EFFECT OF ADDITION OF FIBRES ON MECHANICAL AND DURABILITY PROPERTIES OF NO-FINES CONCRETE

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SUBMITTED BY

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DECLARATION

I, hereby declare that the thesis **"Effect Of Addition Of Fibers On Mechanical And Durability Properties Of No-Fines Concrete"** which is submitted in partial fulfillment of the requirement for the award of the degree of **Master of Engineering** in **Structural Engineering** in the Department of Civil Engineering (CED), Thapar University, Patiala, is an authentic record of my own independent and original research work carried out by me under the supervision and guidance of **Dr. Shruti Sharma**, Associate Professor, Department of Civil Engineering (CED), Thapar University, Patiala.

The matter embodied in this thesis has not been submitted in part or full to any other university or institute for the award of any degree.

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This is to certify that the above declaration made by the student concerned is correct to the best of my knowledge and belief.

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ABSTRACT

The aim of this research work is to study the effect of addition of fibers on various mechanical and durability properties of no-fines concrete. No-Fines concrete (NFC) was first prepared and then the modifications in mechanical and durability properties were studied by adding different types of fibres in the form of Polypropylene fibre (NFC-P), Jute fibre (NFC-J) and Steel fiber (NFC-S). Polypropylene fibers of 12 mm length were used at a volume fraction of 0.2% whereas jute fibers of 15 mm length were used at a volume fraction of 0.1%. Hooked end steel fibers with aspect ratio of 66.67 were used at a volume fraction of 1%. Results show that hooked end steel fiber and jute fiber had a considerable effect on mechanical properties of no-fines concrete while polypropylene fibers gave a slight increase to the compressive strength, split tensile strength and flexural strength in comparison to the no-fines concrete. Steel fibres enhance the mechanical properties significantly with 190% increase in Compressive Strength, 20% increase in Split Tensile Strength and 142% increase in Flexural Strength. Results for mechanical properties of NFC-J were on a higher side as compared to NFC-P and controlled no-fines concrete but on a lower side when compared to NFC-S. This is due to the lower elastic modulus and strength of polypropylene fibers than jute fibers and steel fibers. Therefore in can be said that addition of steel fibres in NFC gives the best mechanical properties. With the addition of all types of fibres, the permeability decreases but with a small amount. The permeability of NFC-P, NFC-J and NFC-S is decreased by 13.67%, 17.49% and 8.19% from control sample. The addition of fibres does not affect the abrasion resistance of NFC by a significant margin. The results show that steel fiber is best for increasing the properties of no-fines concrete without much decrease in permeability. The primary purpose of no-fines concrete is to pass water through it. This water can corrode the steel fibres easily. Therefore steel fibres are not much preferred. Jute fibres also provides good strength to no-fines concrete without much decrease in permeability and abrasion resistance. Hence they can be utilized effectively. Also they are cheaper than steel and polypropylene fibres.

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CHAPTER 1
INTRODUCTION

1.1 GENERAL

No-fines concrete (NFC) is a mixture of cement, coarse aggregate and water which are mixed to give a permeable structural material. It does not contain fine aggregate/sand. It is also known as pervious concrete. It has significantly less strength typically due to its high void ratio. In the no-fines concrete, the crushed gravel is replaced with coarse aggregate and fine aggregates are completely removed which make it a special type of concrete. It is also called as Porous Concrete. Void ratio of no-fines concrete is 18 – 40% as compared to 3 – 5% of conventional concrete[1]. The main use of this type of concrete is in low traffic volume pavements, residential road, pathways, sidewalks, parking lots, etc. It is also known as pervious concrete, porous concrete, enhanced porosity concrete and gap graded concrete **[2]**.

In this work, it is proposed to study the effect on mechanical and durability properties of NFC modified with different types of fibres like Polypropylene fibres, Jute fibres and Steel fibres. The application of the prepared modified NFC will be in road pavements which are having low traffic volume. In **Figure 1.1(a) and 1.1(b)**, the difference in physical appearance of regular concrete and no-fines concrete is shown. It can be seen from the figure that NFC have a large number of voids due to absence of fine aggregate.

Figure 1.1 (a) No-Fines Concrete. (b) Conventional Concrete.

1.2 NO-FINES CONCRETE

1.2.1 Background

Initially concept of no-fines concrete was introduced in European Countries but in developing countries like India this concept is on the rise. The earliest use of no-fines concrete was seen in 19^{th} century in England mainly in load bearing walls. The reduction in the cost of production was the main reason behind its development. This concept was highly on the rise during Second World War due to less availability of cement. USA started using this special type of concrete during 1970s whereas in India this concept is introduced during 2000. After 1970s the main purpose behind using no-fines concrete became its permeability instead of lesser cost **[3]**.

In recent years due to an increase in awareness of environmental protection new sustainable methods for construction are being pushed by new researchers. This leads to the popularity of no-fines concrete. This concrete has been awarded as the best management practices because it reduces the surface runoff by absorbing the rain water into the soil **[2]**. It is also used as a pavement material in the regions where storm water is the major issue.

1.2.2 Applications

No fine concrete can be used in many applications but due to poor performance in mechanical properties it is restricted to use it in certain applications. The main use of pervious concrete is limited to the pavements subjected to lesser traffic volumes. In its starting ages it was used as load bearing walls but now parking lots is the main area where no-fines concrete is used. Following are the other applications of NFC:

- Roads of residential areas
- Parking Lots
- Sidewalks/footpaths
- Tennis Courts
- Decks of swimming pool
- Courtyards
- Walls

1.2.3 Advantages And Disadvantages

On the one hand if strength of no-fines concrete is lesser than conventional concrete, there are some advantages of no-fines concrete.

- The most important advantage of NFC is its ability to pass water through it resulting in recharge of ground water.
- No-fines concrete has a lower unit weight and higher thermal insulating values than conventional concrete.
- There is also lesser shrinkage in case of no-fines concrete.
- It also helps in decreasing the flood possibilities in urban areas.
- Elimination of glaring effect is also possible with its use **[2]**.

There are various disadvantages of no-fines concrete such as:

- Its bond strength is very less and therefore results in lower compressive strength than conventional concrete.
- Sometimes clogging may occur on the upper layer which may lead to decrease in permeability.
- Also for laying and construction purpose skilled engineers are required. Its maintenance is difficult as compared to conventional concrete.
- In various countries there are no codal recommendations for design of this type of concrete.

1.2.4 Properties of NFC

As the material properties contribute to the properties of no-fines concrete, they should be properly studied. Therefore, understanding of the material properties is necessary to choose the no-fines concrete for most suitable use.

- **Structure**

No-fines concrete differs completely in structure from conventional concrete. Here materials are held together only by cement paste whereas in conventional concrete the structure consists of paste including cement and fine aggregate. It has high void ratio with open type structure. Its strength is dependent only upon bond made up of cement paste.

- **Shape of Aggregates**

Particles of spherical shape are ideal that are used in no-fines concrete for effective bonding which increase the number of bonding points. Particles which are elongated and flaky should be avoided.

- **Mix proportions**

Different mix proportions are used for different applications. The aggregate to cement ratio is kept between 6:1 and 10:1 for construction in buildings, where the main purpose of no-fines concrete is to stop capillary action of water. Here higher strength is not required as it is used in load bearing walls only. Recently it is being used as a pavement material so aggregate cement ratio is to be kept 4:1 according to ACI. This is done to withstand heavy load by achieving high bond strength **[4]**.

- **Water Content**

The purpose of addition of water in concrete is to start the setting process. Adequate amount of water is added to get a proper bond between the aggregate and cement paste. According to ACI, the water cement ratio in case of no-fines concrete lies between 0.27 and 0.43 **[4]**. If the content of added water remains low then the required, the bond formed by cement paste with the aggregates does not gain adequate strength. On the other hand if water is added more than the optimum value cement paste may segregate below the matrix making the no-fines concrete to be impermeable.

