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Impact Resistance of Lightweight Chopped Worn-Out Tires Concrete

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Abstract

This study summarizes results of an experimental investigation of the impact resistance of 12 lightweight concrete slabs made from incorporating chopped worn-out tires (Ch.W.T.) into the mixes as a partial replacement of the sand in mortar mixes, and as partial replacement for both sand and gravel for concrete mixes; volumetrically.

The main variables were; the partial replacement ratio (PRR) and the shape of the falling mass (striker). Data were obtained pertaining to compressive strength, static and dynamic modulus of elasticity, and modulus of rupture. In addition, the crack pattern under impact loading was studied to provide insight into the internal behavior and failure mechanism of lightweight Ch.W.T. concrete slabs.

Results of this work indicate that incorporating Ch.W.T. into mortar and concrete mixes succeeded in reducing its unit weight from 17.9% to 26.2% according to type of mix and partial replacement ratio. In contrast, the ultimate impact resistance, expressed in the number of blows required for complete separation of the specimen, increased from 91% to 186% for mortar mixes depending on the partial replacement ratio and the type of falling mass; and did not decreased significantly for concrete mixes.

Keywords: Chopped worn-out tiers; Compressive strength; Flexure strength; Impact; Lightweight concrete; Modulus of elasticity; Slabs.

مقاومة الصدم لخرسانة مفروم الإطارات خفيفة الوزن

الخلاصة

يوجز هذا البحث نتائج دراسة مختبرية لمقاومة الصدم لـــ (12) بلاطة خرسانية خفيفـــة الوزن مصنعة من إدماج مفروم الإطارات في الخلطة الخرسانية باستبداله بجزء معين من حجم الرمل في خلطات المونة، وبجزء معين من حجم كل من الرمل والحصى للخلطات الخرسانية.

كانت المتغيرات الرئيسية هي نسبة الإستبدال الجزئي وشكل الكتلة الساقطة (المطرق). أستحصلت البيانات بما يخص مقاومة الإنضغاط، معامل المرونة الساكن والحركي ومقاومـــة الإنثناء. بالإضافة إلى ذلك، تمت دراسة أنماط التشقق تحت الحمل الصدمي لتعطينا فكرة عن التصرف الداخلي وآلية الفشل للبلاطات المصنعة من خرسانة مفروم الإطارات خفيفة الوزن.

إن نتائج هذا البحث تشير إلى أن إضافة مفروم الإطارات إلى خلطات المونة والخرسانة قد نجح في تخفيض كثافتها بنسبة تتراوح من 17.9% إلى 26.2% حسب نوع الخلطة ونسبة الاستبدال الجزئي. وبالمقابل فإن مقاومة الصدم القصوى، والمعبر عنها بعدد الضربات اللازمة لتهشيم النموذج، قد إزدادت بنسب تتراوح من 91% إلى 186% لخلطات المونة حسب نســبة الاستبدال الجزئي ونوع الكتلة الساقطة، ولم تظهر هبوطاً كبيراً للخلطات الخرسانية.

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Introduction

Lightweight Concrete Has Been Used Successfully For Many Years For Structural Members And Systems In Buildings And Bridges. In Addition To Its Lighter Weight, Which Permit Saving In Dead Load And So Reduces The Cost Of Both Superstructures And Foundations, This Concrete Provides Better Heat And Sound Insulation Than Concrete Of Normal Density[1].

Most Structures Are Generally Designed To Withstand Static Loads, And Some Are Designed To Resist Dynamic Loads, Such As Those Caused By Wind, Explosions, Machine Vibration, And Impact.

Impact May Be Defined As A Collision Between Two Bodies, Which Occurs In A Very Short Interval Of Time During Which The Two Bodies Exert On Each Other Relatively Large Impact Forces. Missile Impact, Fragments Impact, Vehicle Impact With Structures, And Ship Collision Are Some Examples Of Impact[2].

