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Effect of Elevated Temperature on Punching Shear of Regular and Irregular Shaped Self-Compacted Concrete Slabs

Luma Fadhil H.*
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Abstract

The exposure of reinforced concrete slabs to high temperature causes changes in their structural behavior.

This work aims to study the post-heating behavior of self compacted concrete (SCC) regular (square) and irregular (trapezoidal) shaped flat plates and assessing the residual punching shear strength of these slabs.

Twenty four reduced scale reinforced concrete slab specimens divided into two main groups (square and trapezoidal slabs), each of which consists of twelve slab identical in size and shape but different in concrete compressive strength (30,50,70) MPa. These specimens are subjected to different temperature levels (100, 300, 500) ^{0}C and still heated in that temperature level for one hour using an electric furnace and the results are compared with specimens tested at room temperature 25 ^{0}C.

The effect of specimen shape, heating level, concrete compressive strength on the punching shear resistance of slabs are discussed in details.

Results indicate that the reduction in punching shear strength is ranged between (0 and 16) %, for square slab, at maximum temperature exposure (500)^{0}C, while this rate is ranged between (6.3 and 40.4) % for trapezoidal slabs. This indicates that the punching shear resistance of regular shaped slabs is higher than that of irregular shaped slabs.

Keywords: Punching shear, self compacted concrete, elevated temperature, regular and irregular shaped flat plates.

تاثير التدرج الحراري على مقاومة القص الثاقب للبلاطات المنتظمة وغير المنتظمة الشكل والمكونة من الخرسانة الذاتية الرص

الخلاصة

ان تعرض البلاطات الخرسانية المسلحة الى درجات الحرارة العالية تسبب تغيرا واضحا في اداء وظيفتها. يهدف هذا البحث الى دراسة مقاومة القص الثاقب للبلاطات الخرسانية ذاتية الرص (منتظمة وغير منتظمة الشكل), بالاضافة الى دراسة تاثير الحرارة على مقاومة القص الثاقب لهذه البلاطات. تم اجراء الدراسة على 24 بلاطة خرسانية مسلحة مقسمة الى مجموعتين رئيسيتين تختلف عن بعضهما في شكل النموذج (مربع وشبه منحرف), كل مجموعة تحتوي على 12 بلاطة متماثلة في الشكل والابعاد ولكن تختلف عن بعضها في مقاومة الانضغاط للخرسانة (30,50,70) MPa . تم تعريض جميع هذه النماذج الى درجات حرارة مختلفة (100,300,500))^{0} م لمدة ساعة كاملة ثم تم مقارنتها مع تلك النماذج التي تم فحصها بدرجة حرارة الغرفة 25 ^{0} م . في هذا البحث تم دراسة تاثير شكل النموذج, درجة حرارة الحرق

* Engineering College, University of Al-Mustansyria /Baghdad

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

ومقاومة الانضغاط للكونكريت على مقاومة القص الثاقب للبلاطات بشكل مفصل. حيث لوحظ انخفاض واضح في مقاومة القص الثاقب بمقـدار (0-16)% للبلاطـات المربعـة و (4،6-4،40)% للنماذج الشبه منحرفة عند اعلى درجة حرارة تعرضت لها النماذج وهي (500)^{0}م، وهذا يدل على ان مقاومة القص الثاقب للبلاطات المنتظمة الشكل اعلى منها للبلاطات الغيـر منتظمة الشكل.

Introduction

Flat plats are very common and competitive structural system for cast in place slabs in buildings since no beam is involved. The means that the formwork of these slabs is very simple and economic. Using this type of structure presents however a serious disadvantage because of the risk of a brittle punching failure at the connection between the slab and the column[1].

Large scientific efforts have been done in the past to predict the punching shear strength of the slab – column connection. However, some punching failures that occurred during the past decades showed that it is necessary to improve design methods to avoid this type of failure [1].

Technological advances in this field came with new materials and techniques to improve punching shear resistance of flat plates such as, adding fibers into the concrete [2]or using special types of concrete like self compacted concrete[3]and high strength concrete [4].

Self compacted concrete (SCC) is a very important advance in concrete technology in recent time. The specific properties of SCC help to improve the quality of concrete structures of today [5].

