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EFFECT OF HEATING ON SHEAR STRENGTH IN WASTE PLASTIC LIGHTWEIGHT CONCRETE BY USING A NEW TEST SPECIMEN

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ABSTRACT: The re-use of plastic waste as an alternative to partial volume of sand in the concrete rids Iraq of harmful waste plastic piles as well as reduces demand for natural sand and dependence on remote sand quarries. Moreover, encourages lightweight concrete (LWC) production, which reduce the loads and increases the efficiency of the insulation. Certainly, when speech is going about the waste plastic, it should go through its weak point, which is heating. This study aims to investigate the shear properties (with different ratios of longitudinal steel reinforcement) of both structural & non-structural waste plastic LWC before and after heat exposure. This study involves many trails in order to determine the efficiency of reusing waste plastic in the production of both structural & non-structural waste plastic LWC. A special new test specimen is presented here by the researcher called W-Shear Test specimen (WST) in order to achieve aims of this study. Twenty-four of W-ST specimens are cast in this study. They are divided into six groups; each group consists of four W-STs. In every group, three W-STs out of these four are reinforced with different longitudinal steel bars in order to investigate the failure behaviour. W-STs are cast from normal weight concert (NWC), structural and nonstructural LWC and tested before and after heat exposure to 200oC. These tests include slump, fresh density, dry density, compressive strength, tensile splitting strength, flexural strength, Young’s modulus, in addition to shear capacity (P) and slip (D) of W-STs. The results of this study support the re-use of plastic waste as a sand volume substitution of fine aggregate to produce LWC that resists shear stresses after heat exposure.

Keywords: waste plastic, structural and nonstructural lightweight concrete, heat, shear

1- INTRODUCTION

Many of the remains of waste plastic strewn here and there in Iraq. The problem is that some canning food and beverage companies re-use it, which poses a threat to human consumption. These remains can be reused in industry because, it is well-known that some disadvantages of the reusing lack of waste plastic are harming the environment, increasing energy consumption, pollution, global warming, unsustainable using of resources, increasing amount of waste to landfills and wasting natural resources. Therefore, it is worth to produce structural and nonstructural LWC from the waste plastic.

Structural LWC has an oven - dry density < 2000kg/m3, and a cylinder compressive strength > 17.0 MPa (6, 23, 30). Generally speaking, its strength is by 25% to 35% less than2normal, but it is by 25% to 35% lighter (3). Structural and nonstructural LWC offer design significant cost savings and flexibility by decreasing the dead load that provides longer spans, smaller size structural members, thinner sections, shorter stories, less reinforcing steel, lower cost of the foundation and better fire resistance because of its lower coefficient of thermal expansion and its lower thermal conductivity (3).Although the subject of using waste plastic shredded particles has been studied by many researches, the researches that deal with studying the effect of heat on the shear behavior of both the non-structural and structural waste plastic LWC (when shredded plastic particles replaced by sand volume) stayed very limited. Jo et al. 2006 (25) produced polymer concrete with very high mechanical properties and durability performance when used an unsaturated polyester resin based on recycled PET (polyethylene terephthalate) mixed with inorganic aggregates. They contributed to reducing the cost of the material and saving energy in addition to solving some solid waste problems posed by plastics.

Pezzi et al. 2006 (31) evaluated the physical, chemical, and mechanical concrete properties involved plastic material particles as aggregate. The results showed that the addition of polymeric materials in fraction 10% in volume to cement matrix does not show a significant variation of the mechanical features of concrete. Marzouk et al. 2007(29) studied the shredded particles of waste plastic bottle as sand-substitution in composite constructional materials. They concluded that the waste plastic may be successfully used as a sand-substitution fine aggregates in cementitious concrete composites, which seems to offer a low-cost material with appropriate properties. Batayeneh et al. 2007 (19) showed the compressive strength deterioration with an increment in the proportion plastic content although weight loss. For the plastic proportion of 20% sand, the compressive strength is reduced up to 70% compared to that of normal concrete. Zainab Z. I. & Enas A. A. 2008 (34) used waste plastic as a partial replacement for sand by 0%, 10%, 15%, and20% with concrete mixtures. Researchers insured that reusing of waste plastic as a sand substitution aggregate in concrete presents a good approach to reduce the cost of materials. Kou et al. 2009 (28) partially replaced river sand by PVC plastic waste grains in percentages of 0%, 5%, 15%, 30% and 45% (by volume). The prepared concrete was lighter, more ductile, and higher in resistance with lower in drying shrinkage and to chloride ion penetration, but the workability, compressive strength and splitting tensile strength were reduced. Semiha A. et al. 2010 (33) investigated two groups of mortar samples, 1st made with only PET fine aggregates and, 2nd made with PET in addition to sand aggregates. Researchers concluded that there is a reliable advantage from using waste PET granules as aggregate in the production of structural LWC. Baboo Rai et al.2012 (18) prepared waste plastic concrete mixes with and without super plasticizer tested at room temperature. They found that the decrease in workability then compressive strength, due to partial replacement of sand by waste plastic is insignificant and can be improved by adding of super plasticizer. Brahim Safi et al. 2013 (20) used waste plastic as fine aggregate instead of sand in preparing self-compacted mortars. Sand is substituted with plastic at a dosage of 0%, 10%, 20%, 30% and 50% by weight of sand.3Researchers found a reduction of 15% and 33% for mortar containing 20-50% plastic waste.

Materials

The materials used in this study are as follows:

- **Cement:** Type I Portland cement is used in all study mixtures. The physical and chemical properties of cement used are presented in Tables (1)&(2) respectively. These features conformed to the Iraqi Standard Specification No.45/1984(35).
- **Fine aggregate:** Al-Sodour natural sand is used as fine aggregate. Bulk Specific Gravity=2.52, dry loose unit weight=1570 kg/m3, absorption=2.28 and Sulfate content as%SO3=0.17. The sieve analysis is shown in Table (3). Results indicate that fineggregate used is within the requirements of the Iraqi Specification No.45/1984(35), ASTM C33-03(8), ASTM C 128-03(9) and ASTM C 29-03(10).

