Kaunas University of Technology
Faculty of Civil Engineering and Architecture

Complex Admixture Influence on the Self Compacting Concrete properties

Master's Final Degree Project

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Structural and Building product engineering (T000M021)

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Declaration of Academic Integrity

I confirm that the final project of mine, Arvind Balakrishnan, on the topic „Complex Admixture Influence on the Self Compacting Properties "is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this project.

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Arvind Balakrishnan **“**Complex Admixtures Influence on the Self-Compacting Concrete Properties”. *Master’s* final project / supervisor prof. dr. Žymantas RUDŽIONIS/ Faculty of Civil Engineering and Architecture, Kaunas University of Technology.

Keywords: Self-compacting concrete (SCC), compressive strength, self-compacting fiber reinforced concrete (SCFRC), pulverized fuel ash (PFA), polyolefin fiber, fresh and hardened concrete properties.

SUMMARY

Self-compacting concrete mix is mostly known for its high flowability and high resistance to segregation and bleeding. These properties of concrete lead to finishing without using compacting or vibrating equipment. Addition of mineral admixtures, such as pulverized fuel ash, and superplasticizers improves the SCC properties and increase rheological parameters. This thesis discusses results of the experimental investigation on properties of SCC and SCFRC with the inclusion of polyolefin fibers with a difference of 0, 3, 6, 9 kg per m^3, Glenium superplasticizer and containing PFA replacement rates of 0%,20%,40%,60% cement mass. The fresh properties of the concrete mix had been studied through segregation, bleeding, slump flow and slump flow time T_{500}. The hardened properties of SCC had been studied through compressive and flexural strength, ultrasonic pulse velocity and CMOD test at age of 7, 28, 56 days hardening time.

Arvind Balakrishnan „Kompleksinių priedų įtaka susitankinančio betono savybėms“. Baigiamasis magistro darbas / vadovas prof. dr. Žymantas RUDŽIONIS“ Statybos ir architektūros fakultetas, Kauno technologijos universitetas.

Raktiniai žodžiai: susitankinantis betonas (SSB), stipris gniuždant, susitankinantis pluoštu armuotas betonas (SSPAB), lakieji pelenai (LP), poliolefino pluoštas, šviežio ir sukietėjusio betono savybės.

SANTRAUKA

Susitankinantis betono mišinys pasižymi ypač dideliu takumu ir yra atsparus segregacijai ir vandens atsiskyrimui. Šios betono savybės leidžia atlikti betonavimo darbus nenaudojant jokios sutankinimo ar vibravimo įrangos. Mineralinio priedo, tokio kaip lakieji pelenai, ir superplastiklių įdėjimas pagerina SSB savybes ir taip pat padidina reologinių savybių parametrus. Šiame darbe nagrinėjami SSB ir SSPAB savybių eksperimentinio tyrimo rezultatai, į kuriuos įmaišyta 0, 3, 6, 9 kg poliolefino pluošto 1 m^3 betono mišinio, Glenium superplastiklis ir 0%, 20%, 40%, 60% cemento masės pakeista lakiųjų pelenų priedu. Šviežio betono mišinio savybės bus tiriamos nustatant išsisluoksniavimo, vandens atsikyrimo, pasklidimo ir pasklidimo trukmės T_{500} rodiklius. Sukietėjusio SSB savybės buvo ištirtos nustatant stiprį gniuždant ir lenkiant, ultragarsiniu impulso greičiu ir CMOD bandymu po 7, 28, 56 dienų kietėjimo trukmės.

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Introduction

In the present scenario of the construction industry, the self-compacting concrete and self-compacting fiber reinforced concrete is a special type of concrete mixture which is widely used in construction industry, whereas it is first developed in the year of 1988 due to its various properties such as high durability and high flowability which is resistant to bleeding and segregation [1,2]. Both the construction industry and the public are concerned about the lack of raw material and the effect of waste on the environment. Due to the manufacturing of cement from the natural source and the abundant use of cement by the construction industry lead to its extinct [3,4]. This special type of concrete is highly useful for difficult casting conditions and reduce overall construction cost. To obtain higher flowability/workability superplasticizer or chemical admixtures are necessary to use in self- compacting concrete. SCC and SCFRC made products are high in quality, illustrates perfect finishing and free from defects which are called as voids, as results of the best filling ability of self-compacting concrete lead without honeycomb structure formed in the concrete [5]. This type of concrete can also be derived with the addition of finer particle of industrial waste such as pulverized fuel ash and silica fumes. This type of addition of finer particle of pozzolanic material used as mineral admixture as a replacement of cement in SCC [6]. Superplasticizer can change the concrete viscosity and also to the expansion of the concrete viscosity, a different type of fillers is used such as fly ash, pulverized fuel ash, silica fume, quartzite filler, stone powder etc [7]. hence use of a partial amount of waste fly ash as replacement of cement provide various benefits such as increases workability, decreases permeably of concrete and increase the cohesiveness of concrete [8]. It has been found that 20% replacement of PFA by cement mass in concrete gives higher compressive strength. Addition of the mineral admixtures results in providing the required amount of self-compacting concrete viscosity and constantly reducing bleeding and segregation [9]. Other than mineral admixtures agricultural admixtures such as fuel ash, palm oil, groundnut husk ash, and rice hull ash can also be used as a mineral admixture in self-compacting concrete [10]. From past few years using of fibers in the concrete mixture is gaining considerable attention. Due to environmental exposure, poor construction and the presence of chloride ions in a concrete lead to corrosion, microcracks, degradation and steel corrosion [11].

Pulverized fuel ash is a material obtained from the combustion of coal at high temperatures and pressures in power stations which produces electricity and as a waste material of different types of ash is removed. The waste from the clinker such as 'fine' ash fraction is passed top wards with the flue gases and collected by highly efficient electrostatic precipitators before reaching the atmosphere. Fly ash is also recognized as the pulverized fuel ash (PFA). It is mainly serene of extremely fine, glassy sphere structure and looks similar to cement. Fly ash is mostly stored in the power plant or disposed to the landfills. According to the statistic report for years 1987 – 1990, 410 million tons of pulverized fuel ash was produced from different sources all over the world. Only 16 % of the totals were utilized in the construction sector [12].

The chemical composition of pulverized fuel ash is not similar to Portland cement (pc). It won't hydrate with water straightforwardly yet needs lime and water to hydrate. In concrete, the lime required emerges from the hydration of the cement. Fly ash is constantly utilized in a mix with Portland concrete, regularly in the range with 80% of Portland cement and 20% PFA to 60% of Portland cement and 40% PFA remains, based on the application [13].

Using of pulverized fuel ash in the different field saves an environment from degradation by landfills. Pulverized fuel ash is used recently in many applications such as to replace naturally available raw materials and minerals, which can decrease the use of raw material in the environment. PFA is also used as a raw material in the manufacture of flowable fill concrete as a purpose to satisfy self-leveling, SC backfills substantial which is a compressed in the form as a granular fill. Flowable fill concrete or SCC is consists of combinations of Portland cement and a filler material which contain some mineral admixtures, for example, PFA. The filler material is generally comprising of fine aggregate however some flowable fill concrete may contain around equivalent parts of coarse and fine aggregate [14].

The availability of PFA is mainly classified into 2 major classes which are specified based on their natural composition which is obtained from the type of source coal burned; they are determined as Class C and Class F. Basically Class F PFA is obtained from the burning of a bituminous or anthracite coal and Class C PFA is generally waste obtained from the heating of sub-bituminous coal and lignite. Mostly, Class C PFA has highly cementitious properties when it is added to pozzolanic material due to reaction with free lime, but in case of Class F is very barely cementitious but when the composition is combined with water it provides little cementitious properties. There were no specific requirements to determine the class of PFA from the source of coal which is burned. Class F can also be produced from a non-bituminous type of coal and bituminous coal can produce PFA which are not class F. The size of ash obtained should have a finesse of 45 μs or less, and amount of carbon content present in PFA called as a loss on ignition (LOI), which should be less than 4% [15].

Fibers becoming very useful material to overcome those type of problems because of its various benefits. Normal conventional standard concrete and self-compacted concrete both have good compressive strength with low tensile strength. Addition of small quantity of fibers can decrease shrinkage cracking [16] also increase the toughness and tensile strength [17]. Nowadays in the market different type of fibers are available in different geometrical shapes. Fibers can be manufactured by using various kind of materials like steel, carbon, palm, polypropylene, glass, asbestos, synthetic and natural materials [18,19]. Steel fibers are most widely used fibers among all the fibers because of high modulus of elasticity and tensile strength. Steel fibers are used to decrease the thickness, obtaining higher strength properties and applies to road construction, precast concrete, tunnel, airports, and building industry. On steel fiber reinforced concretes, extensive studies are done from last few years to increase the mechanical properties and durability [20,21]. Steel fibers have various benefits, but it leads to steel corrosion and cracks in certain environmental conditions. As well on the topic of steel corrosion, various studies were carried out and still, studies are being carried out to reduce this problem [22,23]. Polyolefin fibers nowadays widely used because of its significant benefits such as it increases concrete strength and decreases the unit weight of concrete [24]. Polyolefin fibers have great influence in term of strength, ductile and flexibility than steel fibers [25]. Polyolefin fibers are lightweight than steel fibers and it has no effects with water. Polyolefin fibers reinforced concrete showed better results in term of steel corrosion and cracks [26]. From past few years' researchers are conducting experimental studies on beneficial aspects of polyolefin fibers in normal conventional concrete, lightweight concrete, foamed concrete and high-performance concrete [27,28,29].

As per proposition that to keep slump flow and V-channel test, replacement of cement with fly ash would require an expansion in water/powder proportion and a decrease in superplasticizer measurement. Higher substitution levels prompted a decrease in the compressive quality, tensile strength, ultrasonic pulse velocity of cement (UPVC) and so on. The decrease is higher at early ages however diminishes at a later age [30].

In spite of the fact that the absorption increments with expanding PFA content, the adsorption value of SCC containing high volume (80%) of PFA is beneath 2% at 56 days of curing. Including expanding measures of PFA in SCC lessens the drying shrinkage. Also, there is a change in shrinkage with the expansion in PFA content. Substituting cement with 80% PFA can decrease the shrinkage by two third [31].

Based on the SCC mix the carbonation depth is continuously increased when the age of the concrete is increased from 90 days to 365 days. For SCC mixes, deicing salt surface leads to the reduction of weight loss when there is a constant increase in PFA content except with mix replacement range of 15% PFA with cement mass. SCC mixes made with PFA reduces the rapid chloride ion penetrability to the very small range which varies from less than 700 to 400 Coulomb at the age difference of 90 and 365 days respectively [32].

Best SCC at 20 and 40% replacement of fly ash. Addition of PFA decrease fresh property but flexural and tensile strength increase. Addition of fly ash provide a good result and also based on the economy [33]. Mostly 20% and 40% provide an increase of compressive strength and best test results and also increase bleeding and segregation. The high ash volume as a replacement of the cement mass up to 60% negatively affected the fresh and hardened concrete properties but improved resistance bleeding and segregation in both SCC and SCFRC. PFA addition by 0.22% of volume concrete reduce the properties of fresh concrete but slightly enhanced the hardened properties of the concrete [5].

The production of polyolefin fiber-reinforced self-compacting concrete has a high-performance at fresh stage behavior when compared with steel-hooked fibers. In addition, it is possible to produce it without high powder content and admixtures even with fiber content up to 10 kg/m^3. For high polyolefin fiber content mixtures in the concrete, compressive strength slightly decreased and tensile strength increased 30% compared with normal self-compacting concrete, though it was 10% lower with a control steel fiber-reinforced self-compacting concrete. The dispersion obtained for the polyolefin fiber-reinforced self-compacting concrete with 4.5 kg/m^3 and 6 kg/m^3 was explained with the analysis of the fracture surfaces due to the lack of uniformity in the number and distribution of fibers. Concretes with high polyolefin fiber contents in which it is possible to reduce or even eliminate traditional steel reinforcement in structural applications is suitable for meeting with the principal standards and recommendation models. With the bond improver, the mixture with 10 kg/m^3 exceeded the requirements of the EN-14651[34].

It is determined that the maximum amount of fiber content can be used without affecting the flowability and filling ability of SCC. The amount of fiber which can be used in the mix is mostly determined and influenced by the amount of paste and mortar volume, also the type of the fiber. The flow table test does not provide the perfect result for SCFRC its only evaluate deformability of SCC which cannot perfectly determine the restricted deformability. The test like the flow time and filing capacity ratio are also used to determine the maximum amount of fiber to produce on the mix [35].

According to the researchers, the addition of steel or polypropylene fiber increases the fresh property like reduction of the bleeding and use of polypropylene fiber reduce the optimum content by cement weight. It also increases the compressive strength at 28 days but steel fiber provides the high strength to the self-compacting concrete [36].

The fiber does not affect the compressive strength when exposed to less than 400^0 C but an increase in temperature leads to increase the compressive strength of SCFRC. Based on the size of the specimen the cubical size specimen provide the best compressive strength than cylindrical specimen because its easy to transfer the heat to center part of the cylindrical specimen from surface but cubical the distribution of heat is irregular which derives to the conclusion that avoids using the symmetrical shape use the shape of column with cubical shape which provides the better residual compressive strength [37].

Aim

The present investigation aims are to study the properties of fresh and hardened self-compacting concrete and self-compacting fiber reinforced concrete and also to determine the best workability of the concrete mix. PFA was added at replacement rates of 0%, 20% of cement mass with 3, 4.5, 6, 9 kg/m^3 of polyolefin fiber. Subsequently, segregation, bleeding, slump flow, slump flow T_{500} and flow table tests were conducted on fresh concrete. The compressive, flexural, UPVC and CMOD test of hardened concrete at ages 7, 28, and 56 days were also investigated.

Task

- To determine the fresh and hardened properties of normal cement mortar with the replacement of cement mass to mineral admixture (in PFA case) to a certain extent and also investigate the best replacement ratio of mineral admixture.

- To determine the fresh and hardened properties of self-compacting mortar with the replacement of cement mass to mineral admixture (in PFA case) to a certain extent and also investigate the best replacement ratio of mineral admixture.

- To determine the fresh and hardened properties of self-compacting concrete and self-compacting fiber reinforced concrete with PFA as replacement of cement mass to 20% with the addition of fiber content up to 9 kg/m^3.

- To determine the residual flexural tensile strength of fiber reinforced self-compacting concrete using crack mouth opening displacement test method.

- The main aim of this thesis is to determine the best type of SCFRC using fresh and hardened properties of SCFRC.

1. Material and method

1.1. Cement

Ordinary Portland cement of grade CEM I 42.5 (Rocket cement M-600, AB 66 Cement, Sweden) was used. Cement characterization test was conducted in accordance with EN 197-1:2000 [38]. Tables 1 shows the chemical composition of the cement respectively.

Table 1: Chemical composition of cement

Oxide composition	Content (%)	Limit in EN-197-1 specification
SiO_2	22.1	14-25
Al_2O_3	5.3	3-8
Fe_2O_3	2.2	0.5-6
CaO	63.7	60-67
MgO	2.4	0.1-4
SO_3	3.1	1-3
Na_2O	0.73	0.2-1.3
K_2O	0.94	0.2-1.3

1.2. Pulverized fuel ash or fly ash

PFA meets the general requirements of EN 450-1:2005 standard [39] satisfied class C for initial preliminary test. Table 2 presents the chemical composition and physical characteristics and table 3 provide the sieve analysis test of pulverized fly ash. Fly ash of class C is used in main thesis progress according to the standard of EN 450-1:2005 [39].

Table 2: Chemical composition and physical characteristic of pulverized fuel ash

Oxide composition	Content %	Limit of EN 450-1:2005 specification class C

SiO_2	59.00	36-60
Al_2O_3	27.26	23-35
Fe_2O_3	3.70	3-17
CaO	6.90	3-8
MgO	1.40	0.5-5.4
SO_3	1.00	0.1-2.1
K_2O	0.90	0.5-6
L.O.I	4.62	< 5 % by mass

Figure 1. Sieved pulverized fuel ash

1.3. Aggregate

The aggregates like crushed dolomite sand with the maximum size of 0-2 mm were used as the fine aggregate for initial tests with mortar. For the thesis, local sand of 0-1 mm and 0-4 mm of size were used and local coarse aggregate with a size of 4-16 mm was used.

1.3.1. Fine aggregate

The shape and size of the aggregate are the important factors on self-compacting concrete. Natural sand which confirms to EN 933-1 [40] specification was used. Table 3 and 4 show the fine grading analysis of 1 mm and 4 mm fine aggregate.

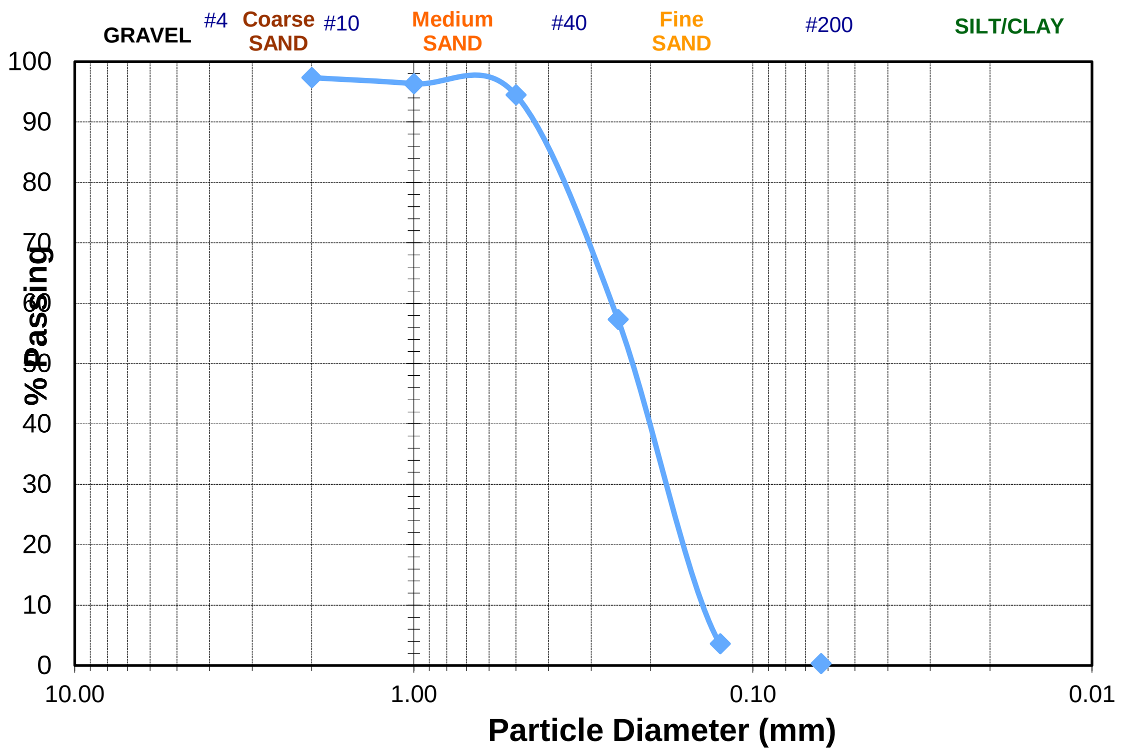
Figure 2 and 3. size of 0-4 mm and 0-1 mm fine aggregate

Figure 4 and 5. sieve analyzed of 1 mm and 4 mm fine aggregate

Table 3: Sieve analysis of 1 mm of fine aggregate

Sieve Number	Diameter (mm)	Mass of sand (g)	Soil Retained (%)	Soil Passing (%)
#8	2.00	26.5	2.7	97.4
#16	1.00	10	1.0	96.4
#30	0.50	18.7	1.9	94.5
#60	0.25	371.7	37.2	57.3

#120	0.13	537.5	53.8	3.6
#240	0.06	32.8	3.3	0.3
Pan	0.000	2.8	0.3	0.0

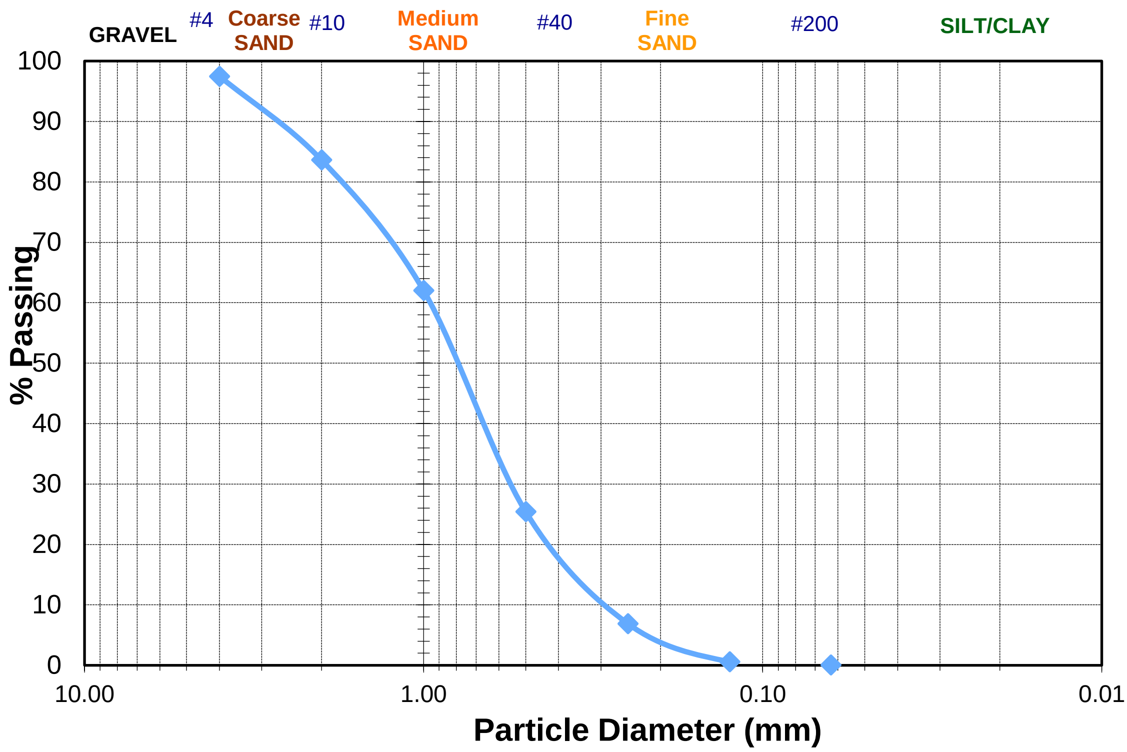


Graph 1. Percentage of passing ability vs particle diameter of 0-1 mm of fine aggregate

Table 4: Sieve analysis of 0-4mm of fine aggregate

Sieve Number	Diameter (mm)	Mass of sand (g)	Soil Retained (%)	Soil Passing (%)
#4	4.00	25.1	2.5	97.5
#8	2.00	138.7	13.9	83.6
#16	1.00	216	21.6	62.0
#30	0.50	366.1	36.6	25.4
#60	0.25	185	18.5	6.9
#120	0.13	63.3	6.3	0.6

#240	0.06	5	0.5	0.1
Pan	0.000	0.8	0.1	0.0



Graph 2. Percentage of passing ability vs particle diameter of 4 mm of fine aggregate

1.3.2. Coarse Aggregate

The coarse aggregate is obtained from local quarry called Rizgoniai quarry and the size of the coarse aggregate is 4 – 16 mm which confirms to the EN 933-1 [40] specification

1.4. Polyolefin fibers

The polyolefin fiber percentages used was selected from previous research journals and experimental mixes. Based on the analysis of the reports providing the amount of fiber was used to the maximum amount of 9 kg/m^3 to avoid the decline of compressive strength in concrete. The polyolefin fiber physical properties are provided in table 5.

