CHAPTER THREE

EXPERIMENTAL WORK

3.1 General

The main purpose of this research work is to investigate the structural behaviour and shear capacity of nanosilica reactive powder concrete (NSRPC) beams having many variables. From each mix used in casting these beams, control specimens were taken which allowed investigating the mechanical properties of this new concrete. The investigated properties include compressive strength, splitting tensile strength, modulus of rupture and modulus of elasticity.

The parameters considered in the present experimental program are carefully outlined and a full detailed description of the test beams is given. The experimental setup and instrumentation part of the test program are explained .

3.2 Test Program

In all, sixteen simply supported NSRPC beams were tested up to failure under the action of two point symmetric loading Fig. 3.1. The beams were singly reinforced, rectangular in section and had constant dimensions. The overall length of each beam was 1500 mm, clear span 1400mm, width 100mm, and overall depth 200mm. The beams were designed to fail in shear and in order to evaluate the actual capacity of nanosilica reactive powder concrete in shear, all of the test beams (except one) had no steel stirrups. The only shear reinforced beam was included in the test program to show qualitatively the contribution of shear reinforcement in the overall shear capacity of NSRPC beams.

The main parameters studied in the experimental program were:

1-Percentage of nanosilica (NS)

2-Percentage of silica fume (SF)

3-Volume fraction of steel fibers (V_f)

4-Longitudinal steel reinforcement ratio (ρ) where ρ=As/(bd)

5-Shear span to effective depth ratio (a/d)

6-Presence of steel stirrups

7-Dual absence of (NS) and (V_f)

To study the effect of each parameter, a typical NSRPC beam was considered with the following properties: NS=3%, SF=15%, V_f=2%, ρ=0.0742, a/d=3.5, No steel stirrups.

The effect of each parameter was investigated while keeping the values of the remainder parameters constant. Accordingly, and for convenience, the sixteen test NSRPC beams were classified into seven groups (as listed in Table 3.1) such that the value of only one parameter was varied in the beams of a specified group with the values of the other parameters kept constant representing those of the mentioned typical beam.

The dimensions and details of all the test beams are shown in Fig. 3.2 to 3.7 and Table 3.1. Following is a description of each of the seven groups of this experimental program.

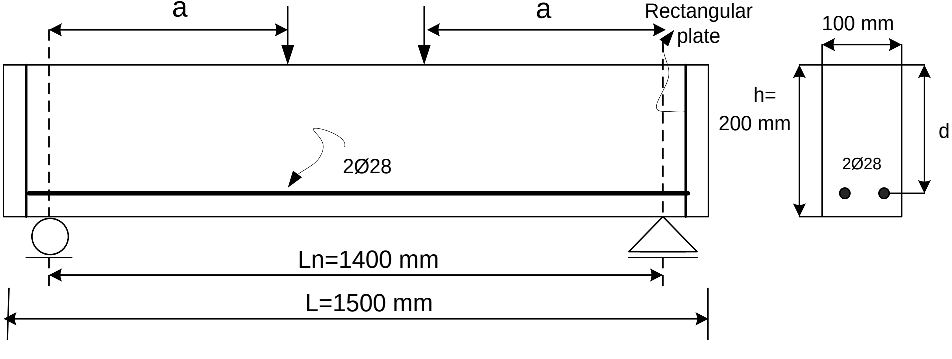

Fig. 3.1:Details of Typical Tested Beam Designed to Fail in Shear

3.2.1 Group 1-Changing NS

Four beams were considered in this group, designated as B1, B2, B3 and B4.In these beams SF=15%, V_f=2%, ρ=0.0742, a/d=3.5 and had no steel stirrups. The NS content was 0% (for B1), 1%(for B2), 2%(for B3) and 3%(for B4).These represent percentages of cement by weight as an addition and not as replacement of cement.

The main purpose of this group is to study the effect of nanosilica content on the shear strength of NSRPC beams. Strictly, the use of nanosilica in a reactive powder concrete mix generally improves the properties of the concrete when hardened and the 3% NS value was found the mostly effective ratio among the four investigated ratios.

It must be pointed out here that an extra mix having NS=4% was also tried in this research program but, in comparison with the 3% NS mix, it gave weaker properties of the hardened concrete. Therefore it was concluded that a percentage of NS content greater than 3% in the mix would not be beneficial for improvement of concrete strength and economically undesirable and thus it was rejected.

3.2.2 Group 2-Changing SF

Three beams were constructed to describe this group, designated as B5, B6 and B4. In these beams NS=3%, V_f=2%, ρ=0.0742, a/d=3.5 and had no steel stirrups. The percentages of SF were varied 5%(for B5), 10%(for B6) and 15%(for B4). These represent percentages by weight of cement as an addition and not as replacement of cement.

According to this group, the influence of silica fume content on the shear capacity of NSRPC beams can be observed. The 15% value of SF was found optimum since it led to a relatively slight increase in the hardened concrete properties than the other two percentages of 5% and 10%.

It is also of interest to not here that two extra mixes having SF=20% and 25% were also tried but gave weaker strength results of the hardened concrete than the mix of SF=15%. Therefore these two extra percentages of SF were disregarded in the test beams.

3.2.3 Group 3-Changing Vf

Three beams were considered in this group, designated as B7, B8 and B4. In these beams NS=3%, SF=15%, ρ=0.0742, a/d=3.5 and had no steel stirrups. The V_f content was 0%(for B7), 1%(for B8) and 2%(for B4).

According to this group, the influence of the volume fraction of steel fibers on the structural behaviour and shear strength of NSRPC beams can be detected. Taking into consideration the aspect ratio of the steel fibers used and the type of concrete mix, a maximum of 2% fibers content was considered practical to achieve uniform distribution of fibers within the fresh and hardened concrete.

If a higher percentage of V_f was used, mixing problems would arise as a result of the substantial immediate loss of workability of the mix and non-uniform distribution of fibers due to the effect of fibers balling which would require great efforts and relatively long vibration time to manufacture a beam.

3.2.4 Group 4-Changing ρ

Three beams were used to describe this group, designated as B4, B9 and B10. In these beams NS=3%, SF=15%, V_f=2%, a/d=3.5 and had no steel stirrups. The longitudinal steel reinforcement ratio ρ was varied as follows: ρ=0.0742(for B4), ρ=0.0857(for B9) and ρ=0.0911(for B10).

According to this group, the influence of the longitudinal steel reinforcement ratio (ρ) on the shear capacity of NSRPC beams can be investigated. For fixed dimensions of a reinforced concrete beam section, the use of larger steel area of bars in the section does normally enhance its shear strength as a result of the increased "dowel action".