The Impact Load Applied To A Structure Depends On The Striker Velocity, The Masses Of The Structure And The Striker, The Resulting Deformations, The Shape Of The Striker, And The Material Properties Of The Structure[3,4].

Because Of The Nature And Method Of Production Of Lightweight Concrete, The Occurrence Of Weak Sections Is Often Possible[5]. This In Turn May Reduce The Impact Resistance Of Lightweight Concrete. Such A Drawback Can Be Overcome By Using Lightweight Chopped Worn-Out Tires (Ch.W.T.) Concrete, Which Provides A Suitable Solution For Both Economic Production Of Lightweight Concrete And Increasing Its Impact Resistance[6].

Experimental Program

Identical Two Series Of Specimens Were Tested To Determine The Impact Resistance Of Lightweight Ch.W.T. Concrete Slabs. The First Series Was Exposed To A Cylindrical Striker Having A Conical Head (Missile Type), While The Second Series Was Exposed To A Cylindrical Striker, With The Same Mass And Diameter Of The First One; But With A Circular Head- Fig.1 (B).

In Each Series, Both Ch.W.T. (Concrete And Mortar) Mixes With Their Corresponding Plain Mixes (Without Ch.W.T.), Were Included. The Methodology Of Aggregate Replacement Was To Substitute A Certain Volume Of Aggregate By The Same Volume Of Ch.W.T. , But With Different Partial Replacement Ratios (Prr's) For The Sand And The Gravel. Thus, The Prr Is The Substituted Volume Divided By The Original Volume.

The Prr And The Mix Proportion After Replacement Is Recalculated Again By Weight Of Cement As Shown In Table 1.

Materials And Mix Procedure

All Mixes Used Ordinary Portland Cement (Type I) Taken From One Batch. The Sand Consisted Of Washed And Dried Natural River Sand With A Size Range Of 0.15-4.75mm, And Had A Bulk Specific Gravity Of 2.6. The Gravel Consisted Of Washed And Dried Natural Gravel With A Size Range Of 1.18-9.5mm, And Had A Bulk Specific Gravity Of 2.7. The Sand And Gravel Conformed To The Grading Zones Of Astm C33-86.

The Ch.W.T. Used In This Work Had A Maximum Size Of

6.35mm And A Specific Gravity Of 0.95. Table 2 Shows The Sieve Analysis Of The Ch.W.T. Used In This Work. The Physical And Chemical Properties Of Ch.W.T. Are Listed In Table 3.

The Mixes Were Produced Using A Horizontal Pan-Type Mixer. The Dry Constituents Were Initially Mixed For 1.0 Minute. With Ch.W.T. Mixes, The Ch.W.T. Were Then Incorporated Into The Dry Mix Through A Dispenser, And The Mixing Continued For Another 1.0 Minute To Allow Uniform Distribution Of The Ch.W.T. In The Mix. After Adding The Water, The Constituents Were Then Mixed For A Further 2.0 Minutes To Produce A Homogeneous Mix.

Specimen Preparation

The Impact Specimens Were A Square Slab Of 500mm In Length And 80mm In Thickness. Two Impact Specimens In Addition To Three Control Cylinder (150×300 Mm In Size); Three Control Beams (100×100×400mm In Size); And Three 100×200mm Cylinders, Were Cast From Each Batch.

All Concrete And Mortar Mixes Were Cast In Steel Moulds And Placed In 2 Layers Except The 150×300mm Cylinders Which Were Cast In 3 Layers.

Compaction Of All Specimens Was Achieved By Use Of Vibrating Table. The Time Of Vibration Was About 45 Seconds For Plain Mixes And About 90 Seconds For Ch.W.T. Mixes. The Moulds Were Left Covered For 24 Hours, Then De-Molded And Placed In A Moist-Curing Condition For 28 Days, Except For The 100×200mm Cylinders Which Were Cured For 7 Days Only And Air-Dried For 21 Days. All Other Specimens Were Air Dried For 24 Hours Before Testing.