Table 5: Properties of polyolefin fibers

Properties	Polyolefin fiber

Form	White color fiber
Length	50mm, */- 5%
Diameter	500 μm
Elastic Modulus	>11 GPa
Tensile Strength	500 N/mm2
Softening Point	150 °C
Bulk Density	910 kg/m^3

Figure 6. Polyolefin fibers

1.5. Superplasticizer

MasterGlenium SKY 700 is a new type of admixture which is obtained from the modification of polycarboxylic ether. This type of superplasticizer has mainly developed to serve in the high strength concrete where the concrete is needed with the quality of highest strength, durability and workability is required. This type of concrete is free of chloride & low alkali. It is compatible with all types of cement and also reduce the water content and cement mass ratio. This type of superplasticizer is used to produce high-performance concrete with higher workability and high early strength. This admixture is compatible with fly ash, rice hull ash and other types of high pozzolanic material.

Figure 7. MASTER Glenium SKY 700

2. Test methods and formula

There are 4 different test methods are used to find the comparison between the concrete properties

2.1. Flow table test:

The flow table test is used to determine the consistency of fresh mortar by measuring the spread of the concrete on a flat plate subject to jolting. It is done according to the standard of EN 12350-5:2009 [41].

Figure 8. Flow table test

2.2. Ultrasonic Pulse velocity Test:

UPVC works under the principle of a pulse of longitudinal waves vibration is produced by the electro-acoustical transducer held in contact with one surface of the concrete under the test. After traversing a known path length in the concrete, the pulse of vibration is converted into an electrical signal by the second transducer and electronic timing circuits enable the transit time of the pulse to be measured. This test method is used to determine the find the voids present in the concrete and quality of concrete in relation to standard requirements by passing the waves in the concrete surface. It is calculated by the standard EN 12504-4:2004 [42] and the formula is given below.

V = L/T

Where: V is the pulse velocity, in km/s;

L is the path length, in mm;

T is the time taken by the pulse to transverse the length, in µs.

2.3. Flexural strength Test:

The specimens can be casted in form of a prism with different size are subject to a bending moment by the application of load through upper and lower rollers. The maximum load sustained is recorded and the flexural strength is calculated based on the specification of EN 12390-5:2009 Part 5 [43]. It is calculated by the formula is given below.

$Rf = 1.5*Ff*I/b^3$

R_f is the flexural strength, in MPa (N/mm^2);

F_f is the maximum load applied, in N;

I is the distance between the supporting rollers, in mm;

b is the side square section, in mm.

2.4. Compression Strength Test:

The compression test is mostly compatible with all type of specimens and its size. The specimen is tested to determine failure by the first crack in a compression testing machine. The maximum load sustained by the specimen is recorded and the compressive strength of the concrete is calculated based on the specification of EN 12390-3:2001 [44]. The formula for calculation is given below.

$Rc = Fc/Ac$

Where Rc is the compressive strength in N/mm^2;

Fc is the maximum load at failure in N;

Ac cross-sectional area of the specimen in mm^2.

3. Initial test methods

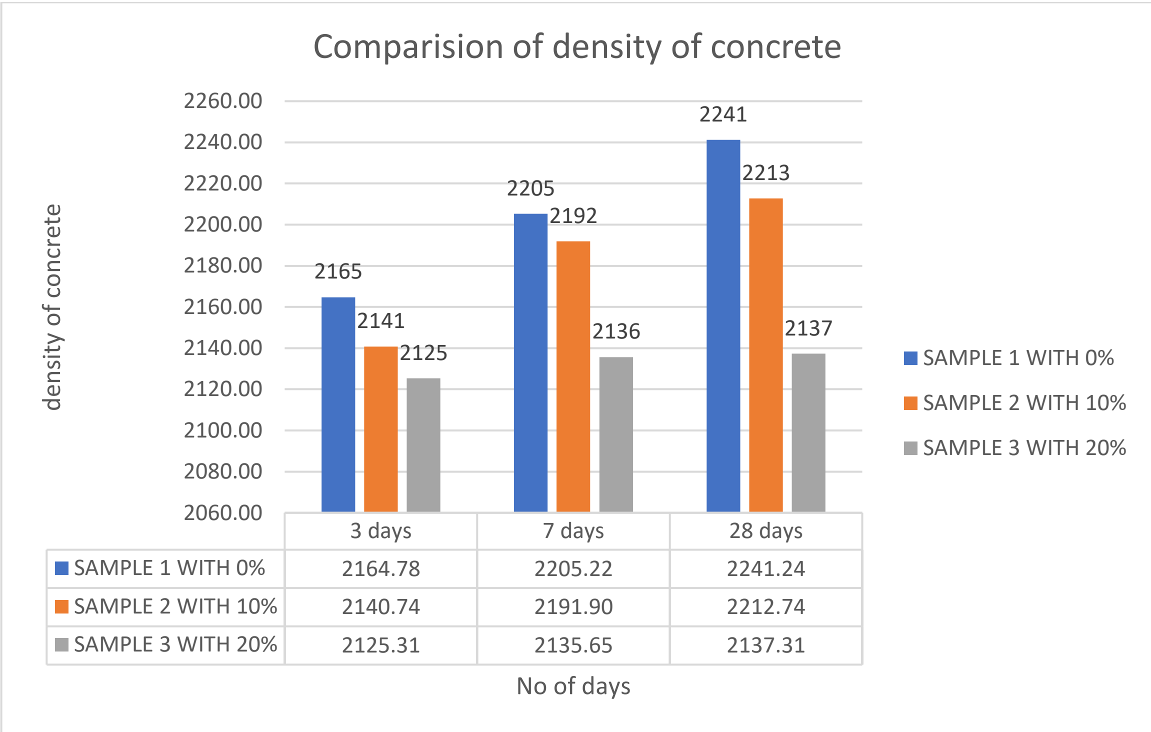
3.1. Procedure

Before casting of a specimen, the mixture is made of with 450g of cement and 1250g of fine aggregate (From France siliceous quarry) with water of 225 ml is taken. The water is added with cement mix slowly for 30 seconds in the mixture and then sand & PFA is added and mixed in high speed for 30 seconds and the mix is in still for 30 sec and finally mixed in high speed for 60 sec and the flow table is used to determine the consistency of the concrete. Then the specimen is cast into 9 prisms with the size of 40x40x160 mm with cement, fine aggregate, PFA and water. Each specimen is with different percentage of PFA and it is compacted into a mold for 25 times and the specimens were demolded after curing for 24 hrs at a controlled laboratory environment, and then the prisms were cured in a water curing tank and test are done at 3,7,28 days.

Figure 9, 10, 11. Crack deformation of prism after 3, 7, 28 days

3.1.1. Density

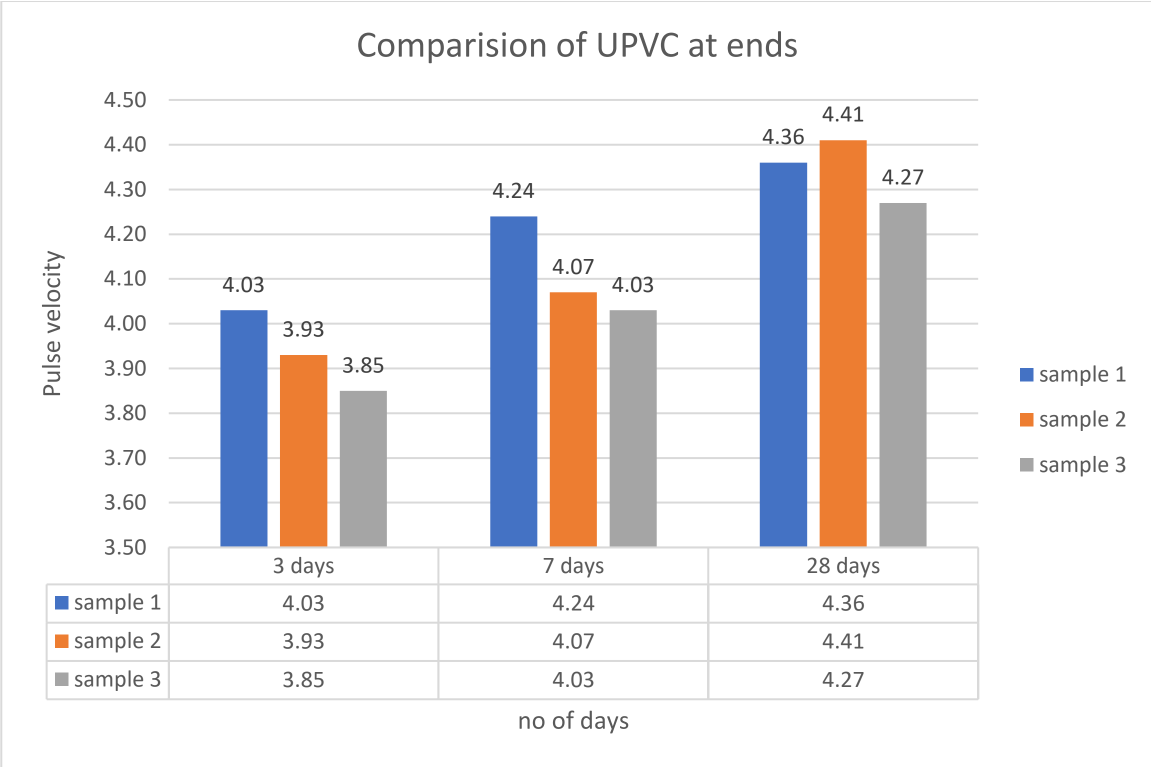
The use of Class C fly ash in the proportion usually results in substantially less reduction or perhaps no reduction in heat of hydration and from the results shown that use of 20% of pulverized fuel ash at 28 days show the difference in the density of concrete. The density of concrete is decreased as PFA is increased which determine the PFA reduce the density which leads to light-weight concrete but the hardened properties are highly effected which not meet the standards of normal concrete. A graph of a density of specimen was plotted as shown in graph 3.



Graph 3. density of concrete vs replacement of PFA on normal concrete

3.1.2. Ultrasonic pulse velocity

Ultrasonic pulse velocity of concrete is mainly related to its density and modulus of elasticity. In this test, it is determined to detect the cracks without any destruction method. The concrete specimen with a reduced flow of velocity in specimen with respect to time is due to the specimen not well compacted , or if there is an increase in water content lead to segregation of concrete during placing or there are internal cracks or flaws, although the same materials and mix proportions are same used in specimen improper casting leads to effect. The values obtained mostly ranged from 3.82 to 4.80 km/s where the quality of concrete in terms of uniformity, perfect compaction, incidence or absence of internal flaws and cracks of concrete is in good quality is determined. A graph of a comparison of UPVC was plotted as shown in graph 4.



Graph 4. Ultrasonic pulse velocity vs replacement of PFA on normal concrete

3.1.3. Flexural strength test

A Flexural strength test was carried out on each specimen at the different percent of PFA. The flexural strength of each specimen was determined. From the flexural force obtained on the concrete specimen is used to calculate the flexural strength of concrete. The specimen was tested at the age of 3, 7, 28 days. From the results obtained its determined that there is the increase in flexural strength at the use of 10 % of PFA as substituents of cement. A graph of Comparison of Flexural strength was plotted as shown in graph 5.

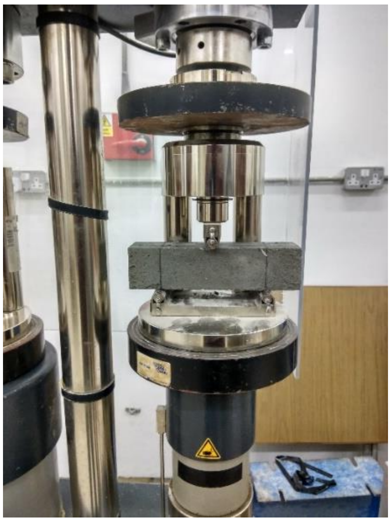
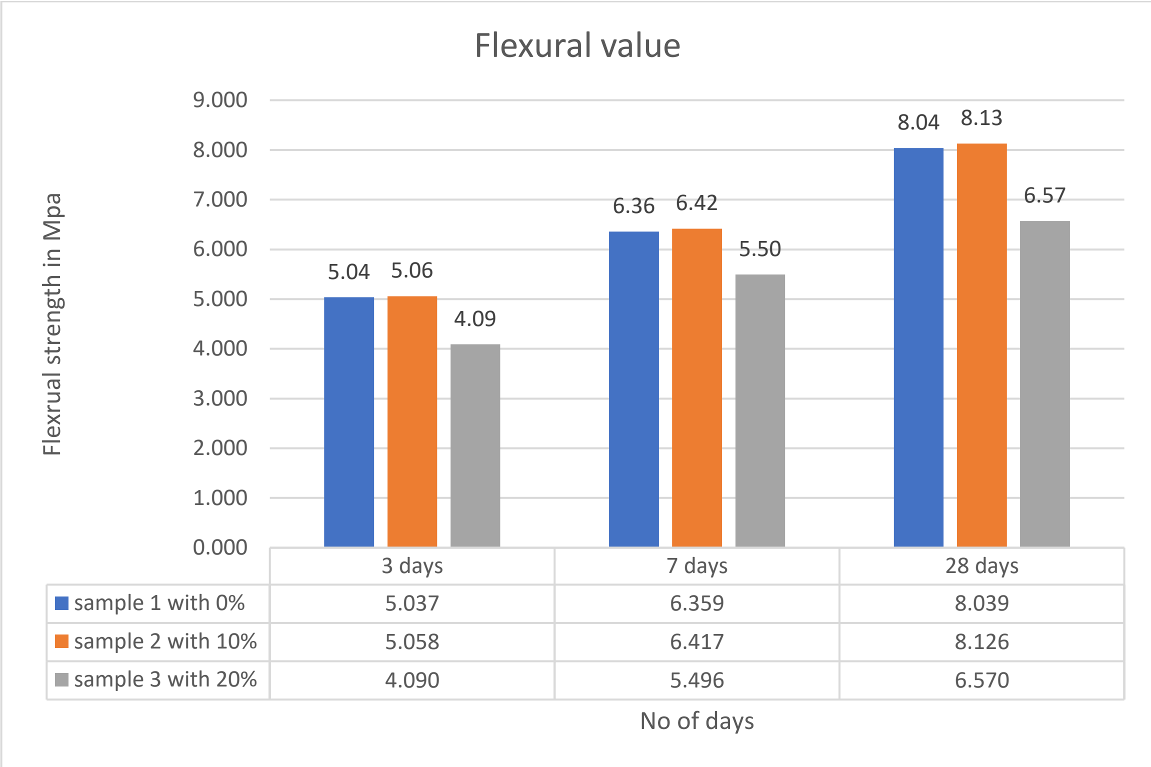


Figure 12 and 13. Flexural strength at 7, 28 days



Graph 5. Flexural strength vs replacement of PFA on normal concrete

3.1.4. Compressive Strength Test

Based on the results of the compressive test show the variation of compressive strength of all mixes at different ages. Examining of strength at 3, 7 and 28 days determine that there is an increase in strength of prism with 10% of pulverized fuel ash, but 20% PFA mortar has a reduced compressive strength. The decrease in compressive strength is almost 21% as compared with 20% PFA after 28 days of curing is done. Comparison of compression strength was plotted as shown in graph 6.

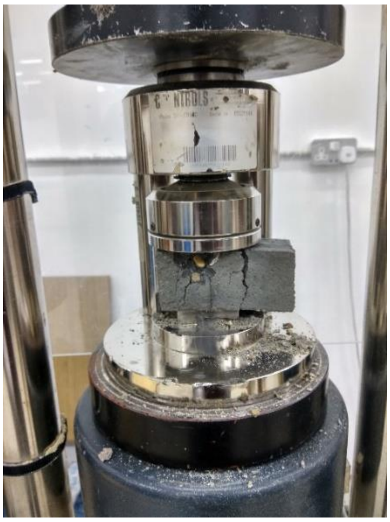
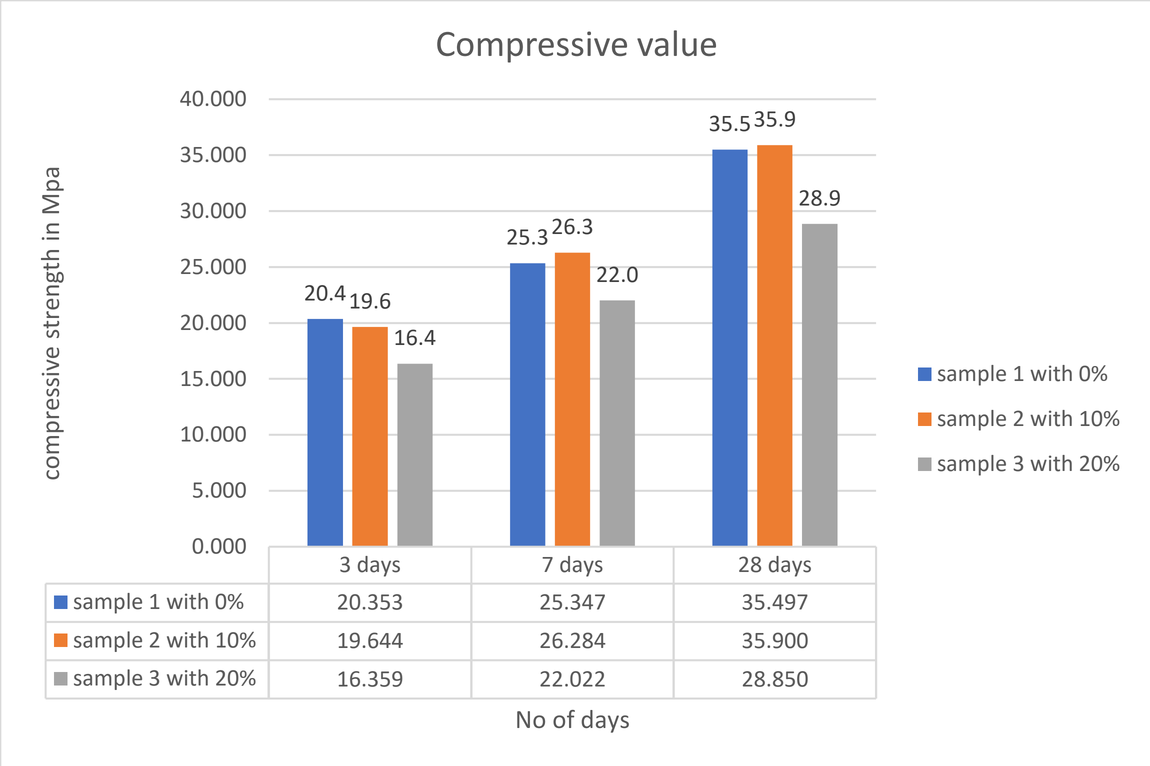


Figure 14 and 15. Compressive strength at 7, 28 days



Graph 6. Compressive strength vs replacement of PFA on normal concrete

3.2. Initial Test for SCC with replacement of 0,10,20,40 % PFA

3.2.1. Procedure

Before casting of a specimen, the material is mixed with an initial state of cement, PFA and water for 30 seconds. The fine aggregate is added with cement mix slowly for 30 seconds in a mixture and then admixture is added and mixed in high speed for 30 seconds and the mix is in still for 30 sec and finally mixed in high speed for 60 sec and the flow table is used to determine the consistency of the concrete. Then the specimen is cast into 12 prisms with the size of 40x40x160 mm with cement, fine aggregate, PFA and water. Each specimen is with different percentage of PFA and it is cast into a mold for without compaction and the specimens were demolded after curing for 24 hrs at a controlled laboratory environment, and then the prisms were cured in a water curing tank and test are done at 3,7,28 days.

Figure 16. Mortar mixer

3.2.2. Flow table

The slump flow test was performed according to EFNARC and the spread diameter (d_m) of all the mixtures kept within the range of 250 ± 10 mm. The flow of the mixtures was also visually observed for bleeding, segregation, and inconsistency. The deformability of SCM mixtures was expressed in terms of relative flow area (T_m) using:

$T_m = [d_m/d_o]-1$

where d_o is the diameter of the base of mini-slump cone (d_o = 100 mm), and d_m is the mean value of the two perpendiculars measured spread diameters of d_1 and d_2, $d_m = (d_1 + d_2)/2$.