- **Grading Of Aggregates**

In making of no-fines concrete, size of aggregates is normally kept same. Size of aggregates ranges from 10 to 20 mm. To reduce the tendency of filling up of void spaces, lesser amount of small size aggregates are used **[3]**.

- **Density**

Density of no-fines concrete is lesser as compared to conventional concrete due to the more number of voids present in it. Its density lies in the range of 1600 to 1900 kg/m^2 **[5]**. That is in the upper range category of light weight concrete. Various factors on which density of no-fines concrete depends are size, shape and density of aggregates used and also the water - cement – aggregate ratio. It also depends upon the degree of compaction.

- **Permeability**

Permeability is the rate of flow of water through a porous media. In case of no-fines concrete the value of permeability lies in the range of 0.1 to 0.5 cm/sec **[2]**. Permeability of no-fines concrete is dependent upon the materials, degree of compaction and placing operations. Some researchers also obtained the permeability values for no-fines concrete as high as 0.05 cm/sec.

- **Compressive Strength**

The value of compressive strength of no-fines concrete may vary from 3.5 N/mm^2 to 28 N/mm^2 and hence in can be used in a large number of applications **[5]**. The compressive strength has a typical value of around 17 N/mm^2. This value depends upon mix proportions and the properties of material used and also placement and compaction methods adopted in making process.

- **Flexural strength**

The no-fines concrete may have flexural strength value varying from 1 to 4 N/mm^2 **[5]**. Its value may vary depending upon aggregate-cement-water ratio, degree of compaction and porosity.

1.3 FIBRE REINFORCED CONCRETE

Most of the construction nowadays is done using concrete as a main component. Concrete is very strong in compression and hence every engineer wants to make full use of this property rather than tensile strength. Steel bars are used to increase tensile strength of concrete. If we consider the pavements, here steel reinforcement is used to transfer the load using beam action.

Another way out to increase the tensile strength, as suggested by researchers, is introduction of various kinds of fibres into concrete matrix. These fibres also arrests the cracks whereas the shrinkage of steel can lead to development of cracks and hence results in lower strength. The fibres have the tendency to distribute throughout the concrete section but to take full advantage of fibres they should be used in optimum quantity and size. When the no-fines concrete was used as load bearing walls, only its compressive strength come into action. But now with advent of time applications of no-fines concrete is no longer limited to load bearing walls as it is also used in pavement application which requires higher flexural as well as tensile strength in addition to compressive strength. The introduction of polypropylene, jute and steel fibres leads to increase in these properties. The addition of polypropylene, jute and steel fibres showed an impressive increase in flexural and tensile strength of conventional concrete.

1.4 CONSTRUCTION OF NO-FINES CONCRETE

The construction of no-fines concrete requires an experienced engineer as well as a properly compact sub grade. According to ASTM D 1557 the sub grade should be compacted not less than 92% of the maximum density when no-fines concrete is directly placed on sandy soils **[2]**. In case of clayey soils the compaction factor depends upon the kind of pavement and open graded stones can be placed in a layer over the soil. Prior to the placement of no-fines concrete above sub grade it should be moistened so that bottom layer of no-fines concrete should not set and dry too early. The quantity of water is very crucial in case of no-fines concrete because too much water leads to segregation and too little water leads to depreciation of bond strength. A good proportioned mix looks gives a sheen or wet–metallic appearance. The water gets easily evaporated from no-fines concrete so this should be kept in mind that the construction operations are quick and curing is done at proper time. Either of the fixed forms or slip form paver can be used to place the no-fines concrete for a pavement. It is placed approximately 9 to 12 mm thicker than the required pavement elevation. A typical construction process of no-fines concrete can be seen in **Figure 1.2**.

Compaction of no-fines concrete is done with rods and rolling. After compaction rolling is done over the pavement to consolidate the concrete which leads to strong bond between aggregate and cement paste. It also creates a smooth surface for riding. Rolling should not be done in excess because it can collapse the voids. **Figure 1.3** shows the compaction of no-fines concrete using roller. Joints in no-fines concrete are made following the same rules as that of concrete. Sometimes the pavements made of no-fines concrete are not jointed as small cracks are not visible on the texture of pavement. Curing becomes more important in case of no-fines concrete as its structure is open and rough making it more exposed to evaporation. Sufficient water is provided through curing for hydration process which provides required strength to the pavement preventing ravelling. Generally curing is done within 20 min after consolidation and continued for 7 days.

Figure 1.2: Construction Process of no-fines concrete.

Figure 1.3 Compacting no-fines concrete using roller.

1.5 MAINTENANCE OF NO-FINES CONCRETE

The main part of maintenance includes the clogging of pores of no-fines concrete. Various types of small particles coming from the vehicles or surface run off can clog the pores decreasing in permeability. When local materials like sand etc are loaded directly on the pavement, it also leads to clogging so it should be avoided. Studies have found that there is gradual decrease in permeability with time due to clogging. This problem cannot be dealt with maintenance technique of conventional concrete. To maintain the no-fines concrete pavement various methods are adopted. Most common method is pressure washing the pavement. Also the debris from the pores can be pulled out by applying vacuum pressure. As these methods are not effective further studies are being carried out to develop maintenance methods **[6]**.

1.6 NO-FINES CONCRETE IN INDIA

India is a developing nation and lot of ground surface in urban areas is being covered by impermeable materials with the ongoing development processes. Secondly the ground water table in India is constantly going down due to surface runoff of water. No-fines concrete pavements deals with both of the problems. Many cities in India are prone to floods which can be solved with introduction of permeable pavements.

Various parking lots, low volume traffic pavements and sidewalks can be constructed by no-fines concrete through water can pass and recharge ground water. In small town and villages interlocking pavement tiles can be effectively replaced with no-fines concrete pavements. On the soils with low permeability this pavement can retain the water in its voids for longer time till it percolates through the soil. With the introduction of Smart City campaign by Government of India, it is very important to grow the ideas which can solve both the purposes at same time.

1.7 OBJECTIVES OF THE WORK

No-fines concrete was used only in building applications prior to its use as pavement. But due to its low flexural strength its use was very limited. The main purpose of this research work is to improve the properties of NFC so that its performance can improve and it can be used for buildings as well as low traffic volume pavements. The analysis of available literature and some standard tests were performed on no-fines concrete in this study. To enhance the mechanical properties of NFC, various kind of fibres such as Polypropylene fibres, Jute fibres and Steel fibres were added and their effect on NFC was investigated.

The objectives of the proposed work are.

- Thorough study of available research work and literature on No-Fines concrete for pavement as well as non pavement purpose.
- To conduct various tests to evaluate mechanical and durability properties and permeability of NFC.
- Effect on properties of NFC due to addition of as Polypropylene fibres, Jute fibres and Steel fibres is to be studied.

1.8 ORGANISATION OF THESIS

i. Chapter 1 gives introduction and detailed view on the placing and maintenance of no-fines concrete and objectives of the proposed work.
ii. Chapter 2 discusses the available literature needed for undertaking of this research.
iii. Chapter 3 gives in depth knowledge of various materials used and the relevant tests adopted.
iv. Chapter 4 explores the test results and attainment of the objectives.
v. Chapter 5 discusses the test observations in accordance with the objectives set initially. Conclusions are made and further areas of work are discussed.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

The review of literature on this topic shows that the information available on this topic is inadequate for development for use of no-fines concrete in pavement applications. Though in recent years, some quality research has been undertaken but very less research has been done with addition of any material into the no-fines concrete. The underlying passages discuss the already researched properties of no-fines concrete.