Testing And Test Equipment

The Equipment Used For The Impact Test Consist Of Three Main Components- (See Fig. 1):

1. A Steel Frame; Strong And Heavy Enough To Be Held Rigidly During Impact Loading. The Dimensions Of The Testing Frame Were Designed To Allow Observing The Specimen From Its Bottom Surface During Testing. The Impact Specimen Was Placed In Position In The Testing Frame Using Continuous Square Steel Angel Simply Supporting The Specimen From Its Four Sides.
2. A Guiding Pipe With An Inside Diameter Of 55 Mm. The Pipe Was Held Vertically On The Center Of The Slab Using Four Arms Fixed To The Steel Frame, So As To Be Able To Move Upward And Downward Only. The Pipe Used To Drop The Falling Mass From A Controlled Height Of 1200mm.
3. A Cylindrical Falling Mass (Striker) Of Two Types: (I) Conical Head Striker; And (Ii) Circular Head Striker. The Two Strikers Had The Same Mass Of 1535 Gm And The Same Diameter Of 50 Mm.

Prior To Each Test, The Specimen Was White Washed And Placed In Position In The Testing Frame With The Finished Face Up. The Guiding Pipe Is Then Placed In Position As Shown In Fig. 1. The Falling Mass Is Then Dropped Repeatedly, And The Number Of Blows Required For The First Crack To Form At The Bottom Surface And The Ultimate Failure Is Then Recorded.

The First Crack Is Based On Visual Observation, And Painting The Surface Of The Testing Specimen Facilitates To Identify This Crack At An Early Stage. The Crack Pattern And Crack Propagation Were Also Observed And Recorded. Ultimate Failure Is Defined As The Number Of Blows Required For Thoroughly Punching The Specimen Or Breaking It Into Separate Pieces. The Mode Of Failure Depends On The Matrix Properties And Shape Of The Falling Mass, And These Were Carefully Observed After Each Test. Control Specimens Were Tested In The Same Day Of Testing Its Corresponding Impact Specimens. The Control Beams (Prisms) Were Tested For Dynamic Modulus Of Elasticity (E_d) Using The Resonant Frequency Tester According To Bs 1881, And Then Retested For Flexural Strength (F_r) Using Simple Beam With Third-Point Loading According To Astm C78-84. The Control Cylinders Were Tested For Static Modulus Of Elasticity (E_s) According To Astm C469-87a, And Then Retested For Compression Strength (f_c') According To Astm C39-86. The Air Dry Unit Weight Is Obtained From The 100×200mm Cylinders According To Astm C567-85. Each Point Is The Average Of Three Tests. More Details Are Available In Reference [6].

Experimental Results And Discussion

The Impact Resistance Results In Terms Of The Number Of Blows For Both Series Of Tests Are Shown In Table 4. The Table Includes Compression Strength, Modulus Of Rupture, Static And Dynamic Modulus Of Elasticity, And The Number Of Blows To Cause First Crack And Ultimate Failure For Impact Specimens.

Test Results Emphasize Two Factors Which Are Observed With Almost All Types Of Impact Tests. ***Firstly***, The Variation In The Number Of Blows Required To Cause First Crack Among Different Mixes Of Mortar And Concrete Impact Specimen. The Presence Of Ch.W.T. Increased The First Crack Impact Resistance For All Mortar Mixes Tested With The Conical Head Striker (Series I), In Spite Of The Fact That The Presence Of Ch.W.T. In The Mortar And Concrete Mixes Reduced Its Unit Weight Significantly- Table 1. This May Be Related To The Fact That Both Aggregate-Matrix Bond And The Relative Stiffness Of The Aggregate And The Matrix Have A Part To Play In Impact Resistance, And Replacing The Aggregate With Ch.W.T. Reduces The First Crack Impact Resistance Of Concrete Mixes. While In The Relatively More Brittle Mortar Mixes, Ch.W.T. Might Act As A Substitute For Gravel In Addition To Its Damping Effect Which Increases The Impact Energy Absorption Capacity, And This Is Done By Gravel In The Concrete Mixes. This Damping Effect Is Well Reflected By Increasing The Dynamic Modulus Of Elasticity With Increasing Prr For The Mortar And Concrete Mixes Having Ch.W.T.