Table 6. Slump flow value

Fresh properties	SCC 0% PFA	SCC 10% PFA	SCC 20% PFA	SCC 40% PFA	EFNARC criteria
Slump flow	242	249	246	250	250 +/- 10

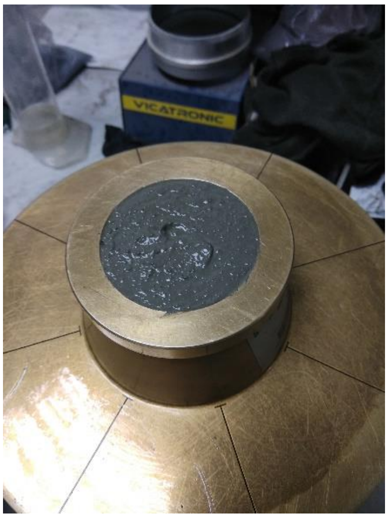
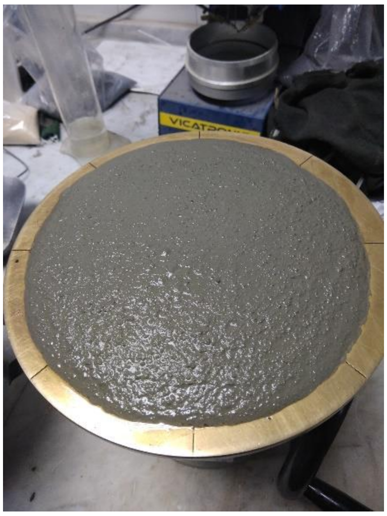
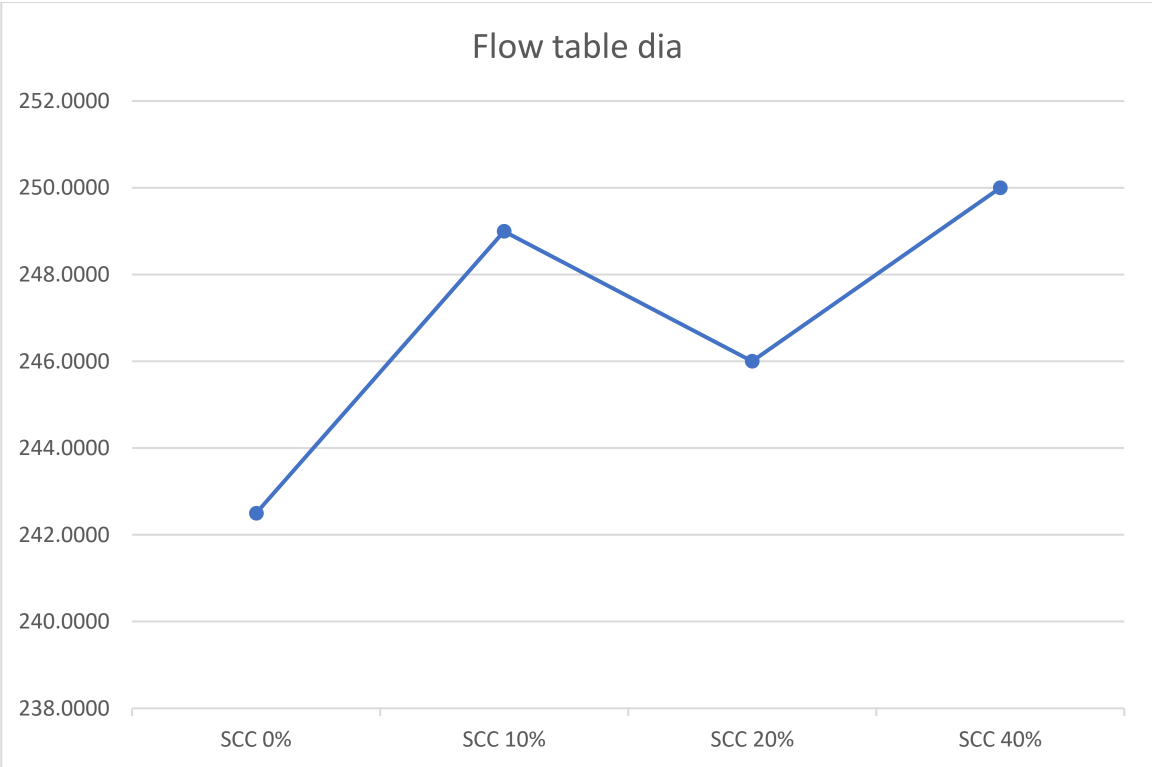
 

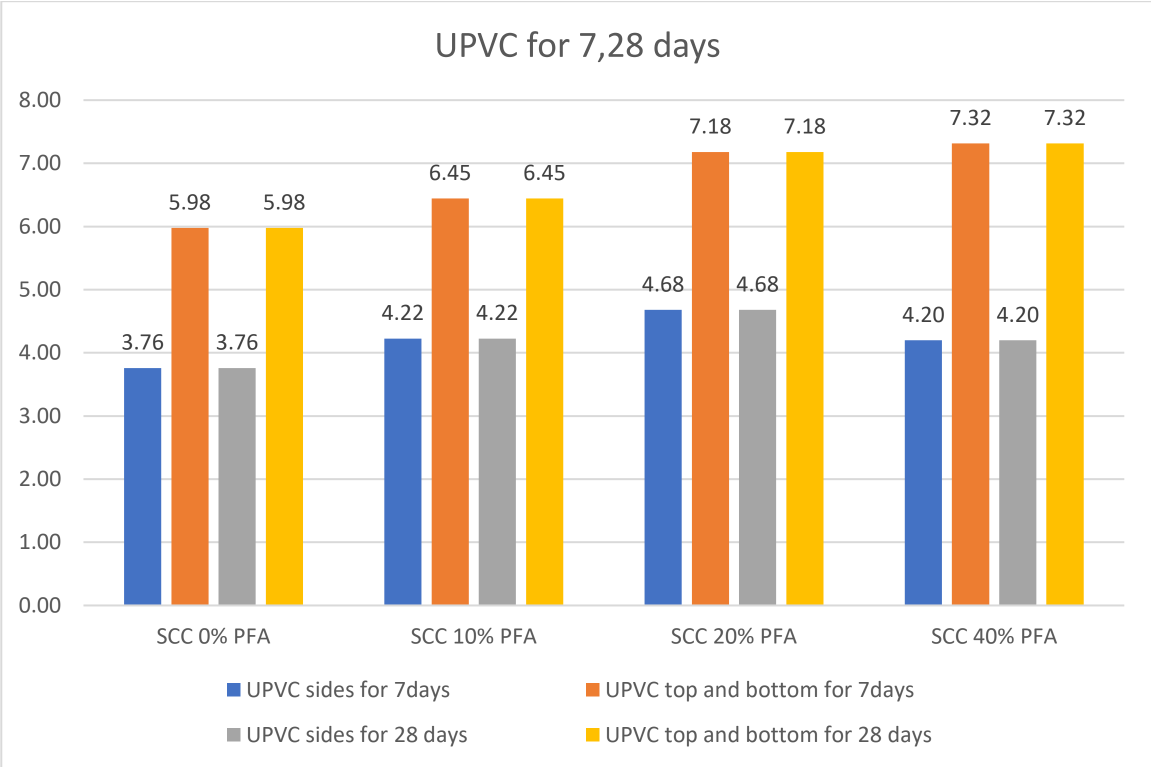
Figure 17 & 18. Flow table test



Graph 7. Flow table diameter

3.2.3. Ultrasonic pulse velocity

Ultrasonic pulse velocity of concrete is related to the flow of time in a specimen by flow velocity without destruction of a specimen but to determine the cracks and flaws. Mostly the flaws and cracks are formed due to improper compaction or increased amount of water content which lead to segregation and bleeding which result to pulse velocity to take more time to travel between the specimen but in this case no compaction is needed due to addition of the admixture, the materials and mix proportions of SCC with the replacement of 0, 10, 20, 40 % of PFA with cement mass ratio are used. The values obtained mostly ranged from 3.76 to 7.32 km/s where the quality of concrete is determined from the value obtained which determined the mixture of concrete made into casting does not form any internal cracks and no segregation. A graph of a comparison of UPVC was plotted as shown in graph 8.

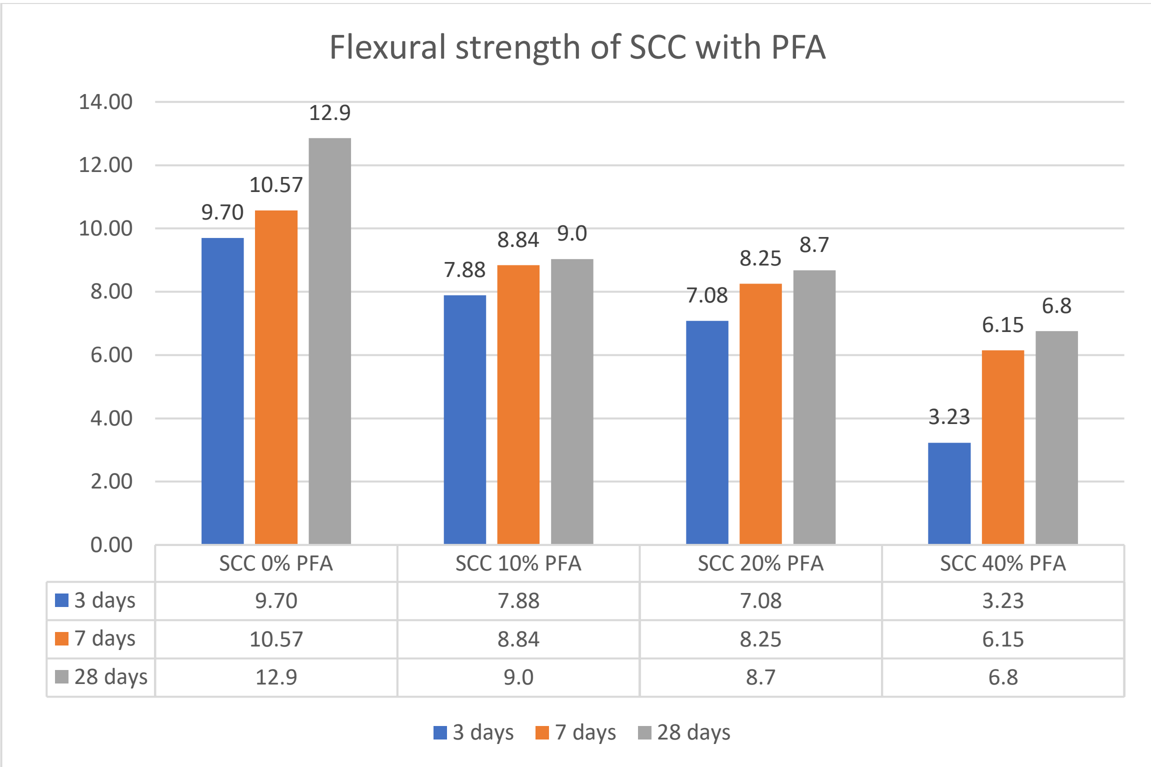


Graph 8. Ultrasonic pulse velocity vs replacement of PFA on SCC

3.2.4. Flexural strength

A Flexural strength test was carried out on each specimen at the replacement of PFA at 0,10,20,40% cement mass ratio. The flexural strength was determined and at the age difference of 3,7,28 days. From the flexural force obtained on the concrete blocks is used to calculate the flexural strength of concrete blocks. From the results obtained its determined that there is a constant decrease in flexural strength but at the use of 20 % of PFA as substituents of cement provided a good strength also a replacement of large quantity of PFA without drastic changes. A graph of a comparison of Flexural strength was plotted as shown in graph 9.

Figure 19&20. Flexural strength of SCC concrete replacement with PFA



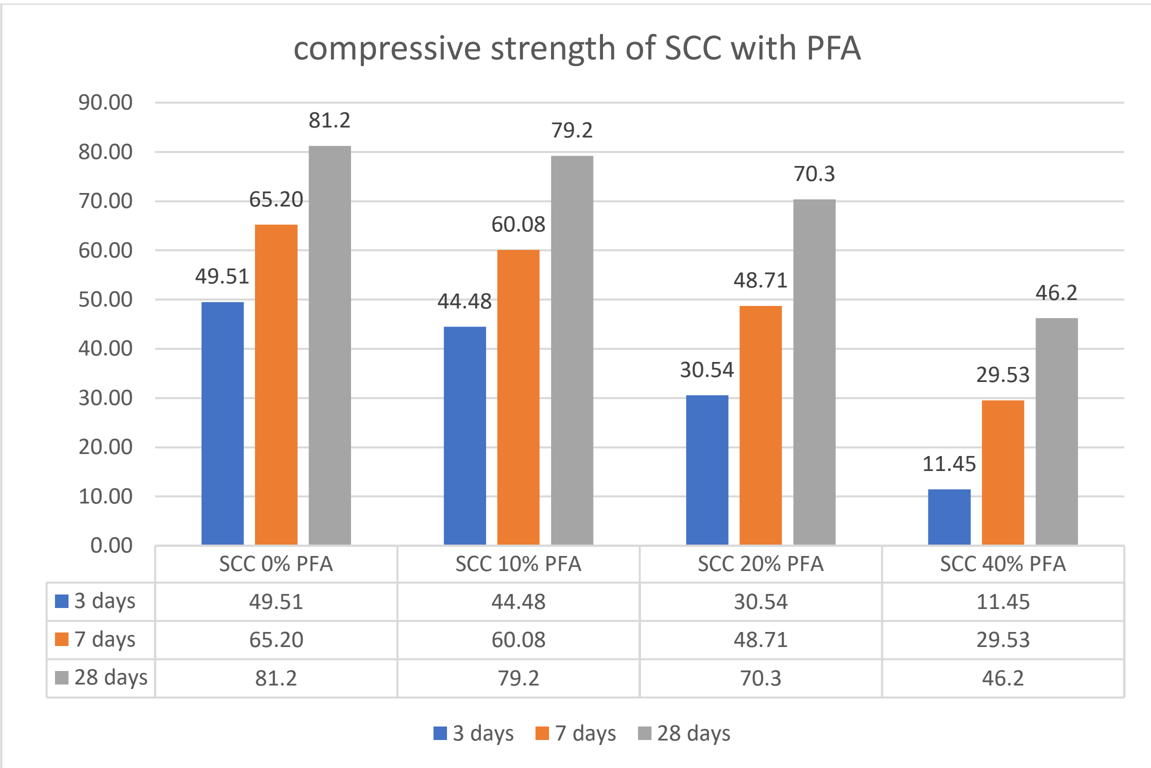
	SCC 0% PFA	SCC 10% PFA	SCC 20% PFA	SCC 40% PFA
3 days	9.70	7.88	7.08	3.23
7 days	10.57	8.84	8.25	6.15
28 days	12.9	9.0	8.7	6.8

Graph 9. Flexural strength vs replacement of PFA on SCC concrete

3.2.5. Compressive strength

Based on the results of the compressive test show the variation of compressive strength of all mixes at 3,7,28 days of ages. There is a difference in strength of prism with 0% and 10% of pulverized fuel ash is low but 20%PFA mortar has a compressive strength reduced to a little extent. The decrease in compressive strength is almost 12% as compared with 20% PFA after 28 days of curing is done. But the replacement content provided is high and also a difference in strength is also satisfy the minimum requirement of the compressive strength. Hence 20% PFA with SCC provide a good result. A graph of Comparison of Compression strength was plotted as shown in graph 10.

Figure 21. Compressive strength of SCC concrete replacement with PFA



Graph 10. Compression strength vs replacement of PFA on SCC

4. Mix Design Methods

The mix design method for self-compacting concrete is different from the normal concrete design. Estimation of perfect mix design involves a different step regarding the proportioning procedure which includes the assortment of type of aggregate which has the best passing ability, c/w ratio and mortar ratio which is the necessity to produce better SCC mix with the obligatory slump flow and workability. Addition of admixture was the final step to produce the trial batch with desired fresh self-compacting properties. The step by step process to determine the best mix design for self-compacting concrete.

Step 1: Determine the flowability of trial batch with slump flow or flow table test performance;

Step 2: Select the type of coarse and fine aggregate with the best passing ability regarding shape& size;

Step 3: Calculate the amount of required cement and water content;

Step 4: Calculate the volume of paste and mortar content;

Step 5: Select the best type of admixture;

Step 6: Prepare the trial batch mixture;

Step 7: Test the trial batch with the attributes of SCC, namely workability, flowability, durability, filling and passing ability, the slump flow test, bleeding and segregation test should be noted;

Step 8: Adjust mixture proportions based on the test results, and then re-batch with further testing until the required properties are achieved.

The concrete mix design is summarized in table 7.

Table 7. Mix design proportion (in kg)

Mixture	Portland cement	Fly ash	FA 0-1 mm	FA 0-4 mm	CA 4-16 mm	Fiber	Water	SP
SCC_0%	500	0	168	672	828	0	212	8.4

SCC_20%	400	100	168	672	828	0	212	8.4
SCCF_20%_3 kg/m^3	400	100	168	672	828	3	212	8.4
SCCF_20%_4.5kg/m^3	400	100	168	672	828	4.5	212	8.4
SCCF_20%_6 kg/m^3	400	100	168	672	828	6	212	8.4
SCCF_20%_9 kg/m^3	400	100	168	672	828	9	212	8.4

4.1. Mixture proportion

The preliminary investigation of this thesis includes the test procedure, assessment of mixture proportion, mixing procedure and replacement of fly ash and admixture and fiber dosage. The testing procedure is limited to the fresh property to determine the perfect mix design.

Table 8. Mix design for casting

Materials	Quantity of material used in the casting	
Fine aggregate 0-1 mm	3.05 kg	
Fine aggregate 0-4 mm	13.24 kg	
Coarse aggregate	15.73 kg	
Portland cement	7.6 kg	
Water	3.45 l (W/C ratio 0.36)	
Fly ash (type C)	1.9 kg (20% of cement mass)	
Superplasticizer	0.1425 kg (1.5% of cement mass)	
Polyolefin Fibers	3 kg/m^3	0.057 kg
	4.5 kg/m^3	0.0855 kg
	6 kg/m^3	0.114 kg
	9 kg/m^3	0.171 kg


Figure 22 & 23. SCFRC concrete mixture

4.2. Mixing and casting of a specimen

The required material quantity is calculated and weighed for the perfect mixing proportion, and the cement was mixed with the pulverized fuel ash or fly ash of type C. The mixture proportion was added with the coarse and fine aggregate. The material is mixed and left drying for 2 minutes in the mixture. Then water was added in the mixture by two types, in which ¾ amount of water is added with the mix as initial start and remaining was added after 30 seconds with the mix to the admixture. The mixture is well mixed for a 3 minute. To obtain a homogeneous mixture. After the mix, the fresh properties test carried out and we performed the casting after the test was done. The specimen was removed from the mold after 24 hours of laboratory room temperature. The specimen was moved to the water chamber for the curing.

5. Final Testing of sample

5.1. Fresh concrete test

To determining self-compacting concrete properties at fresh concrete state, the test like the slump flow test, visual bleeding and segregation were applied. The best workability on the fresh concrete can be determined within 20 min after adding water. All fresh concrete tests were performed in accordance with the European Guidelines for SCC (EFNARC) standards and EN 12350-8:2010.

5.1.1. Slump flow

The slump flow test was performed according to the European guidelines for self-compacting concrete standards and EN 12350-8:2010. This test is performed due to determine the flowability and workability and in this test the cone which includes the measuring of the SCC flow diameter after lifting the cone and also to determine the time take to reach the maximum spread and also time is taken for the concrete to spread in diameter of 50cm (T_{50}). This test determines the flowability and workability of the SCC.

5.1.2. Bleeding

Bleeding is one form of segregation in which water reaches the surface of the concrete and is the lowest specific gravity in all the concrete ingredients. Bleeding can be easily identified in the field by the appearance of a thin layer of water in the top surface of freshly mixed concrete which it was performed according to the European guidelines for self- compacting concrete standards. In this, the bleeding is visually noted during the slump flow test where the flow of water is noted and analyzed.

5.1.3. Segregation

Segregation in concrete is a case of particle separation in concrete applications, in which particulate solids tend to segregate by virtue of differences in the size, density, shape and other properties of particles of which they are composed. It was performed according to the European guidelines for self-compacting concrete standards.

Figure 24. Bleeding and segregation

5.2. Hardened concrete test

The hardened concrete tests performed on compressive and flexural strength in accordance with EN 12390-3, EN 12390-5:2009 and for UPVC is performed according to EN 12504-4:2004respectively. For the compressive, UPVC, and flexural strength tests, 100 mm × 100 mm × 100 mm standard cubes, 160 mm × 40 mm x 40 mm standard prism and 100 mm × 100 mm × 400 mm standard prisms were used, respectively. All tests were conducted at 7, 28, and 56 days. The average value of the three specimens for each test age was determined and recorded.

6. Results and discussion

6.1. Fresh concrete test

6.1.1. Slump flow

The slump flow test is the major fresh property concrete test and the table shows the result of the slump flow test, representing the maximum flow, where the diameter of the slump flow. According to ENRAC recommends that the slump flow diameter for self-compacting concrete is 550 mm to 850 mm. The flow of slump above the diameter of 850mm is considered to cause segregation, whereas if the diameter is below 550 mm indicates that concrete has less flowability where the flow rate is insufficient for passing through the teeming reinforcement. From the results obtained for the slump flow requirement for self-compacting concrete were satisfied with normal SCC and self-compacting fiber reinforced concrete and with fly ash and without fly ash at the replacement rate of 20% of cement mass where 20% considered from the preliminary analysis. The results obtained have a variation that the addition of 20% of fly ash increases the workability and flowability of the normal self-compacting concrete but an excess of the fly ash more than 50% of cement mass effect the flowability and workability of the concrete. The workability and flowability of the all SCFRC mix were reduced due to the increase of the fly ash. Moreover, the flowability of SCC and SCFRC with the replacement of 20% of fly ash with 6 and 9 kg/m^3 did not satisfy the slump flow as required by EFNARC. Results also show that addition of fiber with 3 kg/m^3 and 20% replacement of fly ash does not have the drastic changes when compared to the other mixture.