In the last few years, irregular shaped flat plate slabs are commonly used in high rise residential buildings. Architectural shape, interior layouts and requirements often dictate the use of irregular shaped flat slabs[6]. However, the currently available building codes don't provide specific guidelines for designing irregular shaped flat slabs or building. Therefore, the design and testing of the specimens in this investigation were done experimentally.

The well-known capacity of concrete to withstand high temperature and fire is put to the test by the most recent high and ultra-high performance concrete [7, 8]. There are several reasons to explain such sources of high temperatures, such as strong winds or droughts heat waves. But, according to several scholars, the most critical fire trigger is represented by isolated homes and buildings [9]. The exposure of structural members to high temperature causes change in the properties of their constituents, namely concrete and steel, and in structural behavior. So, in this study the effect of exposure to elevated temperature on the punching shear strength of regular and irregular shaped SCC slabs are tested, evaluated and discussed.

Experimental Programme

Materials

Ordinary Portland cement (type 1) was used in all mixtures. The cement is (Taasloja). Limestone powder LSP with surface area of 3100 cm^2/g was used as filler. The chemical composition of cement and

LSP are shown in Table (1). The chemical composition of cement complies with the Iraqi Standard Specification I.Q.S. No.5, 1984 requirements[10].

Natural siliceous sand of Al-Ukhaider region with maximum size of 4.75mm and fineness modulus, specific gravity and absorption of 2.98, 2.7 and 1.5 % respectively is used in this work. Crushed gravel with maximum size of 10 mm was used. Tables (2) and (3) show the grading of sand and gravel respectively. It's compatible to the limits of I.Q.S. No.45, 1984 requirements for sand and gravel[11]. The test for sand and gravel was made in the Laboratory of Materials in the Engineering College of Al-Mustansirya University

The superplasticizer based on polycarboxylic ether was used, it has the trade mark Glenium 51 (G 51) [12]. While, tap water was used for casting and curing all the specimens.

The steel reinforcement deformed bar mesh of Ø 5mm was used as bottom mesh reinforcement with 10 mm concrete cover. Yield strength of the wires is 310 MPa while the ultimate strength is 550 MPa. Figure (1) shows the arrangement of the wires in regular shaped slabs (square) and irregular shaped slabs (trapezoidal). All the specimens were designed to fail in punching.

Mix Design

Several mixtures were tested in order to find the desired strength. Then three mixtures (S30, S50, S70) were chosen with cube compressive strength of (30, 50, 70) MPa. The composition of mixtures used in this investigation is shown in Table (4)

Fresh Properties

Self compacted concrete is defined as a high performance concrete that has excellent deformability in the fresh state and high resistance to segregation and can be placed and compacted under its self weight without applying vibration. In this study, the slump flow and L-box tests were done. The results of fresh properties are shown in Table (5)

Preparation of Specimens

After testing the fresh properties, the concrete was poured in the moulds. For testing the compressive strength 12 cube of size (150*150*150) mm for each mixture were cast, while, 8 beams of size (100*100*500) mm for each mixture were cast for testing in flexure. For testing punching shear resistance, 4 regular shaped (square) slab and 4 irregular shape (trapezoidal) slab were cast for each mixture. Then, all the specimens were covered with polythene sheets for 24 hours. After that, the specimens were demolded and were put in water for 28 days for curing. After the period of curing, the specimens (cubes, prisms and slabs) were put in an electric furnace to study the effect of elevated temperature (100, 300 and 500) ^{0}C on compressive, flexural, punching shear strengths respectively, and these specimens were tested and compared with the specimens still at room temperature 25^{0}C.

The electric furnace used for heating all the specimens is shown in Figure (2), the applied duration of heating for each level of temperature was 1 hour. This duration is enough to heat the specimens completely. At the end of the exposure time, the furnace was switched off and the specimens were allowed to cool for 24 hours to ensure complete cooling of the specimens.

Results and Discussion

Results of Compressive and Flexural Strengths

In order to obtain a better understanding of the behavior of reinforced concrete slabs after exposure to high temperature, it is important to study the properties of concrete (compressive and flexural strengths) subjected to high temperature in first place.

In this study three cubes of concrete of (150)mm size and two prisms of (100*100*500) mm, with each level of heating and for each mixture, were tested to obtained the compressive and flexural strengths respectively. Table (6) shows the test results, while Figure (3) and (4) show the relation between compressive, flexural strengths with high temperature respectively.