2.2 LITERATURE REVIEW

Previously, no-fines concrete was used for construction only in European Countries. In USA, the development of no-fines concrete is because of the positive response to the use of pervious asphalt concrete. At that time pavement applications of no-fines concrete is limited but it was effectively used as a light weight building material. For the first time pavement of no-fines concrete was constructed in Europe. this lead as an encouragement for the construction of parking lots, roof pavement in various countries like Switzerland ,France , Mexico etc. Main focus of various researches in this field is to enhance the mechanical properties of no-fines concrete.

Wang et al (2006) examined various properties such as compressive strength, permeability, freezing and thawing resistance, split tensile strength and porosity of no-fines concrete made up of Portland cement. No-fines concrete constituting different quantities and types of materials is studied in this paper. The mix design consists of two parts. Part 1 discusses the change in properties with change in aggregate sizes. Part 2 discusses the change in results with introduction of sand, fibres and admixtures. The admixtures used were Air Entraining Admixture (AEA) and High Range Water Reducer (HRWR). Rod compaction was done with 25 blows in three layers. The results discussed in this paper show that the permeability of concrete made with one sized aggregates is more but its strength is less. Compressive strength increases with decrease in size of aggregates. Addition of 7% of sand by weight of coarse aggregate does not affect the permeability but increases the strength considerably from 14.48 N/mm^2 to 22.74 N/mm^2. The same behaviour was seen on addition of fibres as well. The compressive strength value was 20.47 N/mm^2 **[7]**.

Maguesvari and Narasimha (2013) focussed the effect of change in size of aggregates on the behaviour of no-fines concrete. The coarse aggregates which were used was batched in four categories ranging from 4.75 mm to 19.5 mm. Fine aggregate of grading 2 were used with OPC type 1. The aggregate cement ratio was taken as 4.75: 1 with w/c as 0.34. Various mechanical properties were evaluated by replacement of 0 to 50% of sand with coarse aggregate. The results of compressive strength lies between 9.6 N/mm^2 and 26.2 N/mm^2 with permeability results between 0.401 cm/sec to 1.258 cm/sec. Flexural Strength test was also conducted. With the use of 16 mm to 19.5 mm size of coarse aggregate and no fine aggregate, the flexural strength obtained was 3.8 N/mm^2. This value increases with decrease in size of coarse aggregates to 5.2 N/mm^2. This value was obtained when size of coarse aggregates was taken between 4.75 mm and 9 mm. Similar pattern was seen in case of split tensile strength results. The value of split tensile strength increases from 3.75 N/mm^2 to 4.21 N/mm^2 on decrease in size of aggregates. The increase in strength properties with decrease in size of aggregates can be attributed to increase in contact area. The variation of compressive strength, split tensile strength and flexural strength is represented in **Figure 2.1(a), 2.1(b) and 2.1(c)** respectively. Abrasion resistance test was also conducted. The results show that percentage wear remains in between 4% to 6.67%.

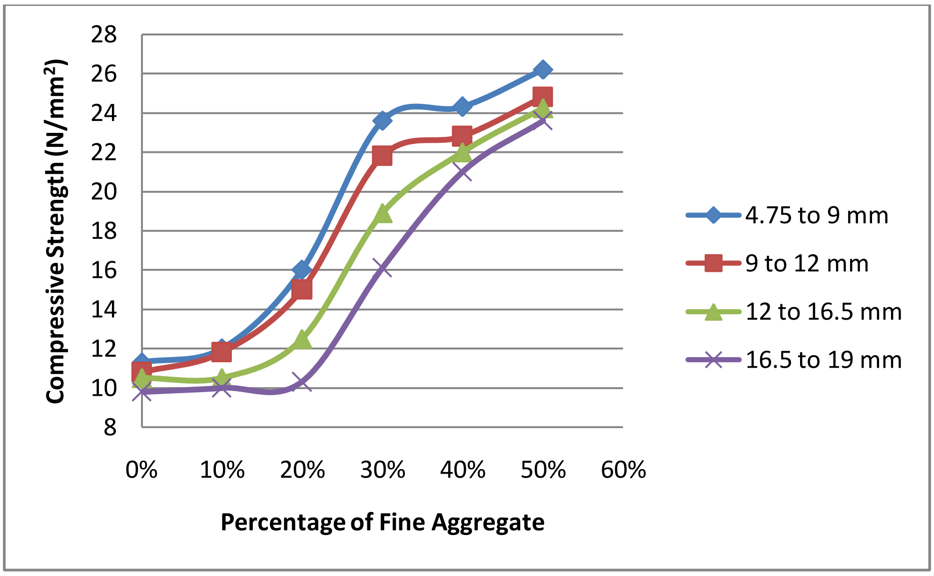

Figure 2.1(a): Variation of Compressive Strength with Percentage of Fine aggregate [8].

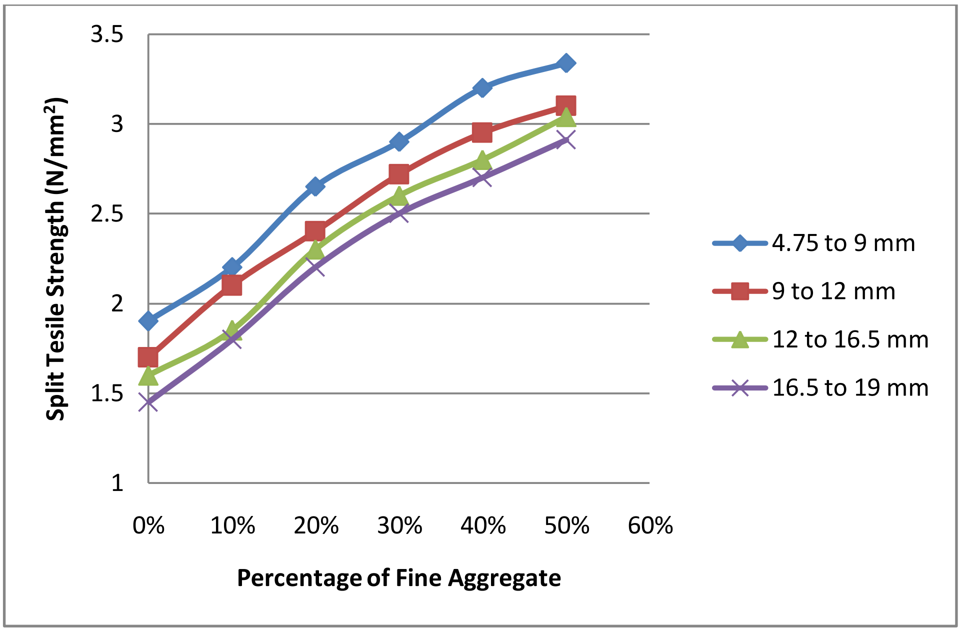

Figure 2.1(b) Variation of Split Tensile Strength with Percentage of Fine aggregate [8].

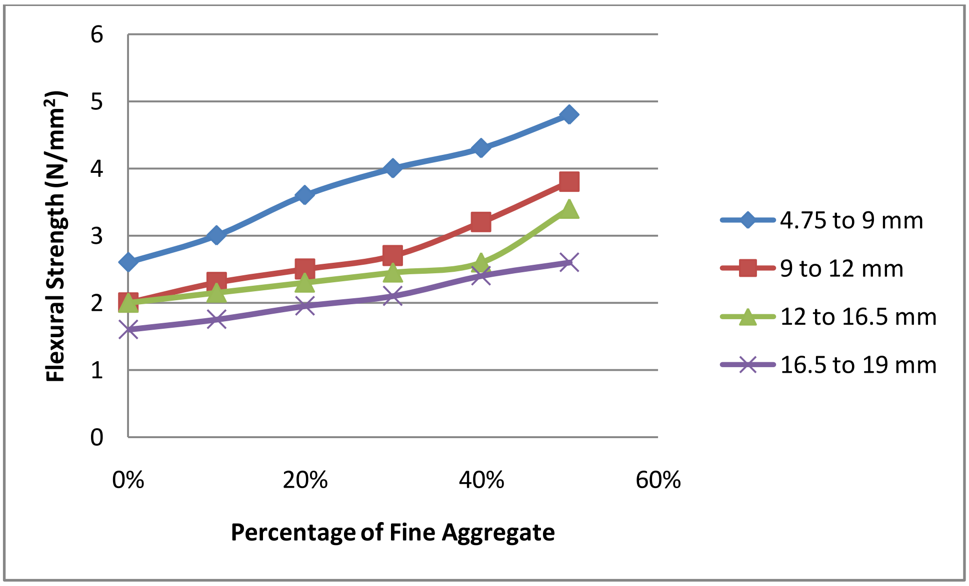

Figure 2.1(c) Variation of Flexural Strength with Percentage of Fine aggregate [8].