- **Coarse aggregate:** Natural river gravel with a maximum aggregate size of 6mm is used because of the dimensions of the reinforced concrete specimen. Specific Gravity=2.24, dry loose unit weight=1496 kg/m3, absorption=0.61 and Sulfate content as%SO3=0.06. Results indicate that coarse aggregate used is within the requirements principles of the Iraqi Specification No.45/1984(35) and ASTM C33-03(8).
- **Waste plastic**: Waste plastic used is the product of shredding big plastic water tanks that brought from plastic shredders located in Kamaliya area (East of Baghdad). It consists approximately of 85% polyethylene and 15% polystyrene, see Plate (1).Waste plastic is analyzed in terms of some physical properties such as density and sieve analysis according to ASTM 330-03(8). Physical and mechanical properties of waste plastic are shown in Table (4). Table (5) shows the sieve analysis.
- **Mixing Water:** Normal tap water is used for mixing concrete.
- **Super Plasticizer**: The super plasticizer used in this work is PCE 600, see Table (6) for the technical description.
- **Reinforcing Steel:** φ4mm deformed bars (fy=557 MPa and fu= 835MPa) is used as skin reinforcement or longitudinal bars that met the ASTM A615-05(11) and ASTMA496-02(12) requirements respectively.
- **Silica fume (Sf):** Sf is added to concrete in order to enhance its properties in compressive strength and bond strength (7, 23). Chemical and physical properties of the used silica fume are shown in Table (7) and Table (8) respectively.

Mixture proportioning

After some trails, three mixtures are taken into consideration; see Table (9):

1. NWC: No waste plastic in concrete mixture.
2. Nonstructural LWC: Waste plastic particles replaced by 75% sand volume.
3. Structural LWC: Waste plastic particles replaced by 75% sand volume.
4. For the groups E and F, and in comparison with the rest groups, it should be pointed out that water cement ration w/c is decreased and silica fume is added to increase compressive strength f/c in order to produce structural LWC. As super plasticizer is added to ensure the required workability of work.

Fresh concrete tests

- **Density:** Compacted fresh density of LWC mix is determined according to the ASTMC567-05(13).
- **Slump test:** The workability of all concrete mixes is measured immediately after mixing using slump test according to ASTM C143–03(14). The w/c is adjusted to maintain approximately equal workability for all mixes, see Table (10) and Plate (2).

Hardened concrete tests

Tests are conducted after 7 and 28 days of curing in water basin, see Plate (3); fourconcrete specimens are tested at each age:

- **Air dry density test**: Conducted according to ASTM C567-05a (13).
- **Cube compressive strength test**: Conducted according to BS 1881-part 116:2000 (21), see Plate (4).
- **Splitting tensile strength test:** Performed according to ASTM C496-04(15), see Plate (5).
- **Flexural Strength test:** Conducted in conformity with ASTMC 78-02(16), see Plate (6).
- **Modulus of Elasticity test:** Measured the static modulus of elasticity of concrete according to ASTM C469-02 (17), see Plate (7).

Laboratory specimens

Twenty-four W-ST specimens are cast in this study, see figure (1). Four special steel molds of 50mm x 140mm x 300mm are fabricated for this purpose, see Plate (8).These twenty-four specimens are divided into six groups, see Table (11). Each group consists of four W-ST specimens. The difference between the four specimens of each group is the longitudinal reinforcement in each specimen. Number of longitudinal reinforcement φ4mm deformed bars varying from 0 bars (i.e. r=0.0), 1 bar (i.e
r=0.003860), 2 bars (i.e. r=0.00773) and 3 bars (i.e. r=0.0116). In addition to the main longitudinal reinforcement, two meshes of skin reinforcement made from φ4mm diameter deformed bars are provided to prevent any failure except at notches.

Electrical temperature furnace is used in this study in providing heat for specimens; see Plate (9). Heating time is kept one hour after reaching 200oC. Later on, after W-ST specimens heating, they are cooled down gradually by exposing them to air for one day.

A day before testing, each W-ST specimen is carefully cleaned; load application and supporting points are marked (shear span to depth ratio a/d≈0.3). Two concentrated loads are used and all specimens are tested till total failure, see Plate (10) and figure (2). Two dial gauges are used to measure slip under load points.

Generally speaking, replacing 75% sand volume by waste plastic leads to decrease in the compressive strength f/c, splitting tensile strength ft and flexural strength fr, see figures(3) to (5). Figure (6) shows how increasing the longitudinal reinforcement number of bars from 0 to 3, increases shear capacity (P). While figure (7) shows the slip (D) when the longitudinal reinforcement number of bars varies from 0 to 3. Finally, figure (8) illustrates D-P relationships for the W-ST specimens of all groups.

Table (11) shows the testing results and the Plates from (11) to (34) show the W-ST specimens after testing.

In order to facilitate quick identification of the specimen designation without referring to Table (11), preferably explain the way used in naming:

Ri : reinforced with (i) number of steel bars.
S : structural concrete
NS: nonstructural concrete
P: waste plastic is used
H: subjecting to heat

Therefore, for example the specimen R3NSPH is the specimen that **R**einforced with **3**longitudinal reinforcing bars, cast from **N**on **S**tructural waste **P**lastic concrete and subjected to **H**eat.

Comparison between results

The experimental shear capacity results (shown in Table 11) are compared withthe empirical formula of Hsu(24):

Vu = 0.822 (f/cc)0.406 (rfy)c

Where Vu is unit shear strength (MPa), c=0.159(f/cc) 0.303, r is steel ratio of longitudinal bars, fy is yield strength of steel bars, f/cc is concrete compressive strength of 150mmcube and is taken as f/c/0.85.

In addition to Hsu formula (26), experimental results are compared with the finite element method solution obtained by using Ansys 11(4), see figures (9) to (14). The solution conducted by Ansys program helps to know the stresses and strains happen in concrete and steel, which clarify failure behaviour of W-ST specimens.

It is worth to mention that the eight nodes element “SOLID65” is used in the present research to model concrete material. The one dimensional two-node element “LINK180”is used to model the rebar. For the steel plates at support and load locations, an eight node solid element “Solid45” is used. All the used elements are defined with nodes thathave three degrees of freedom at each node and translations in the nodal x, y, and zdirections(4).

It is obvious from Table (11) and figures from (15) to (20) that experiments, finiteelement and Hsu results are close to each other's.

