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# Flexural Behavior of Normal and High Strength Self-Curing Self-Compacted Concrete Beams of Local Materials

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**Abstract:** In some construction industries, there are difficulties in achieving the required concrete compaction, Self-compaction is an alternative option. Working with self-compaction self-curing concrete requires a unique approach. This study aims to examine the possibility of producing self-compacting concrete with normal and high self-cure rates. This research observed how both the self-curing and self-compacting concrete behaved under normal and high-strength conditions. Two stages were prepared for this investigation. The first stage of this research studied the effect of a curing agent on the fundamental characteristics of both normal-strength and high-strength self-compacting concrete, with the aim of achieving self-curing self-compacting concrete. The primary variables of this study include the grade of concrete, the type of curing agent, the reinforcing bars, and the dosage of these variables. In the second stage, reinforced concrete beams were cast with one of the two proposed concrete types, and their behavior was studied. The findings were analyzed in terms of the beginning cracking loads, the ultimate loads, and the crack patterns of the testing beams. According to the results, both the normal-strength and the high-strength varieties of self-curing self-compacting concrete are effective in providing structural features, which are absent from the processes of curing and compacting. Curing chemicals are utilized to mitigate the process of water evaporation in self-compacting concrete, hence enhancing the water retention capabilities of self-compacting concretes that possess enough hardened concrete characteristics.

**Keywords:** beams- Self-Compacting Self-Curing Concrete; High-strength; PEG400; LECA; Flexure.

## 1. Introduction

Self-Compacting Concrete (SCC) is a form of concrete that exhibits exceptional workability, characterised by its ability to flow effortlessly and fill intricate spaces without the need for external compaction. This unique concrete variant is renowned for its superior performance and possesses the requisite strength necessary for many applications. Additionally, it has the ability to move effortlessly in constricted areas without any form of separation or leakage [1, 2]. The utilisation of self-compacting concrete (SCC) offers significant commercial advantages due to its ability to be easily placed in intricate structures that contain densely packed reinforcing [2,3]. In the realm of generating economically sustainable self-compacting concrete (SCC), various strategies have been explored. These include the utilisation of substantial quantities of cost-effective pozzolanas to diminish the cement content, as well as the incorporation of affordable high-range water reducers [4].

Enhancing the curing process augments the mechanical properties and long-term performance of concrete. The process of concrete curing poses a significant obstacle within the construction sector, particularly in regions that have water scarcity. Academic The utilisation of curing methods appears to be the most effective approach for achieving optimal strength and durability during the production process [5]. In certain instances, the production of adequate curing conditions may prove challenging. Consequently, the utilisation of self-curing concrete is recommended as available alternative in such scenarios. The technique of self-curing, also known as internal curing, is a novel approach that can be employed to enhance the moisture content within concrete. This method facilitates more efficient cement hydration and mitigates self-desiccation, all without relying on traditional curing methods. The primary objective of the self-curing principle is to mitigate the volatilization of water from concrete, hence enhancing the water retention capability of self-cured concrete in comparison to traditional concrete by the use of chemical curing agents [6,8]. Utilising chemical curing agents that are appropriate for curing concrete in areas that are experiencing a water shortage is one way to ensure the long-term availability of water [8,10]. An alternative approach to internal curing involves the utilisation of porous aggregates as internal reservoirs, which serve the purpose of supplying water to the concrete throughout the hydration process. Internal curing in concrete can be achieved through the utilisation of various materials, including lightweight coarse aggregates such as Lightweight Expanded Clay Aggregate (LECA), lightweight natural sand (LWS), and wood powder. Additionally, chemical curing admixtures like super-absorbent polymers (SAP) and shrinkage reducing admixture (SRA) can also be employed for this purpose [ 10,13]. The utilisation of shrinkage-reducing admixtures (SRA), such as propylene glycol and polyethylene glycol, has been recommended as a means to mitigate the formation of fractures in concrete structures resulting from drying shrinkage. These admixtures incorporate poly-glycol products into the concrete mixture. The process underlying the effects of this admixture is predicated on the physical alteration of the mixing water's surface tension, rather than a decrease in water evaporation [8,14,12]. The compressive strength of self-curing (SC) concrete, which is concrete that cures itself using curing agents rather than water, is approximately 10% lower than that of conventionally cured concrete [17,18]. When contrasted with individuals who do not benefit from a cure, the primary benefit of the SC becomes apparent. Additionally, compared to standard concrete, the hydration processes that resulted from the use of SC were superior as time passed under drying conditions. The amount of water that can pass through SC is significantly less than that of air-cured conventional concrete.

The values for absorptivity and permeability of SC declined with age due to a reduction in the number of pores that were permeable. This was caused by the continuance of the cement hydration process [19]. The utilisation of self-curing self-compacting concrete, also known as SC-SCC, offers the advantages of both self-compaction and self-curing [20,21]. The behaviour and performance of SC-SCC are influenced by the type and dosage of the curing agent [21,22]. Numerous studies endeavour to investigate the impact of curing chemicals on the efficacy of self-compacting concrete, with the aim of achieving self-curing self-compacting concrete [17,23,26]. The utilisation of chemical compounds for the purpose of curing has a negligible impact on the durability of the material [17,27]. SCC and conventional concrete of normal and high strength function similarly [28,29]. When comparing self-compacting concretes and self-curing concretes, those made with SAP have greater flexural strengths [30]. In comparison to the standard specimens, flexural behaviour of chemically cured reinforced concrete beams (such as PEG400) behaved admirably [31].

In order to create self-curing self-compacting concrete (SC-SCC), the effects of combining different curing agent kinds and doses with normal strength self-compacting concrete (NS-SCC) and high strength self-compacting concrete (HS-SCC) are the focus of this investigation. In addition, the performance of SC-SCC beams with reinforcement that are cured with these chemicals will be investigated.

## 2. The importance of research

The objective of this study is to examine two primary focal areas. The initial focus of this study is to investigate the impact of utilising various types and dosages of chemical curing agents on both normal strength and high strength self-compacting concrete. The objective is to achieve self-curing properties in self-compacting concrete. The second objective is to investigate the structural performance of reinforced self-consolidating concrete (SCC) beams produced using the aforementioned concrete mixture. The primary factors considered in the initial phase of this study include the following variables: the grade of concrete (N.S.-SCC and H.S.-SCC), the types of self-curing agents used Polyethylene Glycol 400 (PEG 400) and Light-Weight Expand Clay Aggregate (LECA), and the dosage of curing agents (PEG 400 at 2%, 3%, and 4% of the cement weight, and LECA at 2%, 3%, 4%, and 5% of the cement weight). The primary factors considered in the second stage of the study include the grade of concrete, the longitudinal rebar sizes (Φ10, Φ12, and Φ16), and the type of curing agent. The study yields empirical results that can be included and utilized by academics in order to evaluate and utilize this particular form of material. The

primary novelty of this work is in the comparative examination of the characteristics and performance of normal and high strength self-compacting concrete (SC-SCC) mixtures. This investigation incorporates the use of various internal curing materials as well as longitudinal reinforcement bars of varying diameters (Φ10, Φ12, and Φ16).
The significance of this study is in its ability to generate comprehensive data for researchers and engineers who are interested in the utilisation of normal strength or high strength self-compacting concrete (SCC) in challenging environments such as desert sites or locations where concrete curing processes pose difficulties.

## 3. Materials and specimens for the tests

The tests conducted in this study were performed at the Construction Materials Laboratory, which is located within the Civil Engineering Department of the Faculty of Engineering at University of Basrah. The next sections will cover the testing processes, as well as the materials utilised, the design of the test specimens, and how they were created.

### *3.1 Materials*

All of the combinations in this investigation employed regular Portland cement (Iraqi in origin, Karasta type) (CEM II/A-L 42.5R). Analysis of the cement's physical and chemical qualities revealed that it meets Iraqi standard standards (IQS 5:2021) [32]. The fine aggregate component is often made out of natural sand from Basrah. Grading of fine and coarse aggregate according to ASTM, physical and chemical properties IQS No.45/1984 [33]. The properties of fine aggregate according to ASTM C-33 [34]. It is clean and nearly free from impurities with a specific gravity (2.5) and a fineness modulus of (2.61). Its Chemical and Physical properties are shown in (Table 1) while its grading is shown in (Table 2).

Table 1. Chemical and Physical properties of the sand.

| Properties | Test Result |
|---|---|
| Density (kg/m$^3$) | 1650 |
| Specific gravity | 2.50 |
| $SO_3$ % | 0.38 |
| Cl % | 0.06 |
| Absorption % | 0.05 |

Table 2. Grading of the sand.

| Sieve Size (mm) | Passing by Weight % | ASTM C-33 Specification % |
|---|---|---|
| 9.5 | 100 | 100 |
| 4.75 | 100 | 95-100 |
| 2.36 | 93.1 | 80-100 |
| 1.18 | 63.5 | 50-85 |
| 0.60 | 41.5 | 25-60 |
| 0.30 | 17.6 | 5-30 |
| 0.15 | 4.7 | 0-10 |

The gravel of normal size (5-20) mm that was used from Basrah quarry classification shown in Table (3). Table (4) show the physical and chemical properties of gravel, that conforms to ASTM C-33 [34].

Table 3. Grading of Coarse aggregate used.

| Sieve Size (mm) | %Passing by Weight | ASTM C-33* Specification % |
|---|---|---|
| 25 | 100 | 100 |
| 19.5 | 95.4 | 90-100 |
| 9.5 | 45.3 | 20-55 |
| 4.75 | 8.9 | 0-10 |
| 2.36 | 1.2 | 0-5 |

Table 4. Physical and Chemical Properties of gravel used.

| Properties | Test Result |
|---|---|
| Density ($kg/m^3$) | 1620 |
| Specific gravity | 2.64 |
| $SO_3$ % | 0.075 |
| Cl % | 0.091 |
| Absorption % | 0.09 |

In this work, tap water used for sample casting and processing. Table (5) shows the chemical properties of used water that conforms to EN-1008:2002 [35].