Abite et al (2014) discussed the effect of addition of rubber waste and fine sand in sub base on mechanical properties and structural integrity of pavements. The author used the falling weight deflectometer (FWD) to investigate the mechanical property. FWD, shown in **Figure 2.2**, is based on a non destructive technique which is used to evaluate stress strain properties of different layers of pavements. Three different types of pervious concrete pavement sections were tested. These sections were having different sub base materials. The construction of pavement was done according to the NRMCA guidelines. The compressive strength comes out to be 11.5 N/mm^2 and unit weight of pervious concrete is calculated as

1792 kg/m^3. Normal concrete pavement shows greater resistance towards the impulsive loads as compared to no-fines concrete pavement that is the normal concrete pavement showed lesser deflection than pervious concrete pavements. Out of the 3 samples of pervious concrete, the sample in which no addition was made bears more load than the samples having fine aggregate and rubber crumbs in its sub base.

Figure 2.2: Falling Weight Deflectometer (FWD) [9].

Patil and Murnal (2014) investigated the change in strength of no fines concrete with different water cement ratios and sizes of aggregates. The author also studied the effect of replacement of cement with fly ash on strength properties. OPC 43 grade cement was used with 20 mm and 10 mm sizes of coarse aggregates were used in equal proportions. Class F fly ash with specific gravity of 1.92 was used. The test results of this paper are tabulated below in **Table 2.1 and 2.2**.

Table 2.1 Mix proportions and test results without Fly ash [5].

S. No.	Proportions (Cement : Aggregate)	Water Cement Ratio	7 days Compressive Strength (N/mm^2)	28 days Compressive Strength (N/mm^2)
1	1 : 5.8	0.43	3.2	4.5
2	1 : 5.53	0.42	4.0	5.8
3	1 : 5.46	0.40	4.2	5.9
4	1 : 4.41	0.40	14.36	19.2
5	1 : 4.41	0.38	15.22	20.2
6	1 : 4.41	0.36	12.3	17.5
7	1 : 4.41	0.34	9.5	14.2

Table 2.2 Mix proportions and test results with Fly ash [5].

S. No.	Proportions (Cement : Aggregate)	Water Cement Ratio	Percentage of Cement replaced with Fly ash	7 days Compressive Strength (N/mm^2)	28 days Compressive Strength (N/mm^2)
1	1 : 4.41	0.38	20	16.52	21.4
2	1 : 4.41	0.38	40	13.20	17.8
3	1 : 4.41	0.38	60	6.66	11.2
4	1 : 4.41	0.38	80	5.02	8.4

The author concludes that compressive strength of no-fines concrete increases linearly with decrease in water cement ratio up to an optimum value of 0.38. The optimum mix proportion of cement: aggregate is found out to be 1:4.41. The compressive strength after 28 days for this mix proportion is 20.2 N/mm^2. On replacement of cement with fly ash the compressive strength of no-fines concrete increases up to 20% and then decreases. So the maximum value of compressive strength can be achieved with mix proportion of 1:4.41, water cement ratio of

0.38 and replacing 20% of cement with fly ash. The flexural strength test was also conducted and the maximum value obtained was 3.14 N/m^2.

Arhin and Madhi (2014) investigated the best design mix of no fines concrete from the testing of 5 design mixes so as to obtain higher value of compressive strength and flexural strength with a good permeability. Three compaction techniques i.e. self compaction, proctor hammer and rod compaction were also compared. The design mixes and proportions of the materials used are given in **Table 2.3**.

Table 2.3 Material Proportions taken in study [10].

Mix Design	Cement (%)	w/c ratio	Coarse aggregate (%)	Fine aggregate (%)
Control Mix	15.11	0.34	82.69	2.20
Mix 1	15.11	0.34	81.96	2.93
Mix 2	15.11	0.34	81.22	3.67
Mix 3	15.11	0.34	80.49	4.40
Mix 4	15.11	0.34	79.76	5.13

The Compressive strength, flexural strength and permeability test results are given below in **Figure 2.3(a), 2.3(b) and 2.3(c)** respectively.

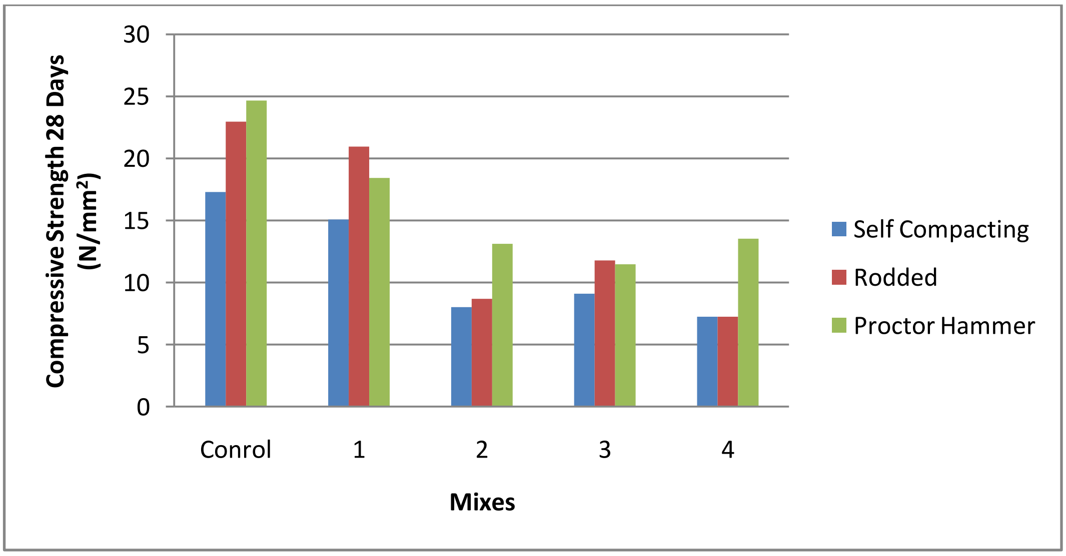

Figure 2.3 (a) Compressive Strength test results [10].

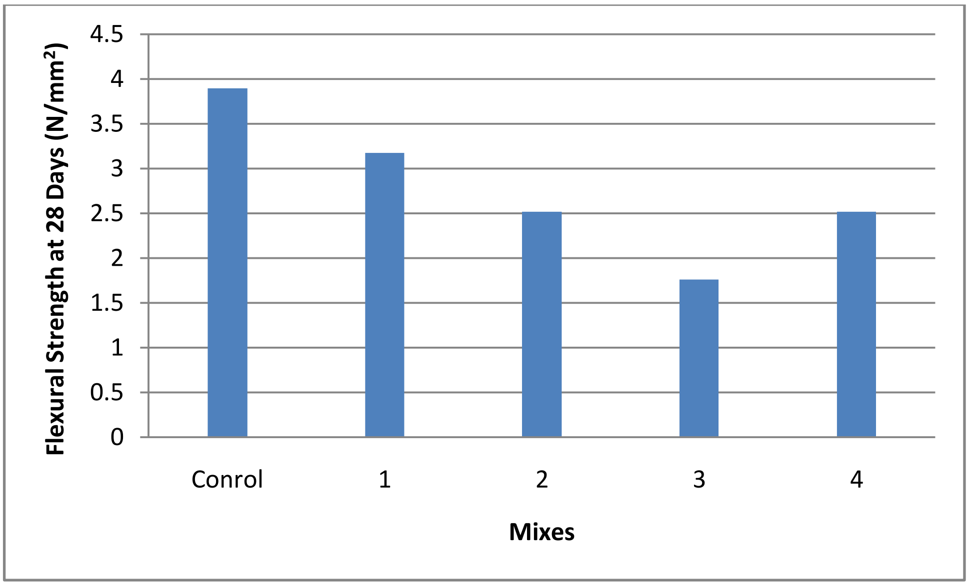

Figure 2.3 (b) Flexural Strength test results [10].