Table 9. Slump flow of SCFRC concrete

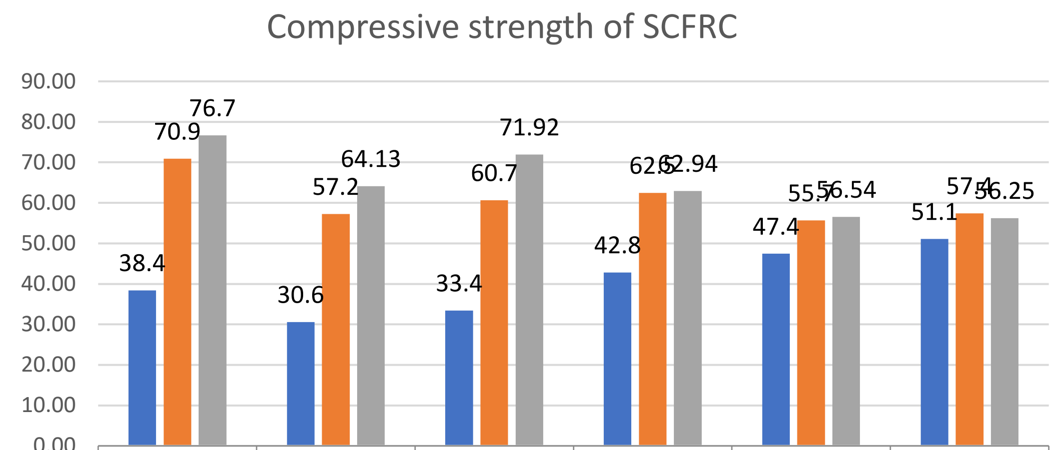
Mixture	Slump flow in mm
SCC_0%	520
SCC_20%	720
SCCF_20%_3 kg/m^3	730
SCCF_20%_4.5 kg/m^3	680
SCCF_20%_6 kg/m^3	420

SCCF_20%_9 kg/m^3	350

6.2. Hardened test

6.2.1. Compressive strength

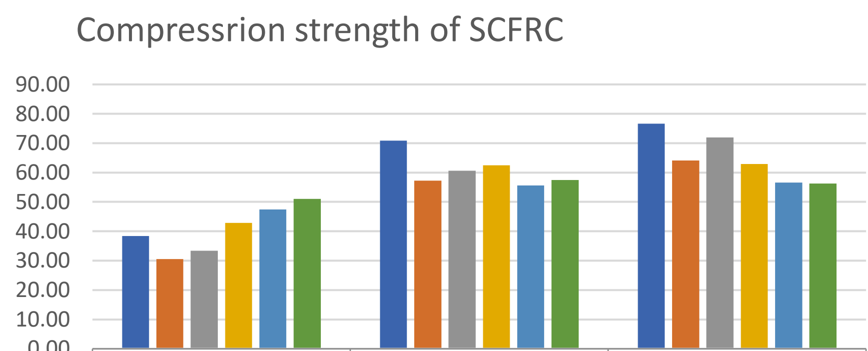
In the graph of compressive strength test results for normal self-compacting and self-compacting concrete with fiber at the ages of 7,28 and 56 days is showed. Results showed the development of compressive strength varied in self-compacting concrete and self-compacting fiber reinforced concrete. The compressive strength of self-compacting concrete and self-compacting fiber reinforced concrete was decreased due to the increase of the fiber. The best compressive strength, of self-compacting concrete of SCFRC at the age of 7,28,56 days was obtained when fly ash was added with a replacement of cement rate at 20% of cement mass ratio with 3 kg/m^3 of polyolefin fiber. The compressive strength was decreased by 20.38%, 19.2% and 16.3% at the age of 7, 28 and 56 days when 20% of fly ash is replaced with the cement mass ratio. Compressive strength was decreased by 13.01%, 14.4% and 6.45% at the age of 7,28,56 days whereas the 20% fly ash and 3Kg/m^3 of polyolefin fiber were added. Compressive strength was decreased 11.88%, 17.91% at the age of 28 and 56 days whereas the 20% fly ash and 4.5 kg/m^3 of polyolefin fiber was added respectively and there is an increase of 11.50% compressive strength in 7 days. Compressive strength was decreased 21.48%, 26.27% at the age of 28 and 56 days whereas the 20% fly ash and 6 kg/m^3 of polyolefin fiber was added but there is an increase in strength to 23.47% at the age of 7 days. Compressive strength was decreased 19 %, 26.64 % at the age of 28 and 56 days whereas the 20% fly ash and 9 kg/m^3 of polyolefin fiber was added but there is an increase in strength to 32.94 % at the age of 7 days. The percentage of decrease in the compressive strength of SCC was shown in the graph. The compressive strength of SCCF was lower than normal self-compacting concrete except the SCCF with 3kg/m^3 has the second highest compressive strength at the age of 56 days. Adding of a higher amount of fiber negatively distress the compressive strength of concrete. Thus, an addition of fiber lead to the negative effect on concrete properties, which affect the compaction of SCC and result in the reduction of compressive strength of the self-compacting concrete. The results and differentiation in compressive strength for a different type of concrete are shown in graph 11 to 15.



	SCC OF 0% PFA	SCC OF 20% PFA	SCC OF 3KG_20% PFA	SCC OF 4.5KG_20% PFA	SCC OF 6KG_20% PFA	SCC OF 9KG_20% PFA
7 DAYS	38.41	30.58	33.41	42.83	47.42	51.06
28 DAYS	70.88	57.25	60.66	62.46	55.65	57.42
56 DAYS	76.68	64.13	71.92	62.94	56.54	56.25

■ 7 DAYS ■ 28 DAYS ■ 56 DAYS

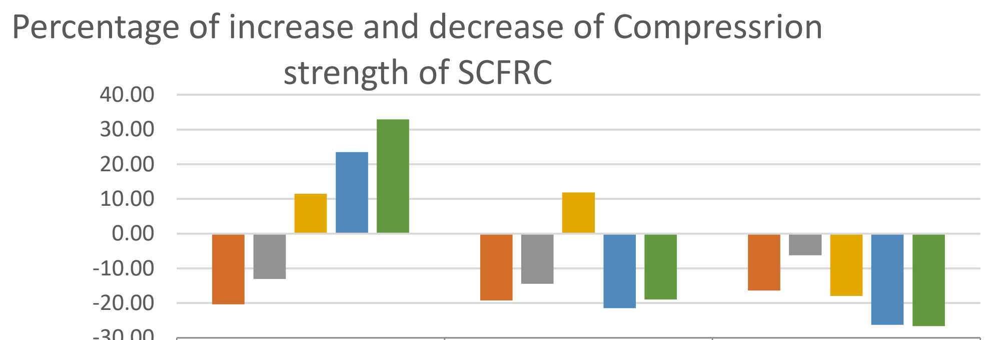
Graph 11. Compressive strength vs different replacement of SCFRC



	7 DAYS	28 DAYS	56 DAYS
SCC OF 0% PFA	38.41	70.88	76.68
SCC OF 20% PFA	30.58	57.25	64.13
SCCF OF 3KG_20% PFA	33.41	60.66	71.92
SCCF OF 4.5KG_20% PFA	42.83	62.46	62.94
SCCF OF 6KG_20% PFA	47.42	55.65	56.54
SCCF OF 9KG_20% PFA	51.06	57.42	56.25

■ SCC OF 0% PFA ■ SCC OF 20% PFA ■ SCCF OF 3KG_20% PFA
■ SCCF OF 4.5KG_20% PFA ■ SCCF OF 6KG_20% PFA ■ SCCF OF 9KG_20% PFA

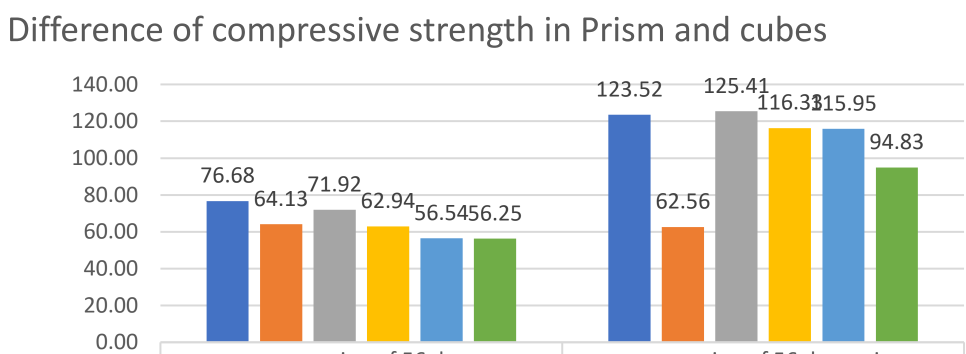
Graph 12. Compressive strength vs different replacement of SCFRC with 7,28,56 days



	7 DAYS	28 DAYS	56 DAYS
SCC OF 20% PFA	-20.39	-19.23	-16.36
SCCF OF 3KG_20% PFA	-13.01	-14.42	-6.21
SCCF OF 4.5KG_20% PFA	11.50	11.88	-17.91
SCCF OF 6KG_20% PFA	23.47	-21.48	-26.27
SCCF OF 9KG_20% PFA	32.94	-18.99	-26.64

SCC OF 20% PFA SCCF OF 3KG_20% PFA SCCF OF 4.5KG_20% PFA
SCCF OF 6KG_20% PFA SCCF OF 9KG_20% PFA

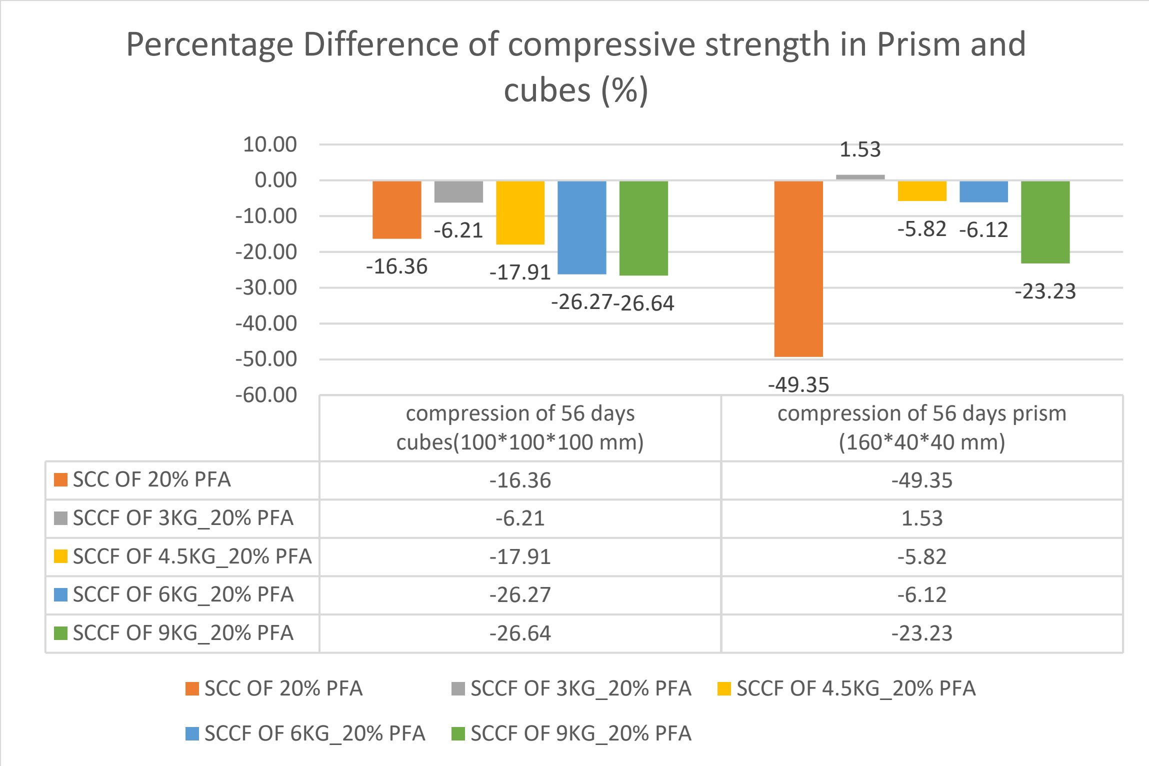
Graph 13. Percentage of increase and decrease of compression strength of SCFRC



	compression of 56 days cubes(100*100*100 mm)	compression of 56 days prism (160*40*40 mm)
SCC OF 0% PFA	76.68	123.52
SCC OF 20% PFA	64.13	62.56
SCCF OF 3KG_20% PFA	71.92	125.41
SCCF OF 4.5KG_20% PFA	62.94	116.33
SCCF OF 6KG_20% PFA	56.54	115.95
SCCF OF 9KG_20% PFA	56.25	94.83

SCC OF 0% PFA SCC OF 20% PFA SCCF OF 3KG_20% PFA
SCCF OF 4.5KG_20% PFA SCCF OF 6KG_20% PFA SCCF OF 9KG_20% PFA

Graph 14. Difference of compressive strength in Prism and cubes of SCFRC

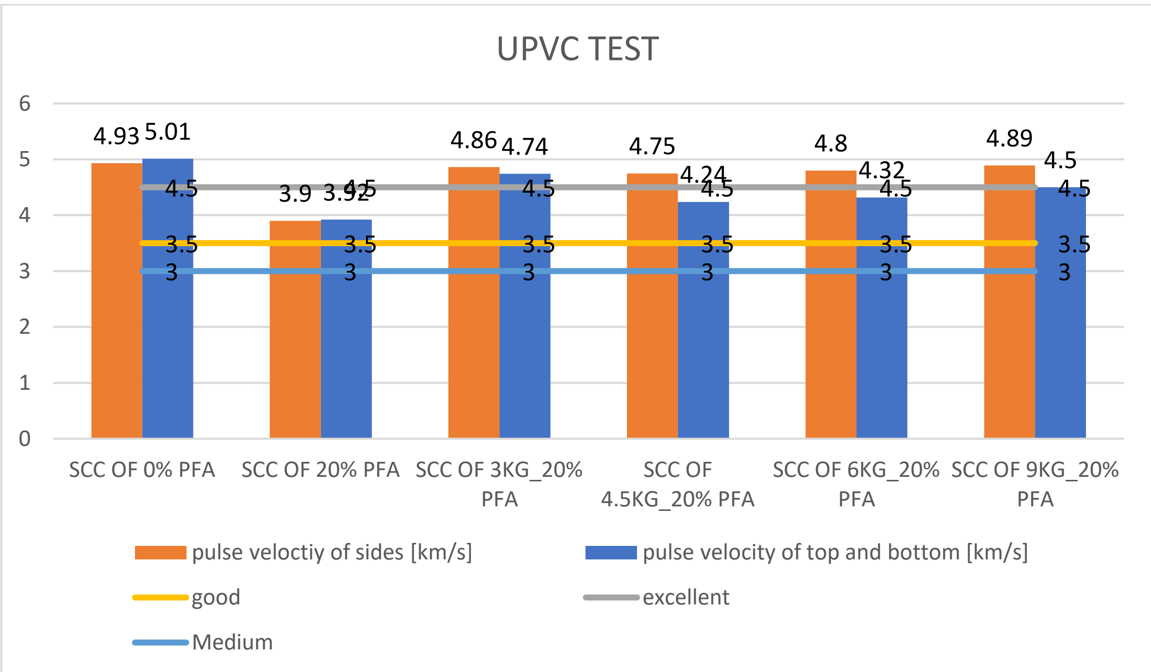


	compression of 56 days cubes(100*100*100 mm)	compression of 56 days prism (160*40*40 mm)
SCC OF 20% PFA	-16.36	-49.35
SCCF OF 3KG_20% PFA	-6.21	1.53
SCCF OF 4.5KG_20% PFA	-17.91	-5.82
SCCF OF 6KG_20% PFA	-26.27	-6.12
SCCF OF 9KG_20% PFA	-26.64	-23.23

Graph 15. Percentage Difference of compressive strength in prism and cubes (%)

6.2.2. Ultrasonic pulse velocity test

The ultrasonic pulse velocity test determines the sample at the final test specimens are cast without any cracks or voids. It is determined by the non-destructive testing method.



Graph 16. Ultrasonic pulse velocity test of SCFRC

6.2.3. Flexural Strength

From the graph 17 and 18 show the result of the flexural strength for the self-compacting concrete and self-compacting fiber reinforced concrete mixture with the age of 28 and 56 days. The addition of the fly ash and polyolefin fiber increases the flexural strength of the concrete at the rate of 2.12%, 2.91%, 6.24%, 9.90% at the age of 56 days respectively.

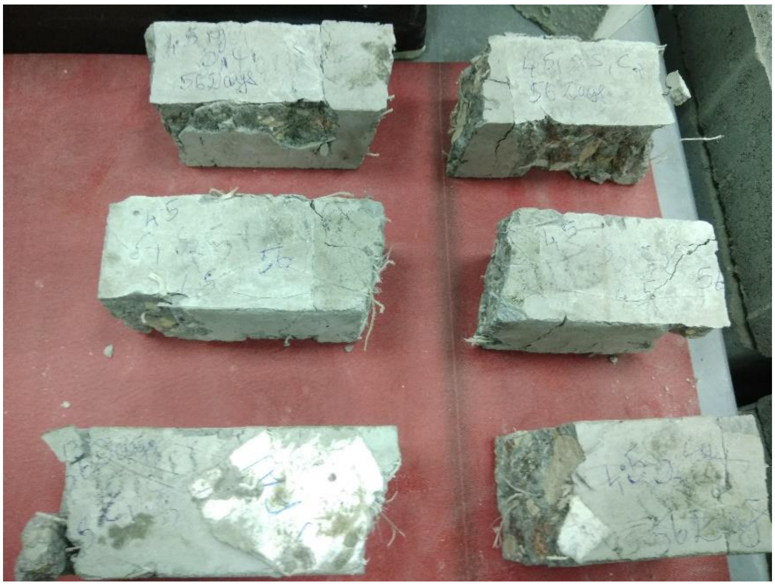
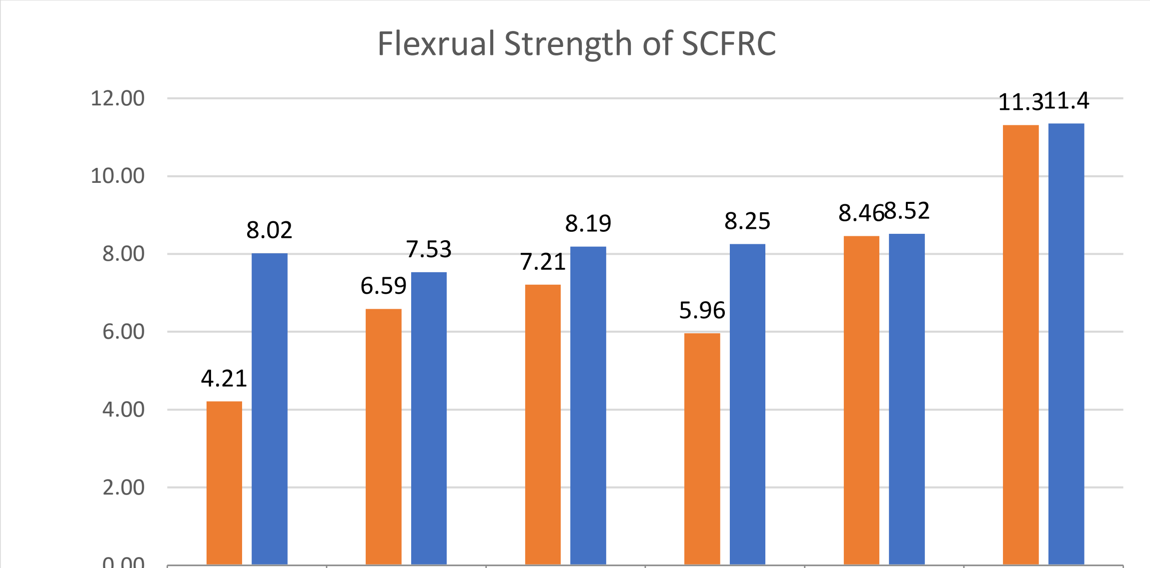
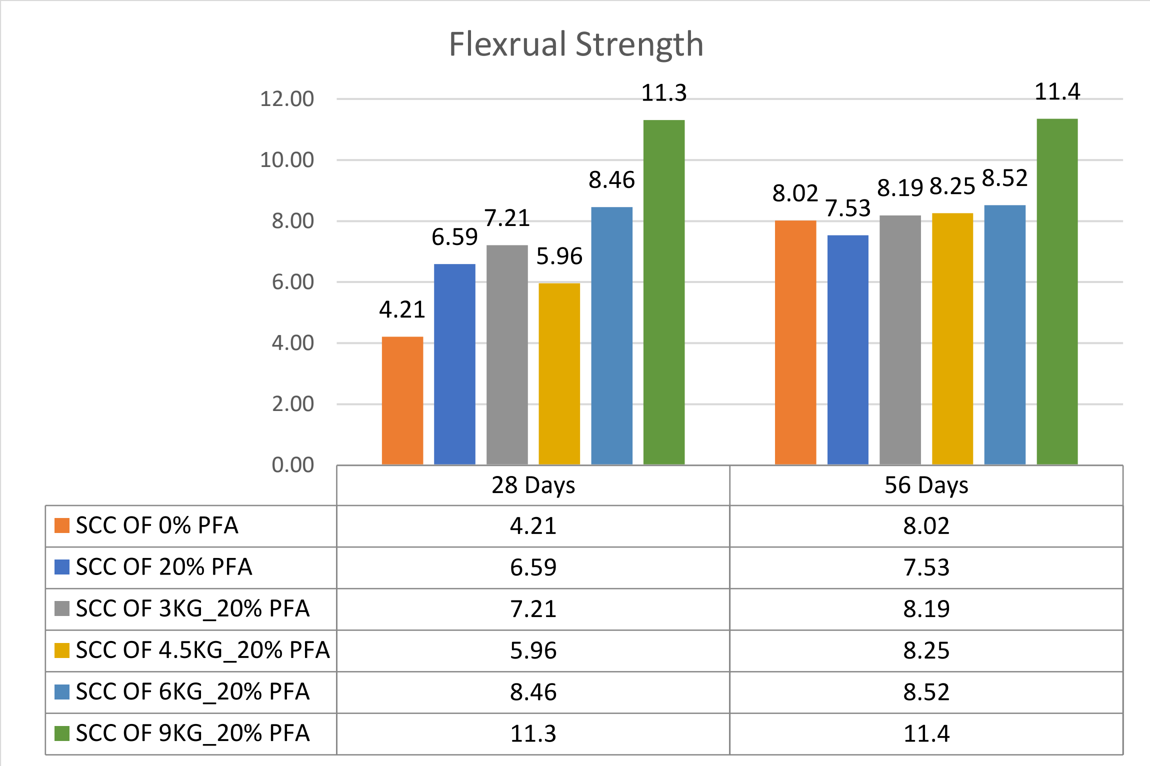