Table 5. Water Properties.

| Type of test | Result (ppm) | EN-1008:2002 Specifications (ppm) |
|---|---|---|
| $SO_3$ | 50.06 | 1000 Max. |
| PH | 7.89 | ---- |
| Cl | 31.95 | 500 Max. |
| TDS | 122 | 3000 Max. |
| Turbidity | 107.63 | ---- |
| $CO_3$ & $HCO_3$ | 50.03 | 1000 Max. |
| Organic Mater | 6.98 | --- |

There are two distinct categories of admixtures that are commonly employed. The initial substance can be classified as a chemical admixture, whilst the subsequent substance can be categorised as a pozzolanic admixture. The study utilised a specific high range water-reducing (HRWR) admixture, known as Master Glenium 54, manufactured by BASF_CC UAE/Gl_54_09_07/v2/03_16. This admixture was employed to enhance the workability of concrete without the need for additional water. The substance meets the criteria specified in the European standard (EN 934-2) for superplasticizers, as well as the standards stipulated in the American standard (ASTM-C-494 type G and F) [11]. The Table (6) is shown the Properties of Master Glenium 54.

Table 6. Properties of Master Glenium54 (SP-MG).

| Form | Whitish to straw coloured liquid |
|---|---|
| Relative density | 1.07 |
| Ph | 5-8 |
| Chloride content | None |

Limestone Powder (LSP), this material, known as Al-Gubra in the local area, was purchased at a nearby market and subsequently utilised to raise the total quantity of powder (comprised of cement and filler). The density of the (LSP) had a specific gravity of 2.4, and the chemical composition is presented in Table (7).

Table 7. Chemical composition of L.S.P.

| Chemical Properties | Content % |
|---|---|
| $SiO_2$ | 1.39 |
| $Fe_2O_3$ | 0.15 |
| $Al_2O_3$ | 0.78 |
| $CaCO_3$ | 88.35 |
| MgO | 0.14 |
| $SO_3$ | 0.23 |
| L.O.I | 8.96 |

Two different self-curing regimens were implemented. The initial method involved the utilisation of chemical curing agents, but the subsequent approach involved the utilisation of Lightweight Expanded Clay Aggregate (LECA) as internal reservoirs. In this study, the self-curing agent employed is Polyethylene glycol PEG400, which serves as a liquid chemical agent for the purpose of internal concrete curing. The substance is devoid of chlorides and generates an interior membrane that serves to safeguard and impede excessive water evaporation in fresh concrete. Polyethylene glycol PEG400's specifications, straight from the factory (Table 8).

Table 8. Technical information of Polyethylene Glycol PEG400.

| Parameter | Unit | Specifications | Result |
|---|---|---|---|
| Appearance | Visual | Aclear-colourless liquid | Passes |
| Colour 25% Aq. | Hazen | Between 0-20 | 7.000 |
| Solubility | Visual | Freely soluble in water and alcohol | Passes |
| Ph 5% Aq. | ---- | 4-7.5 | 6.65 |
| Viscosity @100C | cst | 6.8-8 | 7.63 |
| Moisture content (by KF) | % | 0-0.5 | 0.1 |
| Arsenic | ppm | <3 | <3.0 |
| Heavy metals | ppm | <5 | <5.0 |
| Sulphated ash | % | <0.1 | <0.1 |
| Average molecular weight | --- | 380-420 | |

The Light-Weight Expand Clay Aggregate, commonly referred to as LECA, was manufactured through the process of heating in a rotary kiln at a temperature of approximately 1200 °C. The Lightweight Expanded Clay Aggregate (LECA) was procured from the Bahrain Complex Company and delivered into Iraq, specifically in the city of Najaf. (Table 9) shows the properties of Light-weight Expanded Clay Aggregate (LECA). The specific gravity of LECA (1.3).

Table 9. Grading of Light Expand Clay Aggregate (LECA).

| Sieve Size (mm) | Passing by Weight % | ASTM C-330 * Specification % |
|---|---|---|
| 12.5 | 100 | 100 |
| 9.5 | 91 | 80-100 |

| | | |
|---|---|---|
| 4.75 | 31 | 5-40 |
| 2.36 | 16 | 0-20 |
| 1.18 | 2 | 0-10 |

During this investigation, three different varieties of reinforcing bars were utilised. The first type which is used for circular plain bars with a diameter of ten millimeters (10 mm) to serve both as stirrups and as the primary reinforcement. While for a main reinforcement, Grade 420 MPa. deformed steel were used-tensile steels with a diameter of twelve and sixteen millimeters, respectively. Several tests were carried out in order to collect data on the elongation, modulus of elasticity, yield stress, and ultimate stress of the material. The test results are presented in Table 10.

Table 10. the properties of reinforcing bars.

| Bar size mm | Test results | | | ASTM A615/A615M | | |
|---|---|---|---|---|---|---|
| | Yield strength $N/mm^2$ | Ultimate Strength $N/mm^2$ | Elongation % | Yield strength Min $N/mm^2$ | Ultimate strength Min.$N/mm^2$ | Elongation Min. (%) |
| 10 | 495.2 | 655.5 | 11.3 | 420 | 620 | 9 |
| 12 | 590.1 | 676.9 | 12.4 | 420 | 620 | 9 |
| 16 | 610.4 | 721 | 13.5 | 420 | 620 | 9 |

### *3.2 Concrete and test samples*

The initial step in determining the quantities of self-compacting concrete involved a thorough examination of prior studies undertaken by other researchers **[**36**]**. Two different mixtures were utilized. The initial variant is referred to as normal strength self-compacting concrete (NS-SCC), whilst the subsequent variant is denoted as a high-strength self-compacting concrete (HS-SCC). The experimental programme that was being done by separating into two sections. In the first, a curing agent was used to investigate what kind of impact it would have on a mixture of NS-SCC and HS-SCC. In the second phase, the behaviour of beams made from self-compacting, self-curing reinforced concrete was determined. The experimental programme is depicted in Figure 1.

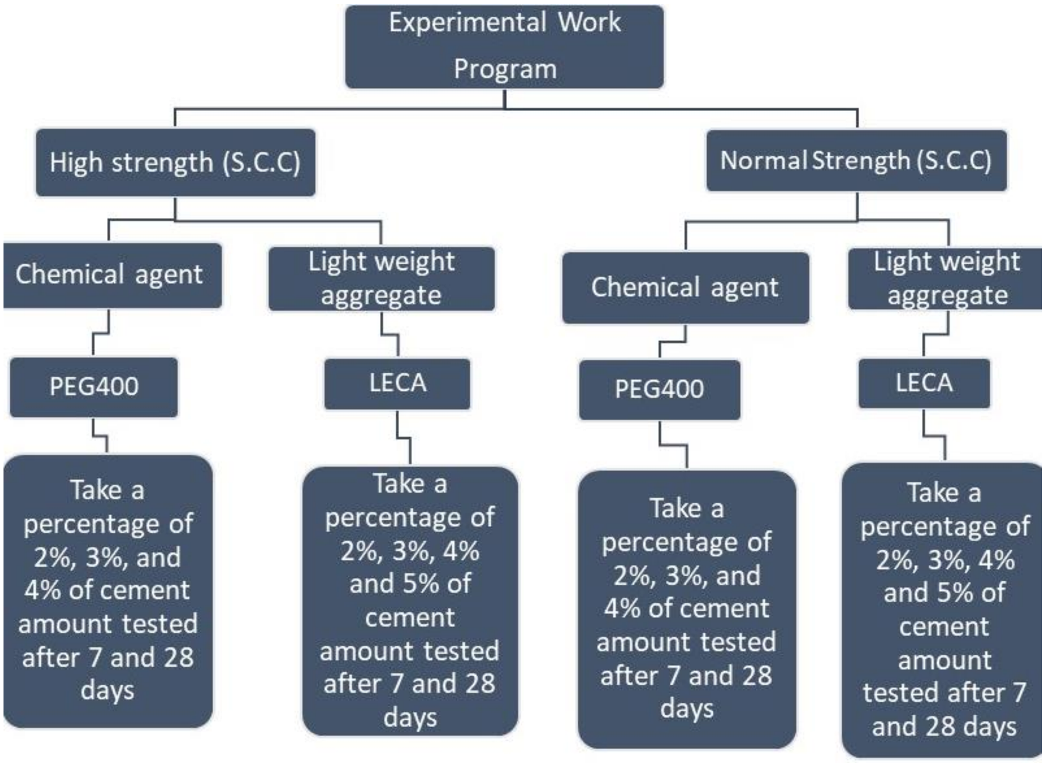


Fig. (1): Flow diagram of the experimental procedure

Two different mixes of self-compacting concrete were treated with self-curing chemicals to produce self-curing self-compacting concrete. The initial choice of the NS-SCC mix is based on previous experiments that have been conducted. The selection of the NS-SCC and subsequent HS-SCC combinations were based on past experiments conducted by [36]. As shown in Table (11). The objective of this study was to determine the optimal amount of curing agent required to achieve satisfactory self-curing and self-compacting properties in concrete.

Table 11. Concrete mixes used Stage (1).

| Mix Type | Mix Code | Cement kg/ $m^3$ | Water kg/$m^3$ | Sand kg/ $m^3$ | Gravel kg/ $m^3$ | LSP. kg/ $m^3$ | SP-MG. kg/ $m^3$ | Curing Agent | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Type | Dosage as % of C |
| Control "C"N.S. | | 405 | 182 | 850 | 850 | 101 | 3.0 | _ | _ |
| N.S.SC-SCC | N-P4-2<br>N-P4-3<br>N-P4-4<br>N-L-2<br>N-L-3<br>N-L-4<br>N-L-5 | | | | | | | PEG400<br><br><br>LECA | 2%<br>3%<br>4%<br>2%<br>3%<br>4%<br>5% |
| Control "C"H.S. | | 511 | 176 | 835 | 835 | 57 | 4.0 | _ | _ |
| H.S.SC-SCC | H-P4-2<br>H-P4-3<br>H-P4-4<br>H-L-2<br>H-L-3<br>H-L-4<br>H-L-5 | | | | | | | PEG400<br><br>LECA | 2%<br>3%<br>4%<br>2%<br>3%<br>4%<br>5% |

In the first stage to investigate the properties of mixture two different curing compounds: a chemical one and a porous aggregate one. As a chemical curing agent, polyethylene glycols PEG400 were utilised with percents of 2%, 3%, and 4% of the total cement content. In addition, LECA was utilised as internal reservoirs in order to assist in the process of internal curing (with percents of 2%, 3%, 4%, and 5% of the total cement content). The work included two additional concrete mixes, namely NS-SCC and HS-SCC, which were previously mentioned. The specimens utilised in this investigation consist of cubes with dimensions measuring 150 × 150 × 150 mm, had prepared to assessing the compressive strength. Cylinders with dimensions of 150 × 300 mm were cast in order to test the tensile strength. Prisms with the size of 100 mm × 100 mm × 400 mm were fabricated in order to assess the tensile flexural strength.