3.2.5 Group 5-Changing a/d

Six beams were considered in this group, to show the effect of varying the shear span to effective depth ratio (a/d) on the shear strength of NSRPC shallow beams. Three of these six beams designated as B4, B11 and B12,had V_f=2% and a/d varied such that a/d=3.5(for B4), 3(for B11) and 2.5(forB12).The other three beams, designated as B8,B13 and B14, had V_f=1% with a/d varied such that a/d=3.5(for B8), 3(for B13) and 2.5(for B14).In all beams of this group, the values of the other parameters were kept constant (NS=3%, SF=15%, ρ=0.0742 and no steel stirrups).

3.2.6 Group 6-Presence of Steel Stirrups

Two beams were considered to describe this group, designated as B7 and B15. In these beams NS=3%, SF=15%,V_f=0%, ρ=0.0742, a/d=3.5 .

Beam B7 had no steel stirrups while beam B15 had 6mm diameter steel stirrups spaced @85mm c/c within its left and right shear spans as shown in Fig. 3.6.

Comparison between the two beam's load carrying capacities will give an idea about the contribution of the presence of steel stirrups on the shear strength of a NSRPC beam.

3.2.7 Group No. 7-Dual Absence of NS and Vf

Two beams were considered to describe this group, designated as B4 and B16. In these two beams SF=15%, ρ=0.0742, a/d=3.5 and no steel stirrups. Beam B4 had NS=3% and V_f=2% while in beam B16 the nanosilica and steel fibers were eliminated (NS=0% and V_f=0%).

Comparison between the two beam's load carrying capacities will give an idea about the amount of decrease in the shear strength of a NSRPC beam due to the dual absence of NS and V_f in the concrete of the beam.

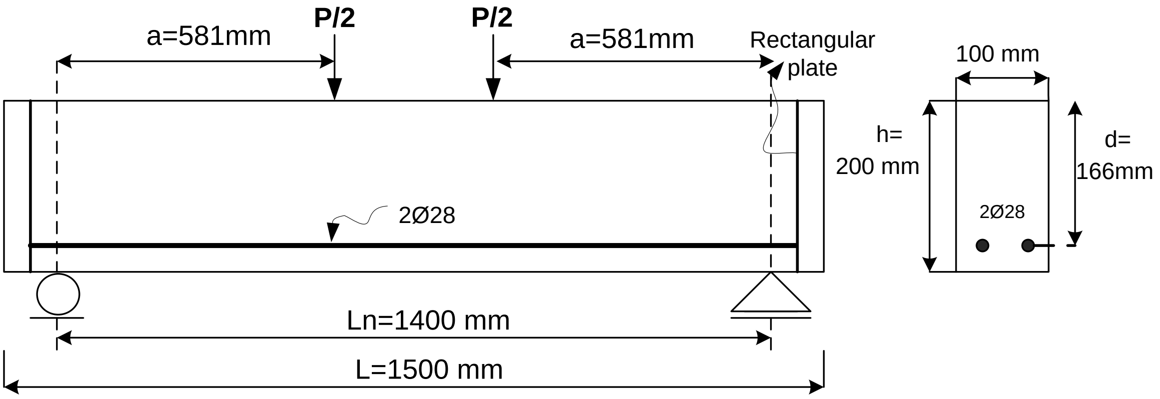

Fig. 3.2:Details of Beams of Group(1,2,3 and7) Tested Beams Designed to Fail in Shear