Figure 25. Flexural strength at SCFRC



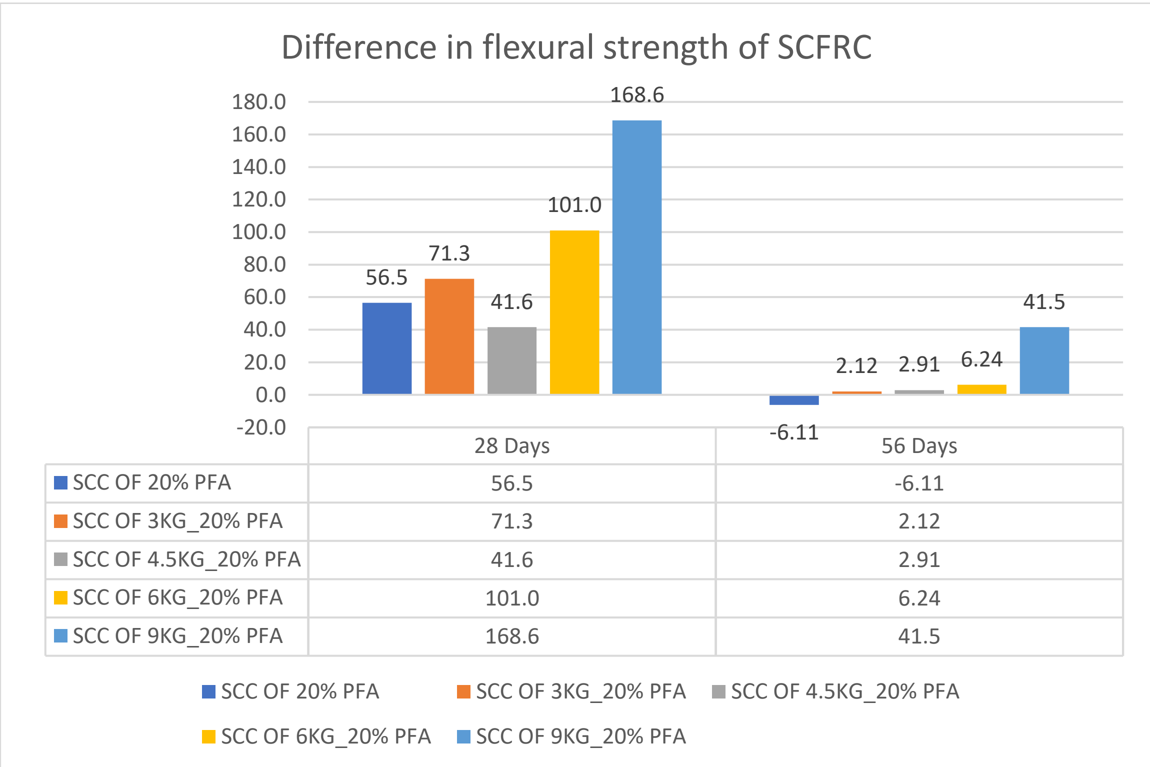
	SCC OF 0% PFA	SCC OF 20% PFA	SCC OF 3KG_20% PFA	SCC OF 4.5KG_20% PFA	SCC OF 6KG_20% PFA	SCC OF 9KG_20% PFA
28 Days	4.21	6.59	7.21	5.96	8.46	11.3
56 Days	8.02	7.53	8.19	8.25	8.52	11.4

Graph 17. Flexural strength vs different replacement of SCFRC



	28 Days	56 Days
SCC OF 0% PFA	4.21	8.02
SCC OF 20% PFA	6.59	7.53
SCC OF 3KG_20% PFA	7.21	8.19
SCC OF 4.5KG_20% PFA	5.96	8.25
SCC OF 6KG_20% PFA	8.46	8.52
SCC OF 9KG_20% PFA	11.3	11.4

Graph 18. Flexural strength vs different replacement of SCFRC with 7,28,56 days



	28 Days	56 Days
SCC OF 20% PFA	56.5	-6.11
SCC OF 3KG_20% PFA	71.3	2.12
SCC OF 4.5KG_20% PFA	41.6	2.91
SCC OF 6KG_20% PFA	101.0	6.24
SCC OF 9KG_20% PFA	168.6	41.5

Graph 19. Difference of flexural strength in prism and cubes of SCFRC

6.2.4. CMOD test

By three-point bending test method, CMOD test was performed on the 28th day of the curing process. All the samples were tested until concrete brakes and large cracks were formed, although concrete wasn't separated into two parts because of high fiber concentration. Concrete broke and cracks were formed but fibers were holding the concrete and resisted to separate. Figure 27 shows the concrete cracks after the CMOD test. The peak force of top load was taken as the result of flexural strength. From the study, it has been observed that sample with 9 kg/m^3 has higher bending strength and bending strength was increasing with the addition of fibers in the concrete mixture. From my analysis, it has been found that residual flexural strength increases with the addition of polyolefin fibers till a certain proportion in concrete mixture and then start decreasing. The following figure shows the variations of bending strength at concrete samples.

Post cracking behavior analysis

Before the CMOD test, all water immersed prisms were taken out from a climatic chamber and kept few hours for drying. After the drying process all the prims cut 1cm deep (deep toward height) in the middle point(length) of prisms. And extensometer holding apparatus was fixed in the concrete surface by using superglue. CMOD test was performed till concrete breaks make 5.5mm displacement. The loading speed of the CMOD test was 0.6mm/min. After the 5.5mm displacement, each sample remains in the single piece because of higher fibers concentration, fibers hold the concrete and resist to separate the concrete into two pieces. Figure 26 shows the prism setup for CMOD test. According to the EN 14651+A1:2007 [45] standard concrete should have higher strength than 1.5 MPa and 1 MPa at 0.5- and 3.5-mm displacement. From the following figure, it can be observed that the CMOD test has also been conducted to SCC without fibers and its cracks are defined. For the sample, SCFRC with 3 kg/m^3 has about 4.5 MPa strength at 0.5 mm displacement, and on 3.5mm displacement has 3.73 MPa strength, while it has the highest strength of 7.21 MPa. Sample with 6 kg/m^3 and 9 kg/m^3 showed better cracking behavior than the sample with 3 $kg/m^3$and 4.5 kg/m^3 because of a higher number of fibers in the cross-section of the samples. Sample with 6 kg/m^3 and 9 kg/m^3 showed higher strength at 3.5 mm displacement than 0.5mm displacement. Sample with 6 kg/m^3 has the highest strength at 0.25 mm displacement and Sample with 9 kg/m^3showed highest strength performance at 2.50 mm displacement. Following graph shows the cracking behavior of concrete samples.

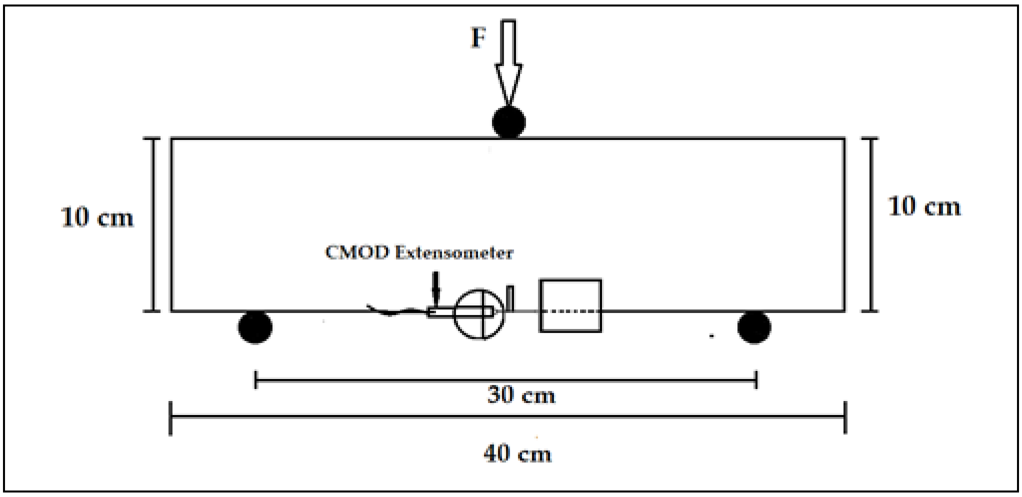
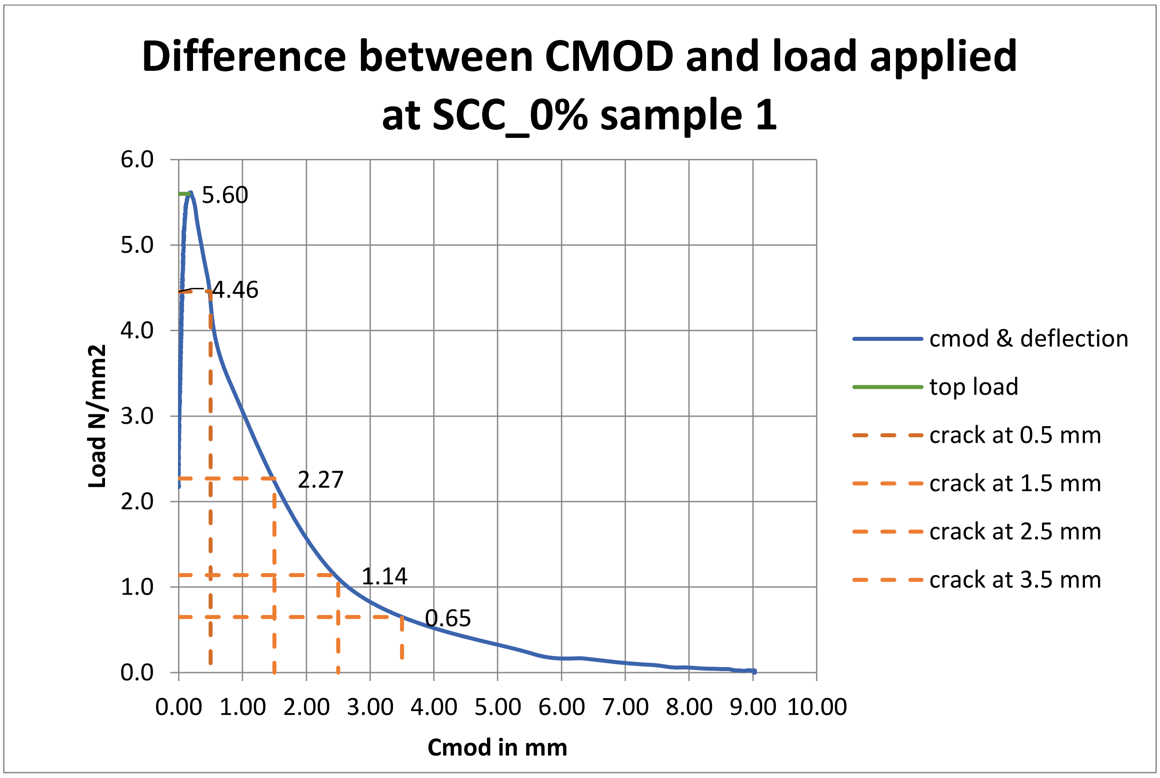
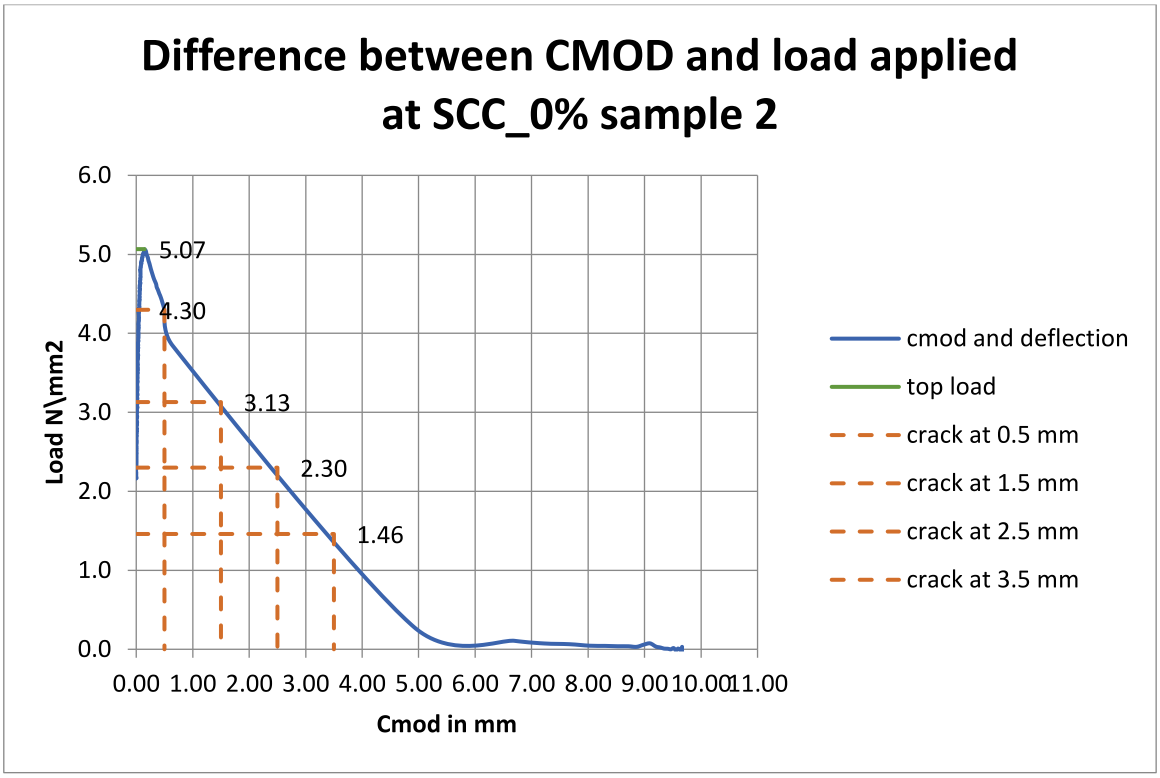


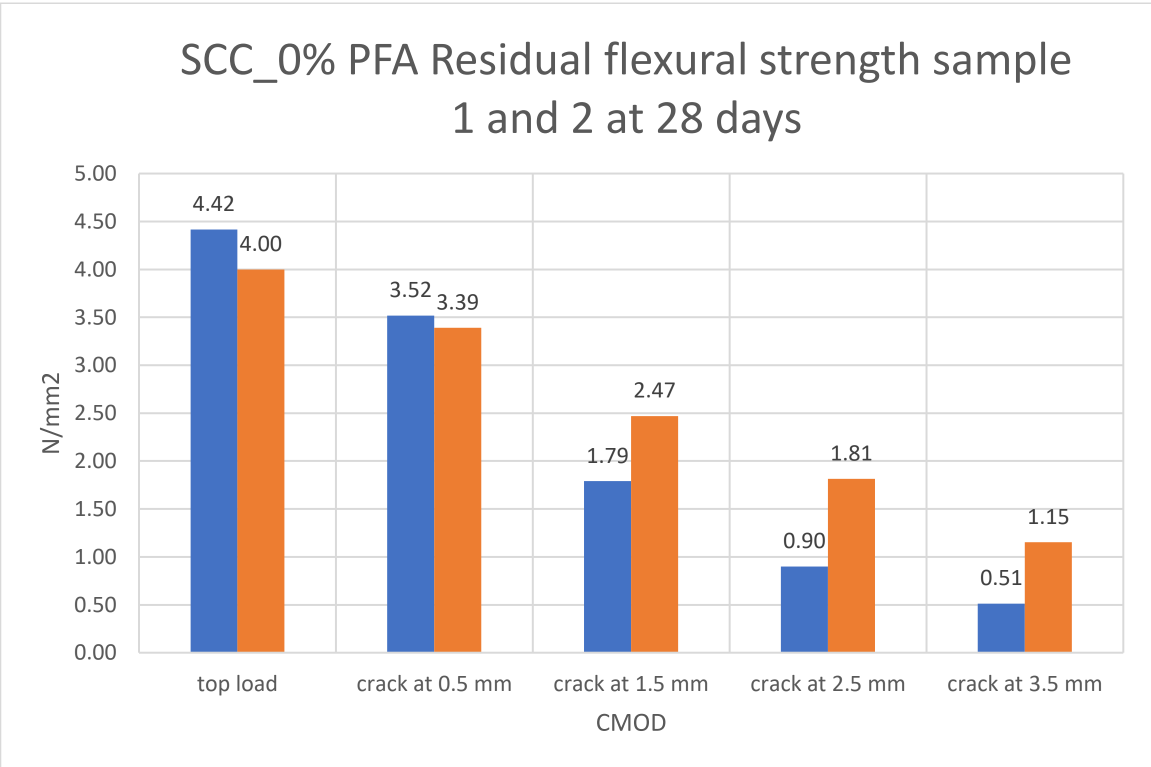
Figure 26. CMOD prism setup



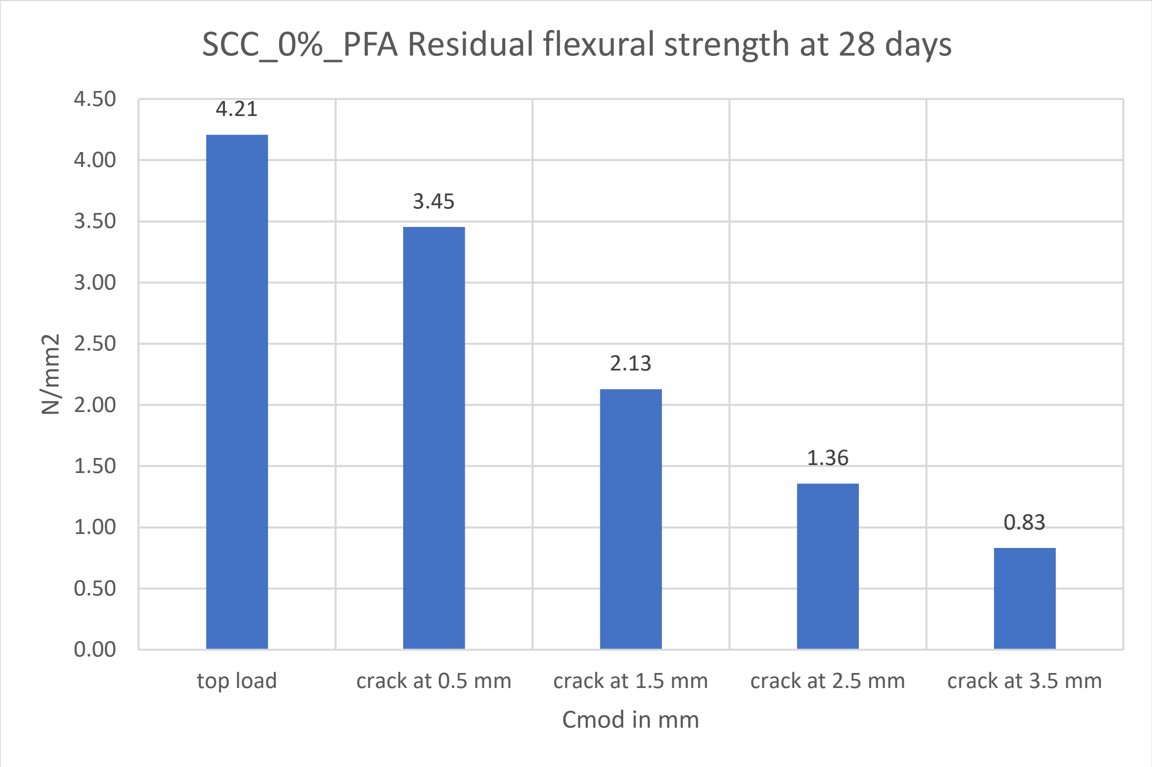
Graph 21. Difference between CMOD and load applied at SCC_0% sample 1



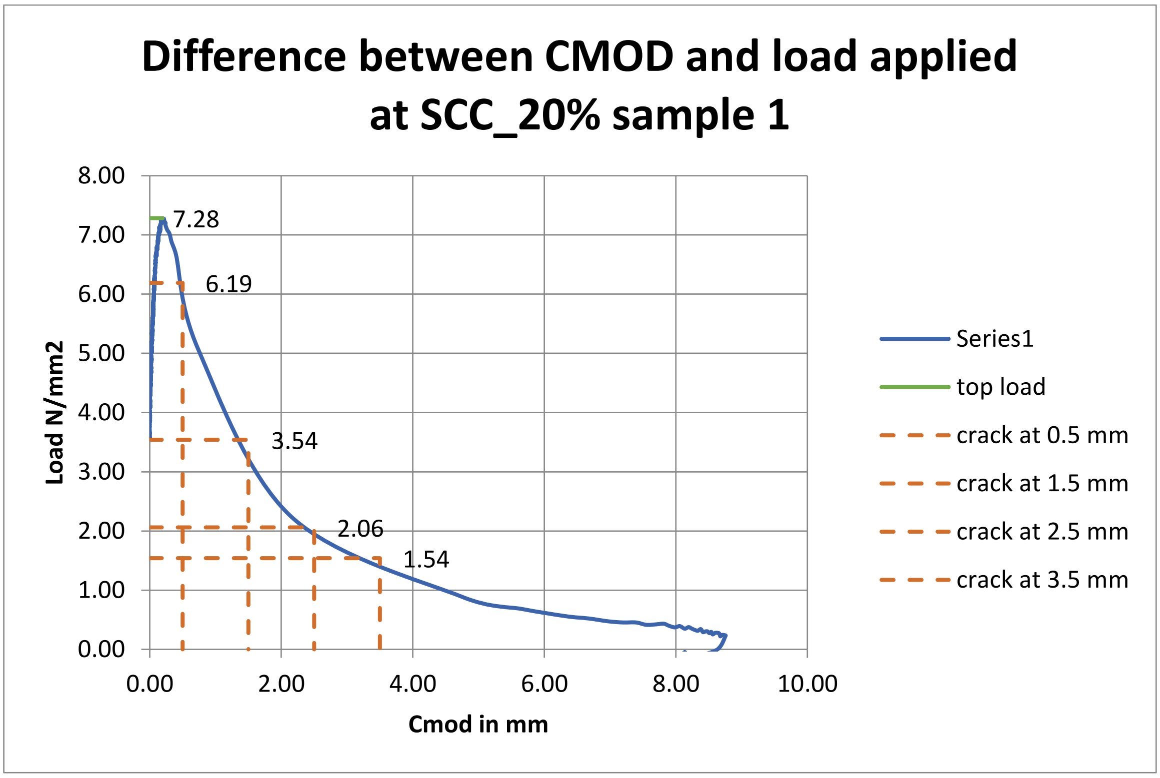
Graph 22. Difference between CMOD and load applied at SCC_0% sample 2