The second step involved selecting the optimal curing agent to reinforcement agent ratios in order to cast self-compacting, self-curing beam samples. In addition, this step involves casting three beams (each beam differs from the other in terms of longitudinal reinforcement, Where the top layer of reinforcement steel has a diameter of 10mm for all beams, nevertheless the lower layer has variable diameters, (125 mm width, 250 mm height, and 2000 mm total length) with different optimal curing agent ratios as shown in the Figure (2). The beams were evaluated as though were simply supported. The beam notations are presented in Table (12). The outcomes were documented and captured through photography. The outcomes pertaining to deflection measurement for every load increment were documented, along with the initial occurrence of cracking and the load at which failure was seen. The quantity and arrangement of

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fractures seen during each incremental load increase until structural failure occurred. Subsequently, the beams were subjected to testing and subsequently photographed in order to visually document the pattern of cracks.

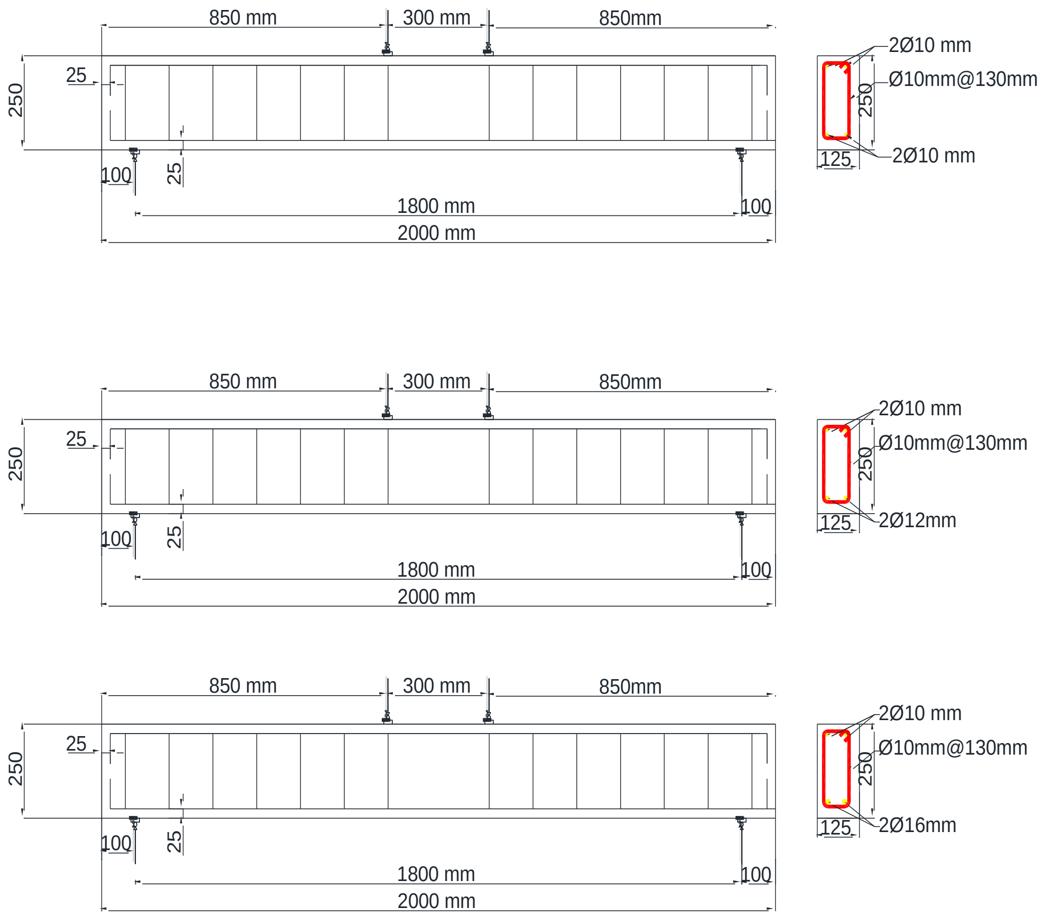


Figure (2) Details of the reinforced beams

Table 12. Notations of the beams Stage (2).

| Beam Name | Beam Description | |
|---|---|---|

| | | |
|---|---|---|
| C<br>N-B1-Φ10<br>N-B2-Φ12<br>N-B3-Φ16<br>H-B1-Φ10<br>H-B2-Φ12<br>H-B3-Φ16 | Control normal and high-strength beam without additives. | |
| N-P4-B1-Φ10<br>N-P4-B2-Φ12<br>N-P4-B3-Φ16<br>N-L-B1-Φ10<br>N-L-B2-Φ12<br>N-L-B3-Φ16 | Normal Strength self-curing self-compacting concrete N.S.SC-SCC | N.S beam using PEG 400<br><br>N.S beam using (LECA) |
| H-P4-B1-Φ10<br>H-P4-B2-Φ12<br>H-P4-B3-Φ16<br>H-L-B1-Φ10<br>H-L-B2-Φ12<br>H-L-B3-Φ16 | High Strength self-curing self-compacting concrete H.S.SC-SCC | H.S beam using PEG 400<br><br>H.S beam using (LECA) |

### *3.3 conducted tests*

The experimental programme was divided into two sections, as previously described. The tests depicted in this section. During the initial phase, the tests conducted on both fresh and hardened concrete align with the guidelines outlined in the European Code for self-compacting concrete [1,11]. The second stage explored the execution of the beam flexure test. The tests conducted on freshly mixed concrete included the slump test, L-BOX test, and V-funnel test, which were employed to assess the properties of self-compacting concrete. The concrete's workability was measured using a standard slump cone, as depicted in Figure (3). The L-BOX test evaluates the ability of the SCC to successfully traverse congested reinforcements. Moreover, segregation is a straightforward phenomenon that may be discerned by experimentation. Figure (4) shows the test instrumentation. The V-funnel flow time refers to the duration required for a specific volume of self-consolidating concrete (SCC) to pass through a constricted opening. This measurement serves as an indicator of the SCC's capacity for filling, assuming that issues such as blockage and segregation do not occur. It is worth noting that the flow time observed during the V-funnel test exhibits a certain level of correlation with the plastic viscosity, as depicted in Figure (5). The tests conducted on hardened concrete encompassed assessments of compressive strength, tensile strength, and flexural strength.

During the second part of the experiment, a beam flexure test was conducted. The load was initially applied and subsequently increased using a flexure testing machine with a maximum capacity of 200 tonnes. One dial gauge with an accuracy of 0.001mm per division and a maximum capacity of 10mm were employed to measure deflection. as shown in Figure (6). The experiment involved recording measurements of mid-span deflection, strain gauge readings, fracture formation, and spearing on the surface of beams. Cracks were identified using a marker pen, and the load at which the first cracks appeared was recorded at the visible crack site. The findings are determined by the starting cracking loads, the ultimate loads, the deflection values, the strain values, the number of cracks, and the pattern of cracks.

Fig. 3. Slump flow test.