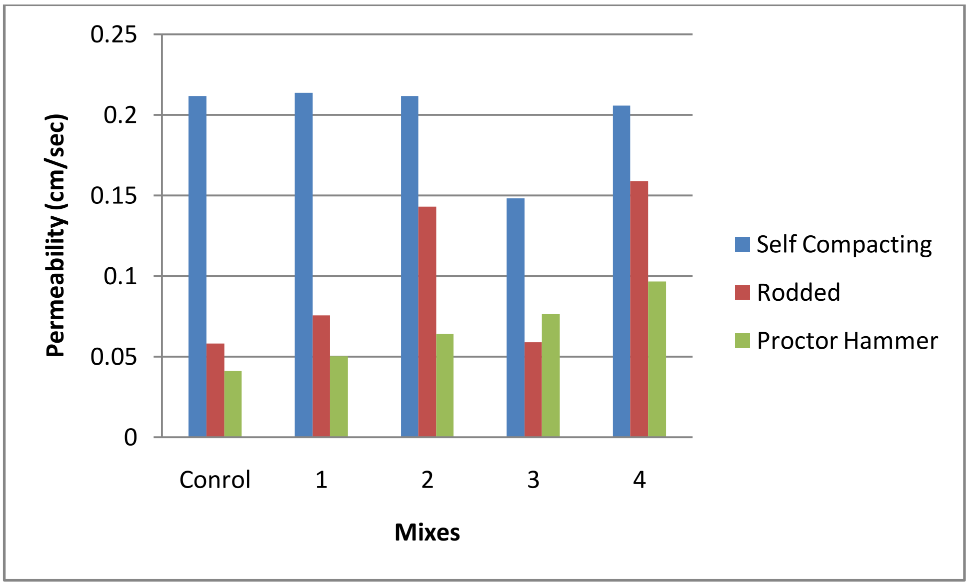

Figure 2.3 (c) Permeability test results [10].

The results, when analyzed, show that the method of compaction is very important in case of no-fines concrete. The compressive strength value is highest in case of proctor hammer method. The author also added fibres in Mix 2 and Mix 3 but the increase in strength is not recorded. The highest compressive strength values in case of control mix can be attributed to addition of a curing admixture whereas in other mixes the more quantity of sand could be the reason behind lesser compressive strength. The flexural strength also decreases with increase in sand content and decrease in quantity of coarse aggregate. The compaction methods also influence the permeability results. The coefficient of permeability is highest in case of self compaction and is least in case of proctor hammer method. Hence it can be observed from results that a no-fines concrete pavement can be made with compressive strength of up to 24 N/mm^2 and having coefficient of permeability equal to 0.059 cm/sec.

Shinde and Valunjkar (2015) discussed the methods and results of various tests such as compressive strength, void ratio etc. performed on no-fines concrete samples. Three mix proportions, taking cement is to aggregate ratio of 1:5, 1:6 and 1:1:5 with size of coarse aggregate ranging from 9 to 12 mm were tested. OPC 53 Grade cement was used. Three design mixes were named as M1, M2 and M3. The water cement ratio for M1 and M3 was taken as 0.32, for M2 0.38. The concrete was mixed with machine mixer and compaction was done with tamping rod. The obtained test results are given in **Table 2.4.**

Table 2.4 Compressive Strength, Void Ratio and Infiltration Rate test results [11].

Mix Design	Compressive Strength (N/mm^2)			Void Ratio (%)	Infiltration rate ($l/min/m^2$)
	7 Days	14 Days	28 Days		
M1	5.23	6.65	6.87	5.7	259
M2	6.18	6.64	7.89	5.9	285
M3	8.88	15.6	19.46	6.2	300

It can be concluded from the above table that the compressive strength of no fines concrete increases drastically from 7.89 to 19.46 on 20% replacement of coarse aggregate with fine aggregate. The author concludes that the compressive strength of no fines concrete is lesser than the conventional concrete for same mix design but its ability to pass water through it makes the no fines concrete acceptable.

Talsania et al (2015) investigated the use of rice husk ash in no fines concrete and its effect on flexural strength and compressive strength. The used rice husk ash was taken from Guru Metachem Private Limited, Ahmadabad. The rice husk ash was grey in colour with particle size less than 45 micron and its chemical composition is given in **Table 2.5**.

Table 2.5 Chemical Composition of Rice Husk Ash [12].

S No.	Constituents	Percentage
1	Silicon Dioxide (SiO2)	85.5 – 95.5
2	Aluminium oxide(Al2O3)	0 – 2.5
3	Iron oxide (Fe2 O3)	0 – 1.5
4	Calcium Oxide (CaO)	0 – 1
5	Sodium Oxide (Na2O)	0 – 1
6	Carbon (C)	2 – 4
7	Potassium Oxide(k2O)	0 – 3

The study was done with OPC 53 grade cement. 10 mm and 20 mm size of coarse aggregates were used in equal proportions. The mix proportion and results of the tests conducted in this study is given in **Table 2.6**.

Table 2.6 Mix proportion and Test results [12].

Mix	Aggregate (Kg/m^3)	Cement (Kg/m^3)	w/c ratio	RHA (%)	28 days Compressive strength (N/mm^2)	28 days Flexural strength (N/mm^2)
$Mix_{0.30}$	1500	375	0.30	0	8.02	1.49
R Mix1				10	8.83	1.87
R Mix2				20	7.86	1.32
$Mix_{0.35}$	1500	375	0.35	0	9.42	1.85
R Mix3				10	10.05	2.38
R Mix4				20	9.19	1.75
$Mix_{0.40}$	1500	375	0.40	0	10.35	2.43
R Mix5				10	10.98	3.05
R Mix6				20	9.78	2.40

Based on the results of the tests conducted it can be seen that that compressive strength and flexural strength increases with increase in water cement ratio. The trends show that the optimum replacement of cement with rice husk ash is 10% in both the cases of flexural and compressive strength and hence it is a possible solution to dispose off RHA.

Amjad (2015) investigates various properties of no-fines concrete with different proportions of materials in mix design. Compressive strength and permeability are two major properties which are studied by the author. Two groups of design mixes were prepared with aggregate cement ratio ranging from 1:4 to 1:12. First group is casted with water cement ratio of 0.40 whereas second group with water cement ratio of 0.50. The mix design and the test results are tabulated below in **Table 2.7**.

Table 2.7 Mix Design and Test results [13].

Sample No.	Mix			Compressive strength (N/mm^2)	Void Ratio %	Permeability (cm/sec)
	Cement	Aggregate	w/c			
S1-1	1	4	0.40	3.24	14.1	0.21
S1-2	1	6	0.40	8.13	11.3	0.03
S1-3	1	8	0.40	5.33	12.4	0.05
S1-4	1	12	0.40	0.82	17.2	0.26
S2-1	1	4	0.50	3.73	13.6	0.19
S2-2	1	6	0.50	8.87	9.8	0.03
S2-3	1	8	0.50	1.77	15.7	0.21
S2-4	1	12	0.50	1.42	19.8	0.26

It is seen from the above results that the optimum aggregate is to cement ratio is 1:6 with the water cement ratio of 0.5. After the aggregate cement ratio of 1:6, the value of compressive strength decreases with increase in aggregate quantity whereas the permeability increases with increase in quantity of aggregates.