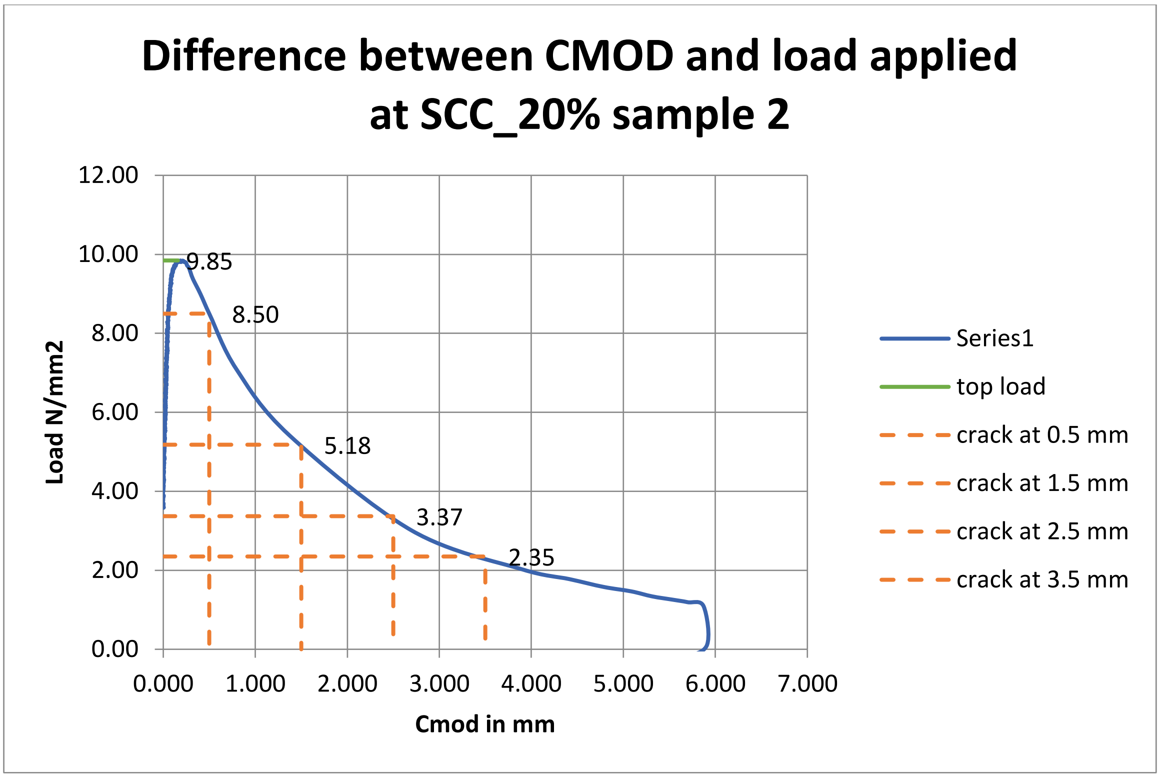
Graph 23. SCC_0% PFA Residual flexural strength sample 1 and 2 at 28 days



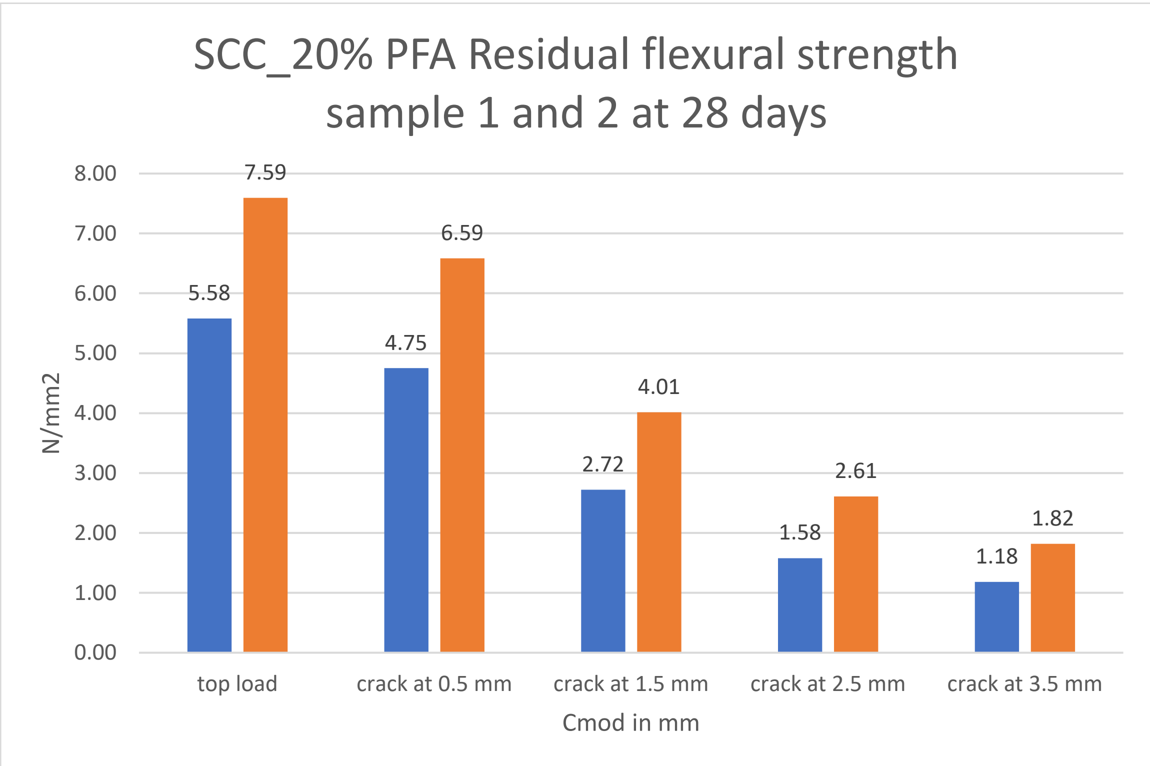
Graph 24. SCC_0%_PFA Residual flexural strength at 28 days



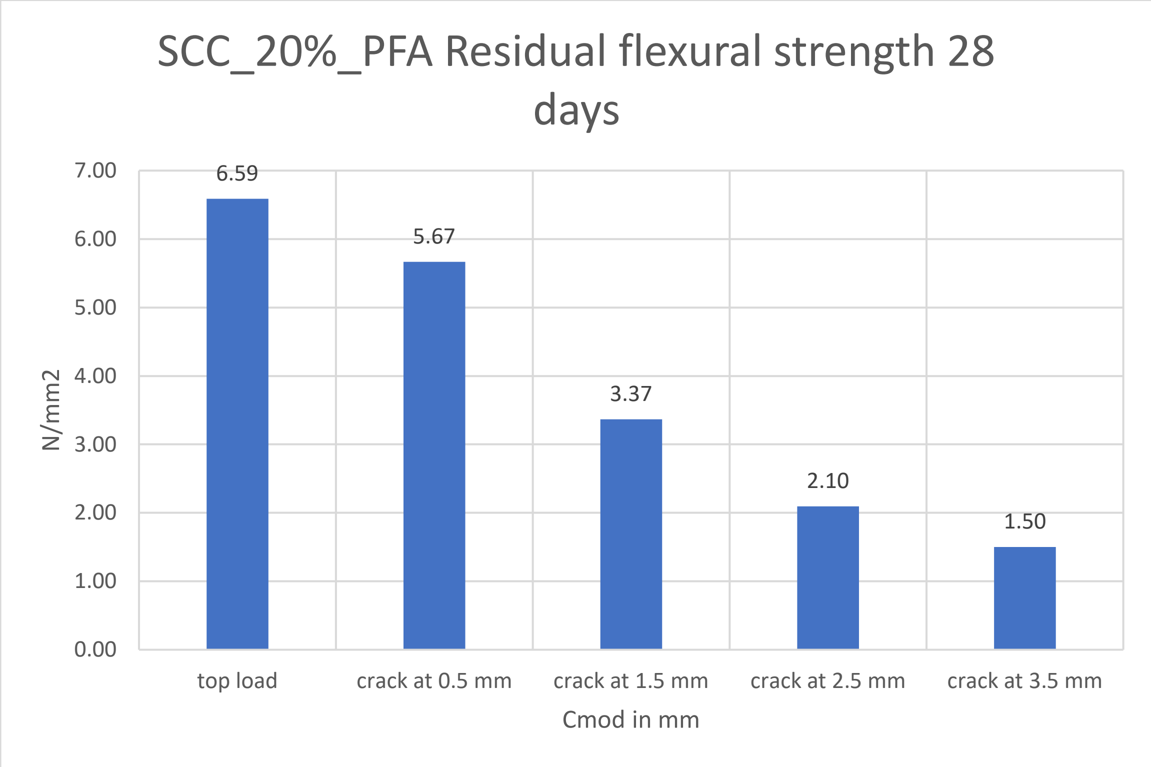
Graph 25. Difference between CMOD and load applied at SCC_20% sample 1



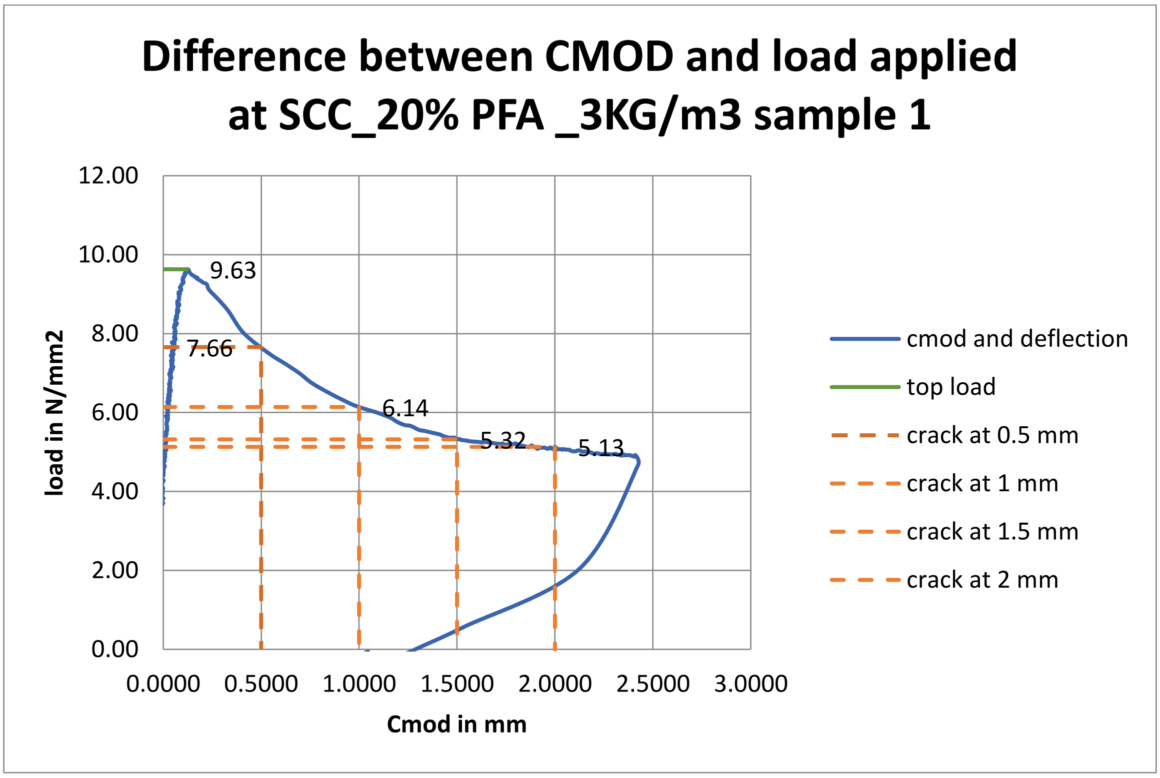
Graph 26. Difference between CMOD and load applied at SCC_20% sample 2



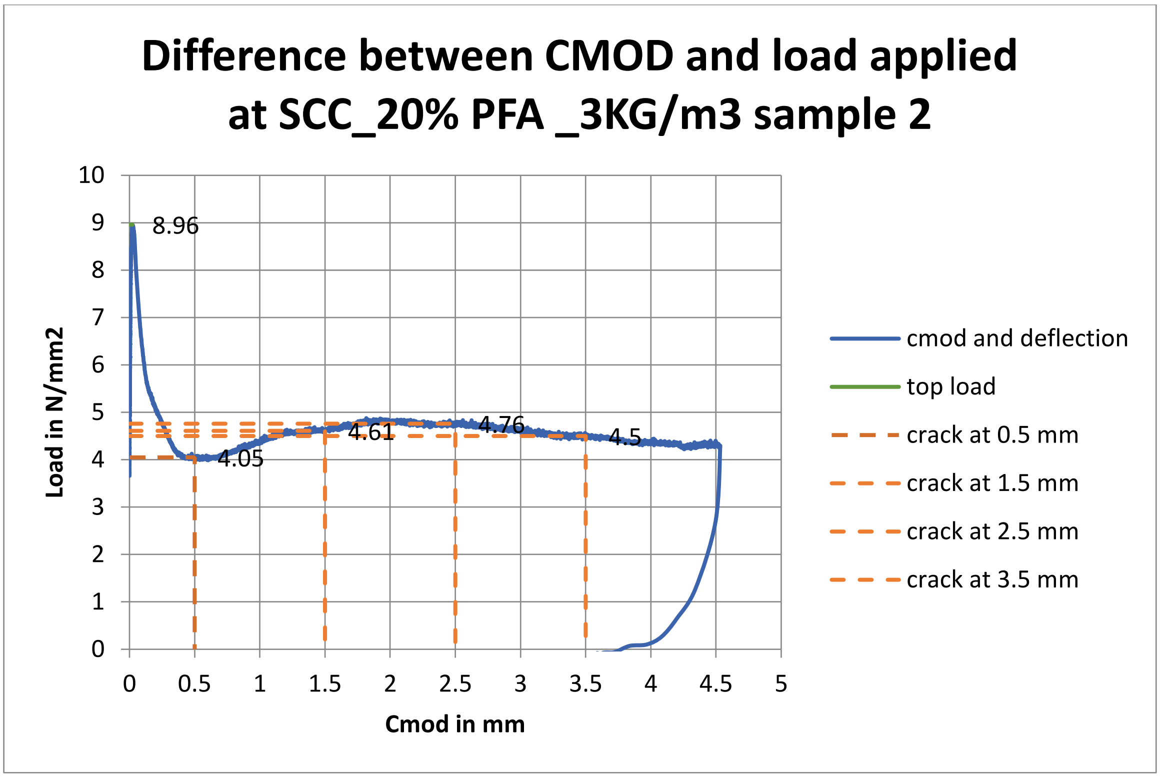
Graph 27. SCC_20% PFA Residual flexural strength sample 1 and 2 at 28 days



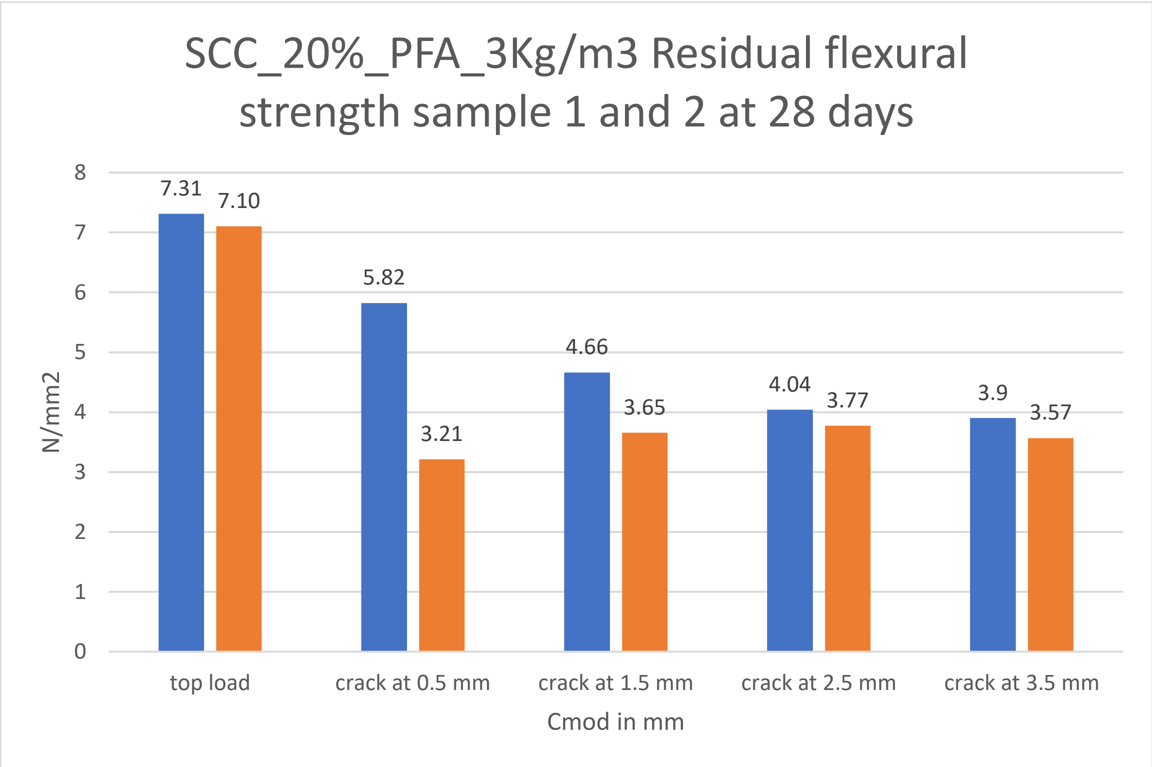
Graph 28. SCC_20%_PFA Residual flexural strength 28 days



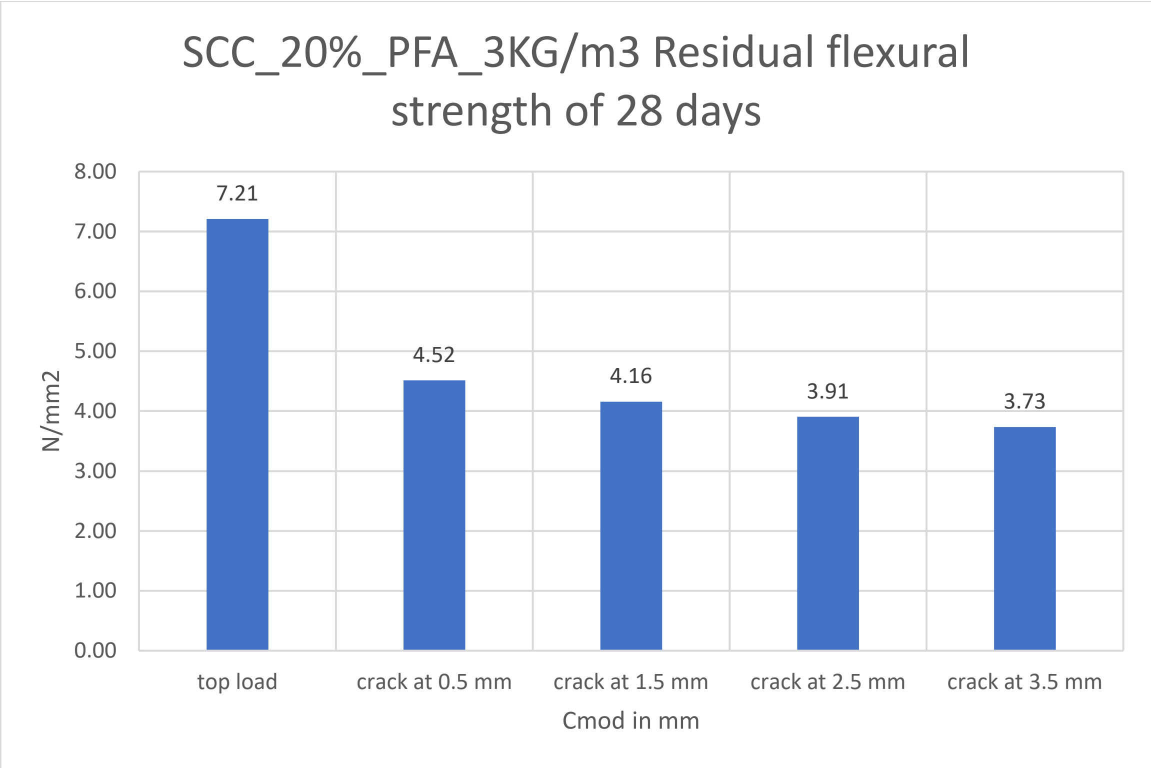
Graph 29. Difference between CMOD and load applied at SCC_20% PFA _3KG/m3 sample 1