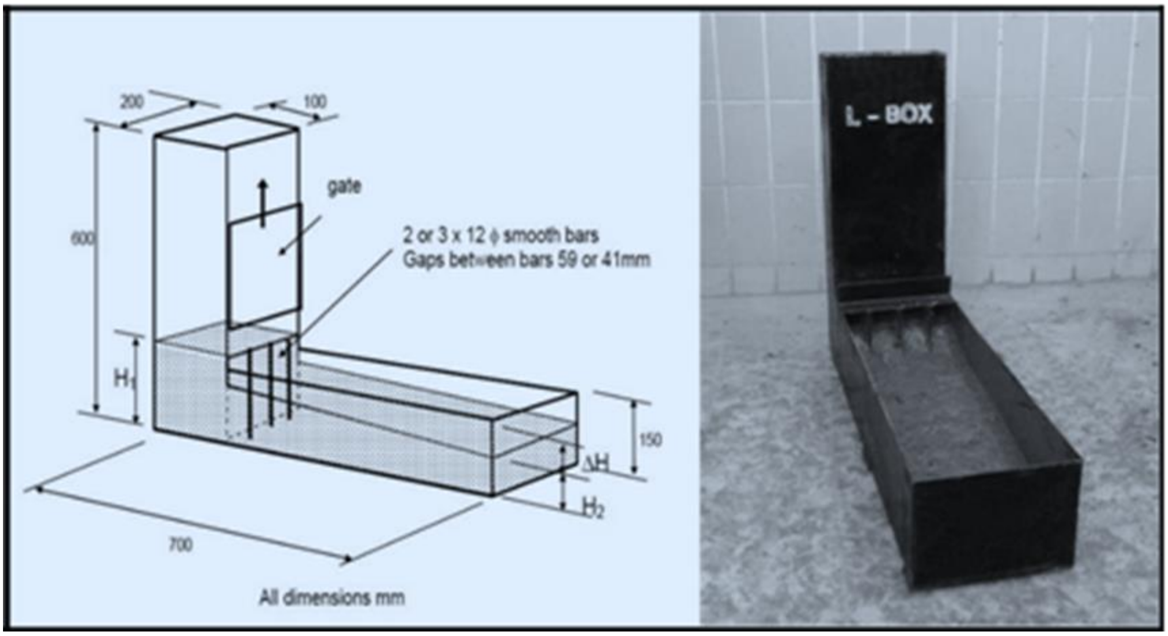


Fig. 4. L-BOX test

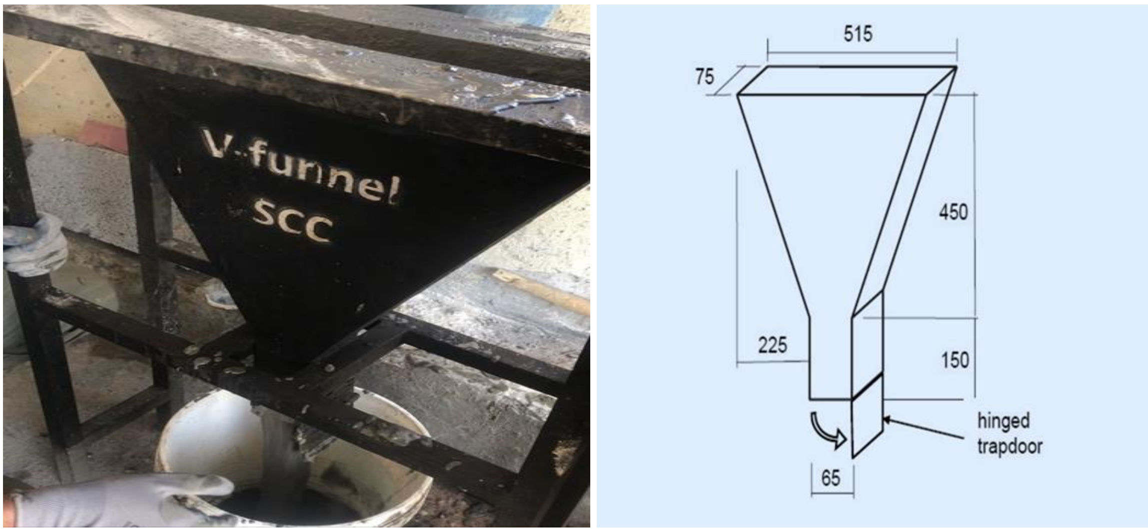


Fig. 5. V-funnel test


Fig. 6. Deflecto-meters and strain gauge.

## 4. Discussion of test results

The outcomes of this investigation were obtained in relation to the compressive strength, tensile strength, and flexural strength during the initial phase, as shown in table (13) and table (14). The results of the second stage's investigation into the behaviour of reinforced concrete beams made with this particular concrete type were determined in terms of the beginning and ultimate loads that caused cracks to form as well as deflection, strain, and crack patterns.

Table (13): Main hardened concrete properties of normal strength SC-SCC

| Mixes | Compressive MPa. | | splitting tensile (ft) MPa. | Flexural (fr) MPa. |
|---|---|---|---|---|
| | 7 days | 28 days | | |
| N.S. | 27.6 | 39.5 | 1.13 | 6 |
| NP400-3% | 23.5 | 30.3 | 1.1 | 7.2 |
| NL-2% | 33.9 | 34.5 | 1.1 | 6.5 |

Table (14): Main hardened concrete properties of high strength SC-SCC

| Mixes | Compressive MPa. | | splitting tensile (ft) MPa. | Flexural (fr) MPa. |
|---|---|---|---|---|
| | 7 days | 28 days | | |
| H.S. | 47.5 | 56.2 | 1.5 | 7.9 |
| HP400-4% | 33.5 | 42.3 | 1.13 | 10.8 |
| HL-3% | 40.4 | 47.0 | 1.3 | 5.4 |

### *4.1 Effect of using interior curing agents on properties of fresh concrete*

The results of the L-BOX tests, as well as the V-funnel tests and slump flow tests of normal strength (SC-SCC), are displayed in Table (15).

The flowability of normal strength self-consolidating concrete (SC-SCC) can be enhanced by increasing the dosage of self-curing agent, which aligns with the findings of earlier researchers [12]. The utilisation of Lightweight Expanded Clay Aggregate (LECA) results in a reduction in flowability. Since the porous material will soak up some of the water used in mixing, and the light aggregates will have less mass than the control mix, the experimental results reveal that the experimental mix has more flow resistance. In doing so, the particle's mass acts as a brake on its motion. The LECA content of this concrete has a negative impact on its flowability. The tabulated data pertaining to the high-strength self-compacting concrete (SC-SCC) is presented in Table (16). The flowability of high strength self-consolidating concrete (SC-SCC) is enhanced by increasing the dosage of self-curing agent. The utilisation of PEG400 exhibits superior performance compared to its normal strength counterpart. The flowability of H.S.SC-SCC is enhanced with an increase in the content of LECA.

Table (15): Main fresh concrete properties of normal strength SC-SCC

| Mixes | Slump flow | | V-funnel (sec) | L-BOX $BR=H_2/H_1$ |
|---|---|---|---|---|
| | D (mm) | $T_{500}$(sec) | | |
| C | 750 | 2.7 | 4.5 | 0.95 |
| $NP_{400}$-2 | 690 | 2.5 | 5 | 1 |
| $NP_{400}$-3 | 700 | 2 | 4 | 0.99 |
| $NP_{400}$-4 | 710 | 3 | 5.5 | 0.98 |
| NL-2 | 700 | 2 | 6 | 0.95 |
| NL-3 | 690 | 3 | 6.3 | 0.93 |
| NL-4 | 670 | 3.5 | 6.5 | 0.90 |
| NL-5 | 670 | 4 | 6.7 | 0.90 |

Table (16): Main fresh concrete properties of high strength SC-SCC

| Mixes | Slump flow | | V-funnel (sec) | L-BOX $BR=H_2/H_1$ |
|---|---|---|---|---|
| | D (mm) | $T_{500}$(sec) | | |
| $HP_{400}$-2 | 700 | 2.3 | 4.5 | 0.99 |
| $HP_{400}$-3 | 700 | 2 | 4 | 0.95 |
| $HP_{400}$-4 | 710 | 2.5 | 4 | 0.90 |
| HL-2 | 670 | 2.5 | 3.5 | 0.93 |
| HL-3 | 680 | 2.3 | 3 | 0.90 |
| HL-4 | 690 | 2 | 2.7 | 0.85 |
| HL-5 | 690 | 2 | 2.5 | 0.85 |

### *4.2 Effects of interior curing agents on mechanical properties*

The figures 7 and 8 showed that the optimal results for the type and dosage of self-curing agent used in both normal and high-strength self-compacting concrete (SC-SCC). The findings acquired at 7 and 28 days following casting SCC.

The optimal value achieved with PEG400 as an additive in N.S.SC-SCC was found to be (3%) of the cement content, whereas in H.S.SC-SCC, the optimal value was determined to be (4%) of the cement weight. The optimal value achieved while including Lightweight Expanded Clay Aggregate (LECA) as an internal reservoir was found to be (2%) of the cement content as an additive for normal strength Self-Curing Self-Compacting Concrete (N.S.SC-SCC). Conversely, for High-Strength Self-Curing self-compacting Concrete (H.S.SC-SCC), the optimal value was obtained at a ratio of (3%) of the cement weight.

### *4.3 Internal curing agents and RC beam behaviour*

Figures (9,10, and 11) depicts the initial loads that caused cracking, as well as the load that caused failure, as shown in table (17). The deflection measurements were acquired at the midpoint of the lower surface of the beam span. The figures depicting the outcomes of deflection can be observed in Figures 12 to 29.

Table 17 presents the initial and Ultimate Cracking Load for tested beams.

| Beam Samples | Load kg. | |
|---|---|---|
| | Initial Cracking Pcr. | Ultimate Cracking Pu. |
| N-B1-Φ10 | 1500 | 6600 |
| N-B2-Φ12 | 1200 | 7100 |
| N-B3-Φ16 | 2500 | 10300 |
| H-B1-Φ10 | 1750 | 6500 |
| H-B2-Φ12 | 2000 | 7500 |
| H-B3-Φ16 | 2700 | 11500 |
| N-P4-B1-Φ10 | 1500 | 6100 |
| N-P4-B2-Φ12 | 2500 | 6750 |

| | | |
|---|---|---|
| N-P4-B3-Φ16 | 3500 | 11500 |
| N-L-B1-Φ10 | 1700 | 6500 |
| N-L-B2-Φ12 | 2000 | 7500 |
| N-L-B3-Φ16 | 2200 | 11750 |
| H-P4-B1-Φ10 | 1500 | 6500 |
| H-P4-B2-Φ12 | 2500 | 8100 |
| H-P4-B3-Φ16 | 2000 | 13750 |
| H-L-B1-Φ10 | 1500 | 6000 |
| H-L-B2-Φ12 | 2000 | 7200 |
| H-L-B3-Φ16 | 2300 | 12500 |

#### *4.3.1 The initial cracking and ultimate loads*

Figures (9,10, and 11) illustrates initial cracking stresses and failure loads. When PEG400 and LWA are used, the typical first cracking loads of high-strength SC-SCC beams and normal SC-SCC beams behave almost the same.

The initial cracking load (Pcr) is similar in the case of using PEG400 for normal strength N.S.SC-SCC and for high strength H.S.SC-SCC when using rebar with a diameter of 10 mm and 12 mm. When using rebar with a diameter of 16 mm, the normal strength N.S.SC-SCC is 75% higher than the high strength H.S.SC-SCC.

The failure load (Pu) has the same values in the case of normal strength N.S.SC-SCC and high strength H.S.SC-SCC when rebar with a diameter of 10 mm is used.

H.S.SC-SCC is 20% higher than the N.S.SC-SCC if 12mm and 16mm diameter rebar are used.

When LECA is used, the (Pcr) values are very similar in N.S.SC-SCC and H.S.SC-SCC when 10 mm and 16 mm rebar are used, and equal if 12 mm rebar is used. As for the failure load, its values are very similar in normal strength and high strength SC-SCC when 10 mm diameter rebar is used. and 12mm, but when 16mm rebar is used, the failure load of H.S.SC-SCC beams is 6% higher than that of normal strength N.S.SC-SCC.

Also, the beam failure load at H.S.SC-SCC when using PEG400 is 10% higher than if using LECA.

Also, beams containing LECA have a 15% higher (Pcr) than using H.S.SC-SCC PEG400.