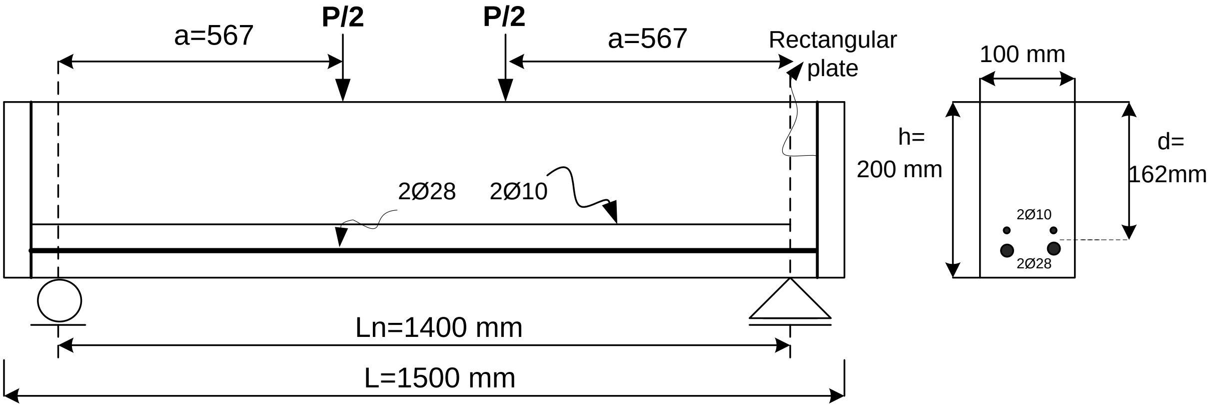

Fig. 3.3:Details of B9 Test Beam Designed to Fail in Shear

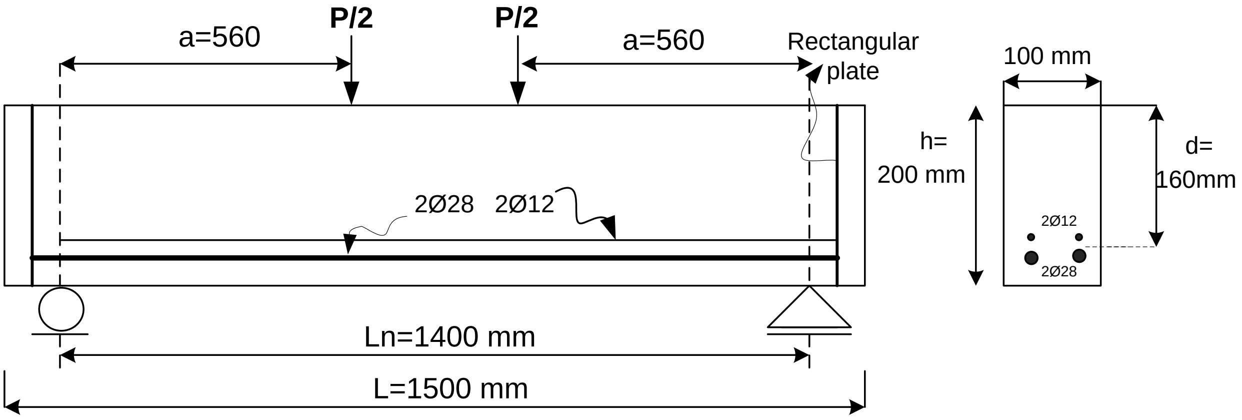

Fig. 3.4:Details of B10 Test Beam Designed to Fail in Shear

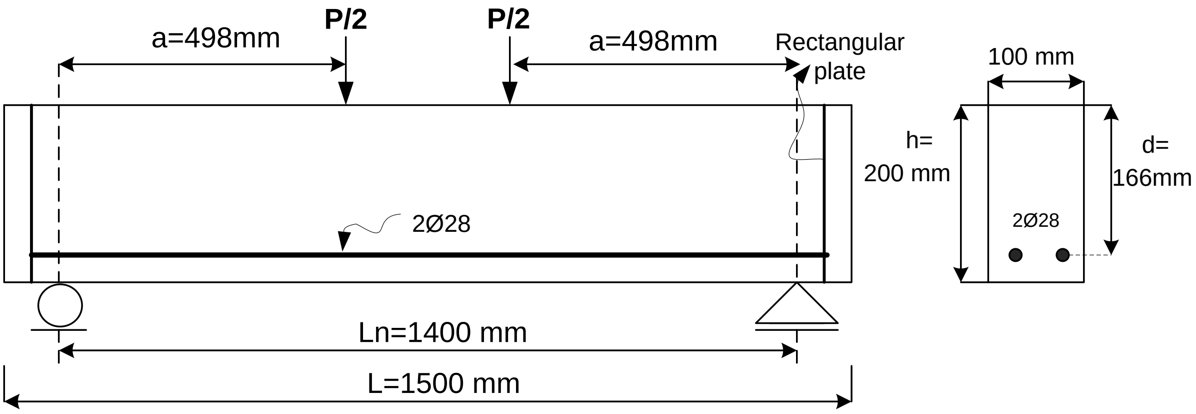

Fig. 3.5:Details of B11 and B13 Test Beams Designed to Fail in Shear

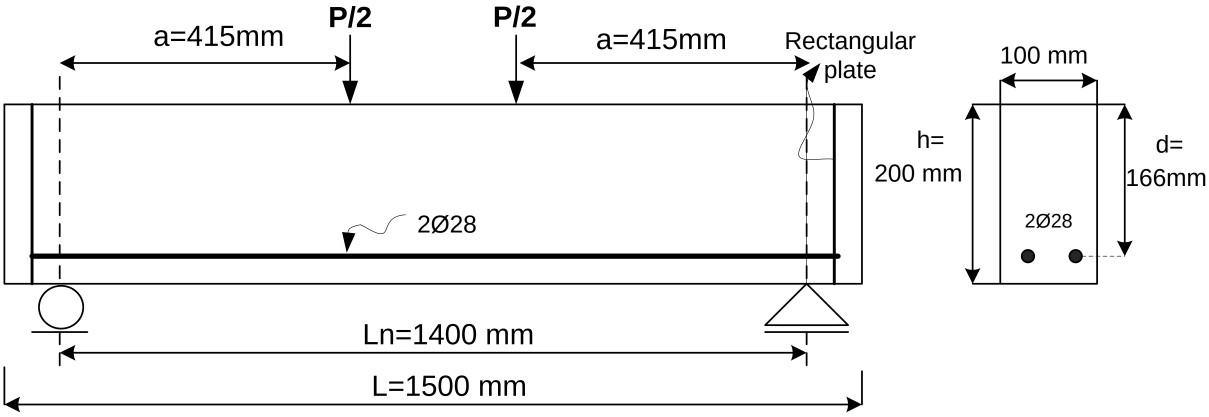

Fig. 3.6:Details of B12 and B14 Test Beams Designed to Fail in Shear

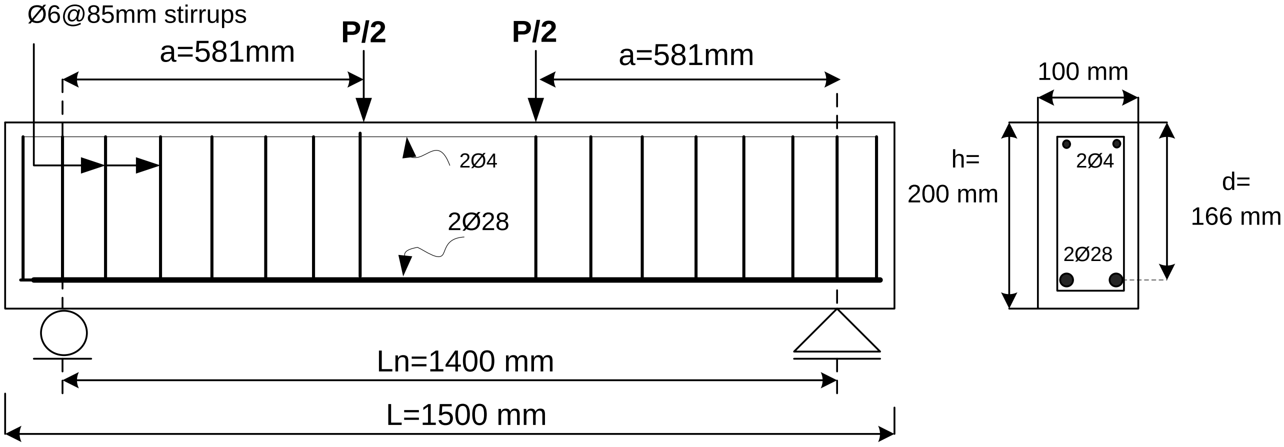

Fig. 3.7:Details of B15 Test Beam Designed to Fail in Shear

Table 3.1:Beam Details and Concrete Properties

Group No.	Variable Designation	beams	NS %	SF%	V_f%	ρ	a/d	stirrups
1	NS	B1	0	15	2	0.0742	3.5	-
		B2	1	15	2	0.0742	3.5	-
		B3	2	15	2	0.0742	3.5	-
		B4	3	15	2	0.0742	3.5	-
2	SF	B5	3	5	2	0.0742	3.5	-
		B6	3	10	2	0.0742	3.5	-
		B4	3	15	2	0.0742	3.5	-
3	Vf	B7	3	15	0	0.0742	3.5	-
		B8	3	15	1	0.0742	3.5	-
		B4	3	15	2	0.0742	3.5	-
4	ρ	B4	3	15	2	0.0742	3.5	-
		B9	3	15	2	0.0857	3.5	-
		B10	3	15	2	0.0911	3.5	-
5	a/d	B4	3	15	2	0.0742	3.5	-
		B11	3	15	2	0.0742	3	-
		B12	3	15	2	0.0742	2.5	-
		B8	3	15	1	0.0742	3.5	-
		B13	3	15	1	0.0742	3	-
		B14	3	15	1	0.0742	2.5	-
6	Presence of Steel Stirrups	B7	3	15	0	0.0742	3.5	-
		B15	3	15	0	0.0742	3.5	Ø6@85mm
7	Dual Absence of NS and Vf	B4	3	15	2	0.0742	3.5	-
		B16	0	15	0	0.0742	3.5	-

3.3 Materials

3.3.1 Cement

Ordinary Portland cement (ASTM Type I) manufactured in Iraq by the trade name "Mass" was used in this research. It was stored in a suitable place to avoid any exposure to hazard conditions. The chemical and physical properties of this cement are shown in Tables 3.2 and 3.3 respectively. Test results indicate that the adopted cement conformed to the Iraqi specification No.5/1984 [54].