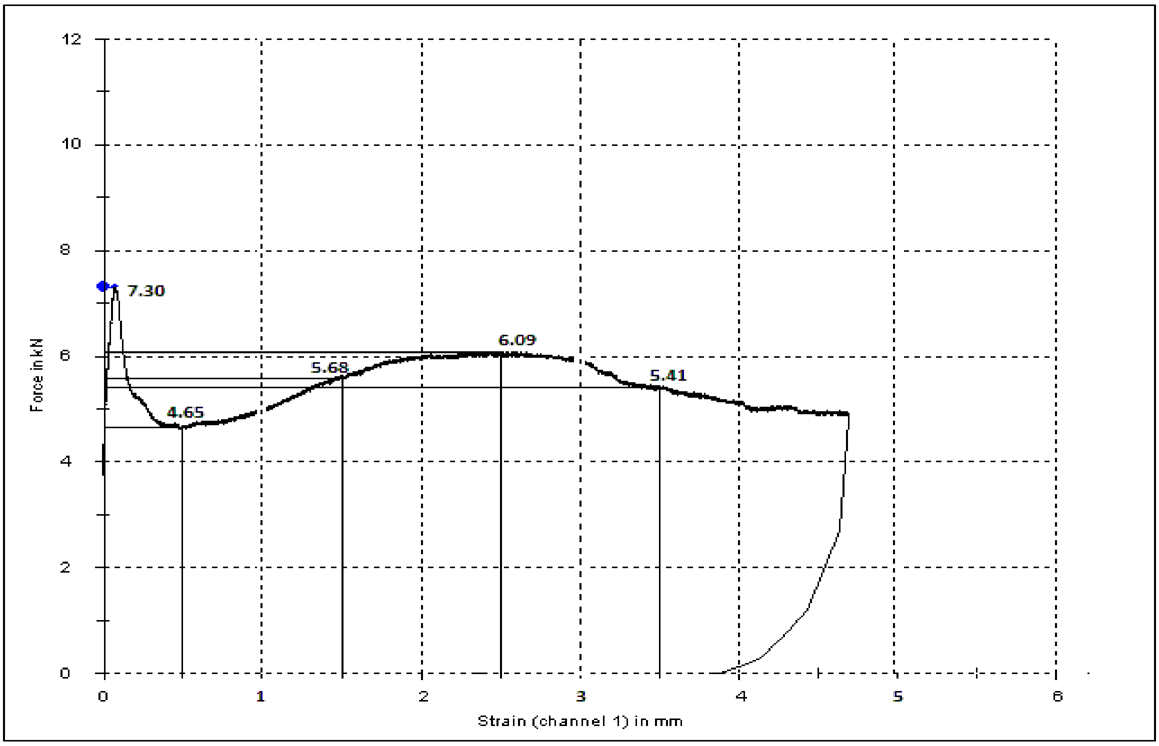
Graph 30. Difference between CMOD and load applied at SCC_20% PFA _3KG/m3 sample 2



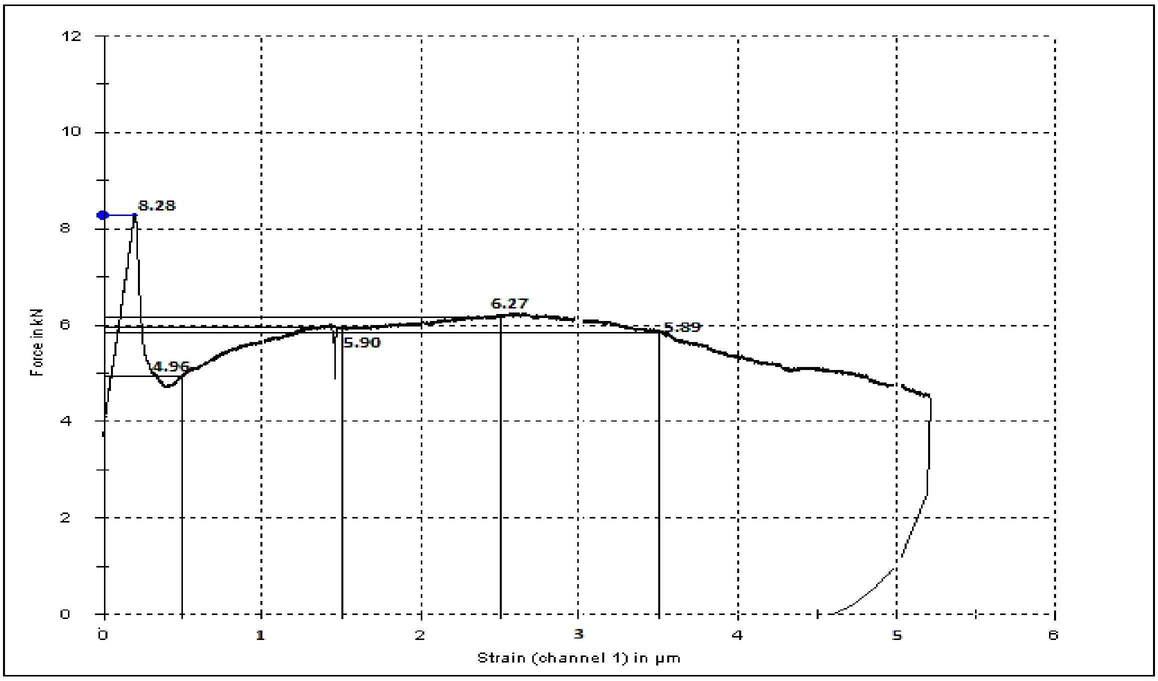
Graph 31. SCC_20%_PFA_3Kg/m3 Residual flexural strength sample 1 and 2 at 28 days



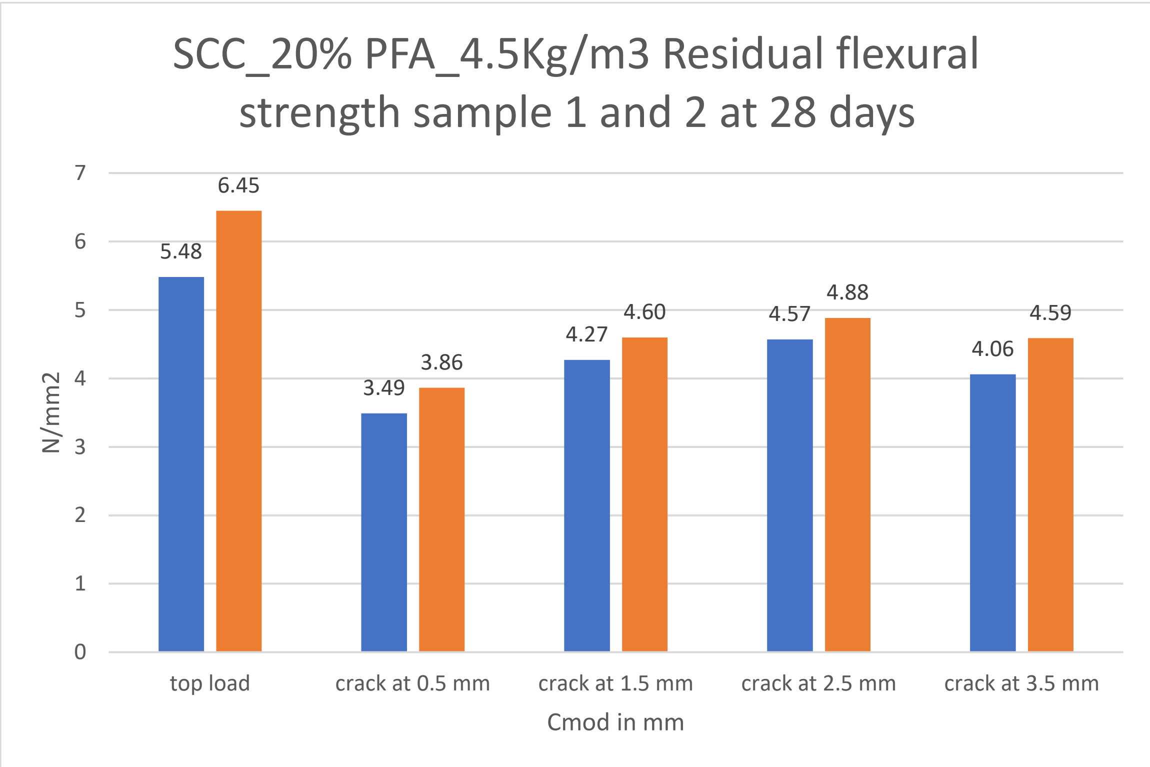
Graph 32. SCC_20%_PFA_3KG/m3 Residual flexural strength of 28 days



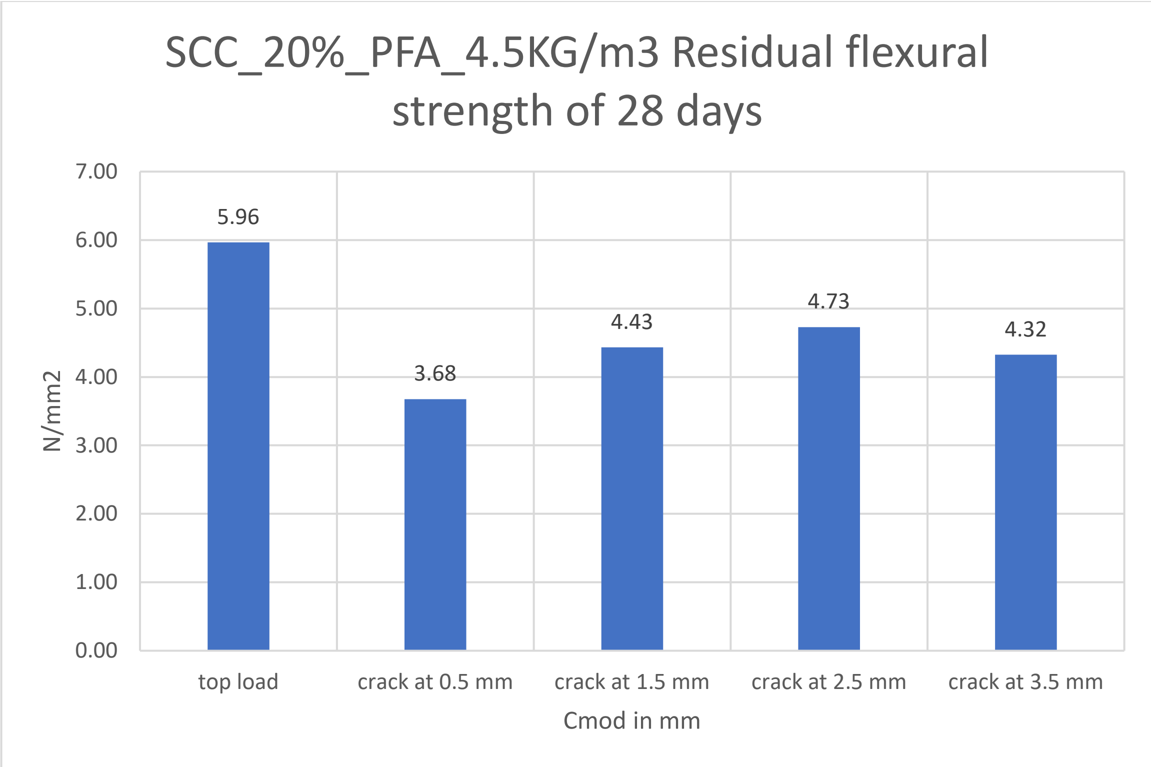
Graph 33. Difference between CMOD and load applied at SCC_20% PFA _4.5KG/m3 sample 1



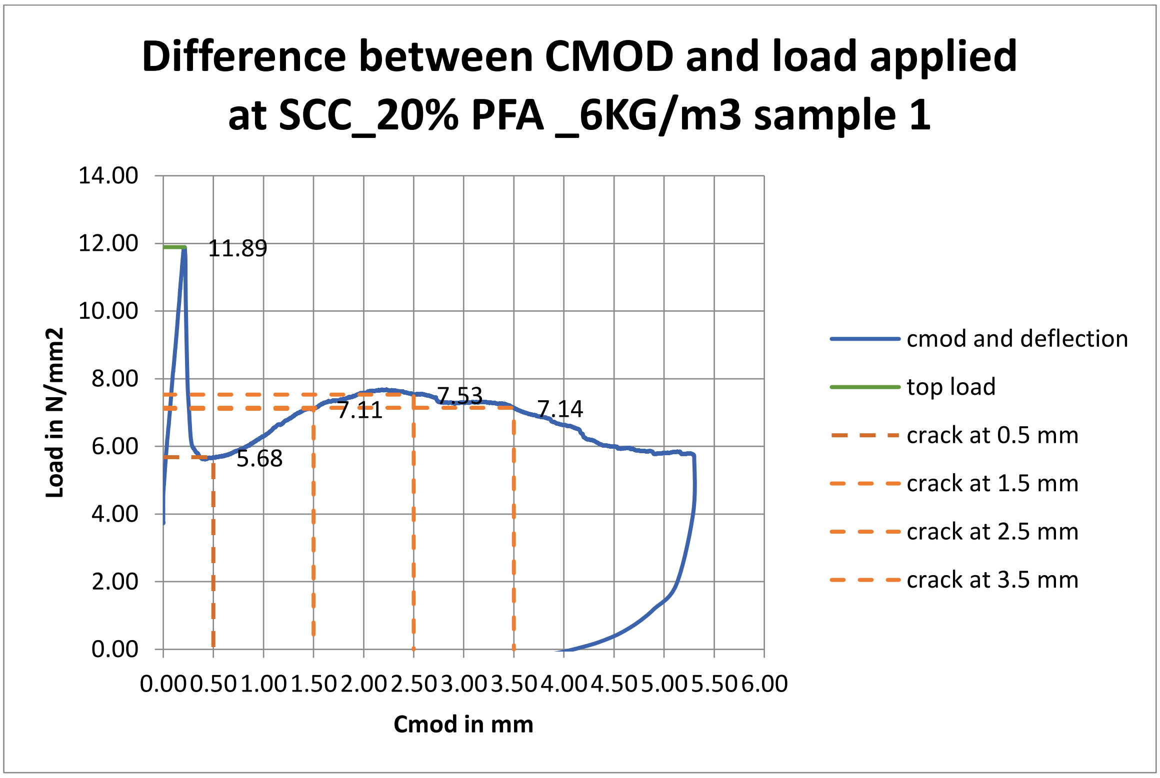
Graph 34. Difference between CMOD and load applied at SCC_20% PFA _4.5KG/m3 sample 2



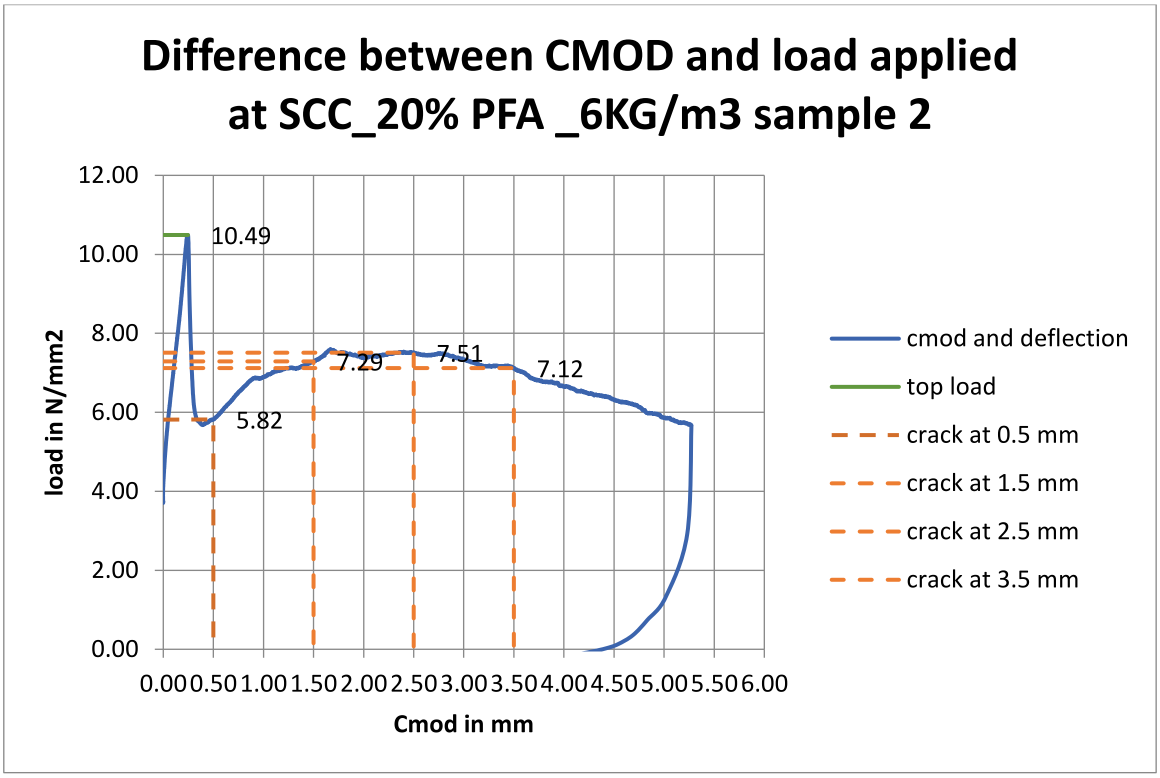
Graph 35. SCC_20% PFA_4.5Kg/m3 Residual flexural strength sample 1 and 2 at 28 days



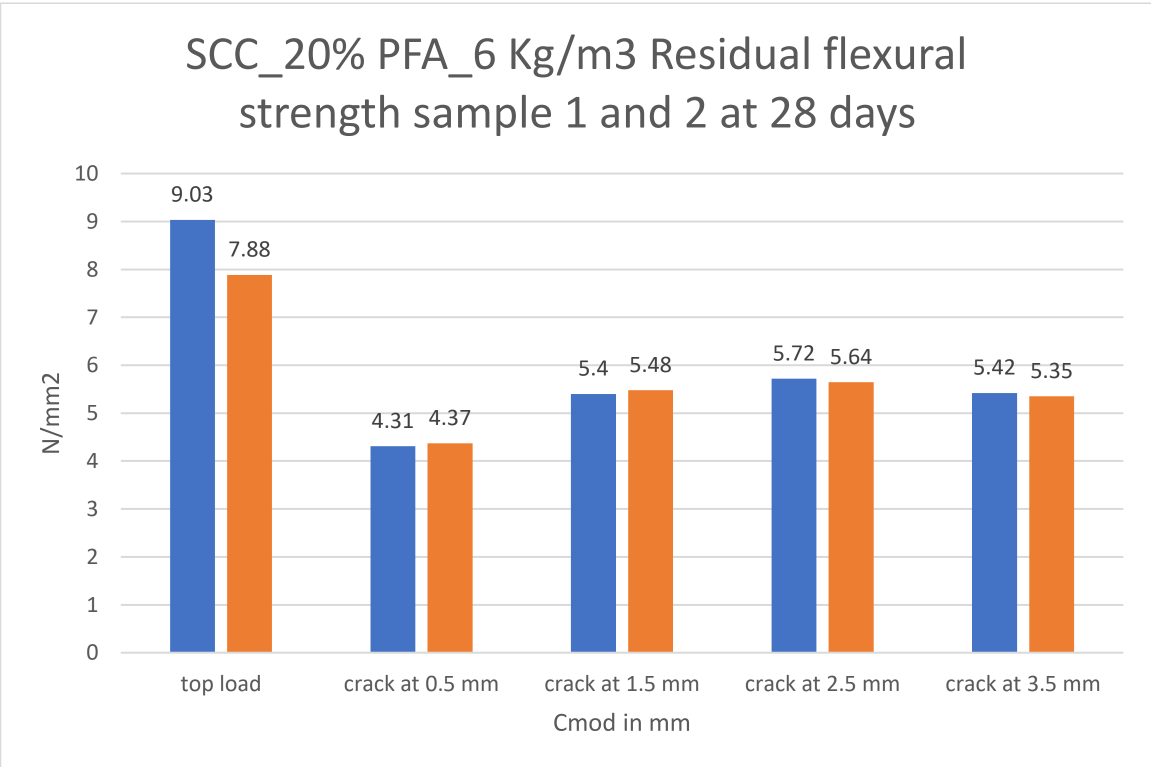
Graph 36. SCC_20%_PFA_4.5KG/m3 Residual flexural strength of 28 days



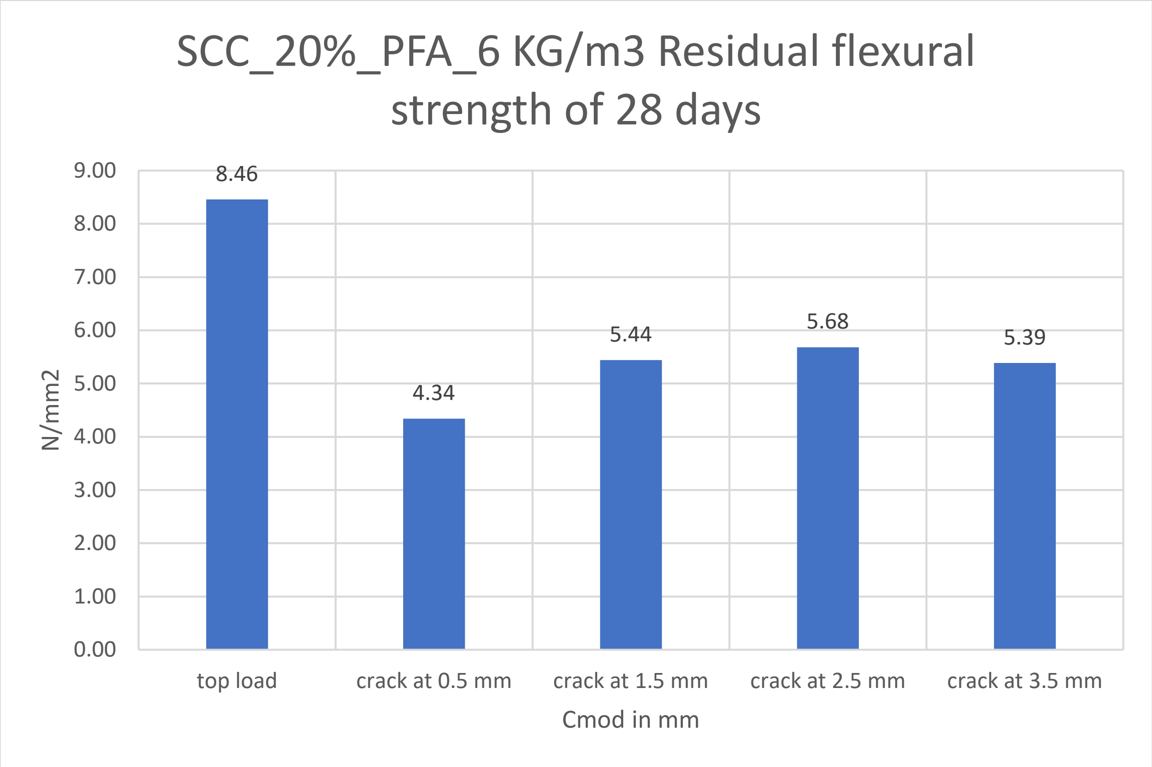
Graph 37. Difference between CMOD and load applied at SCC_20% PFA _6KG/m3 sample 1