Effect of heat on concrete

- **Effect of heating on ordinary concrete (without waste plastic)**: Concrete is a brittle composite material that consists of cement paste (binder) and fine and coarse aggregates. These materials have different physical and mechanical properties, containing different thermal expansion coefficients (1).According to Piasta J., 1984,(34) cement paste thermal expansion is somewhat greater than that of the aggregate at a lower temperature. Thus, in the concrete matrix, the paste of cement is in hydrostatic compression, and the aggregates are in biaxial tension and compression. As the temperature more increases, the thermal strain of the cement paste changes to shrinking (negative) because of chemical changes, while the aggregate continues to expand. The corresponding stresses in concrete are that, the aggregates are in hydrostatic compression and the cement paste is in biaxial tension and compression (34)**.**
- **Effect of heating on waste plastic concrete:** Subjecting the used waste plastic to 200oC leads to melt which releases smoke, carbon monoxide (CO) and carbon dioxide (CO2). However, because of the increasing porosity of LWC, gases confined inside concrete pores escape that reduces the accumulation of internal stresses. So cracking and spalling effects are minimized in concrete. This allows a better accommodation of the thermal expansion of the components of concrete. That is why the effect of heat is less expected in this research. In this research, it is tried to heat waste plastic concrete to 300oC in the beginning (as the researcher did in previous researches in which concrete was heated to 300, 600and 900oC) , (26,27) but after about 28 minutes of specimen heating, the researcher stopped the experiment because combat gases emitted from the electric furnace, coming out from the waste plastic concrete specimen, please care for Plate (35), that is why heating kept to200oC only.

Discussing results

- **Slump** in waste plastic concrete is more than that in normal weight concrete. Please care for Table (10); the comparison between the groups (A&B) and (C&D). This can be attributed to the less adhesive strength between the cement paste and the surface of the waste plastic particles than that between the cement paste and the surface of sand particles.
- **Fresh & Dry densities** for waste plastic concrete are less than that of normal weight concrete. This happens because of the fact that the density of the waste plastic is lower than sand.
- **f/c, ft, fr and E** values in waste plastic concrete is less than that of NWC. That tookplace because waste plastic is hydrophobic material, which may restrict the hydrationof cement besides the fact that the decrease in the adhesive strength between thecement paste and the surface of the waste plastic particles. In addition to that, heatexposing leads to plastic softening which means more decrease in properties.
- **W-ST specimens:** The existence of the notch between load and reaction points leads to predetermine the failure zone (and this is what was planned in advance in this study). The span to depth ratio is small ($a/d \approx 0.3$) which helps all W-ST specimens fail due to either sudden tensile crack formation parallel to the strut axes or compressive crush in normal direction to the strut axes.

It is also noticed that the variation of longitudinal reinforcement affects failure behaviour that happened during specimens testing. From the knowledge based on ACI-ASCE Committee 426(1), three mechanisms of failure seem rational:

1. W-TS specimens that have no longitudinal reinforcement did not accept stress redistribution when the ultimate shear capacity exceeded the inclined cracking capacity. In this way, the compression zone damaged immediately. The result became diagonal tension failure without warning and without increase in external load.
2. While during testing W-TS specimens that have 1 or 2 bars as longitudinal reinforcements, external load increased after diagonal cracking appeared. The longitudinal reinforcement and the compression zone kept on carrying shear until the stress in the reinforcement has gotten the yield point. So, further increase in the external shear resisted just by the compression zone. That is to say, failure occurs when the compression zone is damaged by the combined compression and shear stresses. This failure was not sudden because the yielding reinforcement allowed the diagonal crack to widen, thus gave sufficient warning of incipient failure
3. About the rest specimens that have 2 or 3 bars, the compression zone is damaged by combined stresses before the reinforcement has reached its yield point. Such failure occurred with less warning than the two cases above.

Moreover, this is the justification of why slip (D) decreases while shear capacity (to some extent) increases in some W-ST specimens as shown if figure (8).Furthermore, continue to talk about the longitudinal reinforcing steel bars, it did not occur any case of bond failure between steel and concrete.

The comparisons between the maximum values, see Table (11), are as follows:

- **Generally**, it is seen that the experimental results, results of Hsu formula (24) and results that obtained by Ansys 11 are so close to each other, see figures (15) to (20).
- **When comparing the specimens inside Group A** *(normal weight concrete, noplastic, no heat)*, it is found that shear capacity increases about (236%, 274% and303%) and slip increases about (220%, 320% and 260%) for R1, R2 and R3respectively in comparison with R0 because of the longitudinal reinforcement effect.
- **When comparing the specimens inside Group B** *(normal weight concrete, noplastic, heat)*, it is found that shear capacity increases about (229%, 306% and 362%) and slip increases about (225%, 400% and 325%) for R1H, R2H and R3H respectively in comparison with R0H because of longitudinal reinforcement effect.
- **When comparing the specimens inside Group C** *(non-structural lightweight, plastic, no heat)*, it is found that shear capacity increases about (241%, 295% and336%) and slip increases about (400%, 325% and 250%) for R1NSP, R2NSP andR3NSP respectively in comparison with R0NSP because of the existence of longitudinal reinforcement effect.
- **When comparing the specimens inside Group D** *(non-structural lightweight, plastic, heat)*, it is found that shear capacity increases about (249%, 336% and 418%)and slip increases about (300%, 267% and 167%) for R1NSPH, R2NSPH andR3NSPH respectively in comparison with R0NSPH because of the existence of longitudinal reinforcement effect.
- **When comparing the specimens inside Group E** *(structural lightweight, plastic, no heat)*, it is found that shear capacity increases about (213%, 280% and 357%) and slip increases about (260%, 360% and 200%) for R1SP, R2SP and R3SP respectively in comparison with R0SP because of the existence of longitudinal reinforcement effect.
- **When comparing the specimens inside Group F** *(structural lightweight, plastic, heat)*, it is found that shear capacity increases about (218%, 297% and 393%) and slip increases about (200%, 425% and 300%) for R1SPH, R2SPH and R3SPHrespectively in comparison with R0SPH because of the existence of longitudinal reinforcement effect.
- **When comparing the specimens of Group A and Group B**, shear capacity decreases about (19%, 21%, 13% and 8%) and slip decreases about (20%, 19%, 5%
- and 6%) for R0H, R1H, R2H and R3H in comparison with R0, R1, R2 and R3respectively because of obvious effect of heating.