Table 3.2:Chemical Composition and Main Compounds of Cement*

Oxides Composition	Content %	Limits of Iraqi Specification No.5/1984
CaO	60.6	……..
SiO_2	19.60	……..
Al_2O_3	5.52	……..
Fe_2O_3	3.11	……..
MgO	1.8	<5.00%
SO_3	2.27	<2.80%
L.O.I.	1.6	<4.00%
Insoluble Residue	1.10	<1.5
Lime Saturation Factor, L.S.F	0.93	0.66-1.02
Main Compounds(Bogue´s Equations)		
C_3S	57.04	……..
C_2S	14.83	……..
C_3A	9.25	……..
C_4AF	10.95	………

*Chemical analysis was conducted by the National Center for Construction Laboratories and Researches/Baghdad.

Table 3.3: Physical Properties of Cement*

Physical Properties	Test Results	Limits of Iraqi Specification No.5/1984
Specific Surface Area (Blaine Method),m^2/kg	2650	≥230
Setting Time (Vicat Apparatus), Initial Setting,hr:min Final Setting hr:min	 2:30 4:10	 ≥00:45 ≤10:00
Compressive Strength, MPa 3days 7days	 17 24:7	 ≥15.00 ≥23.00
Soundness(Autoclave Method),%	0.35	≤0.8

* Physical analysis was conducted by the National Center for Construction Laboratories and Researches/Baghdad.

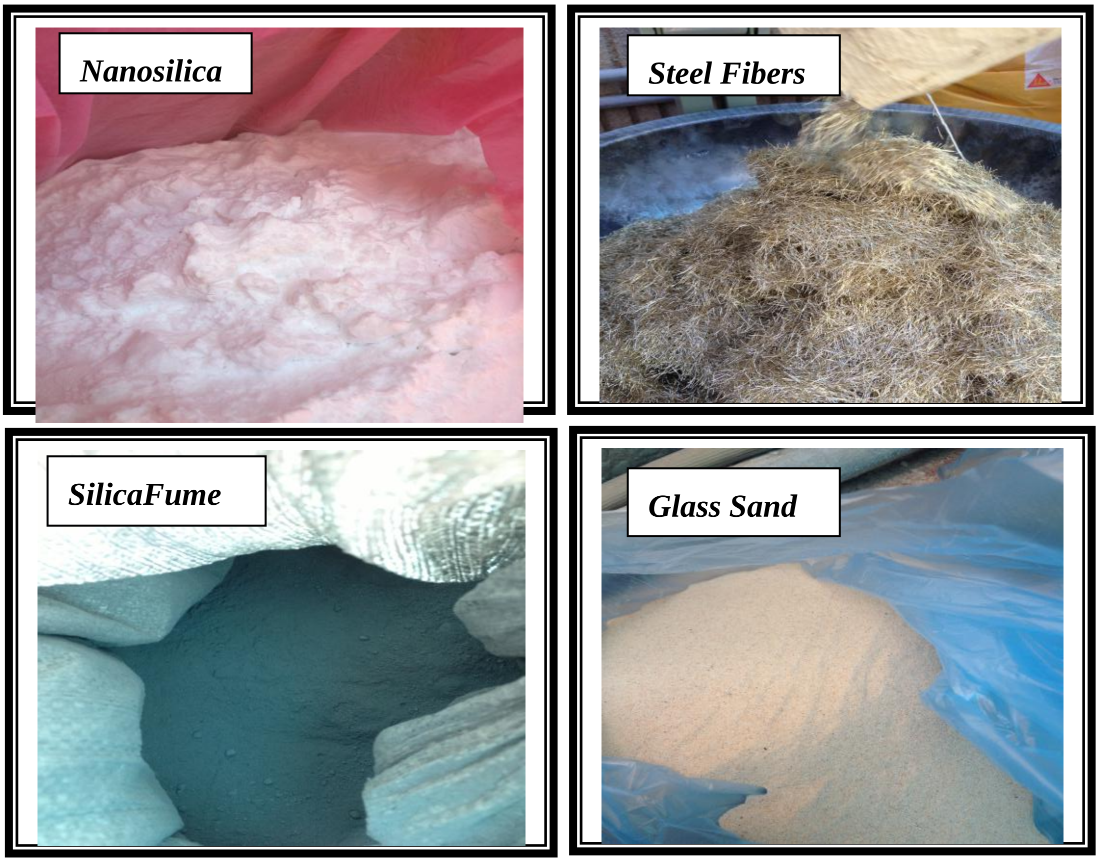

Plate 3.1:Binding and Filling Materials used in NSRPC

3.3.2 Fine Aggregates

Fine silica sand known as glass sand was used. This type of sand was purchased from Sika company. The grain size of this type of sand is 0.08-0.2mm ,the sand grading are within the requirements of B.S.882:1992[55]. The fineness modulus was 3.22. Plate 3.1 shows the glass sand used throughout this research.

3.3.3 Nanosilica (NS)

The nanosilica used in this research named as CAB-O-SIL is made in Germany. The chemical composition of this NS is shown in Table 3.4, and it conforms to the chemical and physical requirements of ASTM C1240-03[56] as shown in Tables 3.5 and 3.6 respectively. According to the manufacturing company, the average primary particle size of NS is 12 nanometers. Plate 3.1shows the Nanosilica used in this research.

The addition of nanofine particles can improve the properties of concrete due to the effect of increased surface area and good filling of voids in the cement paste. Nanosilica is probably the most reported additives used in nanomodified concrete. Nanomaterials can improve the compressive strength and ductility of concrete.

The addition of silica nanoparticles has important implications on the hydration kinetics and the microstructure of the paste such as (a) an increase in the initial hydration rate, (b) an increase of the amount of C-S-H gel in the paste through pozzolanic reaction, (c) reduction of porosity, (d) improvement in the mechanical properties of the C-S-H gel itself [57].

Table 3.4 Chemical Analysis of Nanosilica *

Oxide Composition	Oxide Content%
SiO_2	99.8
Al_2O_3	0.05
Fe_2O_3	0.003
Na_2O	0.05
K_2O	0.03
MgO	0.01
TiO_2	0.03
HCI	0.025

*Chemical analysis has been conducted by the National Center for Geological Survey and Mining.