However, For Specimens With Ch.W.T. , It Can Be Seen That The First Crack Impact Resistance Increases With Increasing Flexural Strength. One Exception Of This Is Mix $\mathbf{M_{45}}$ In Test Series Ii- Table 4.

Secondly, The Variation In The Number Of Blows Sustained At Ultimate Failure Is Also Available But To Much Lesser Degree.

However, Specimens Which Appear To Possess Relatively Low Impact Resistance To First Cracking Are Not Necessarily Weak In Impact, And Do Seem To Have High Impact Resistance To Failure Which Is In Agreement With Previous Work[5]. This Appears To Be Particularly True For Lightweight Ch.W.T. Concrete Specimens As Shown By Mixes $\mathbf{C}_{20,60}$ And $\mathbf{C}_{12,73}$ (Table 4) Which Is Not True For The More Brittle Plain Concrete Specimens As Shown By Mix $\mathbf{C}_{o}$- Table 4.

Influence Of Ch.W.T.

Table 1 Shows The Influence Of Incorporating Ch.W.T. Into Mortar And Concrete Mixes On Their Unit Weight. Using Prr Of 40% (Mix $\mathbf{M}_{40}$) And 45% (Mix $\mathbf{M}_{45}$) For Mortar Mixes Reduced Its Unit Weight By 17.9% And 22.6%, Respectively. While For Concrete Mixes Using Prr Of 20% + 60% (Mix $\mathbf{C}_{20,60}$) And 12% + 73% (Mix $\mathbf{C}_{12,73}$) For Sand And Gravel Resulted In Reducing Its Unit Weight By 22.0% And 26.2%, Respectively.

Table 4 Shows That The Number Of Blows Required For Ultimate Failure Is Increased Significantly With Increasing Prr For All Mortar Mixes In This Work. This Is Felt To Be Due To That Ch.W.T. Acted As Gravel In The Mortar Mixes, And Increased Its Energy Absorption Capacity. For Concrete Mixes Of Series I, Incorporating Ch.W.T. Into The Concrete Mixes Reduced Its First Crack Impact Resistance Significantly**-** Even So, For Mixes With Ch.W.T, The Number Of Blows Required For Ultimate Failure Is Increased By 6.2% With Increasing Prr As Shown By Mixes $\mathbf{C}_{20,60}$ And $\mathbf{C}_{12,73}$- Table 4. While For Concrete Mixes Of Test Series Ii, Incorporating Ch.W.T. Increased The Number Of Blows Required For Ultimate Failure By 9% And 16% For Mixes $\mathbf{C}_{20,60}$ And $\mathbf{C}_{12,73}$, Respectively.

Influence Of Mass (Striker) Shape

Results Of This Work Indicate That, For The Same Impact Energy (For The Same Falling Mass And Height Of Drop), The Number Of Blows Required To Cause Ultimate Failure Using Conical Head Striker (Series I) Is Always Greater Than That Of Circular Flat Head Striker (Series Ii)**-** Table 4, Which Means That The Total Amount Of Energy Required To Cause Failure Is Less In Case Of Circular Flat Head Striker Which Is In Agreement With Previous Work[7]. This May Be Attributed To That A Part Of The Energy Exerted By The Conical Head Striker Is Dissipated By Attempting To Penetrate The Specimen. The Circular Flat Head Striker Required Less Number Of Blows To Cause Ultimate Failure Because That There Is No Energy Dissipated In Attempting To Penetrate The Specimen, Which Is Well Pronounced By The Destructive Mode Of Failure And The Increased Number Of Cracks Caused By The Circular Flat Head Striker. Incorporating Ch.W.T. Into Concrete Mixes Increased Its Energy Absorption Capacity, And This Is Felt To Be The Reason Behind Increasing The Number Of Blows Required To Cause Failure With Increasing Prr, Using Circular Flat Head Striker**-** Rather Than Conical Head Striker.