- **When comparing the specimens of Group A and Group C**, strength capacity decreases about (51%, 50%, 49% and 47%) and slip decreases about (20%, 25%,19% and 22%) for R0NSP, R1NSP, R2NSP and R3NSP in comparison with R0, R1,R2 and R3 respectively because of obvious effect of partial replacing of sand by waste plastic in order to produce nonstructural LWC.
- **When comparing the specimens of Group A and Group E**, strength capacity decreases about (29%, 33%, 28% and 19%) and slip decreases about (16%, 11%,11.5% and 18%) for R0SP, R1SP, R2SP and R3SP in comparison with R0, R1, R2and R3 respectively because of obvious effect of partial replacing of sand by waste plastic in order to produce structural LWC.
- **When comparing the specimens of Group B and Group D**, strength capacity decreases about (59%, 57%, 56% and 55%) and slip decreases about (25%, 8%,45% and 53%) for R0NSPH, R1NSPH, R2NSPH and R3NSPH in comparison withR0H, R1H, R2H and R3H respectively because of obvious effect of partial replacing sand by waste plastic in order to produce nonstructural LWC subjected to heat.
- **When comparing the specimens of Group C and Group D**, strength capacity decreases about (33%, 31%, 25% and 20%) and slip decreases about (25%, 40%,35% and 43%) for R0NSPH, R1NSPH, R2NSPH and R3NSPH in comparison withR0NSP, R1NSP, R2NSP and R3NSP respectively because of obvious effect of heat on nonstructural LWC.
- **When comparing the specimens of Group C and Group E**, strength capacity increases about (47%, 35%, 41% and 54%) and slip increases about (25%, 10%, 35% and 7%) for R0SP, R1SP, R2SP and R3SP in comparison with R0NSP, R1NSP, R2NSP and R3NSP respectively because of obvious effect of replacing 75% volume of sand by waste plastic in order to produce nonstructural and structural LWC.
- **When comparing the specimens of Group D and Group F**, strength capacity increases about (71%, 56%, 55% and 63%) and slip increases about (33%, 9%,91% and 100%) for R0SPH, R1SPH, R2SPH and R3SPH in comparison withR0NSPH, R1NSPH, R2NSPH and R3NSPH respectively because of obvious effect of heat on both structural and nonstructural LWC.
- **When comparing the specimens of Group E and Group F**, strength capacity decreases about (21%, 20%, 18% and 15%) and slip decreases about (20%, 28%,9% and 7%) for R0SPH, R1SPH, R2SPH and R3SPH in comparison with R0SP,R1SP, R2SP and R3SP respectively because of obvious effect of heat on structural LWC.

Conclusions:

The results obtained from this study can help to make decisive engineering decisions concerning the waste plastic LWC structures after exposing to heat such as the possibility of repairing or loads re-evaluating or even removing. The conclusions are:

1. Shredded waste plastic can be used to produce both structural and nonstructural LWC in Iraq.
2. A decrease takes place in strength properties when waste plastic is partially replaced by sand (in order to produce nonstructural LWC). Replacing waste plastic by 75% of sand volume decreases f/c by 68%, ft by 51%, and fr by 48%.Based on that, shear capacity (P) decreases by 51% and slip (D) increased by20%.
3. Rate of decrease in strength properties of LWC due to using waste plastic diminishes when adding some additives to concrete like silica fume and super plasticizer (in order to produce structural LWC). This diminishes the decrements to 45% in f/c, 41% in ft, and 39% in fr. Therefore, this leads to make the decrease in shear capacity (P) becomes 29% and the increase in slip (D) becomes 16%.

4. Heating concrete to 200oC affects the strength properties negatively. Heating NWC decreases f/c by 7%, ft by 4%, and fr by 3.5%, so (P) decreases by 19% and (D) increases by 20%. While heating nonstructural LWC decreases f/c by 12.5%,ft by 19% and fr by15%, that is why (P) decreases by 33% and (D) increases by25%.About structural LWC, decrements are 12% in f/c and 10% in both ft and fr which leads to (P) decrement by 21% and (D) increment by 20%.
5. Existence of longitudinal reinforcement increases valuably shear strength capacity. In addition to that, number of steel bars effectively affects failure behaviour (i.e. ductile behaviour or brittle).

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Table (1). Physical properties of cement

Physical properties	Test results	Standard Specifications IQS 45/1984
Specific surface area (Blaine method), m^2/kg	495	≥ 230
Setting time (Vicate apparatus), Initial setting, h:min Final setting, h:min	 2:55 4:35	 $\geq$00:45 $\leq$10:00
Compressive strength, MPa 3 days 7days	 33.5 38.6	 ≥ 15 ≥ 23
Soundness (Autoclave) method, %	0.3	≤ 0.8

Table (2). Chemical compositions and main compounds of cement

Oxides composition	Content %	Standard Specifications IQS 45/1984
CaO	63.06	-
SiO_2	22.	-
Al_2O_3	6.25	-
Fe_2O_3	3.13	-
MgO	2.95	<5
SO_3	3.03	<2.8
L.O.I.	3.33	<4
Insoluble residue	1.21	<1.5
Lime Saturation Factor L.S.F	0.88	0.66-1.02
Mineralogical Composition (Bogue’s equations)		
C_3S	47.04	-
C_2S	28.11	-
C_3A	10.98	-
C_4AF	6.98	-

Table (3): Sieve analysis of fine aggregate

Sieve size mm	Passing % sand	%passing limit sand(37)
9.5	100	100
4.75	90.2	90-100
2.36	76	75-100
1.18	59	55-90
0.6	48.8	35-59
0.3	23.5	8-30
0.15	4.77	0-10

Table(4). Description of waste plastic

Density (kg/m^3)	453.8
Shape of particles	Pieces with average length of 0.1–4 mm and width of 0.1–3 mm
Color	Different colors
Water absorption, 24 h (%)	0.02
Compressive strength	Poor

Table(5). Sieve analysis for waste plastic

Opening (mm)	Passing %	limit
9.5	100	100
4.75	92.6	85-100
1.18	65.2	40-80
0.3	25	10-35
0.15	10.4	5-25

Table(6). Properties of the used super plasticiser

Property	Description
Main action	Concrete super plasticizer
Appearance	Yellow and liquid
Specific gravity	1.06 at 1.08@ 20° C
Air entrainment	Maximum 1%
Chloride content	Nil to BS 5075 : 1982
Nitrate content	Nil
Handling	No special precautions
Freezing point	0° C. Can be reconstituted if stirred after thawing
Storage life	At least one year. It should not, however, be exposed to excessive heating