Table 3.5 Chemical requirements of nanosilica ASTM C 1240-03

Oxide Composition	NS	Limit of Specification Requirement ASTM C 1240
SiO_2, min. percent	99.8	>85.0
Moisture content , max. percent	1.5	<3.0
Loss on ignition , max	1	<6.0

Table 3-6 Physical Requirements of Nanosilica ASTM C 1240- 03

Physical properties	NS	Limit of specification requirement ASTM C 1240
Percent retained on 45-µm (No.325) sieve, max.	-	<10
Accelerated pozzolanic Strength Activity Index with Portland cement at 7 days, min. percent of control	210.58	>105
Specific surface, min., m^2/g	200	>15

3.3.4 Silica Fume (SF)

Densified silica fume produced by a German company called CAB-O-SIL was used as a mineral admixture added to the concrete mixes of this research. The percentages of silica fume used were 5%, 10%, and 15% by weight of cement as an addition and not as replacement of cement.

Silica fume is a highly active pozzolanic material and is a by-product from the manufacture of Silicon or Ferro-silicon metal. It is collected from the flue gases from electric arc furnaces. Silica fume is an extremely fine powder, with particles about 100 times smaller than an average cement grain. Silica fume is available as a densified powder or in a water-slurry form. It is generally used at 5 to 15% by weight of cementitious materials as a partial replacement in concrete structures that need high strength or significantly reduced permeability to water [58].

The benefits that result from adding silica fume are related to changes in the microstructure of concrete. These changes result from two different but equally important processes:-

1. Physical contribution; Adding silica fume brings millions and millions of very small particles to a concrete mixture, it fills in the spaces between cement grains. This phenomenon is frequently referred to as particle packing or micro-filling. Even if silica fume did not react chemically, the micro-filler effect would bring about significant improvements in the nature of concrete.
2. Chemical contribution; Because of its very high amorphous silicon dioxide content, silica fume is a very reactive pozzolanic material in concrete. As the Portland cement in concrete begins to react chemically, it releases calcium hydroxide. The silica fume reacts with this calcium hydroxide to form additional binder material (calcium silicate hydrate

(C-S-H)) which is very similar to the calcium silicate hydrate formed from the Portland cement [59].

The silica fume used in this investigation is shown in Plate 3.1.Its chemical composition is shown in Table 3.7 and it conforms to the chemical and physical requirements of ASTM C1240-03[56] as shown in Tables 3.8 and 3.9respectively.

Table 3.7: Chemical Analysis of Silica Fume *

Oxide Composition	Oxide Content %
SiO_2	97.24
Al_2O_3	0.044
Fe_2O_3	0.071
Na_2O	0.033
K_2O	0.13
CaO	0.18
MgO	0.38
M_2O_3	0.002
TiO_2	2.5
Cl-	1.83

*Test was carried out at the National Center for Geological Survey and Mining/Baghdad.

Table 3.8: Chemical Requirements of Silica Fume (SF) ASTM C1240-03[56]

Oxide Composition	S.F	Limit of Specification Requirement ASTM C1240
SiO2 min. Percent	90.0	>85.0
Moisture Content ,Max. Percent	0.68	<3.0
Loss on Ignition , Max. Percent	2.86	<6.0

Table 3.9:Physical Requirements of Silica Fume ASTMC1240-03[56]

Physical Properties	S.F.	Limit of Specification Requirement ASTM C 1240
Percent Retained on 45-µm (No.325)Sieve, Max.	7	<10
Accelerated Pozzolanic Strength Activity Index With Portand Cement at 7 days, Min. Percent of Control	128.6	>105
Specific Surface, Min, m^2/g	21	>15

3.3.5 Mixing Water

Ordinary tap water was used for mixing and curing all the concrete specimens used in this research.

3.3.6 High Range Water Reducing Admixture

A superplasticizer commercially named Flocrete PC 260 which conforms to ASTM C494-99[60] type A&G was used in the mixes. It has been primarily developed for producing high performance concrete, self-compacting concrete and mortar, and for concrete production in hot and windy weather with extended workability time. It is almost free from chlorides. Flocrete PC 260 is a high performance superplasticizer admixture based on polycarboxylic ether polymer with long chain specially designed to enable the water content of concrete to perform more effectively. This effect can be used in high strength concrete and flowable concrete mixes, to achieve highest concrete durability and performance. Table 3.10 shows the technical description of Flocrete PC 260.

Table 3.10: Technical Description of Flocrete PC 260*

Chemical Base	Modified polycarboxylates based polymer
Appearance/colors	Light yellow liquid
Freezing point	-7C approximately
Specific gravity @25°C	1.1+-0.02
Air entrainment	Typically less than 2% additional air is entrained above control mix at normal dosages
Dosage	0.5 to 3.0 liter per 100 kg of binder
Storage Condition/Shelf Life	12 months if stored at temperatures between 2°C and 50°C

*Supplied by the manufacturer

3.3.7 Steel Fibers (Vf)

Small steel fibers are usually used in RPC mixes to improve the tensile behaviour of the hardened concrete, making it a little ductile and act as a crack arrester. The steel fibers used in this experimental work were of 0.2mm diameter and 13mm length .They were straight steel fibers manufactured by Bekaert Corporation company and of properties described in Table 3.11.

A thin brass coating was applied to the fibers during the drawing process; therefore, virgin fibers were gold-colored. This coating disappeared during the mixing process and was no longer clearly visible during the casting of concrete mixes. Plate 3.1 shows the ultra fine steel fibers used throughout this research.

Table 3.11: **Properties of the Steel Fibers***

Description	Length (mm)	Diameter (mm)	Density(kg/m^3)	Tensile Strength fy(MPa)	Aspect Ratio
Straight	13	0.2	7800	2600	65

* Supplied by the manufacturer

3.3.8 Steel Bars

In this study, three longitudinal steel reinforcement ratios (ρ) were used 0.0742, 0.0857, and 0.0911.The steel ratio 0.0742 was achieved by using two 28mm bars in the beam, while two 28mm plus two 10mm bars were used in the case of 0.0857 steel ratio and two 28mm plus two 12mm bars were used in the case of 0.0911 steel ratio. Moreover, steel bars of 6mm diameter were also used as stirrups in one beam only (beam B15) to study the effect of the presence of shear reinforcement on the shear capacity of NSRPC beams.

Three specimens for each of these four bar diameters were tested in tension to determine their properties. The results are shown in Table 3.12 and the stress-strain diagrams shown in Fig. 3.8.The results of testing the steel bar met the ASTM A615[61] requirements for Grade 60. The bars were tested in the material laboratory of the Civil Engineering Department at Al-Mustansiriya University/Baghdad.

In order to prevent any possible bond slip failure of the longitudinal steel bars in a specified NSRPC beam of the present research, two rectangular steel plates of 8mm thickness were welded to these steel bars , one at each end. The plates were provided at the ends of the beam beyond the supports as shown in Fig. 3-1.

Table 3.12: Properties of Steel Bars.