Thombre et al (2016) discuss the results of compressive strength and permeability tests conducted on no-fines concrete. Effect of different water cement ratios and sizes of aggregates was studied on properties of no-fines concrete. Three types of mixes were made with different sizes of coarse aggregates. Mix 1 was prepared with the aggregates of 20 mm size, Mix 2 was prepared with aggregate of 10 mm size and Mix 3 was prepared with the aggregate passing through 20 mm sieve and retained on 10 mm sieve. The cement to aggregate ratio for first 3 mixes was taken as 1:5.26 and water cement ratio was taken as 0.35. Another mix was prepared with the addition of a super plasticizer which was named as mix 4. This mix was prepared with cement is to aggregate ratio of 1:4. The maximum compressive strength out of first three mixes was obtained in case of third mix with the value as high as 5.89 N/mm^2 and corresponding void ratio was observed as 15%. With increase in void ratio the compressive strength decreases. This value is increased with addition of super plasticizer up to 16 N/mm^2 with the same void ratio **[14]**.

2.3 CLOSING REMARKS

In this chapter the previous research work done on no-fines concrete has been discussed. It is noted that little research has been done on addition of fibres in no-fines concrete. We intend to take the work forward by adding polypropylene fibres, jute fibres and steel fibres in no-fines concrete whose experimental program and methodology has been discussed in next chapter.

CHAPTER 3
EXPERIMENTAL PROGRAM AND METHODOLOGY

3.1 INTRODUCTION

This chapter outlines the experimental program and methodology followed for analysis of NFC made with and without fibres. The constituent materials and their properties are discussed. The tests adopted for design and testing of modified no-fines concrete is also outlined.

3.2 EXPERIMENTAL PROGRAM AND METHODOLOGY

To assess the properties of various materials used for the preparation of no-fines concrete specimen, an experimental program was made. Different sizes of testing specimens were made to study their performance after casting and curing. **Figure 3.1** shows the complete experimental program. Properties of different materials to be used for the preparation of no-fines concrete specimens were evaluated in the first phase. The entire test program is described in following points:

- Determination of properties of the constituent materials of NFC such as cement, aggregates and fibres as per Indian Standards.
- Casting of Twenty Four cubes of size 150 mm for compressive strength test, for flexure strength Twelve beams of size 150 mm × 150 mm × 700 mm, Twenty Four cylinders of size 150 mm × 300 mm for split tensile strength, Eight cylinders of size 76.2 mm × 127 mm for permeability test and Eight specimens for abrasion resistance test.
- The number of casted specimens is inclusive of the modified NFC samples.
- The Flexure Strength, Permeability and Abrasion Resistance test is conducted after 28 days whereas the Compressive Strength and Split Tensile Strength tests were conducted after 7 as well as 28 Days.
- Corresponding mechanical properties of control NFC and fibre modified NFC are computed in accordance with the relevant Indian Standard codes.
- Permeability of the cylindrical specimens is obtained according to Constant Head Permeability Test.

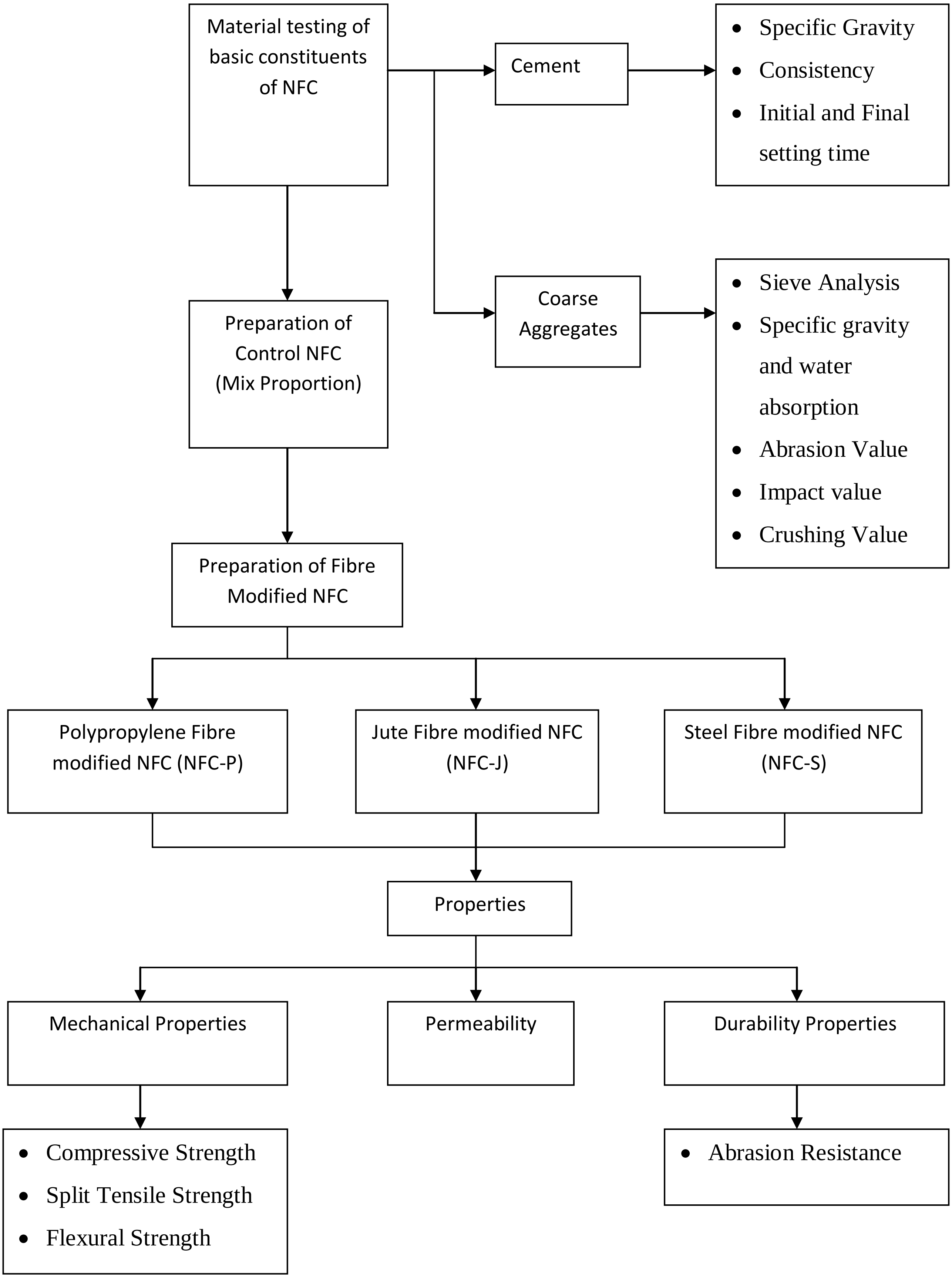

Figure 3.1 Flowcharts Showing Experimental Program.

3.3 TESTING OF BASIC CONSTITUENTS

Materials used in this study are described in the following sections along with their specifications.

3.3.1 Cement

The cement used for this study is Ordinary Portland Cement of grade 43 (OPC43) obtained from single lot. Specifications of OPC 43 is given in IS 8112: 2013. As the code says that OPC 43 should be mixed thoroughly containing calcareous, argillaceous (silica), iron oxide and by burning and grinding at the clinkering temperature to produce the required referred cement. After burning, only gypsum, water and performance improvers can be added not in excess containing 1% of air entraining agents including colouring agents which are non harmful. Mixture should be fresh without lumps. Careful storage of cement helps in prevention in deterioration of its properties due to moisture. The following tests for conducted:

- **Specific Gravity**

It is the ratio of mass of the given volume of cement to equal volume of water at same temperature. This test complies with IS: 4031 (Part 11) – 1988. Water is replaced with kerosene because cement does not set with its addition. The specific gravity of cement is generally 3.15. Test result gave the specific gravity equal to 3.12.