#### *4.3.2 Values of deflection*

The load-deflection curves obtained from the various beams demonstrate a relationship between the justify load and the corresponding deflection values at the center points along the bottom surface of the tested beam. This relationship is true until the occurrence of the initial fracture, regardless of whether the beam is made of normal or high-strength self-compacting concrete (SC-SCC). The initial zone is referred to as the post-cracking zone, which extends from the starting point up to the point of cracking. This zone then transitions into the yielding point, marking the second zone. Finally, the third zone is known as the post-yield zone, which extends from the yielding point up to the point of failure. Since the cracking load is determined by the concrete's tensile strength, early loading histories of the beam's stiffness were nearly comparable at low loading levels. The second zone exhibited discernible variations in behaviour across the several beams. The slope of the curve in this particular region exhibits a nearly linear behaviour, rendering it of utmost significance in the context of design. It serves as a direct indicator of the beam's effective stiffness. With respect to the post-yield region, the beams exhibited an increased capacity to endure larger loads until reaching the point of failure. Figures (12 -29) depict the structural response of beams fabricated using PEG400 and LWA in comparison to control beams composed of normal strength SC-SCC. The measurements were taken at specific locations, namely mid point . The deflection values obtained from the experiments conducted on reinforced N.S.SC-SCC beams indicate that the largest deflection was observed when PEG400 was used, followed by the use of LWA, in comparison to the control beams. This may pertain to the ratios of stiffness and ductility exhibited by the materials in question.

Figures (12 and 29) present the load-deflection characteristics of beams fabricated using PEG400 and LECA for H.S.SC-SCC, in comparison to control beams of N.S.SC-SCC, at designated locations denoted as midpoint The deflection values obtained from the experimental analysis of reinforced H.S.SC-SCC beams indicate that the largest deflection was observed when PEG400 was used, followed by the use of LWA. Based on the data obtained, it can be concluded that the utilisation of LWA (specifically as LECA) demonstrates more efficiency compared to the use of PEG400 as a curing agent in conjunction with H.S.SC-SCC. This may be due to the fact that liquid water adsorption (LWA) functions as internal reservoirs, ensuring an adequate water supply for the completion of hydration processes in high-strength self-compacting concrete (H.S.SC-SCC).

The values exhibited a high degree of alignment with the findings of Muthukumar et al. (2015) [31]. Based on the obtained results, it is recommended to utilise PEG400 in conjunction with N.S.SC-SCC, as it has demonstrated notable enhancements. Conversely, the utilisation of LWA is advised when working with H.S.SC-SCC, as it has exhibited significant improvements.

### *4.3.3 Pattern of Cracks*

The crack patterns observed in all beams that were subjected to testing were documented and subsequently depicted at each incremental load stage until failure occurred. Subsequently, they were subjected to photographic documentation. In this examination, it was observed that all beams subjected to testing exhibited failure in flexure.

The quantity of fractures observed in beams made of normal strength self-consolidating concrete (SC-SCC) exhibited an increase during the various phases of stress. Figures (30–32) illustrate the crack pattern that can be found in beams with normal strength. The crack pattern observed in materials with normal strength The SC-SCC beams exhibited instances when certain beam samples had flexural failure, namely yielding of the steel, resulting in the presence of vertical fissures. Other beam samples were unsuccessful due to flexure-shear failure. Typically, fractures in beams tend to originate in the vertical direction. As the load on the beam increases, these cracks gradually shift in an inclined direction, resulting from the combined influence of shear and flexure. Subsequently, the cracks progress towards the top of the beam, ultimately leading to its splitting.

Figures (33-35) depict the crack pattern observed in high-strength beams. The quantity of fractures in high-strength self-compacting concrete (SCC) beams exhibited a rise throughout the loading phases.
The observed fracture patterns in the high-strength SC-SCC beams suggest that the failure mechanisms of all the beams tested were mostly due to flexural failure and flexure-shear failure, with crack widths that were almost equal. The number of cracks in PEG400 is also lower than in LWA and other compression formats. The occurrence of cracks in normal strength SC-SCC beams is greater compared to high-strength SC-SCC beams, mostly attributed to the increased ductility exhibited by normal strength SC-SCC beams.

## 5. Conclusions

Throughout the course of this study, a number of tests have been carried out in order to evaluate the behaviour and the characteristics of self-curing self-compacting concrete. On the basis of the results of the experiments that were reported in this paper, one could come to the following conclusions:

1. The type of curing agent used in self-curing self-compacting concrete plays a significant role in determining the primary qualities of the concrete, especially in terms of how easily it can be worked and how well it flows.
2. When aiming to produce high-strength self-curing self-compacting concrete, it is advisable to utilise Lightweight Expanded Clay Aggregate (LECA) rather than relying on the usage of chemical agents.
3. For N.S.SC-SCC and H.S.SC-SCC, the best results are seen when PEG400 is used as an additive at 3% and 4% of the cement content, respectively. In the context of utilising LECA (lightweight expanded clay aggregate), the optimal values were found to be 2% for N.S.SC-SCC and 3% for H.S.SC-SCC.
4. In the case of reinforced H.S.SC-SCC beams, the deflection values achieved while utilising LECA were compared to those acquired when employing PEG400, with the former yielding the largest recorded deflection values.
5. Almost the same first cracking loads are seen for PEG400 and LECA in both standard and high strength SC-SCC beams that have been strengthened. In the case of reinforced high-strength self-compacting concrete (H.S.SC-SCC) beams, it was observed that the first cracking loads exhibited an approximate 11% increase when compared to reinforced normal-strength self-compacting concrete (N.S.SC-SCC) beams.
6. The ultimate load values obtained from testing reinforced N.S.SC-SCC beams exhibit minimal variation across different curing chemicals utilised. When considering the situation of H.S.SC-SCC, it was observed that LECA exhibited superior performance compared to PEG400.
7. Both the N.S.SC-SCC and H.S.SC-SCC crack patterns demonstrated that flexural failure and flexure-shear failure are the mechanisms of failure for all tested beams.
8. The amount of cracks that may be seen in PEG400 is significantly lower than that seen in LECA.

In conclusion, the addition of an appropriate quantity of internal curing additive to traditional self-compacting concrete mixes allows for the production of normal-strength self-curing self-compacting concrete as well as high-strength self-curing self-compacting concrete. The utilisation of N.S.SC-SCC and H.S.SC-SCC has proven to be effective in enhancing the performance of structural elements that present challenges in terms of curing and compacting processes. PEG400, which acts as a self-curing agent, is advised for use as a chemical curing agent for normal strength SC-SCC. This is so that the material may be worked more easily while still maintaining acceptable strengths. Curing agents, such as PEG 400, are employed in the reduction of water evaporation from self-compacted concrete. Additionally, the use of LECA serves to function as internal water reservoirs or tanks within the concrete, hence enhancing the ability to retain water of self-compacting concretes.

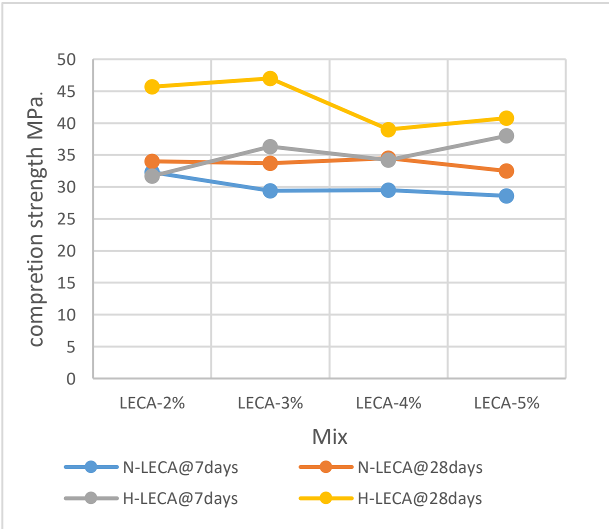


Fig. 8. Compressive strength values for N.S.SC-SCC and H.S.SC-SCC samples when using LECA

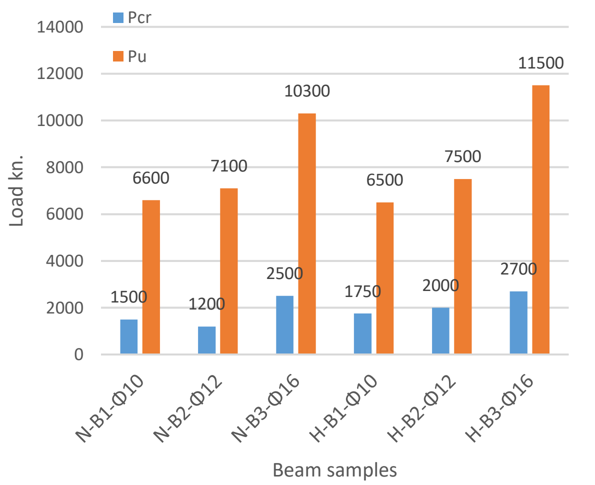


Fig.9 Initial cracking load and failur load of N.S and H.S. reinforced beam samples

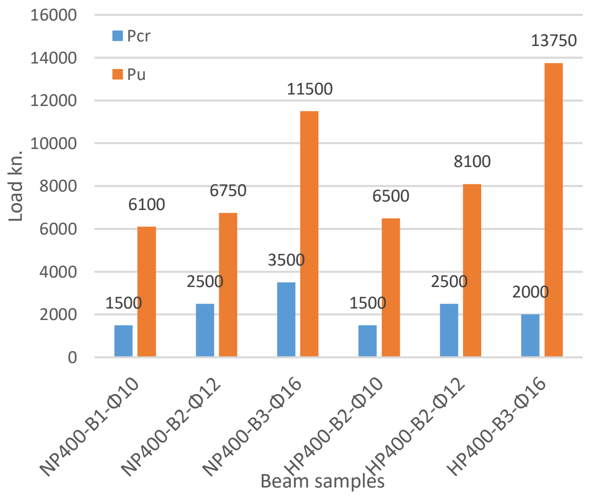


Fig.10 Initial cracking load and failur load of N.S.SC-SCC and H.S.SC-SCC reinforced beam samples when using PEG400