Table (7): Chemical composion analysis of Silica fume

Oxide Composition	Oxide content %	ASTM C1240-05 (7)
SiO_2	91.51	Min. 85%
Al_2O_3	0.73	<1%
Fe_2O_3	0.48	< 2.5%
CaO	0.90	<1%
SO_3	0.97	<1%
$K_2O + Na_20$	1.38	<3%
L.O.I	4.40	Max. 6%
Cl	0.18	< 0.2%
Cao (free)	2.36	<4%

Table (8): Physical properties of Silica fume

Property	Result	ASTM C1240-05 (7)
Strength activity index	106%	≥ 105**
Specific gravity, kg/m³	2.2	-
Physical form	Powder	-
Color	Grey	-
Diameter size	0.15	~0.15 micron
Density	0.6	0.5±0.1kg/liter(dry bulk)
Moisture	0%	< 2%
Specific surface, m^2/g	17	≥ 15

Table (9): Concrete mixtures

Mixture	Groups of Specimens	Cement (kg/m^3)	Aggregate (kg/m^3)	Sand (kg/m^3)	Waste plastic	w/c	silica fume (kg)	Super Plasticizer (liter)
NWC no waste plastic	A & B	420	800	720	0%	0.54	-	-
Nonstructural waste plastic LWC	C & D	420	800	720	75%	0.54	-	-
Structural waste plastic LWC	E & F	420	800	720	75%	0.4	0.15	25

Table (10): Slump values

Group	Concrete type	% Waste plastic	Slump (cm)
A & B	NWC (no waste plastic)	0	8.25
		0	8
C & D	Nonstructural LWC (waste plastic concrete)	75	14.8
		75	15.2
E & F	Structural LWC (waste plastic concrete)	75	19.75
		75	20.25

Table (11): Specimens details and results of conducted tests

Group	Specimen	No. of long. bars	ρ	ρ_{max}	ρ_{min}	Heat to 200°C	Concrete Type	Waste plastic	Tests Results								
									Density (kg/m^3)	fc (MPa)	f_t (MPa)	f_r (MPa)	E (MPa)	Exp. P (kN)	Theor. Hsu [26] P (kN)	F.E. Ansys P (kN)	Exp. Slip Δ (mm)
A	R0	0	-	0.0185	0.00276	no heat	NW Concrete	Without plastic	2317	35.5	3.32	3.46	29100	8.54	3.75	9.91	0.26
	R1	1	0.00386											28.7	20	24.1	1.64
	R2	2	0.00773											32	30.2	32.41	2.1
	R3	3	0.0116											34.4	39.1	34.67	1.84
B	R0H	0	-	0.0176	0.0026	heat			2310	33	3.2	3.34	26210	6.9	3.45	9.60	0.2
	R1H	1	0.00386											22.7	19.25	22.76	1.36
	R2H	2	0.00773											28	28.8	27.89	2
	R3H	3	0.0116											31.9	37.1	30.37	1.74
C	R0NSP	0	-	0.0063	0.0025	no heat	Non-structural LWC	With plastic	1730	11.45	1.63	1.91	17100	4.16	2.03	4.80	0.2
	R1NSP	1	0.00386											14.19	11.2	939	2
	R2NSP	2	0.00773											16.42	15	10.15	1.72
	R3NSP	3	0.0116											18.13	18	10.91	1.42
D	R0NSPH	0	-	0.00557	0.0025	heat			1780	10.02	1.32	1.8	15700	2.8	1.9	3.90	0.12
	R1NSPH	1	0.00386											9.78	10.5	7.48	1.38
	R2NSPH	2	0.00773											12.22	13.86	8.88	1.14
	R3NSPH	3	0.0116											14.5	16.5	10.42	0.84
E	R0SP	0	-	0.011	0.0025	no heat	Structural LWC	With plastic	1900	19.6	2.11	2.34	22100	6.1	2.65	6.31	0.22
	R1SP	1	0.00386											19.12	14.7	13.62	1.82
	R2SP	2	0.00773											23.17	20.64	18.58	2.34
	R3SP	3	0.0116											27.9	25.6	19.28	1.52
F	R0SPH	0	-	0.0096	0.0025	heat		With plastic	1880	17.24	1.9	2.1	21100	4.8	1.97	5.688	0.2
	R1SPH	1	0.00386											15.27	13.38	13.04	1.28
	R2SPH	2	0.00773											19	18.44	16.34	2.16
	R3SPH	3	0.0116											23.69	22.63	18.27	1.64


Plate (1): Waste plastic sample


Plate (2): Slump tests


Plate (3): Curing process

Plate (4): Cube Compressive test

Plate(5): Splitting tensile test

Plate(6): Flexural strength test

Plate (7): Concrete Modulus of Elasticity Test

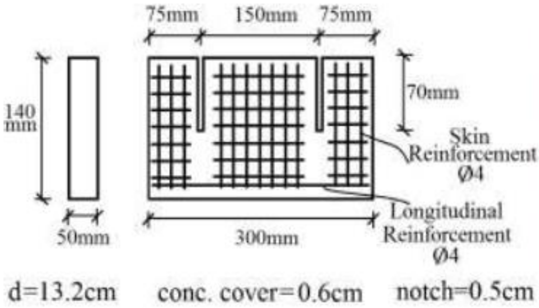
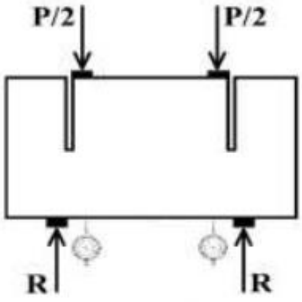


Fig.(1): W-ST Specimen

Plate (8): Typical steel mold with skin reinforcement

Plate (9): The electric furnace used

Plate (10): Testing of Specimens



a / d ≈ 0.3
bearing plate= 2*5cm

Fig.(2): Testing of Specimens

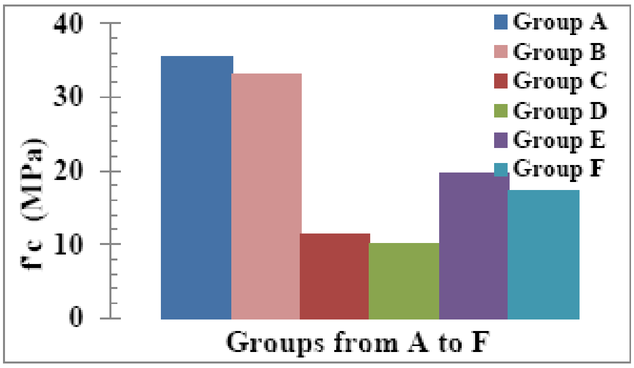


Fig.(3): Compressive Strength for all Groups (A,C&E tested before heating while B,D&F tested after heating)