- **Consistency**

It is defined as percentage of water by weight of cement needed to form cement paste of viscosity at which Vicat's apparatus a plunger of 10 mm diameter penetrates to a depth of 5 to 7 mm above the base of mould. The test complies with IS: 4031 (Part 4) – 1988. This test is essential for finding out cement paste consistency as cement paste consistency may alter setting time. The value observed from the experiment is 27%.

- **Initial and Final setting time**

The test of initial and final setting time was performed according to specifications of IS: 4031 (Part 5) – 1988. It is defined as the period passing between the times when water is put in to cement and at the time when needle of cross section 1 mm^2 fails to penetrate to a depth of 5 to 7 mm of the test block from the base of mould. Final setting time is the time period passing between the time when water is initially added to the cement and the time at which a needle of 1 mm^2 makes an impression on the paste in the test mould but needle of 5 mm^2 does not give any impression.

- **Compressive Strength**

Compressive strength of a material is its capacity to take loads which tend to reduce its size as opposite to tensile strength which withstands elongating loads. The minimum compressive strength of cement should be as per IS: 4031 (Part 7) – 1988 so that concrete strength is not affected. The properties of OPC 43 are given in the **Table 3.1**.

Table 3.1 Properties of OPC43 used in this study.

S. No.	Property	Value obtained	IS Code used
1	Specific Gravity	3.12	IS : 4031 (Part 11) – 1988
2	Consistency	27%	IS : 4031 (Part 4) – 1988
3	Initial setting time	37 minutes	IS : 4031 (Part 5) – 1988
4	Final setting time	191 minutes	IS : 4031 (Part 5) – 1988

3.3.2 Aggregates

Coarse aggregates of size of 10 and 20 mm in equal proportion are used. The aggregates were thoroughly washed to remove any unwanted particles such as dust, dirt etc. and then surface dried. A 24 hour period was observed after putting them in the oven to remove the excess moisture. The aggregates were then taken out and brought to room temperature. The aggregates had angular shape and greyish colour. The following experiments were performed on aggregates.

- **Sieve Analysis**

It is used to determine the particle size distribution of coarse aggregates. It is also known as gradation test. Standard set of IS sieves were used to sieve the samples. Fineness modulus is the empirical factor which is attained by adding the total percentage of aggregates retained on each sieve set and dividing sum by 100. The observed value of finesses modulus is 6.13. Sieve analysis for 10 mm and 20 mm aggregates is shown in **Table 3.2 and 3.3** below:

Table 3.2 Sieve Analysis of 10 mm coarse aggregates.

S. No.	IS Sieve (mm)	Weight Retained (g)	Percentage Retained	Passing Percentage	Cumulative Percentage
1	12.5	291	5.82	94.18	5.82
2	10	1329	26.58	67.60	32.40
3	4.75	2762	55.24	12.36	87.64
4	2.36	476	9.52	2.68	97.16
5	Pan	134	2.68		
6	Total	5000		Sum	123.02
7				FM	6.23

Table 3.3 Sieve Analysis of 20 mm coarse aggregates.

S. No.	IS Sieve (mm)	Weight Retained (g)	Percentage Retained	Passing Percentage	Cumulative Percentage
1	80	0	0	100	0
2	40	0	0	100	0
3	20	206	4.12	95.88	4.12
4	10	4542	90.84	5.04	94.96
5	4.75	237	4.76	0.30	99.72
6	Pan	15	0.30		
7	Total	5000		Sum	198.8
8				FM	6.98

- **Specific Gravity and Water Absorption**

The specific gravity and water absorption tests were performed according to specification of IS: 2386 (Part 3) – 1963. The specific gravity test gives the strength of an aggregate. It indicates towards the quality (density) of rock. Higher the specific gravity better is the strength of aggregate and vice versa. Experimental value of specific gravity is of 10 mm aggregate is 2.66 and 20 mm aggregate is 2.69.

Water absorption test helps in measurement of strength of aggregate in terms of its porosity. Higher porosity gives higher water absorption and less strength. Experimental value of water absorption for 10 mm aggregate is 0.64% and for 20 mm aggregate is 0.55%.

- **Abrasion Value**

Abrasion value gives the indication of aggregate abrasion and toughness characteristics. IS: 2386 (Part 4) – 1963 was used for undertaking of this experiment. Los Angeles Abrasion test was performed to find the abrasion value of aggregates. The aggregate should be able to resist crushing, disintegration and degradation from any process in its manufacturing, stockpiling and placing production and compaction. Experimental value of sample is 18%.

$$\text{Impact Value} = \frac{B}{A} \times 100 \qquad \text{Eq. 3.1}$$

Where,

B = Difference between initial and final weight of sample.
A = Initial weight of sample.

- **Impact Value**

Impact resistance of aggregates is referred to as their toughness. Impact value tells us about the resistance of an aggregate to sudden impact. The experiment was performed according to IS: 2386 (Part 4) – 1963. Movement of vehicle exerts impact load on the pavement aggregates and therefore should be tough enough to prevent splitting of aggregates. Aggregate impact value hence point towards toughness or resistance to impulsive impact which differs it from its performance under uniformly increasing compressive load. Three samples were tested which gave an impact value of 14.3. Aggregate impact value for an aggregate is given by the equation

$$\text{Impact Value} = \frac{B}{A} \times 100 \qquad \text{Eq. 3.2}$$

Where,

B = Weight of fraction passing through 2.36 mm IS Sieve.
A = Weight of oven dried sample

- **Crushing Value**

Crushing value is measured by applying compressive loads steadily. The output value gives the crushing resistance of aggregates. The experiment was performed according to IS: 2386 (Part 4) – 1963. The testing specimen gave the average crushing value of 13.

$$\text{Impact Value} = \frac{B}{A} \times 100 \qquad \text{Eq. 3.3}$$

Where,

B = Weight of fraction passing through 2.36 mm IS Sieve.
A = Weight of surface dry sample

The representation of the properties of coarse aggregates is given in **Table 3.4 and Table 3.5.**

Table 3.4 Properties of 10 mm aggregates.

S. No.	Property	Experimental Value	IS Code Used
1	Specific Gravity	2.66	IS : 2386 (Part 3) – 1963
2	Water absorption	0.64%	IS : 2386 (Part 3) – 1963
3	Abrasion value	18%	IS : 2386 (Part 4) – 1963
4	Impact value	14.3	IS : 2386 (Part 4) – 1963
5	Crushing value	13	IS : 2386 (Part 4) – 1963

Table 3.5 Properties of 20 mm aggregate

S. No.	Property	Experimental Value	IS Code Used
1	Specific Gravity	2.69	IS : 2386 (Part 3) – 1963
2	Water absorption	0.55%	IS : 2386 (Part 3) – 1963
3	Abrasion value	18%	IS : 2386 (Part 4) – 1963
4	Impact value	14.3	IS : 2386 (Part 4) – 1963
5	Crushing value	13	IS : 2386 (Part 4) – 1963

3.4 FIBRES USED

3.4.1 Polypropylene fibres

The main objective behind addition of polypropylene fibres is to increase the flexural and tensile strength of concrete as well as to resist the cracks. Polypropylene fibres of 12 mm length and 0.91 kg/m^3 density were added while casting of specimens. Specifications of polypropylene fibres given by the supplier which are used in this study are given in **Table 3.6**. The fibres were uniform white in colour as shown in **Figure 3.2**

Table 3.6 Properties of Polypropylene fibres

S. No.	Property	Value
1	Length (mm)	12
2	Appearance	White Colour
3	Density (kg/m^3)	0.946
4	Tensile Strength (N/mm^2)	350

Figure 3.2 Polypropylene Fibres used in this study.