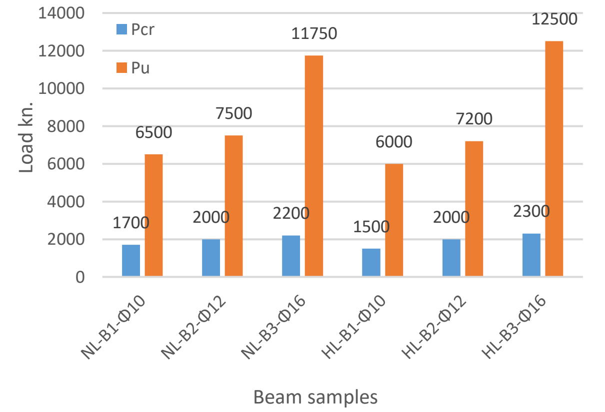


Fig.11 Initial cracking load and failur load of N.S.SC-SCC and H.S.SC-SCC reinforced beam samples when using LECA

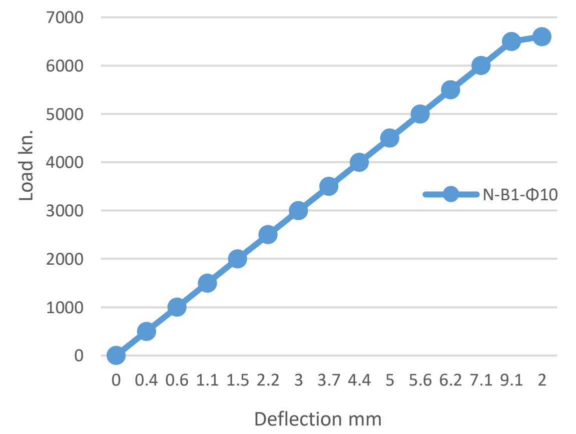


Fig.12 Load-deflection values for N.S.Φ10 beam

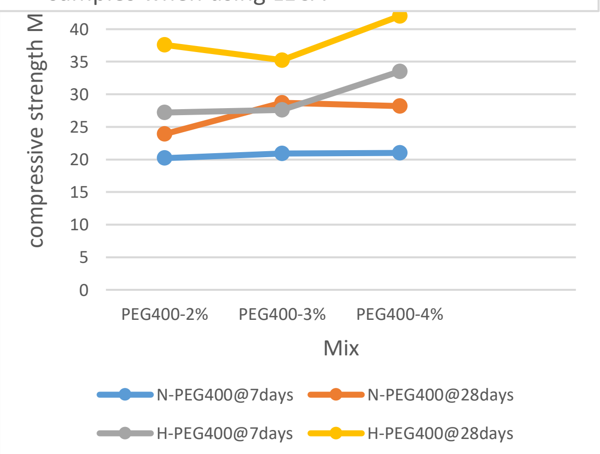


Fig. 7. Compressive strength values for N.S.SC-SCC and H.S.SC-SCC samples when using PEG400