Nominal Bar Diameter (mm)	Yield Stress (MPa)	Yield Strain (mm/mm)	Ultimate Stress (MPa)	Modulus of Elasticity (MPa)
6	500	0.00200	580	191000
10	600	0.00300	697	197000
12	627	0.00305	679	200000
28	555	0.00259	634	216000

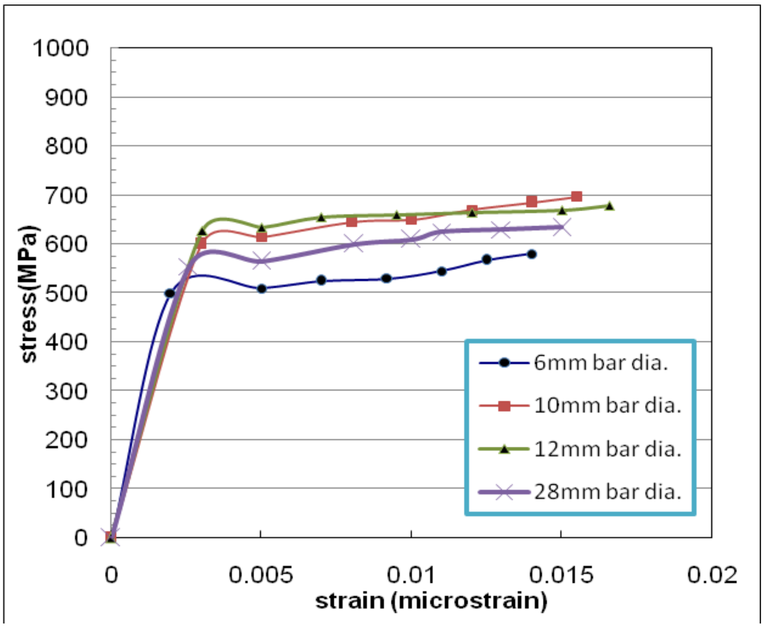

Fig. 3.8:Stress-Strain Curves for Steel Bars

3.4 Molds

Wooden molds were used for casting the beam specimens as shown in Plate 3.2 . Each mold consisted of a bed and four movable sides. The sides were fixed to the bed by screws.

Plate 3.2:The Wooden Molds Used in Casting NSRPC Beams

3.5 Concrete Mix Design

Several mixes were originally considered. The dominate mix in all specimens was 1:1cement :sand with 0.2 water cement ratio plus 3% by weight of binder of Flocrete PC260 admixture. It is to be pointed out that no coarse aggregate was incorporated in the mix. The maximum concrete compressive strength attained was 157.6 MPa at 28 days. Nine types of mixes were used in the present research as listed in Table 3.13. Each mix was designated $M_{i,j,k}$ where:

i=percentage of nanosilica (NS)
j=percentage of silica fume(SF)
k=percentage of steel fiber(Vf)

3.6 Mixing of Concrete Batches

Initially the small trial batch mixing was done in a small rotary mixer of 0.01m^3 capacity. Later on, all mixing was done in a large horizontal rotary mixer of 0.15m^3 capacity. The mixing sequence was as follows: the desired quantity of silica fume was mixed in dry state with the required quantity of cement. This operation was continued for 5 minutes to ensure that the silica fume powder was thoroughly dispersed between cement particles. Then, fine sand was added mixing was continued for 5minutes.

Since nanosilica is not easy to disperse uniformly due to its high surface energy, it was stirred with the solution of water and superplasticizer at high speed (120 rpm) for 1 minute and the solution of water and superplasticizer was added into the rotary mixer and the whole mix ingredients were mixed for a sufficient time.

Table 3-13:Properties of the Different Types of NSRPC Mixes

Mix Designation	Used for Beams	Cement kg/m^3	Sand kg/m^3	Nano-silica %	Nano-silica kg/m^3	Silica fume %	Silica Fume kg/m^3	Steel fibers %	Steel fiber kg/m^3	w/c	Flocrete PC 260 %
M $_{0-15-2}$	B1	1000	1000	0	0	15	150	2	156	0.2	3
M $_{1-15-2}$	B2	1000	1000	1	10	15	150	2	156	0.2	3
M $_{2-15-2}$	B3	1000	1000	2	20	15	150	2	156	0.2	3
M $_{3-15-2}$	B4,B9, B10,B11,B12	1000	1000	3	30	15	150	2	156	0.2	3
M $_{3-15-1}$	B8,B13, B14	1000	1000	3	30	15	150	1	78	0.2	3
M $_{3-15-0}$	B7,B15	1000	1000	3	30	15	150	0	0	0.2	3
M $_{3-10-2}$	B6	1000	1000	3	30	10	100	2	156	0.2	3
M $_{3-5-2}$	B5	1000	1000	3	30	5	50	2	156	0.2	3
M $_{0-15-0}$	B16	1000	1000	0	0	15	150	0	0	0.2	3

The mixer then was operated for 5 minutes to attain reasonable fluidity. Fibers were uniformly distributed into the mix slowly in 5 minutes during mixing process, and then the mixing process continued for additional 3 minutes. In total, the mixing of one batch required approximately 30 minutes. Several effects were noticed when adding the fibers to the concrete matrix, the most striking of which was the great reduction in workability which was reduced as the fiber content was increased. These results were also noticed by other investigators [62,63,64].

3.7 Casting Procedure

Before casting, all molds were well cleaned and their internal surfaces were lightly oiled to avoid the adhesion of hardened concrete to the internal surface of the molds. Before placing the concrete mix in the molds, the longitudinal steel bars were placed in position at the base of the mold. The concrete mix was placed in the mold in three equal layers. Each layer was compacted by using electrical vibrating table for one minute. Then, the top surface of the cast specimen was well finished using a steel trowel, so that the upper surface of the wooden block is kept level with the concrete surface. The cylinders were filled with concrete in three equal layers and the prism molds were filled with concrete in two equal layers; each layer was compacted using the same vibrating table. After the top layer had been compacted, it was leveled by using a steel trowel. After this stage, all the specimens were covered with plastic sheets to avoid cracks associated with water-loss shrinkage. From each mix of the nine different NSRPC mixes listed in Table 3.14 the following control specimens were cast to determine the properties of the hardened concrete:

1.Three 100mm dia.x200mm long cylinders for compressive strength.
2.Three 100mm x 100mm x 400mm prisms for modulus of rupture.
3.Three 100mm dia. x 200mm cylinders for modulus of elasticity.

4.Three 100mm dia. x 200mm cylinders for splitting tensile strength.

3.8 Curing of Specimens

The concrete specimens were demolded 24 hours after casting . They were then steam cured at about 90°C for 48 hours in water bath. The samples were then left to cool at room temperature, then placed in water and left to cure for 28 days. Plate 3.3shows the curing system.

Plate 3.3:Curing of Specimens

3.9 Material Properties

A series of tests were conducted on the control specimens to determine the compressive strength, splitting tensile strength, modulus of rupture and modulus of elasticity of NSRPC at the age of 28 days. Results of these tests are shown in Table 3.14. Each property value in this table represents the average of three control specimens.