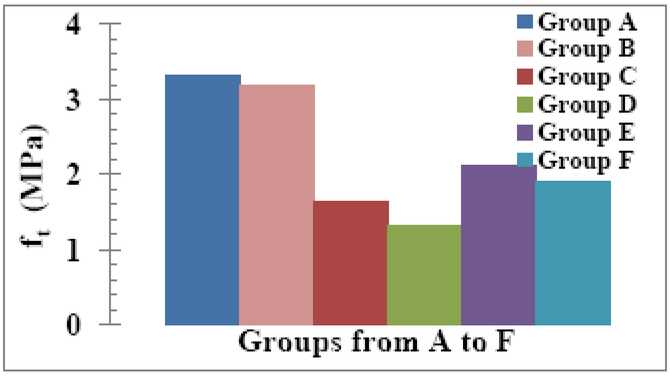


Fig.(4): Tensile Strength for all Groups (A,C&E tested before heating while B,D&F tested after heating)

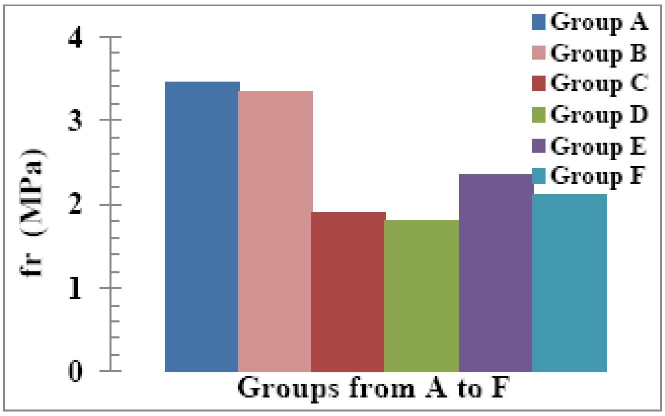


Fig.(5): Fracture Strength for all Groups (A,C&E tested before heating while B,D&F tested after heating)

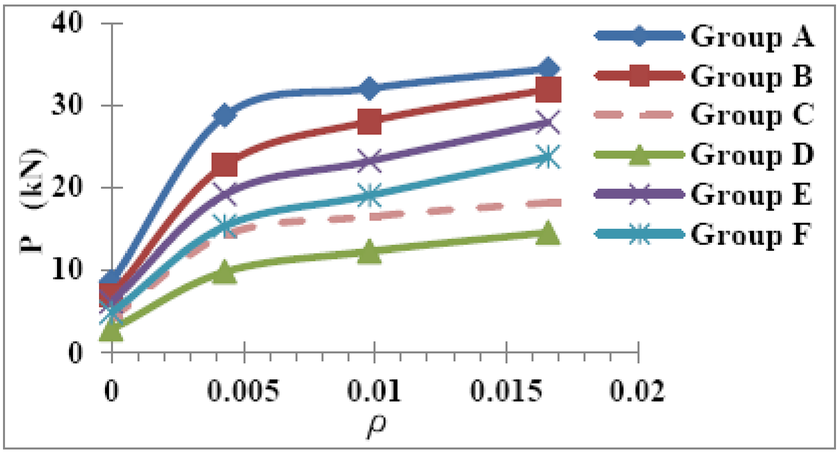


Fig.(6): P-ρ for all Groups
(A,C&E tested before heating while B,D&F tested after heating)

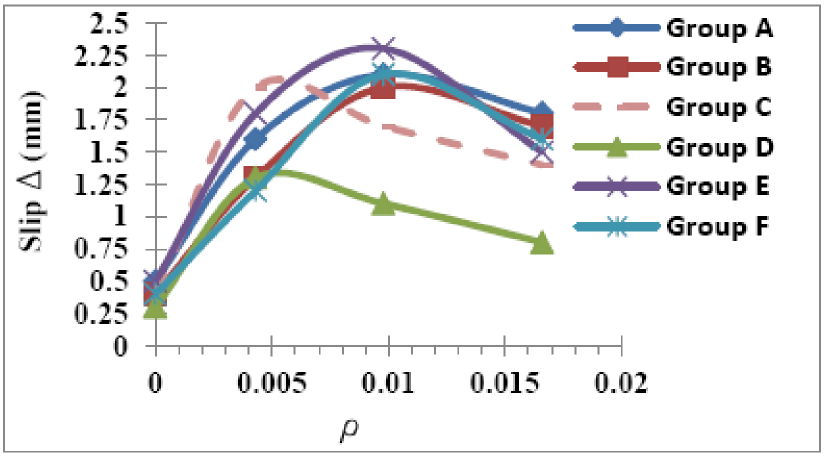


Fig.(7): Δ-ρ for all Groups
(A,C&E tested before heating while B,D&F tested after heating)

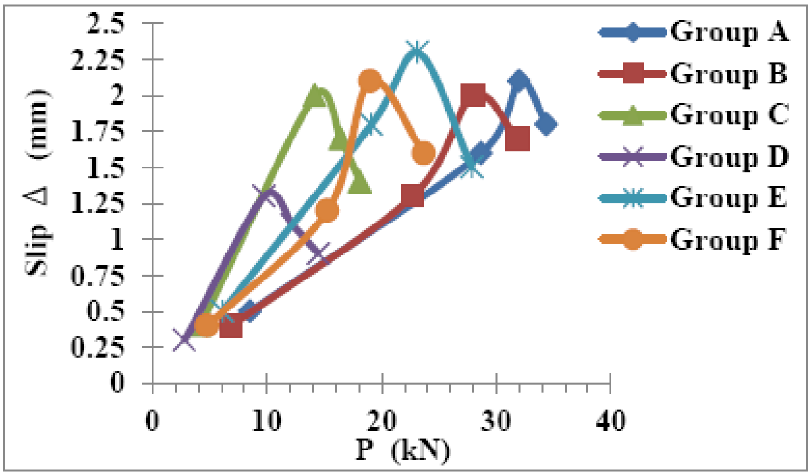


Fig.(8): Δ - P for all Groups
(A,C&E tested before heating while B,D&F tested after heating)