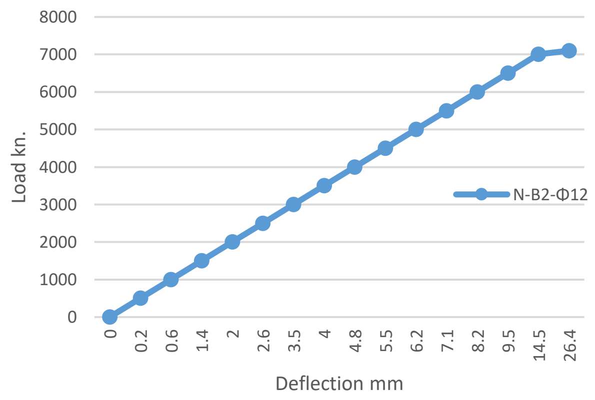


Fig.15 Load-deflection values for N.S.Φ12 beam

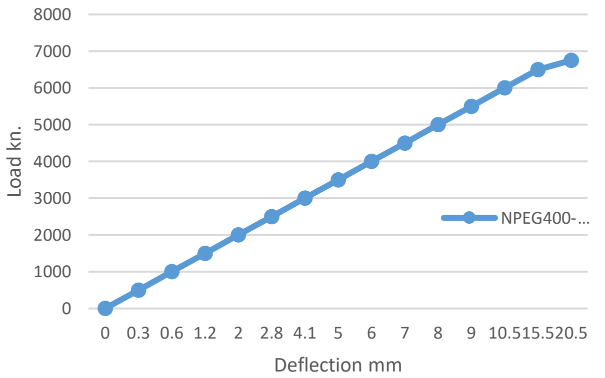


Fig.16 Load-deflection values for N.S.SC-SCC Φ12 beam when using PEG400

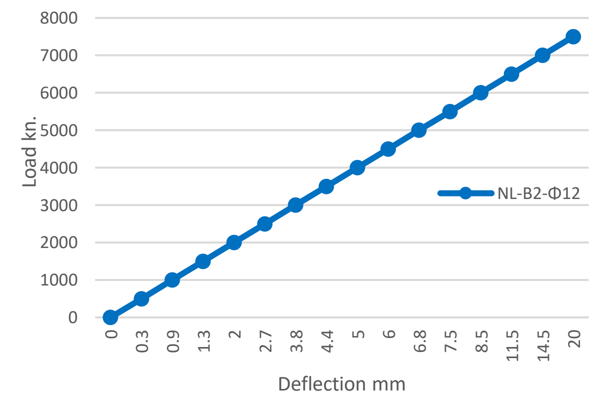


Fig.17 Load-deflection values for N.S.SC-SCC Φ12 beam when using LECA

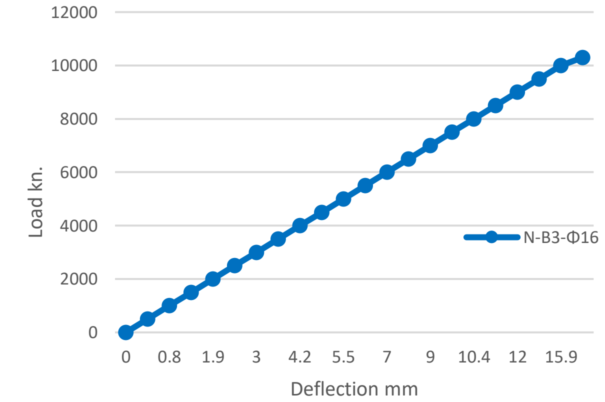


Fig.18 Load-deflection values for N.S.Φ16 beam

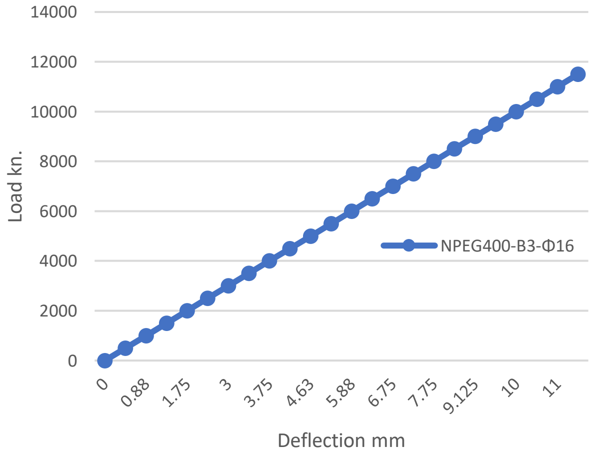


Fig.19 Load-deflection values for N.S.SC-SCCΦ16 when using PEG400

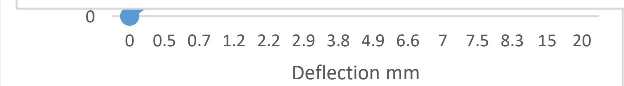


Fig.13 Load-deflection values for N.S.SC-SCC Φ10 beam when using PEG400

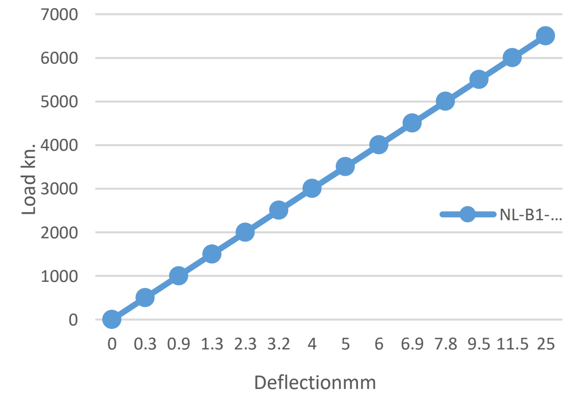


Fig.14 Load-deflection values for N.S.SC-SCC Φ10 beam when using LECA

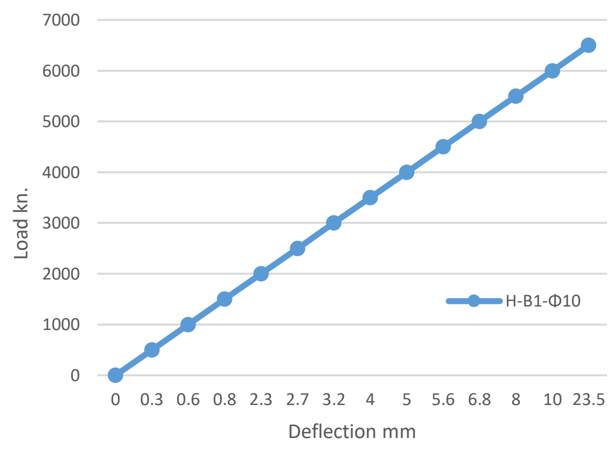


Fig.21 Load-deflection values for H.S.Φ10 beam

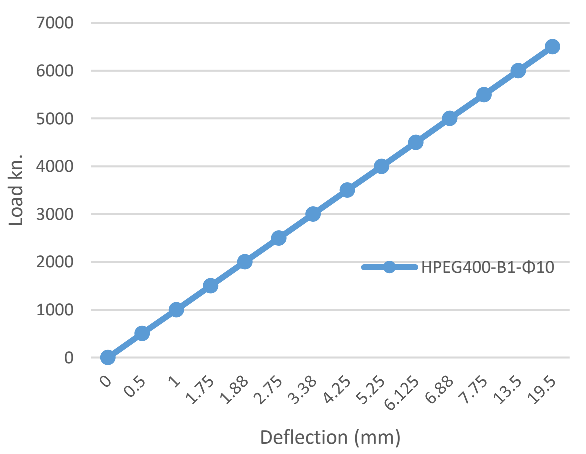


Fig.22 Load-deflection values for H.S.SC-SCC Φ10 beams when using PEG400

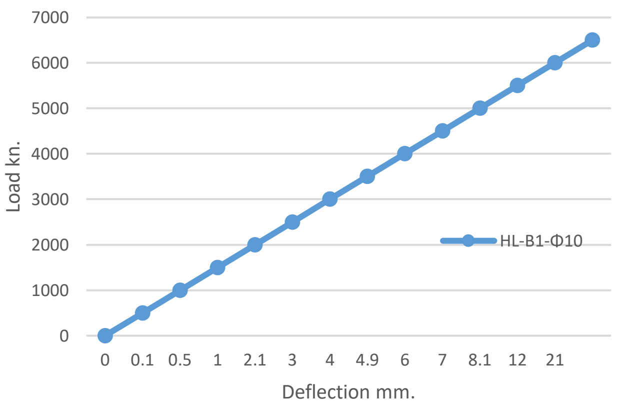


Fig. 23 Load-deflection values for H.S.SC-SCC Φ10 beams when using LECA

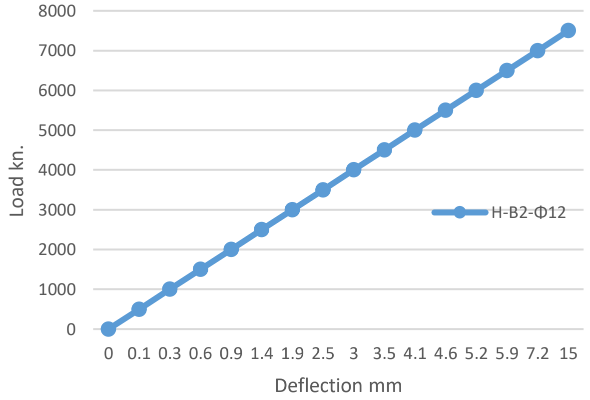


Fig. 24 Load-deflection values for H.S.Φ12beams

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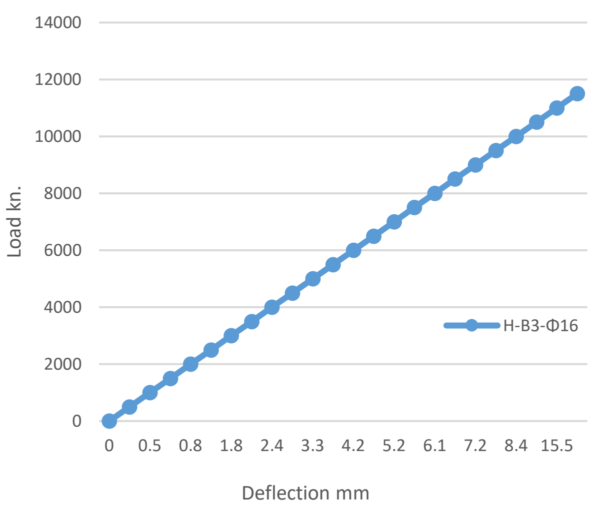



Fig.27 Load-deflection values for H.S. Φ16 beam


Fig.28 Load-deflection values for H.S.SC-SCC Φ16 beam when using PEG400

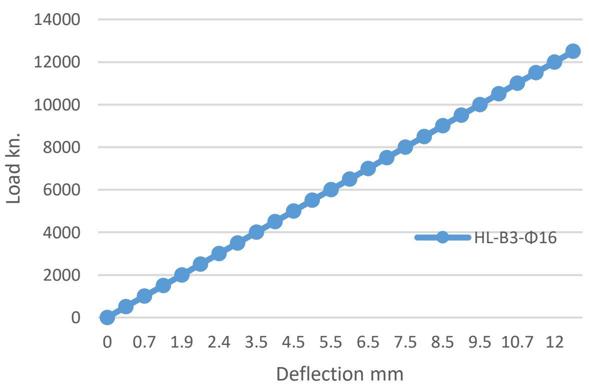



Fig.29 Load-deflection values for H.S.SC-SCC Φ16 beam when using LECA

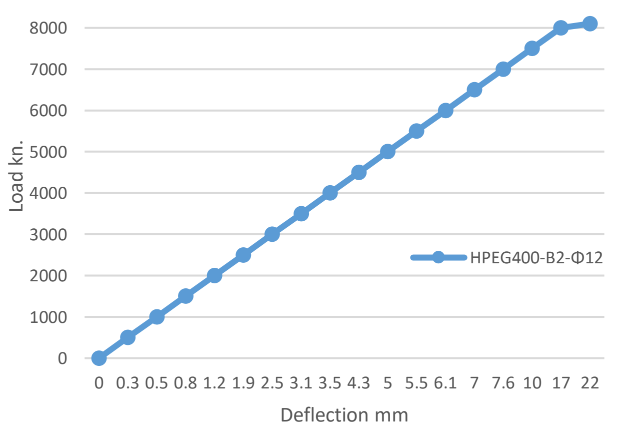



Fig.25 Load-deflection values for H.S.SC-SCC Φ12 beam when using PEG400

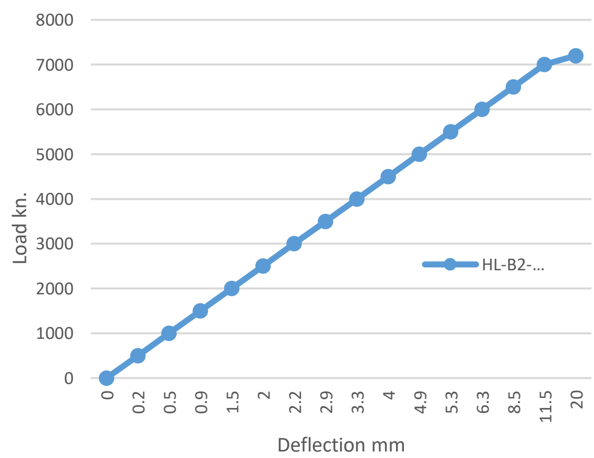



Fig.26 Load-deflection values for H.S.SC-SCC Φ12 beam when using LECA

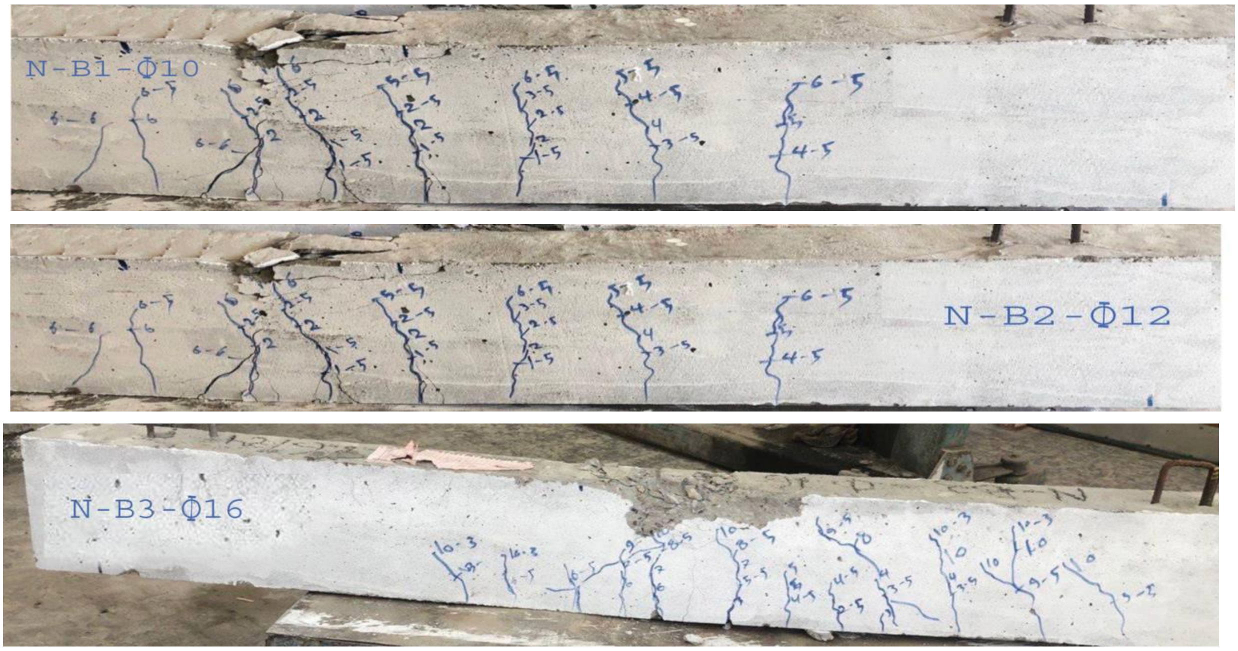



Fig. 30. Crack patterns for N.S. beam.