3.9.1 Compressive Strength

The compressive strength test was carried out in accordance with ASTM C39-86[65]. 100x200 mm cylindrical control specimens were used to determine the compressive strength of NSRPC using a digital compression testing machine of 2000 kN capacity as shown in Plate 3.4. The control specimens were tested at the age of 28 days. The average of three tested cylinders was adopted for each mix ,as shown in Plate 3.6.

Plate 3.4:Compressive Strength Test

3.9.2 Splitting Tensile Strength

100x200 mm cylinders were prepared according to the ASTM C496-86 specification [66]. The splitting tensile strength of NSRPC was determined using the same machine as for compressive strength determination. Cylinders were tested at the age of 28 days and the average of three tested cylinders was adopted for each mix as shown in Plate 3.7. The splitting tensile strength values were calculated by the following expression:

$f_{spf} = 2P / (\pi d L)$ ………(3-1)

where:

f_{spf} = Splitting tensile strength (MPa)

P = Maximum applied load (N)

d = Diameter of the cylinder (mm)

L = Length of the cylinder (mm)

3.9.3 Modulus of Rupture

100x100x400 mm concrete prisms were prepared according to the ASTM C192-88[67]. Modulus of rupture of NSRPC was determined using a 1000 kN capacity testing machine ,as shown in Plate 3.5. Prisms were tested using the two points loading with clear span of 300 mm according to the ASTM C78-84 [68] .They were tested at the age of the 28 days and the average of three tested prisms was adopted for each mix as shown in Plate 3.8. The following formula was used to calculate the modulus of rupture.

$f_{rf} = PL /(bh^2)$……… (3-2)

where:

f_{rf} = Modulus of rupture (MPa)

P = Maximum applied load (N)

b = Width of the prism (mm)

h= Depth of the prism (mm)

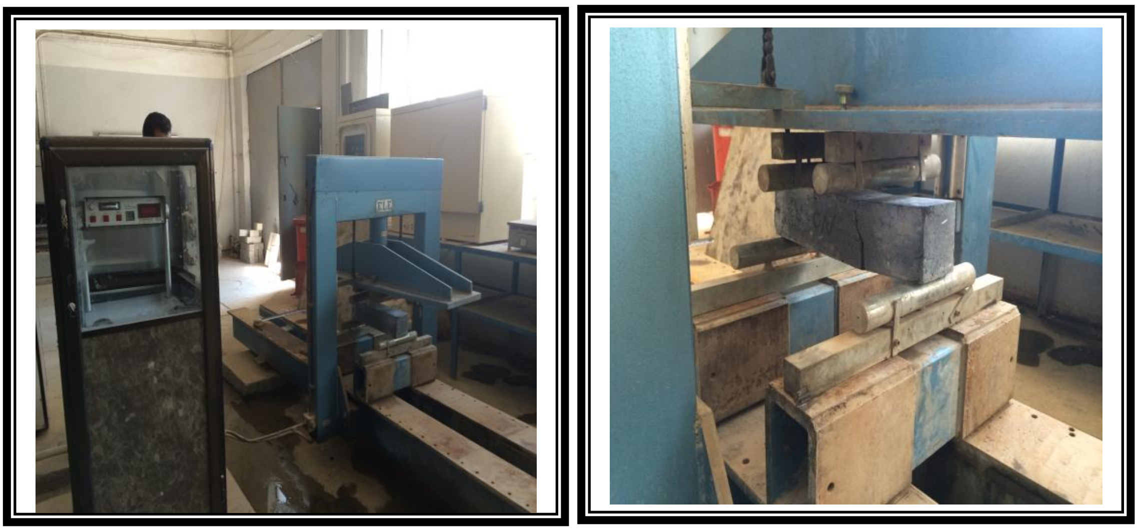

Plate 3.5:Modulus of Rupture Test

3.9.4 Static Modulus of Elasticity

This test was carried out on 100x200 mm cylindrical control specimens. The 40% of ultimate compressive strength of concrete specimen was applied on the concrete cylinders to perform the elastic modulus test as specified by ASTM C469 - 87a [69]. The control specimens were tested at the age 28 days. Static modulus of elasticity of NSRPC is calculated using the following expression:-

$Ec = [(S2 - S1) / (e2 - 0.00005)] \times 10^{-3}$ ……… (3-3)

where:

Ec= Static modulus of elasticity of RPC, GPa

S2 = Stress corresponding to 40% of ultimate load, MPa

S1= Stress corresponding to a longitudinal strain (0.00005), MPa

e2 = Longitudinal strain produced by stress S2

Table 3.14: Properties of Hardened NSRPC:

Mix Designation	Nano-silica %	Vf %	Silica fume %	Compressive Strength f'_{cf} (MPa)	Splitting Tensile Strength f'_{spf} (MPa)	Modulus of Rupture f'_{rf} (MPa)	Modulus of Elastisity Ec (GPa)
M $_{0\text{-}2\text{-}15}$	0	2	15	120	17.2	19	47.81
M $_{1\text{-}2\text{-}15}$	1	2	15	138.3	22.3	25.8	51.04
M $_{2\text{-}2\text{-}15}$	2	2	15	152	24.3	27.7	53.3
M $_{3\text{-}2\text{-}15}$	3	2	15	157.6	25	28.5	54.21
M $_{3\text{-}1\text{-}15}$	3	1	15	128	17.9	19.4	48.36
M $_{3\text{-}0\text{-}15}$	3	0	15	98	7.3	7.6	43.59
M $_{3\text{-}2\text{-}10}$	3	2	10	148.7	23.8	27	52.77
M $_{3\text{-}2\text{-}5}$	3	2	5	140.6	23.2	25.4	51.42
M $_{0\text{-}0\text{-}15}$	0	0	15	75	5.3	5.4	38.6

Plate 3.6:Compression Failure of NSRPC Cylinders

Plate 3.7: Tensile Splitting Failure of NSRPC Cylinders

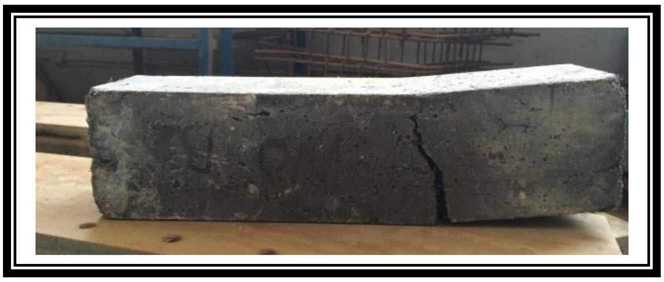

Plate 3.8:Flexural Failure of NSRPC Prism

3.10 Test Measurement and Instrumentation

3.10.1 Load Measurements

The beams were tested in the Structural Laboratory of the Civil Engineering Department, College of Engineering, University of Al-Mustansiryia/Baghdad .The machine used for testing the beams was (MFL) hydraulic universal testing machine of 300 Ton capacity, as shown in Plate 3.9. A steel beam to provide two point load was used (over the beam centerline) with a variable total span of (570, 404 and 238) mm and according to the respective a/d ratios of (2.5, 3 and 3.5).