From the results illustrated in Table (6) and in Figures (3 and 4) the following conclusions are obtained:

1. The compressive strength decreases by about (4.6-20.6, 1.4-17.8, 0.3-29.3)% for S30, S50 and S70 mixes respectively, when the specimens subjected to (100, 300, 500) ^{0}c compared with reference specimens tested at room temperature.
2. The flexural strength also decreases with the increase of heating level. This reduction is about (2.2-15.5, 1.4-15.7, 2.1-23.2)% for (S30, S50 and S70) respectively.
3. it is noticed that, at 500 ^{0}c the reduction in compressive and flexural strengths in high strength SCC (S70) is higher than that of normal strength SCC (S30) by about 42.2%for compressive strength and by about 49.7% for flexural strength. These results are consistent to the rule that, high strength concrete is more sensitive to high temperature because of its reduced porosity, which favor steam-pressure build up and decrease thermal diffusivity [13].

Results of Punching Shear Strength of Slabs Exposed to Different Level of Temperature

Punching test was carried out on two series of slabs as follows:

Series 1: this series consists of 12 regular shaped (square) slabs with dimensions (45*45*5) cm.

Series 2: this series consists of 12 irregular shaped (trapezoidal) slabs with dimensions (45*20*70) cm.

All the slabs were supported along their perimeter and tested by pushing down square steel column of dimensions (4*4) cm on the center of gravity of each slab. While the deflection was measured using a dial gauge of 0.01 mm sensitivity. Figure (5) shows the loading test system. Table (7) and (8) show the results of first crack load, ultimate load, first crack deflection, ultimate load deflection, failure perimeter and failure angle for slabs in series 1 and 2 respectively. While Figure (6) shows the failure pattern and Figure (7) and (8) show the load deflection curves for slabs in series 1 and 2 respectively.

From Tables (7, 8) and Figures (6-8), the following observations are noticed:

1. First crack loads are approximately equal for all slabs. While the deflection at

first crack is different from one slab to another, this may be attributed to the stiffness of the concrete.

2. The ultimate load increases with the increase of concrete strength. This increment is about 35.1% in square slabs and range from 4.8 to 11.9% in trapezoidal slabs. This may be attributed to the fact that, the rising of concrete strength increases the punching shear strength, but high strength concrete presents lower toughness [3].
3. It is clear from test results that, the value of ultimate load capacity are related to compressive strength, which decreases when exposed to high temperature. The reduction in ultimate load for square specimens, subjected to (100, 300, and 500)^{0}c if compared with slabs tested at 25^{0}c, are (2.7-13.5, 22-26, 0-16) %, while these rates are (14.2-36, 15.9-45.5, 6.3-40.4) % for trapezoidal specimens. These results are different from those obtained by other researchers[4].
4. It is observed that the ultimate loads for square slabs are higher than that for trapezoidal slabs (except for S30T25). This may be because that, the area subjected to the applied load in irregular shaped slabs is smaller than that in regular shaped slabs and that resulted in marginal decrease in punching shear strength [14]. These results are similar to that obtained by other researchers[14], but different to that obtained by reference[6].

Conclusions

1. When subjected to high temperature, the compressive strength decreases by about (0.3-29.3) % compared to specimens tested at room temperature.
2. The flexural strength also decreases with the increase of heating level by about (1.4-23.2) % compared to specimens tested at room temperature.
3. At 500 ^{0}C the decrease in compressive and flexural strengths in HSSCC (S70) is higher than that in NSSCC (S30) by about 42.2% for compressive strength and by about 49.7% for flexural strength. These results are consistent to the rule that, high strength concrete is more sensitive to high temperature because of its reduced porosity, which favor steam-pressure build up and decrease thermal diffusivity.
4. First crack loads are approximately equal for all slabs. While the deflection at first crack is different from one slab to another, this may be attributed to the stiffness of the concrete.
5. The ultimate load increases with the increase of concrete strength. This increment is about 35.1% in square slabs and range from 4.8 to 11.9% in trapezoidal slabs. This may be attributed to the fact that, the rising of concrete strength increases the punching shear strength, but high strength

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Table (1) Chemical Composition of Cement and LSP