Modes Of Failure Under Impact

Fig. 2 Shows The Mode Of Failure Of The 12 Specimens Tested In This Work. The Figure Shows That The Failure For Plain Mortar And Concrete Specimens Were More

Brittle Than Failure Of Specimens With Ch.W.T. And, For The Same Mix, Failure Of The Specimens Tested By The Circular Flat Head Striker (Series Ii) Were More Destructive With More Number Of Cracks Than Failure Of Specimens Tested By The Conical Head Striker (Series I). The Predominant Mode Of Failure Foe Specimens Of Series Ii Is To Fracture Into 3 Or 4 Pieces, While The Predominant Mode Of Failure For Specimens Of Series I Is To Fracture Into 2 Or 3 Pieces. For The Two Series, Failures Of Concrete Specimens Were By Bond Of Gravel. For All Specimens Tested In This Work The Crack Started At The Center Of The Bottom Face Of Specimens And Moved Increasingly Outward As The Number Of Blows Increased. And For Specimens Failed With More Than One Major Crack (More Than Two Pieces), The Crack Pattern Was That Only One Major Crack Is Appeared At The Beginning Of The Test And With Increasing The Number Of Blows Up Continued Increasing In Width And Length Until The Specimen Is Fractured Into Separate Pieces.

Conclusions

The Main Conclusions Derived From This Investigation Are As Follows:

1. Incorporating Ch.W.T. Into Mortar And Concrete Mixes As A Partial Replacement Of Aggregates Volumetrically Reduced Its Unit Weight From 17.9% To 26.2% Depending On The Mix Type.
2. Addition Of Ch.W.T. Increased The Impact Resistance Of Mortar Mixes From 91% To 186% Depending On The Partial Replacement Ratio And The Type Of Falling Mass; And Did Not Decreased The Ultimate Impact Resistance Of Concrete Mixes Significantly.
3. For The Same Impact Energy (The Same Falling Mass And Height Of Drop), The Circular Flat Head Striker Had More Destructive Mode Of Failure, More Number Of Cracks, And Required Less Number Of Blows To Cause Ultimate Failure, Than The Conical Head Striker.
4. Reducing The Material Flexural Strength Reduces The First Crack Impact Resistance Of The Specimen.
5. A Low Impact Resistance To First Cracking Does Not Necessarily Indicate Low Impact Resistance To Failure.

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Notation

E_d	= Dynamic Modulus Of Elasticity Of Concrete, Kn/Mm^2.
E_s	= Static Modulus Of Elasticity Of Concrete, Kn/Mm^2.
f'_c	= Compressive Strength Of Concrete In Uniaxial Compression, Mpa.
F_r	= Flexural Strength (Modulus Of Rupture), Mpa.
Ch.W.T.	= Copped Worn-Out Tires.
Prr	= Partial Replacement Ratio.

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Table 1- Mix proportion and unit weights.

Mix	Cement content kg/m^3	w/c ratio	Reference Mix proportion by weight	PRR by volume %	PRR by weight of cement	Mix proportion after replacement by weight	Slump (mm)	Air dry unit weight kg/m^3	Reduction in unit weight %
M_0	450	0.50	1 : 3.6	0	0.00	1 : 3.6	7	2188	0.0
M_{40}	450	0.50	1 : 3.6	40 of sand	0.53	1 : 2.2	3	1796	17.9
M_{45}	450	0.50	1 : 3.6	45 of sand	0.60	1 : 2.0	5	1694	22.6
C_0	450	0.49	1 : 1.5 : 2.25	0	0.00	1 : 1.5 : 2.25	25	2340	0.0
$C_{20,60}$	450	0.49	1 : 1.5 : 2.25	20 of sand + 60 of gravel	0.59	1 : 1.2 : 0.90	10	1826	22.0
$C_{12,73}$	450	0.49	1 : 1.5 : 2.25	12 of sand + 73 of gravel	0.64	1 : 1.32 : 0.61	13	1760	26.2

Table 2 – Sieve analysis of Ch.W.T.

