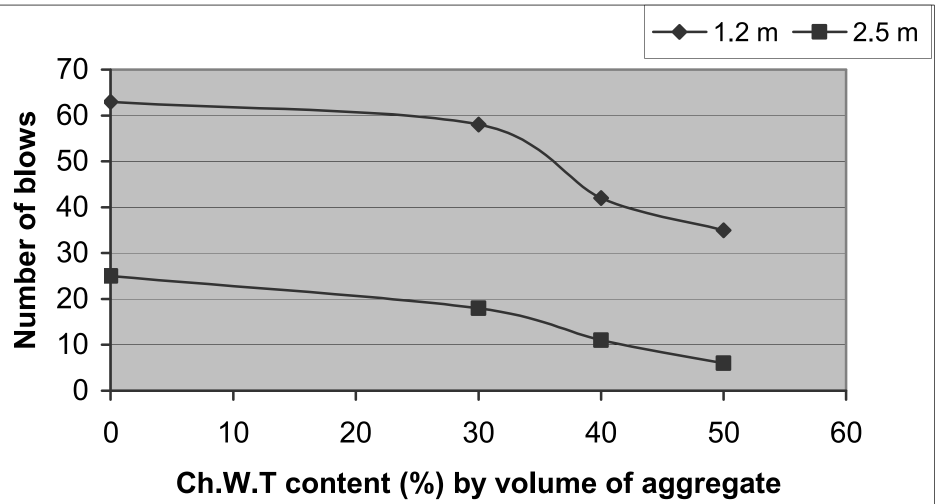

Fig (5): Effect of Ch.W.T. content on the number of blows to failure

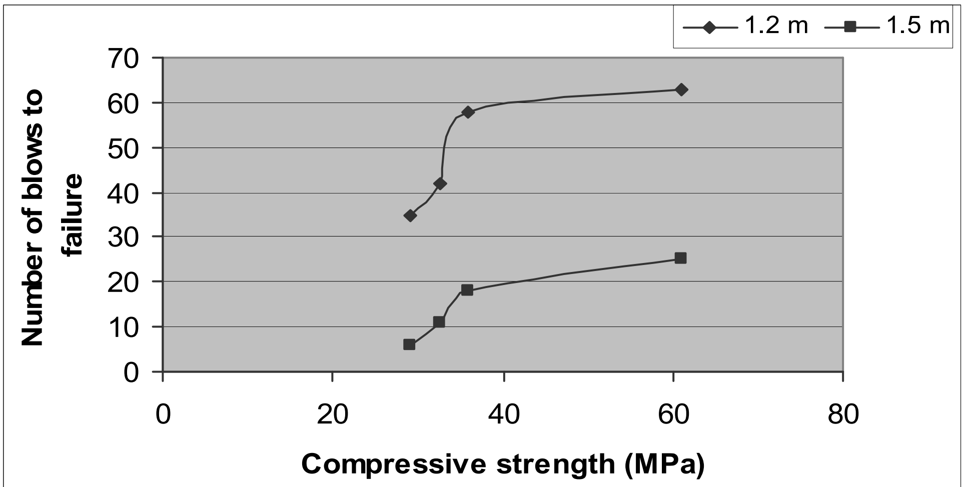

Fig (6): Relationship between compressive strength and nomber of blows to failure

11. Conclusions

Depending on the results of this investigation, the following conclusions can be drawn.

1. The compressive strength decreases significantly with the increases of Ch.W.T. content in the concrete.
2. The modulus of elasticity decreases remarkably with the increase of the Ch.W.T. content. The static modulus of elasticity of Ch.W.T. concrete is ranged between (40.5 to 26.7) GPa. The dynamic modulus of elasticity of Ch.W.T. concrete is ranged between (46.6 to 37.8) GPa, thus the dynamic modulus of elasticity was greter than the static modulus of elasticity and that depended the PRR of aggregate of Ch.W.T.
3. The addition of Ch.W.T. has decreased the impact resistance of the concrete mix significantly, hence, to height 1.2 m the percentage degreases of number of blows ,which caused first cracks was 52% for concrete have 50% Ch.W.T replacement and 44% to caused failure.
4. For the same impact energy (for same falling mass and same height of drop) increasing of Ch.W.T. content caused more destructive mode of failure, more number of cracks, and required less number of blows to cause ultimate failure.
5. A low impact resistance to first cracking does not necessarily indicate low impact resistance to failure (Ch.W.T. concrete have a good energy absorption).

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