Oxides		Cement %	LSP %
Calcium oxide	CaO	62.44	56.10
Silicon oxide	SiO_2	20.25	1.38
Aluminum oxide	Al_2O_3	4.73	0.72
Ferric oxide	Fe_2O_3	4.32	0.12
Magnesium oxide	MgO	2.19	0.13
Sulphur trioxide	SO_3	1.88	0.21
Loss on Ignition	L.O.I	3.5	40.56
Insoluble residue	I.R	1.33	-
Lime saturated factor	L.S.F	0.66	-
C3A		8.10	-

Tests of cement were made in the National Center for Construction Laboratories and Research and for LSP were made in Faluja Cement Factory

Table (2) Grading of Fine Aggregates

Sieve size (mm)	% Passing by weight	IQS 45-84 limits zone-2-
10.0	100	100
4.75	93.5	90-100
2.360	85.6	75-100
1.180	76.0	55-90
0.600	42.7	35-59
0.300	10.7	8-30
0.15	1.9	0-10

Table (3) Grading of Coarse Aggregate

Sieve size (mm)	% Passing by weight#	IQS 45-84 limits
20	100	100
14	99	90-100
10	57	50-85
5	4.5	0-10
2.36	0	-------

Table (4): Mix Proportions of all Mixes by Weight.

Mix notation	Cement Kg/m^3	LSP Kg/m^3	Sand Kg/m^3	Gravel Kg/m^3	Water L/m^3	Superplasticizer L/m^3
S30	367	195	841	791	183	4
S50	474	105.3	807.4	784	180	8.1
S70	540	64	880	780	155	18

Table (5): Results of Slump Flow Diameter, T50, BR, T20 and T40

Mix	D (mm)	T50 (sec)	BR	T20 (sec)	T40 (sec)
S30	770	3.5	1.0	1.5	2.2
S50	720	4.1	0.93	2.2	4.0
S70	658	8.1	0.82	5.5	7.3

Table (6): Results of Compressive and Flexural Strengths

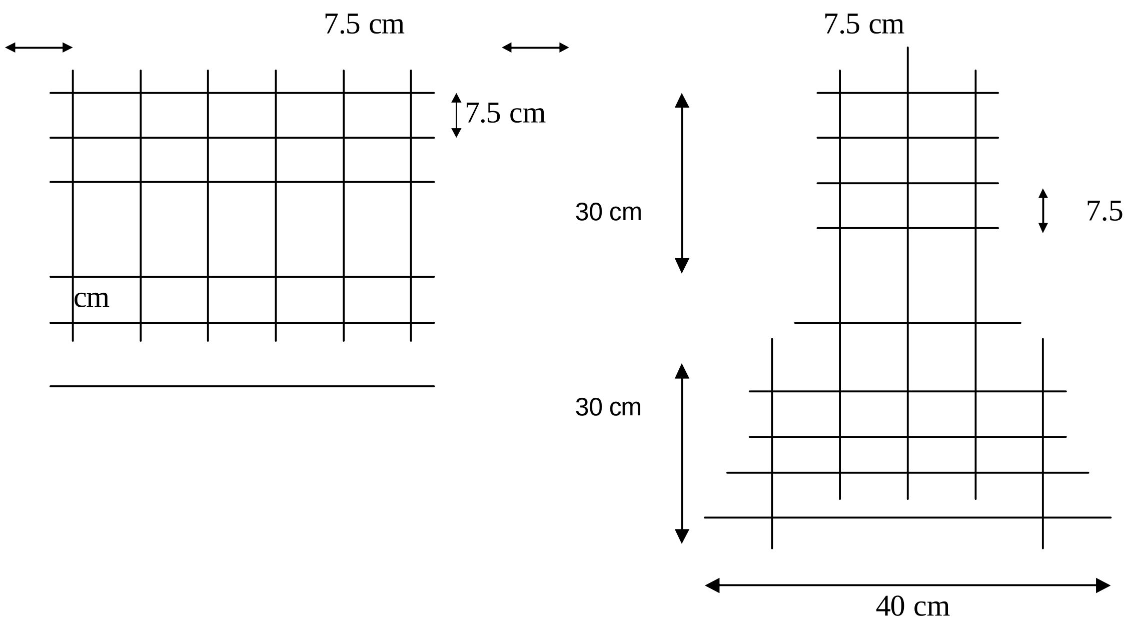
Mixture No.	Compressive Strength (MPa)*				Modulus of Rupture (MPa)**			
	T25	T100	T300	T500	T25	T100	T300	T500
S30	32.5	31.0	28.5	25.8	4.5	4.4	4.1	3.8
S50	48.8	48.1	45.3	40.1	7	7.1	6.8	5.9
S70	68.5	68.3	62.7	48.4	9.5	9.3	8.8	7.3