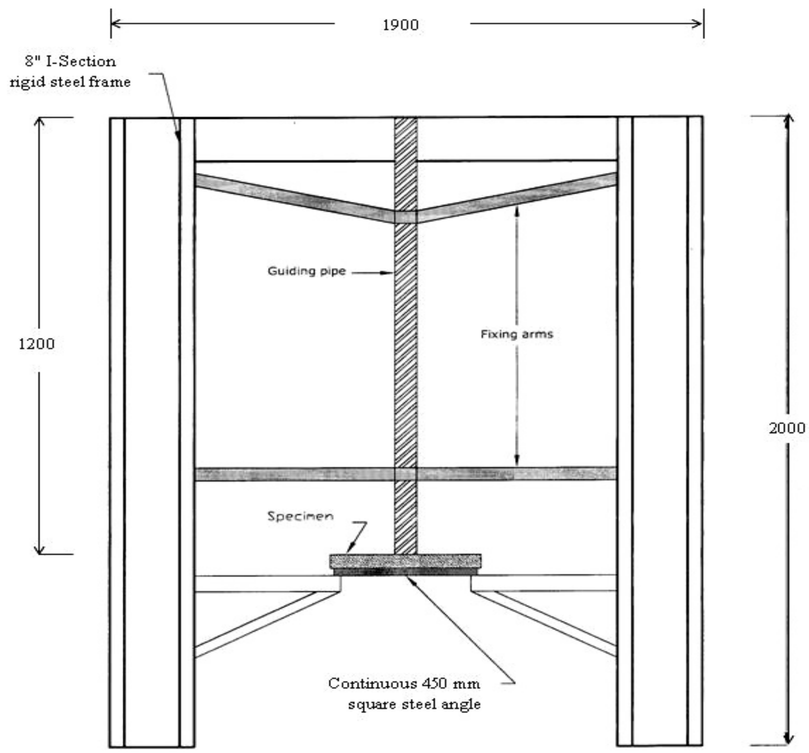
Sieve size (mm)	Percentage passing
6.35	100
4.75	92
2.36	32
1.15	5
0.60	[illegible]
0.15	0.3
0.0075	0.0

Table 3 – Properties of Ch.W.T.

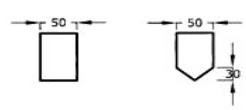
Propriety	Description
Speed of combustion	Very slow
Impact effect	Nil
Sun light effect	Nil
Water absorption	Negligible
Weak acid and bases effect	Nil

Table 4 – Mechanical properties and impact resistance.

Mix	f'_c MPa	f_r MPa	E_s kN/mm^2	E_d kN/mm^2	Conical head mass (series I)		Circular flat head striker (series II)	
					No. of blows to first crack	No. of blows to failure	No. of blows to first crack	No. of blows to failure
M_0	28.12	3.36	14.4	27.73	116	146	75	91
M_{40}	12.60	2.85	8.40	13.15	252	389	73	174
M_{45}	11.24	2.14	7.80	15.34	237	418	82	193
C_0	27.32	4.05	21.5	37.28	412	448	236	264
$C_{20,60}$	10.50	1.95	8.60	10.49	203	411	196	288
$C_{12,73}$	29.25	2.22	6.70	13.74	209	437	211	306