Group A

Plate (11): R0
(Group A, NWC, no waste plastic, 0 bar long. reinf. & no heat)

Plate (12): R1
(Group A, NWC, no waste plastic, 1 bar long. reinf. & no heat)

Plate (13): R2
(Group A, NWC, no waste plastic, 2 bars long. reinf. & no heat)

Plate (14): R3
(Group A, NWC, no waste plastic, 3 bars long. reinf. & no heat)

Group B

Plate (15): R0H
(Group B, NWC, no waste plastic, 0 bar long. reinf. & subjected to heat)

Plate (16): R1H
(Group B, NWC, no waste plastic, 1 bar long. reinf. & subjected to heat)

Plate (17): R2H
(Group B, NWC, no waste plastic, 2 bars long. reinf. & subjected to heat)

Plate (18): R3H
(Group B, NWC, no waste plastic, 3 bars long. reinf. & subjected to heat)

Group C

Plate (19): R0NSP
(Group C, non-structural LWC, waste plastic, 0 bar long. reinf. & no heat)

Plate (20): R1NSP
(Group C, non-structural LWC, waste plastic, 1 bar long. reinf. & no heat)

Plate (21): R2NSP
(Group C, non-structural LWC, waste plastic, 2 bars long. reinf. & no heat)

Plate (22): R3NSP
(Group C, non-structural LWC, waste plastic, 3 bars long. reinf. & no heat)

Group D

Plate (23): R0NSPH
(Group D, non-structural concrete, waste plastic, 0 bars long. reinf. & subjected to heat)

Plate (24): R1NSPH
(Group D, non-structural concrete, waste plastic, 1 bar long. reinf. & subjected to heat)

Plate (25): R2NSPH
(Group D, non-structural concrete, waste plastic, 2 bars long. reinf. & subjected to heat)

Plate (26): R3NSPH
(Group D, non-structural concrete, waste plastic, 3 bars long. reinf. & subjected to heat)

Group E

Plate (27): R0SP
(Group E, structural concrete, waste plastic, 0 bars long. reinf. & no heat)

Plate (28): R1SP
(Group E, structural concrete, waste plastic, 1 bar long. reinf. & no heat)

Plate (29): R2SP
(Group E, structural concrete, waste plastic, 2 bars long. reinf. & no heat)

Plate (30): R3SP
(Group E, structural concrete, waste plastic, 3 bars long. reinf. & no heat)

Group F

Plate (31): R0SP
(Group F, structural concrete, waste plastic, 0 bars long. reinf. & subjected to heat)

Plate (32): R1SP
(Group F, structural concrete, waste plastic, 1 bar long. reinf. & subjected to heat)

Plate (33): R2SP
(Group F, structural concrete, waste plastic, 2 bars long. reinf. & subjected to heat)

Plate (34): R3SP
(Group F, structural concrete, waste plastic, 3 bars long. reinf. & subjected to heat)