Table (7): Test Results for Series 1 (Square Specimens)

Slab No.	First crack load (kN)	Ultimate load (kN)	First crack deflection (mm)	Deflection at ultimate load (mm)	Type of Failure	Failure Perimeter (mm)	Failure angle
S30 T25	7.5	37	0.5	7.1	punching	132	15.1
S30 T100	7.5	36	0.47	5.58	punching	128	15.5
S30 T300	7	35	0.8	8.1	punching	129	14.1
S30 T500	8	32	0.7	6	punching	117	13.1
S50 T25	7	50	0.45	7.6	punching	145	14.7
S50 T100	7	39	0.55	7.0	punching	133	14.1
S50 T300	7	38	0.75	8.8	flexure	-	-
S50 T500	7.5	37	0.6	7.5	flexure	-	-
S70 T25	7	50	0.47	8.4	punching	152	14.4
S70 T100	7	50	0.41	8.8	punching	128	17.4
S70 T300	7	43	0.63	9.6	punching	108	16.9
S70 T500	7	42	0.6	8.5	punching	108	15.1

Table (8): Test Results for Series 2 (Trapezoidal Specimens)

Slab No.	First crack load (kN)	Ultimate load (kN)	First crack deflection (mm)	Deflection at ultimate load (mm)	Type of Failure	Failure Perimeter (mm)	Failure angle
S30 T25	7	42	1.1	5.8	punching	100	18.4
S30 T100	7	36	1.1	7.7	punching	97	20.3
S30 T300	7	34	1.5	5.3	punching	114	18.4
S30 T500	7	27	0.7	5.1	punching	103	17.4
S50 T25	7	44	0.65	5.8	punching	101	19.0
S50 T100	7	37	0.65	3.4	punching	128	14.1
S50 T300	7.5	35	0.8	4.5	punching	112	17.4
S50 T500	7	24	0.9	5.1	punching	126	16.4
S70 T25	7	47	0.55	8.5	punching	108	16.9
S70 T100	7	44	0.65	5.5	punching	109	18.4
S70 T300	7	40	0.85	5.5	punching	90	18.4
S70 T500	7	28	1.3	5.3	flexure	-	-



The dimensions of square specimens are 45*45*5 cm

The dimensions of trapezoidal specimens are 45*20*70 cm

Figure (1) The Arrangement of the Wires in Regular Shaped Slabs (Square) and Irregular Shaped Slabs (Trapezoidal).

Figure (2) The Furnace used

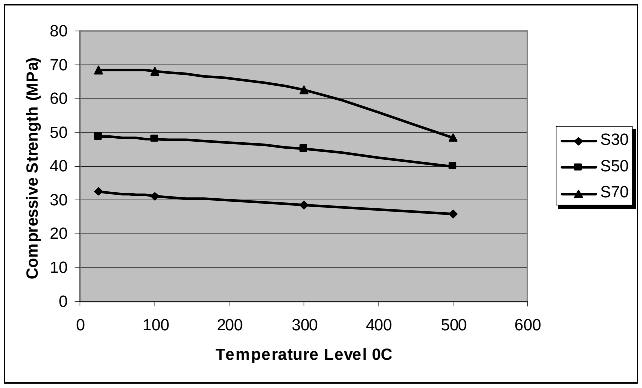


Figure (3): The Relation between Compressive Strength and Temperature level for all Mixes