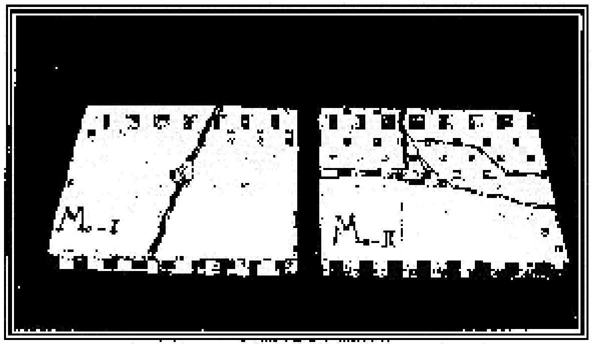
(a) Testing Frame



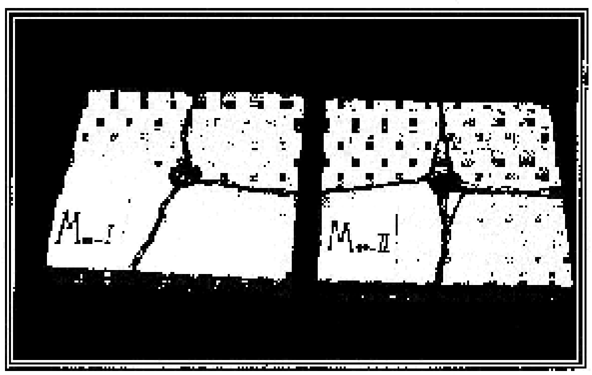
(b) Typing of strikers

Note: All dimentions are in mm

Fig. 1 - Testing equipment



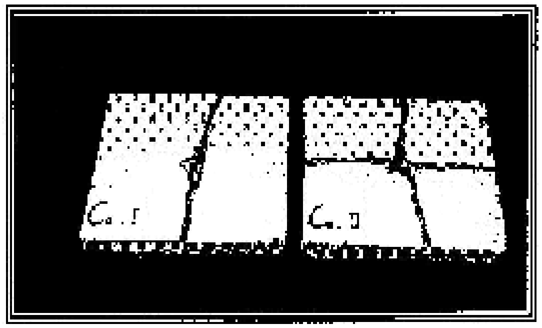
Specimens Mo-I & Mo-II



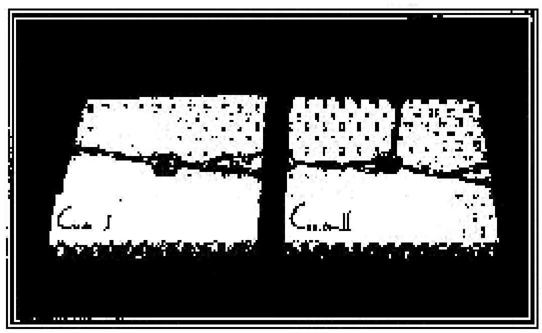
Specimens M_{40}-I & M_{40}-II

Specimens M_{45}-I & M_{45}-II

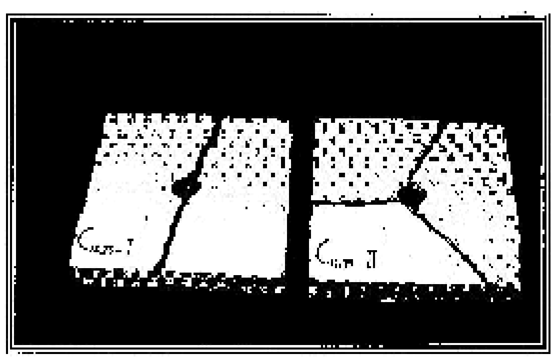
Figure 2(a) Mortar specimens after failure - top face



Specimens Co-I & Co-II



Specimens $C_{20,60}$-I & $C_{20,60}$-II



Specimens $C_{12,73}$-I & $C_{12,73}$-II

Figure 2(b) Concrete specimens after failure - top face