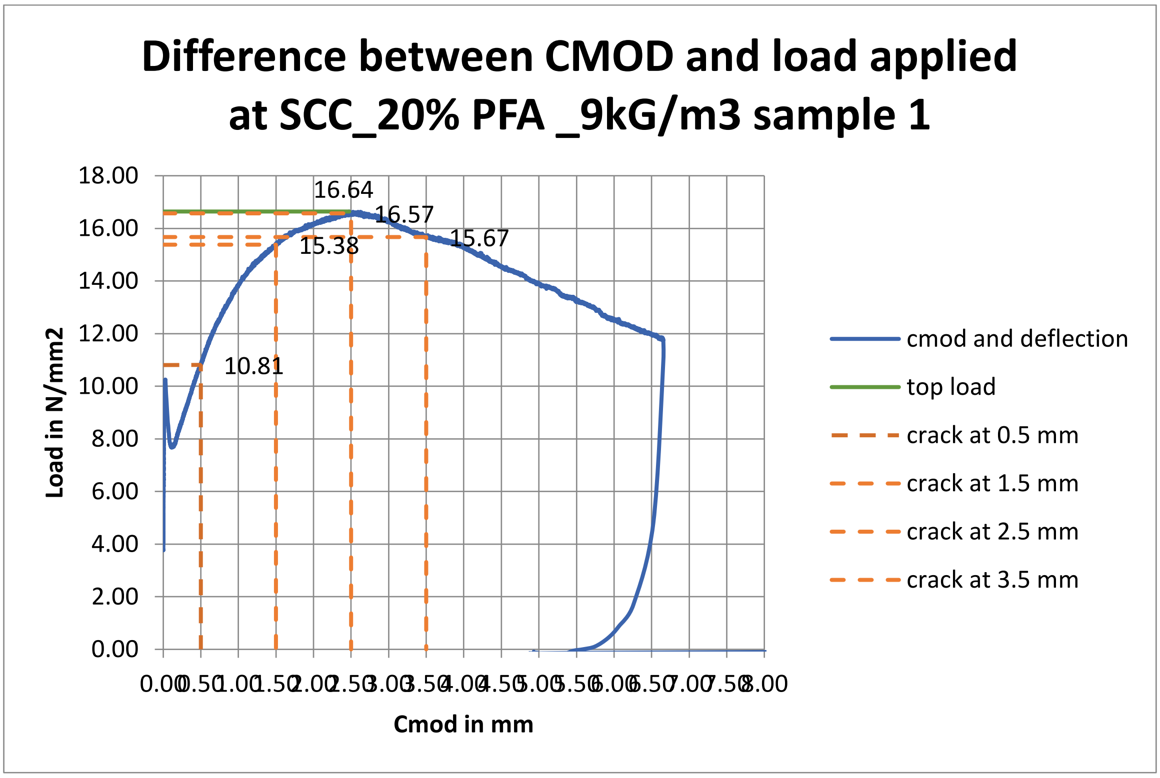
Graph 38. Difference between CMOD and load applied at SCC_20% PFA _6KG/m3 sample 2



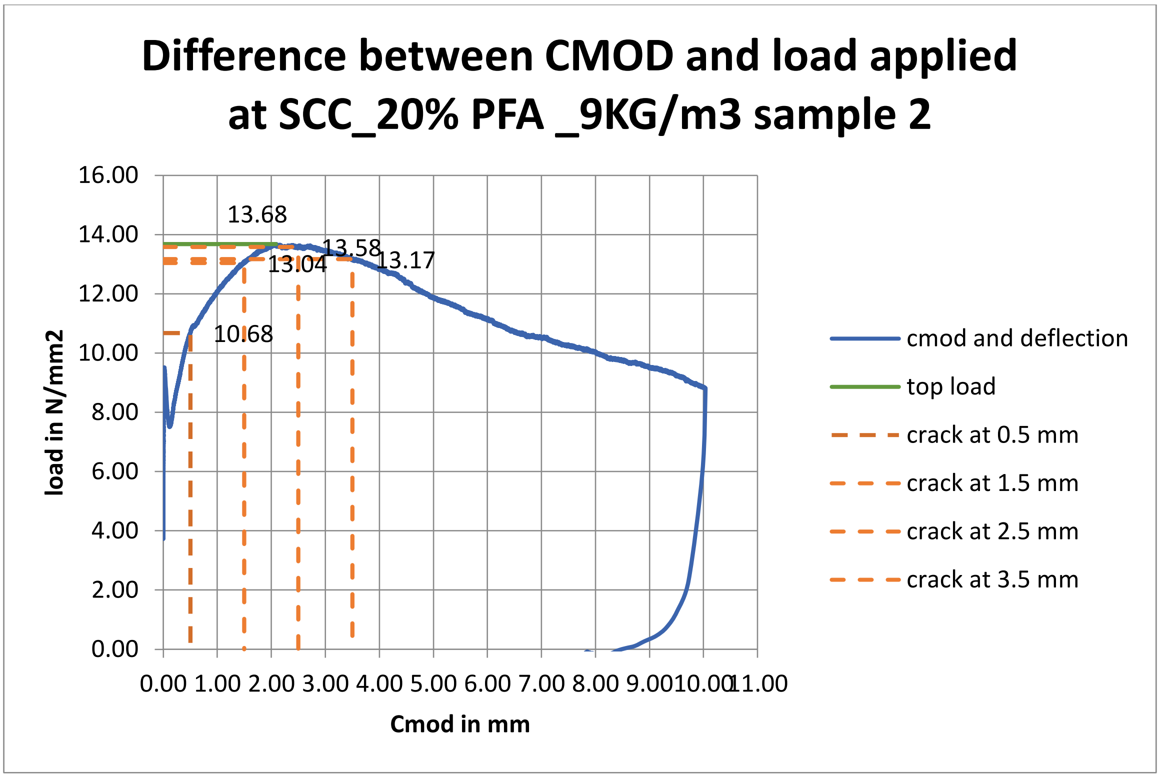
Graph 39. SCC_20% PFA_6 Kg/m3 Residual flexural strength sample 1 and 2 at 28 days



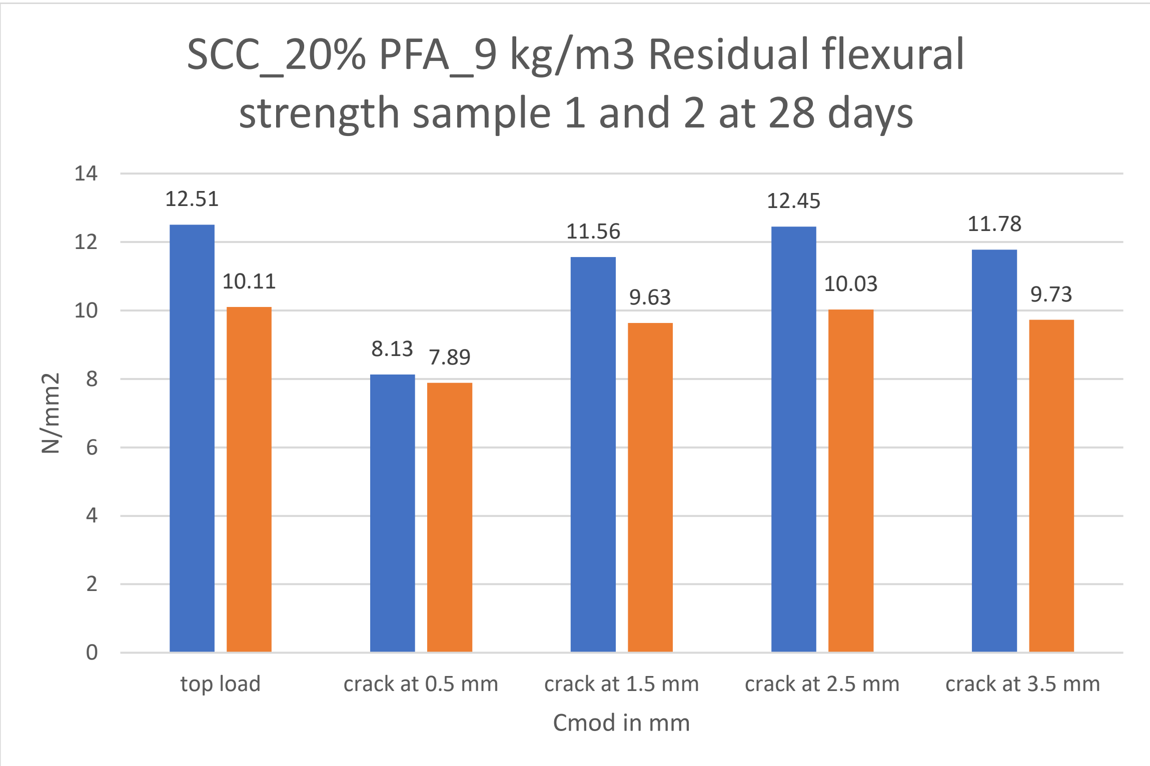
Graph 40. SCC_20%_PFA_6 KG/m3 Residual flexural strength of 28 days



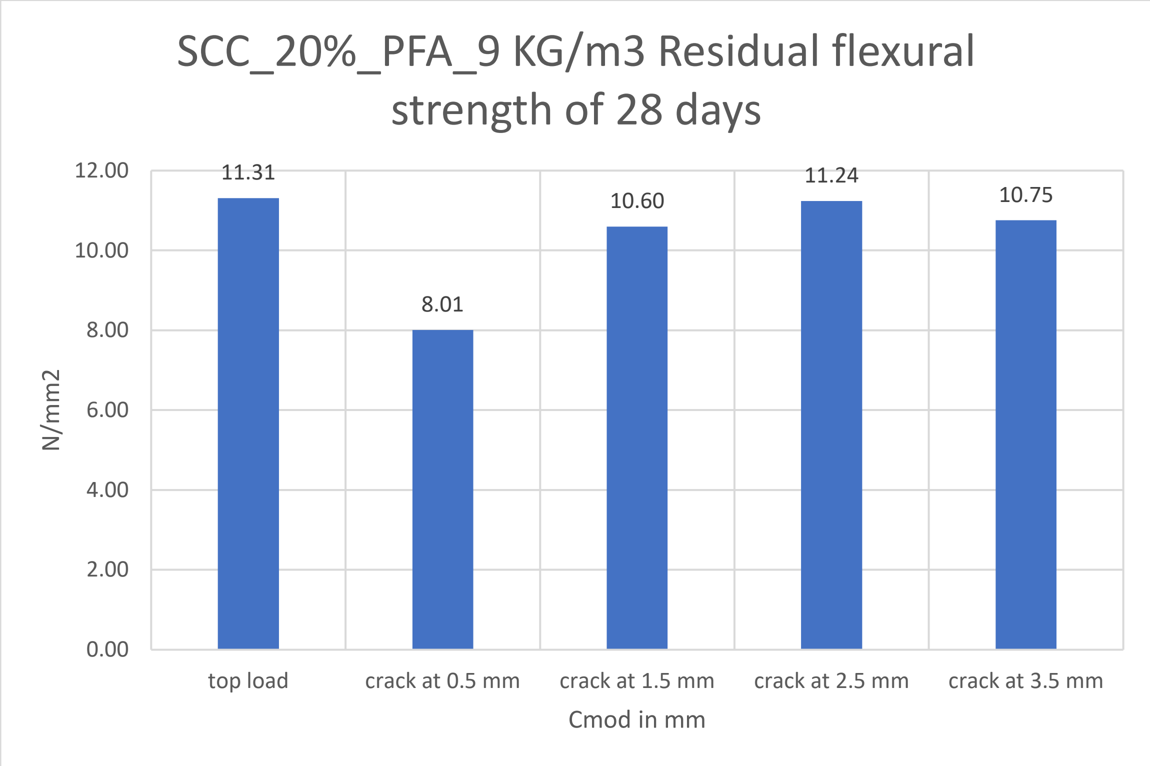
Graph 41. Difference between CMOD and load applied at SCC_20% PFA _9KG/m3 sample 1



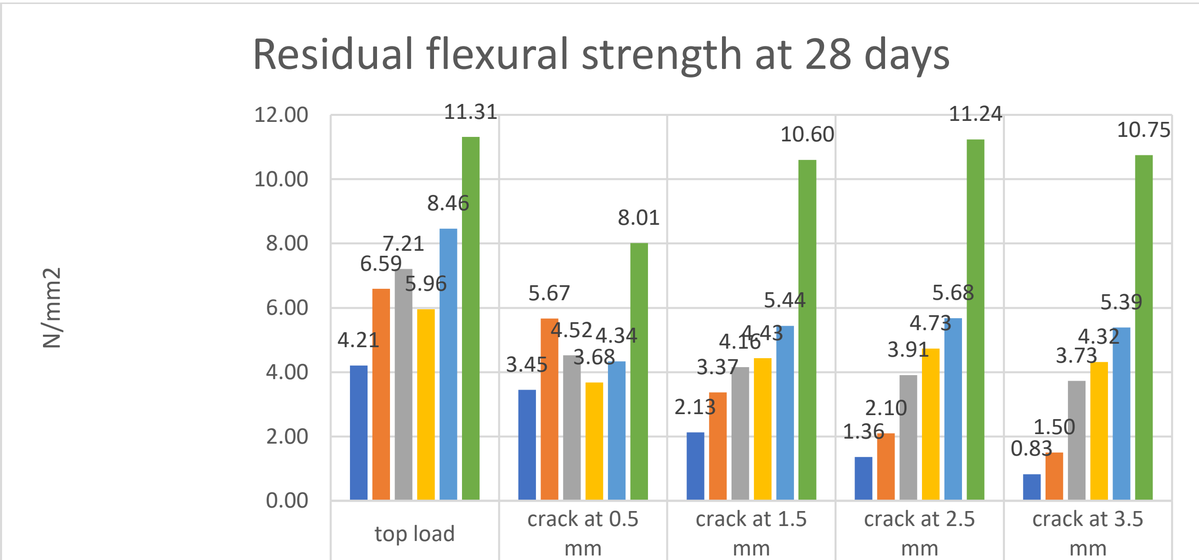
Graph 42. Difference between CMOD and load applied at SCC_20% PFA _9KG/m3 sample 2



Graph 43. SCC_20% PFA_9 Kg/m3 Residual flexural strength sample 1 and 2 at 28 days

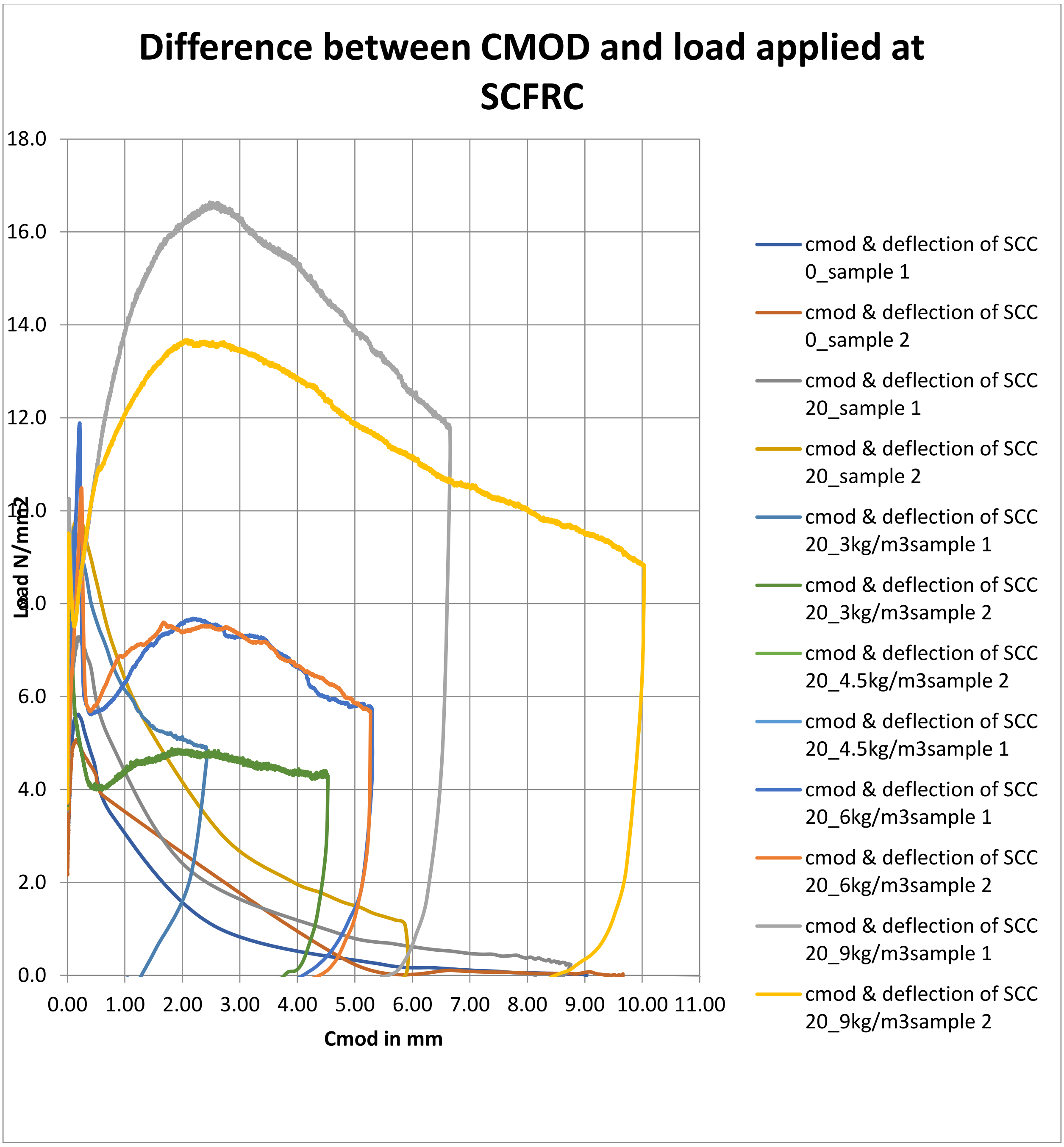


Graph 44: SCC_20%_PFA_9 KG/m3 Residual flexural strength of 28 days



	top load	crack at 0.5 mm	crack at 1.5 mm	crack at 2.5 mm	crack at 3.5 mm
SCC_0%_PFA	4.21	3.45	2.13	1.36	0.83
SCC_20%_PFA	6.59	5.67	3.37	2.10	1.50
SCC_20%_PFA_3KG/m3	7.21	4.52	4.16	3.91	3.73
SCC_20%_PFA_4.5KG/m3	5.96	3.68	4.43	4.73	4.32
SCC_20%_PFA_6KG/m3	8.46	4.34	5.44	5.68	5.39
SCC_20%_PFA_9KG/m3	11.31	8.01	10.60	11.24	10.75

Graph 45: Residual flexural strength Vs different replacement of SCFRC with 28 days



Graph 46: Difference between CMOD and load applied at SCFRC at 28 days.

Figure 27. Cracks at sample after CMOD test

Conclusion

The following conclusion was obtained from the result of this study

- In the initial test the addition of PFA to the normal concrete (mortar) positively affected the properties of the hardened concrete with the PFA replacement by 10% of cement mass, whereas the changes with 20% replacement of PFA does not provide a drastic change but still meet the standard requirements of normal hardened concrete properties.

- The initial test was carried out for self-compacting concrete (mortar) with the replacement of 0, 10, 20, 40 % PFA of cement mass ratio. The inclusion of PFA at a replacement rate of 10 and 20% to cement mass positively affected the fresh concrete properties such as increases the workability and flowability of the self-compacting concrete without bleeding and segregation, which exhibits the slump flow diameter from 246 to 249 mm. In the case of Non-destructive ultrasonic pulse velocity test was done and determined the quality of the mortar in good condition. Addition of PFA up to 40% replacement of cement mass negatively affect the properties of hardened self-compacting concrete such as increase in the amount of PFA decrease the flexural and compression strength of self-compacting concrete but the addition up to 20% of PFA with cement mass does not drastically affect the hardened properties but satisfy the normal standard properties of hardened self-compacting concrete. Also, 20 % replacement of PFA from cement mass provide a valuable economic solution for the extinct of raw materials for the cement production. The high PFA volume as a replacement of cement masses up to 40% negatively effect to the fresh and hardened properties but improves the resistance in bleeding and segregation.

- The addition of PFA to self-compacting fiber reinforced concrete (SCFRC) has positively affected to the properties of fresh concrete with the PFA replacement by 20% of cement mass and 3kg/m^3 of polyolefin fiber reinforcement. The best workability was obtained when the PFA replacement by 20% of cement mass and 3kg/m^3 of fiber reinforcement. Fresh SCFRC samples with the above-mentioned formulation provide the slump flow diameter of 730mm and it was determined the increase of fiber decreases the workability and flowability. Whereas replacement of 20% of PFA with 6 and 9 kg/m^3 did not satisfy the slump flow as required by EFNARC and EN 206:2014 standard. The addition of PFA with 20% replacement of cement mass ratio with 3kg/m^3 of fibers provides best compressive strength results and when there is an increment in the quantity of fibers, it provides a decrease in compressive strength. The compressive strength differs based on the size of the specimen, if the specimen is smaller in size the compressive is increased double the percent of the size ordinary specimen compressive strength. The addition of PFA and fibers increases the flexural strength of concrete at the rate of 2.12, 2.91, 6.24, 41.5 % at age of 56 days.

- In CMOD test were determined the residual flexural strength of fiber reinforced self-compacted concrete at the different point of cracks gaps and it shows, that at the crack of 3.5 mm the residual flexural strength for 9 kg/m^3 of fibers is the highest. When the fiber content increases in the SCFRC the residual flexural strength of the fiber reinforced concrete increases too but decreases the workability and flowability of the SCFRC.

- Based on the test results obtained the pulverized fuel ash which is replaced with 20% of cement mass with fiber reinforcement of 3kg/m^3 to produce high-quality SCFRC with the flexural and compressive strength of 8.19 MPa and 71.9 MPa respectively at the hardening age of 56 days.

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