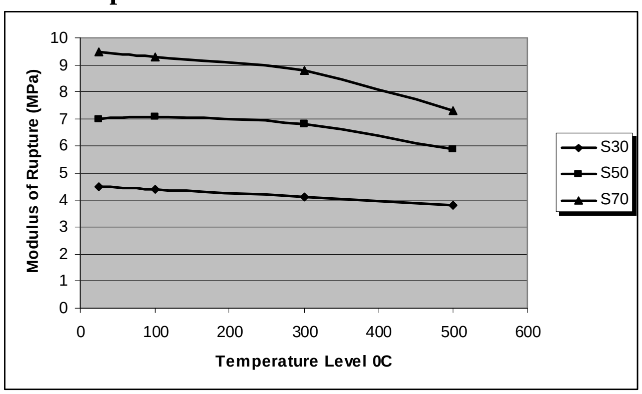


Figure (4): The Relation between Modulus of Rupture and Temperature level for all Mixes

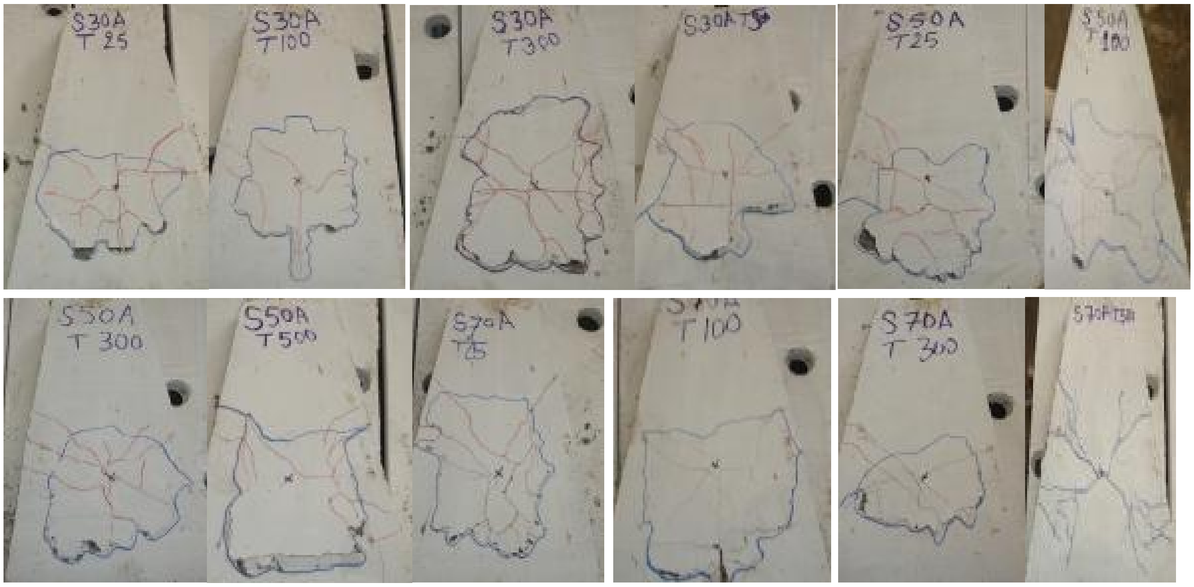
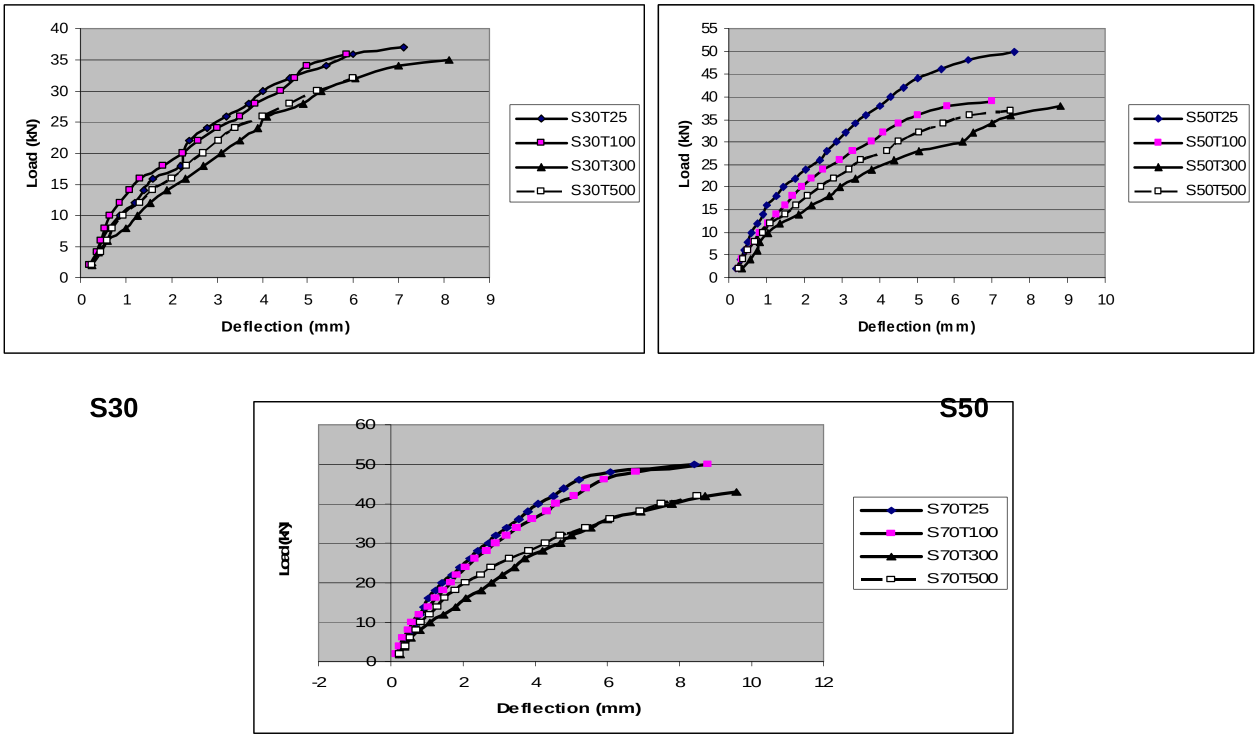