Plate3.9:MFL Universal Testing Machine

3.10.2 Deflection Measurement

Deflection of every test beam was measured at mid-span(i.e at the section of its maximum value). Readings of this central deflection were taken at certain load intervals starting from zero load up to failure, as shown in Plate 3.10. A digital dial gage 0.01mm accuracy was used for the deflection measurements.

Plate 3.10:Location of Digital Dial Gage

3.10.3 Concrete Strain Measurements

A mechanical method was used for measuring the strains in concrete. Demec strain device was used on a length of 150 mm to measure the surface strains. One day before testing, the stainless steel demec button points were mounted on the beam using epoxy. Demec points were fixed in the direction of the inclined tension struts to measure the concrete surface strains normal to the direction of the concrete compression strut. These demec points were fixed at the positions shown in Fig. 3.9.

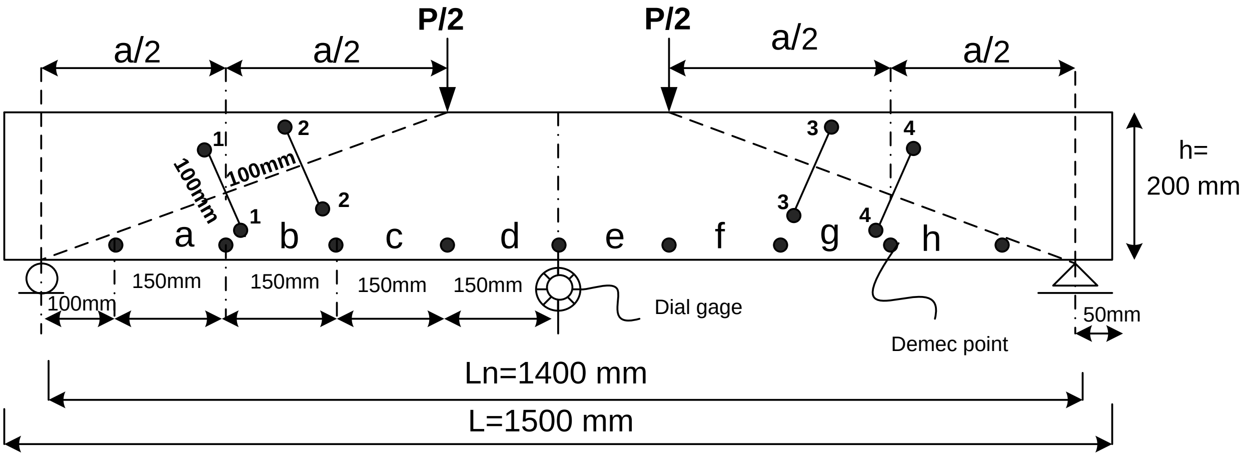

Fig. 3.9 Measurements of Strains and Beam Central Deflection

3.10.4 Crack Width Measurement

Crack widths were measured using a special device made of a set of thin steel plates, as shown in Plate 3.11. The measurement points were located on the main shear crack at mid-depth of the beam**.**

Plate 3.11:Set of Plates Used for Measuring the Crack Width

3.11 Testing Procedure

All beams and control specimens were cured in water tank for 28 days. Before testing, the test beam was cleaned and painted white in order to clarify the crack propagation. The demec point positions were located, and then fixed on the beam. The beam was labeled and the locations of support points, loading points, and the dial gage positions were marked on the surface to facilitate the precise setup of the testing equipment. The beam was placed in the machine on free supported roller at each end with a clear span of 1400mm. Loading was applied through steel plate to avoid stress concentrations on the upper face of the beam.

All beams were tested under two points loading. The dial gage was placed in its position touching the bottom surface of the beam at mid-span.

Before loading was applied, the zero-load readings of the mechanical strain gages as well as the dial gage were recorded and then a load of 5 kN was applied and released in order to recheck the zero-load readings.

The magnitude of the load at every single step of loading was chosen according to the expected strength of the beam. At each load value, concrete surface strains and the dial gage reading were recorded and a search was made for the appearance of the cracks by using a magnifying glass. The positions and extents of the first and the other consequent cracks were marked on the surface of the beam and the magnitude of the applied load at which these cracks occurred was written. The inclined cracking load was reported as being the load causing the critical diagonal crack to cross the mid-depth of the beam. The beam was considered to reach failure when it showed a drop in loading with increasing deformation. The failure load was thus recorded, and the load was then removed to allow taking some photographs of the final crack pattern, as shown in Plate 3.12 .

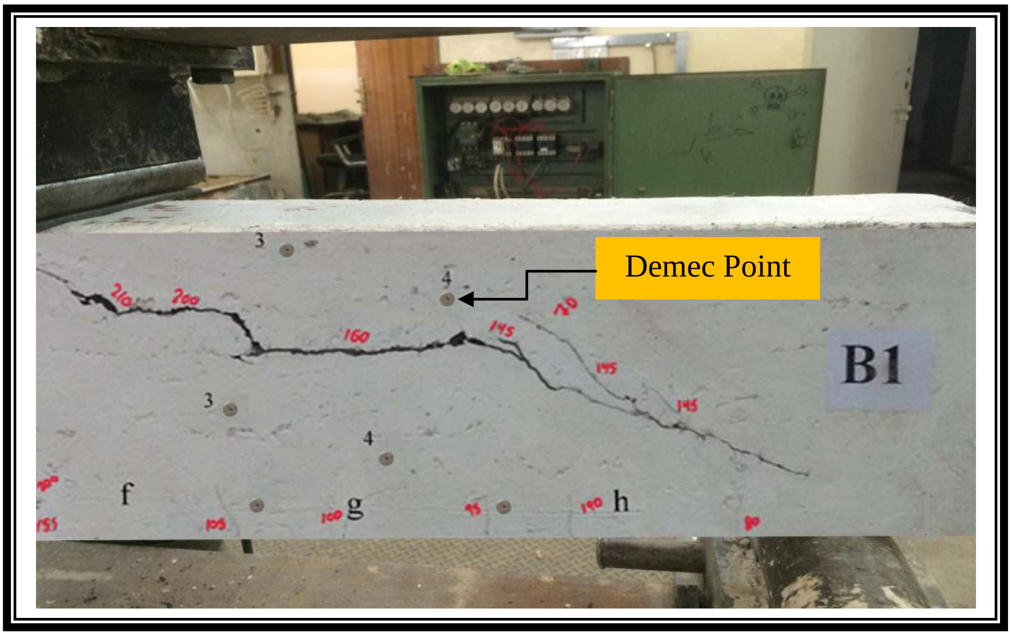

Plate 3.12:Testing NSRPC Beam