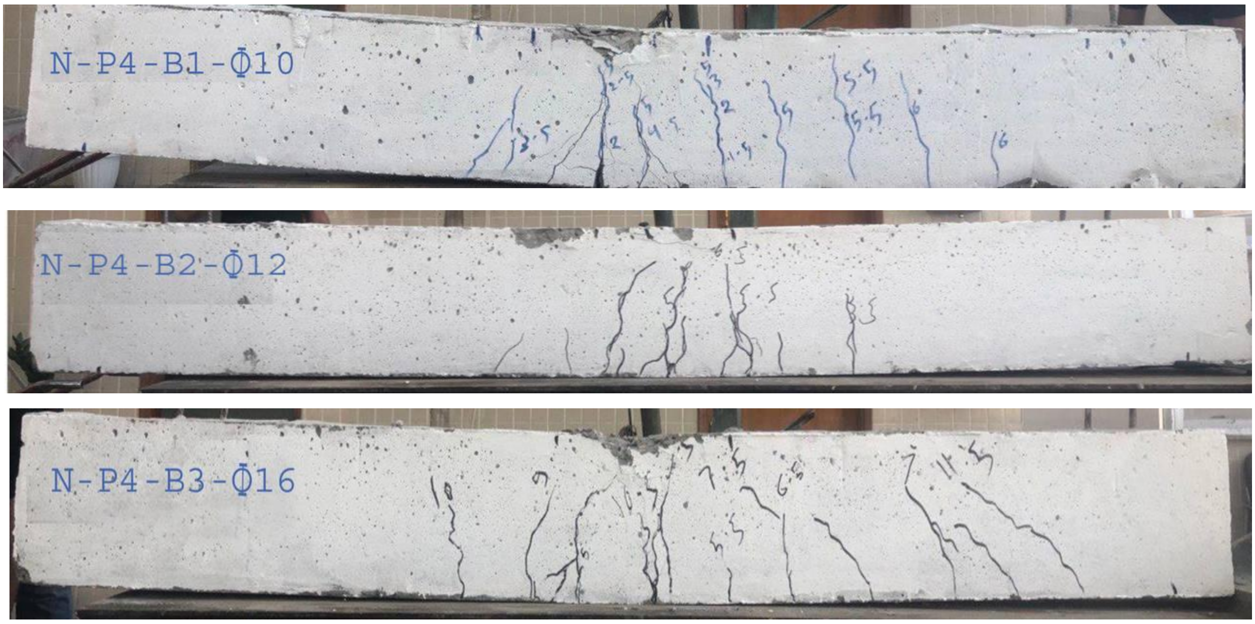
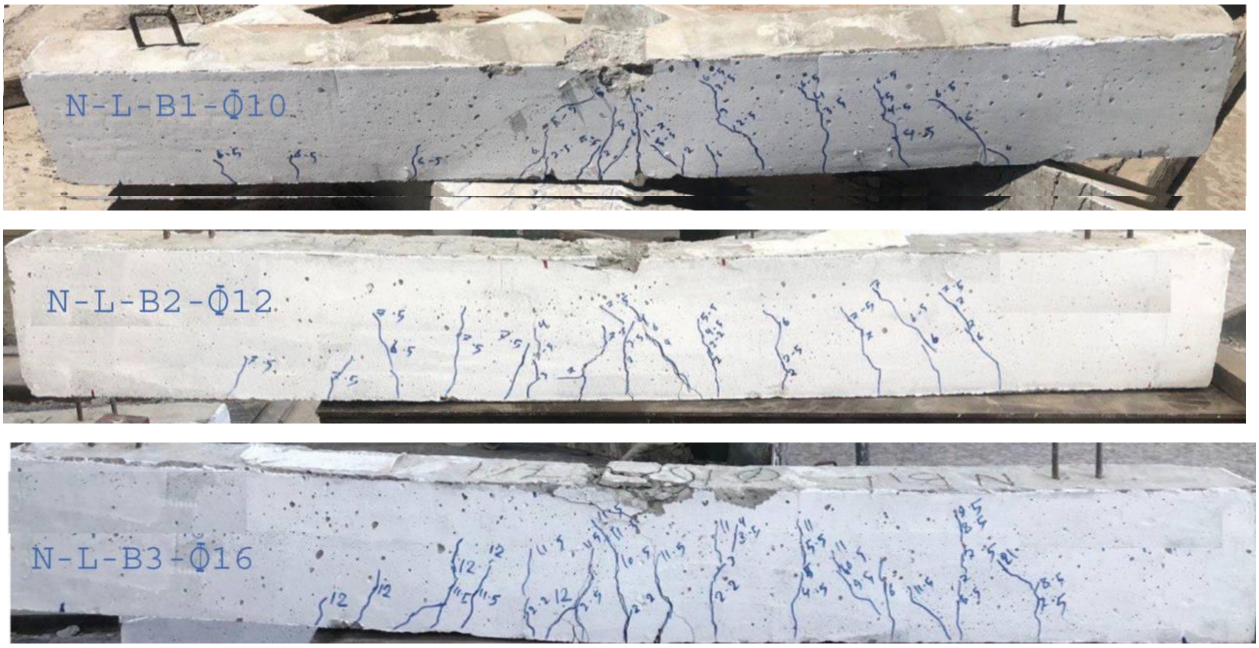



Fig. 31. Crack patterns for N.S.SC-SCC Beam when using PEG400



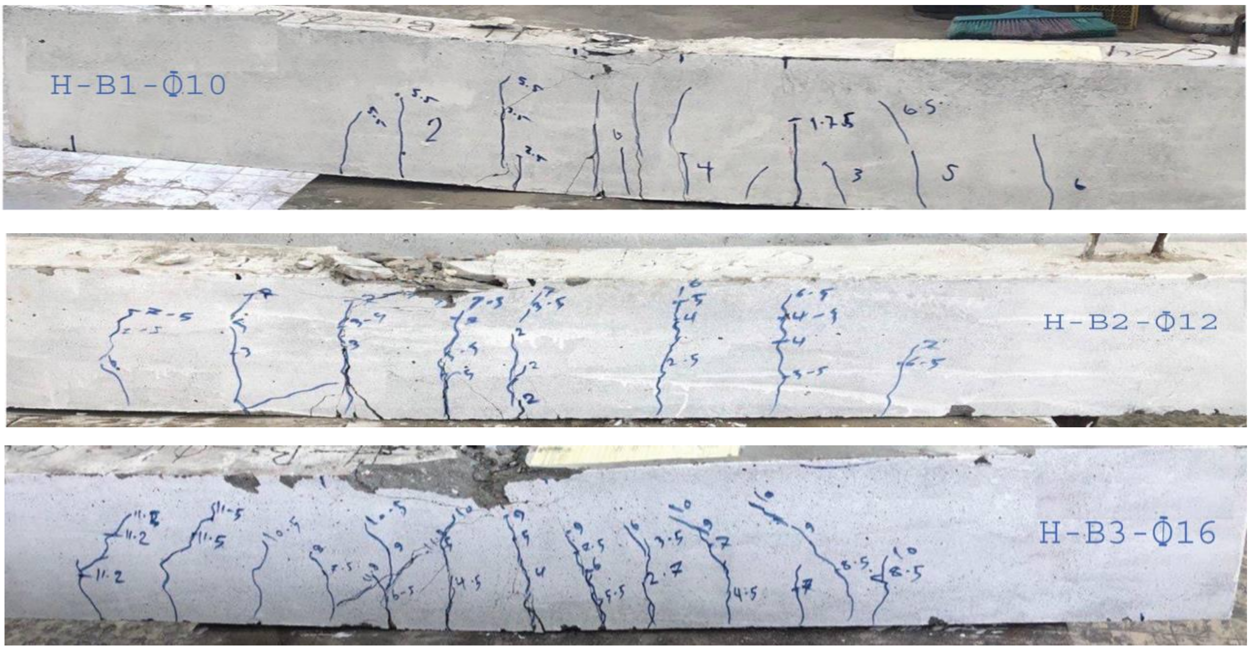




Fig. 32. Crack patterns for N.S.SC-SCC Beam when using LECA

Fig. 33. Crack patterns for H.S. beams.

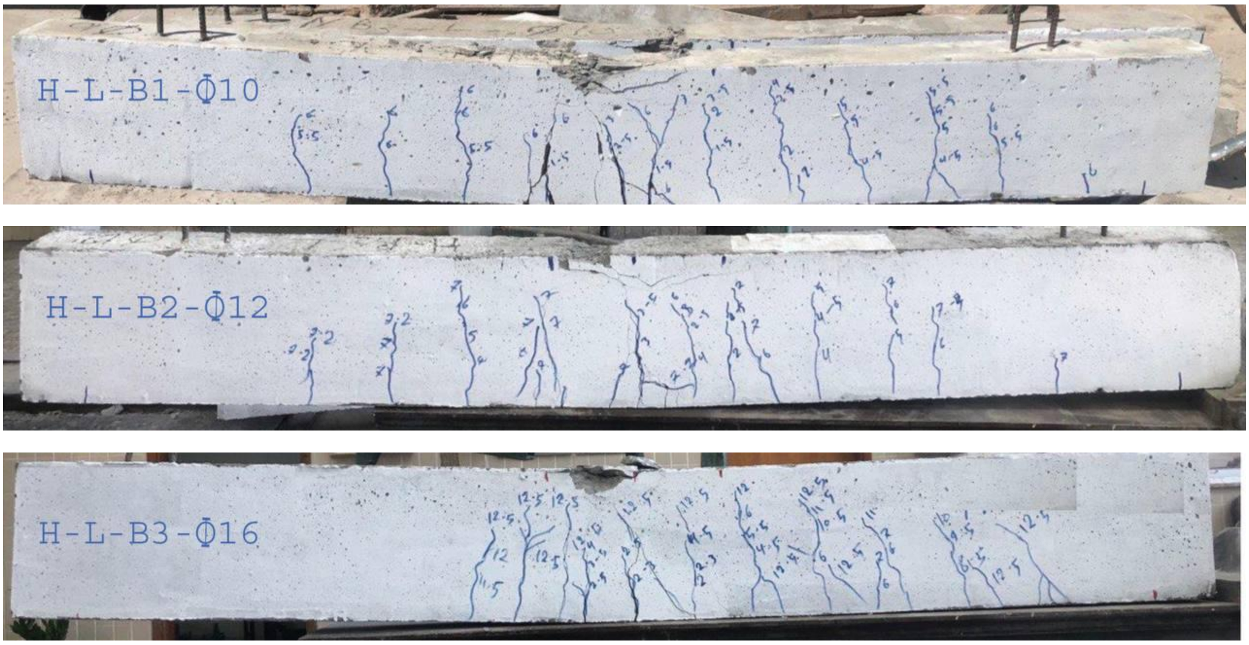




Fig. 34. Crack patterns for H.S.SC-SCC Beam when using PEG400.

Fig. 35. Crack patterns for H.S.SC-SCC Beam when using LECA


Fig. 37 LECA

Fig. 36 PEG400

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**Conflicts of Interest:** The authors declare no conflict of interest.

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