Figure (5): The Loading Test System
Trapezoidal Specimens

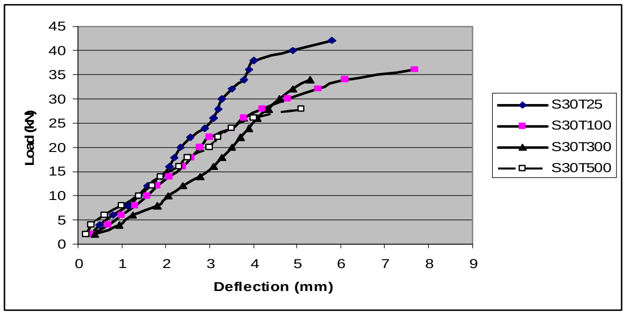
Square Specimens
Figure (6): Failure Patterns for Trapezoidal and Square Slabs

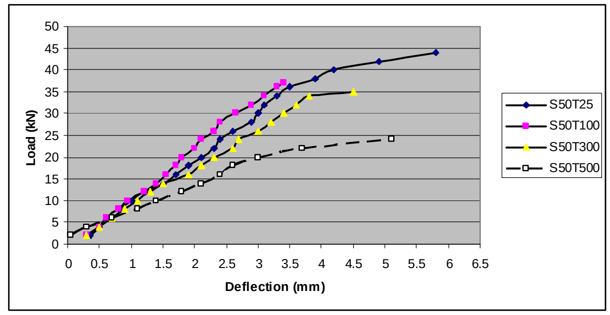


S30 **S50**

S70

Figure (7): load Deflection Curves for Slabs in Series 1(Square Specimens)





S30 **S50**

S70

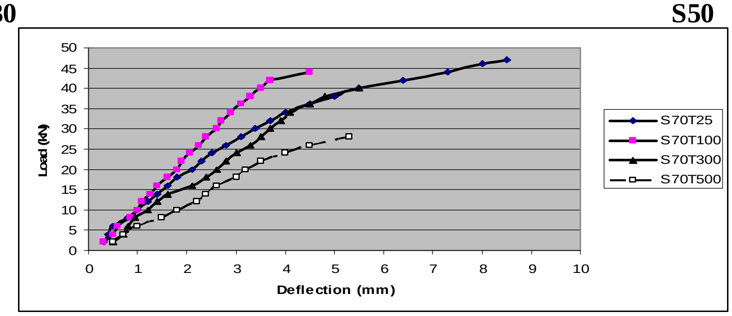


Figure (8): load Deflection Curves for Slabs in Series 2 (Trapezoidal Specimens)