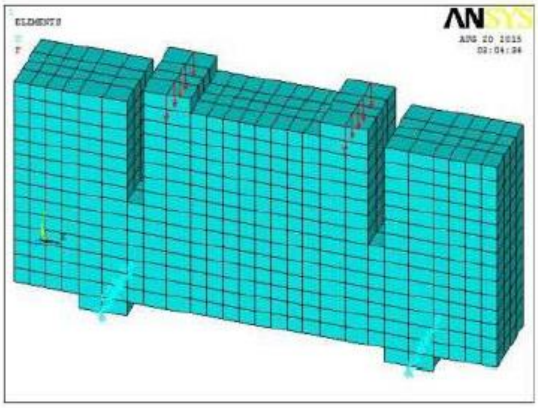


Fig.(9): F.E. mesh

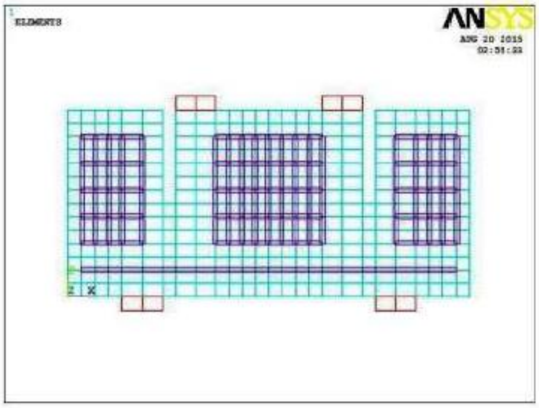


Fig.(10): Reinforcement

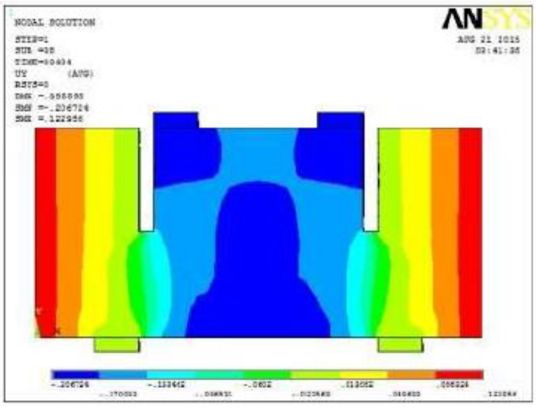


Fig.(11): Slip

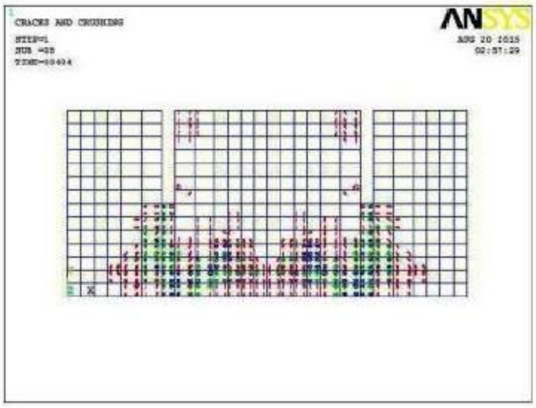


Fig.(12): Cracks

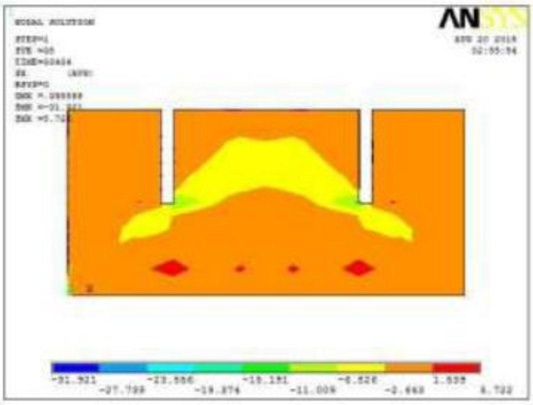


Fig.(13): SX stresses

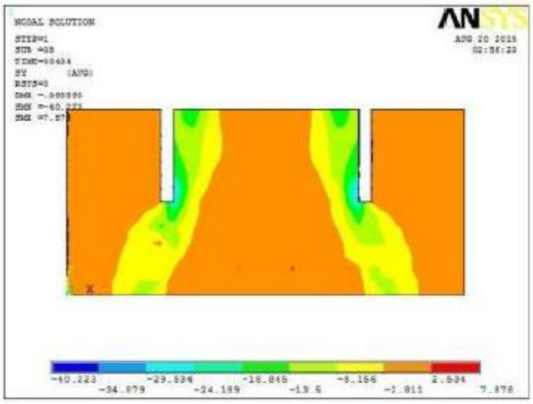


Fig.(14): SY stresses

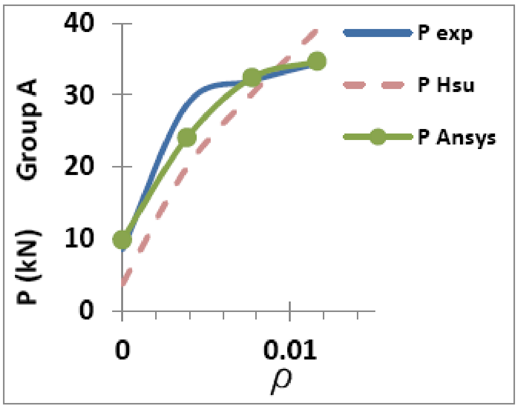


Fig.(15): P-ρ for Group A

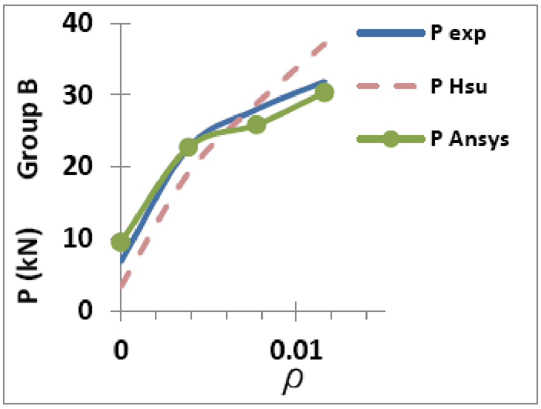


Fig.(16): P-ρ for Group B

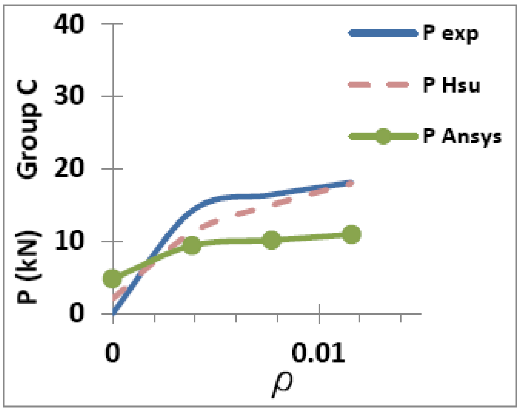


Fig.(17): P-ρ for Group C

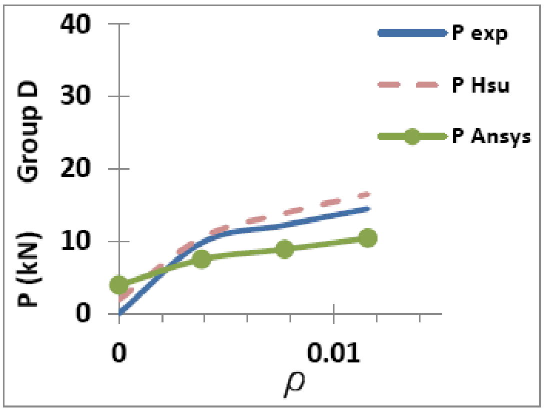


Fig.(18): P-ρ for Group D

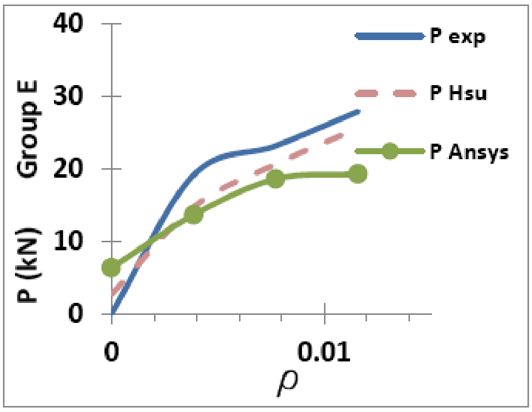


Fig.(19): P-ρ for Group E

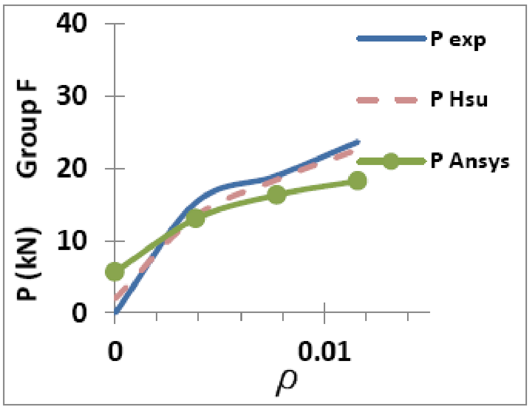


Fig.(20): P-ρ for Group F

Plate (35): Waste plastic concrete 150mm cube heated to 300°C for 28 minutes