3.4.2 Jute fibres

Jute can be the effective material to use it as a reinforcement to arrest the cracks and to increase the strength properties. It is easily available in India. The raw jute fibre of long length is used in this study. The fibre is cut into 15 mm lengths without treating it with anything as shown in **Figure 3.3**. Specifications of jute fibres given by the supplier which are used in this study are given in **Table 3.7**.

Table 3.7 Properties of Jute Fibres

S. No.	Property	Value
1	Length (mm)	15
2	Appearance	Pale Yellow Colour
3	Density (kg/m^3)	1.150

Figure 3.3 Jute Fibres used in this study.

3.4.3 Steel Fibres

Steel fibres used in this study are hooked end with 50 mm length and 0.75 mm diameter which makes the aspect ratio to 66.67. **Figure 3.4** shows the steel fibres used in this research work. The steel fibres were obtained from Kasturi Metal Composites, Amravati.

Figure 3.4 Steel fibres used in this study

3.5 (NFC) CONCRETE MIX DESIGN

The materials with properties mentioned above are used to design a control mix. No-fines concrete is made up of similar materials as that of conventional concrete but the fine aggregate is not added into the mix to make it a pervious material. To obtain the required mechanical properties the grading of coarse aggregates is to be kept narrow in addition to the high permeability. IS: 12727 – 1989 deals only with the no-fines concrete used as a substitute for brick masonry and where the elimination of damping is required. It does not specify anything about the pavement applications of no-fines concrete. ACI 522R-10 is a report on no-fines concrete and its pavement applications published by American Concrete Institute (ACI). This report presents information technically on applications of pervious concrete, its methods of design, materials used, their properties, methods of construction, mixture proportioning, testing, and inspection. Standard ranges of material extent to be taken to prepare pervious concrete as per ACI 522R-15 is given in **Table 3.8**.

Table 3.8 Standard Ranges of materials to prepare no-fines concrete. (ACI 522R-15)

Material	**Proportions (kg/m^3)**
Cement	270 to 415
Coarse aggregate	1190 to 1480
w/c ratio	0.27 to 0.38
Aggregate : Cement	4:1 to 4.5:1

Trial mixes were prepared and the control mix proportions per m^3 were finalised as given in **Table 3.9**.

Table 3.9 Quantities of material taken to prepare a control mix

Material	**Quantity (kg/m^3)**
Cement	350
Water	133
Aggregates (10 mm + 20 mm)	1400
Cement : Aggregate	1:4

Six cubes of size 150mm were casted with the proportions of control mix and demoulded after 24 hours. These cubes were then put into the water tank for curing and tested for compressive strength after 7 and 28 days in the sets of three cubes each. Average value is taken to obtain the compressive strength test results. Results of compressive strength for control mix are given in **Table 3.10**.

Table 3.10 Results of Compressive Strength of Trial Mix

Days	Compressive Strength (N/mm^2)
7 Days Strength	9.56
28 Days Strength	11.45

Analysis of literature is conducted to finalise the optimum content of various kind of fibres. Three batches of different types of no-fines concrete were made. First is without any addition which is termed as NFC-C (Plain no-fines concrete). Second is made with an addition of Polypropylene fibres. Polypropylene fibres were added as 0.2% of the volume fraction of the concrete **[15]**. It is termed as NFC-P (Polypropylene fibres no-fines concrete). Third batch of no-fines concrete is made with addition of Jute fibres. The volume fraction of jute fibres was taken as 0.1% **[16]**. Fourth batch of no-fines concrete is made with addition of hooked end steel fibres. The volume fraction of steel fibres was taken as 1% **[17]**. This batch is termed as NFC-S (Steel fibres no-fines concrete). This nomenclature is given in **Table 3.11**.

Table 3.11 Nomenclature of Different batches of no-fines concrete

Batch	Nomenclature	%age of Fibre (BV)
Plain no-fines concrete	NFC-C	0%
Polypropylene Fibre reinforced no-fines concrete	NFC-P	0.2%
Jute Fibre reinforced no-fines concrete	NFC-J	0.1%
Steel Fibre reinforced no-fines concrete	NFC-S	1%

3.6 CASTING OF NO-FINES CONCRETE

The steps involved in preparing the samples for testing the no-fines concrete is given below:

- First step is to find out the quantities of materials required to make no-fines concrete such as such as cement, water and aggregate in kg.
- Clean the mixer by flushing it with clean water and then measured quantity of coarse aggregate is added into it. This is followed by addition of cement. This dry mix is rotated for one minute and then the measured quantity water is added gradually. Mixing is done for at least two minutes till the concrete is obtained.
- Metallic moulds are used after oiling to protect samples from sticking with them.
- Concrete mix is then poured into the moulds in three layers, compacting each layer with 25 blows of tamping rod. The point here which is to be noted is that vibrating instruments cannot be used in case of no-fines concrete because cement paste may segregate.
- Demoulding of concrete samples is done after 24 hours and kept in water tank for curing in further days up to which they are to be tested. **Figure 3.5** shows the demoulded cylindrical samples.

Figure 3.5 Demoulded Concrete Samples.

3.7 MECHANICAL PROPERTIES

3.7.1 Compressive Strength

Compressive strength of concrete may be described as its capacity to resist breaking when the concrete specimen is subjected to compressive loads. IS: 516 – 1959 describes the procedure to perform this test. Twenty four numbers (Six for each mix) of cube specimens of 150 mm size were casted. These cubes were then tested in universal testing machine (UTM) after 7 and 28 days. The setup used to perform the test is shown in **Figure 3.6**.

Figure 3.6 Compressive Strength testing setup.

3.7.2 Flexural Strength

Flexural strength of concrete is defined as its ability to resist the bending load. It can be well thought out as the most crucial parameter of rigid pavement. The testing procedure is given in IS: 516 – 1959. Twelve numbers of beam specimens of size 150 mm × 150 mm × 700 mm were casted which are then tested after curing of 28 days in UTM of capacity 1000 kN. Rate of application of load was taken as 0.7 N/mm^2/min. Arrangement of sample during the test is shown in **Figure 3.7**. Modulus of rupture is calculated using the formula:

$f_t = PL/bd^2$ if a > 200 mm ; Eq. 3.4

$f_t = 3Pa/bd^2$ if a < 200 mm Eq. 3.5

where,

f_t is modulus of rupture (N/mm^2)

P is the peak load (N)

L is span length (mm)

b is width of beam specimen

d is the depth of specimen

a is distance between line of fracture and the nearest support measured along centre line of tension face.

Figure 3.7 Flexural Strength test setup.

3.7.3 Split Tensile Strength

Split tensile strength test of no-fines concrete was performed after 7 and 28 days of curing. These Cylindrical specimens were tested in compression testing machine (CTM) of capacity 5000 kN in accordance with guidelines of IS: 5816 – 1999. The loading rate is kept as 2 $N/mm^2/min$ throughout the test. The test was performed by placing the specimen longitudinally at centre of the CTM, along with wooden strip placed above at its central surface. **Figure 3.8** shows the arrangement for split tensile strength testing of cylindrical samples.

Figure 3.8 Split Tensile Strength test setup.

Split tensile strength is calculated using the formula:

$f_s = 2P/(\pi dh)$ Eq. 3.6

where,

f_s is the Split Tensile Strength

P is the ultimate load

D is Diameter of cylinder

h is the height of cylinder.

3.8 PERMEABILITY

No-fines concrete is made to pass water through it. This makes permeability the most important property of no-fines concrete. It can be defined as the rate of percolation of water all the way through a permeable media such as no-fines concrete. Constant head method of measuring permeability, described in IS: 2720 (Part 17) – 1986, was used.

Figure 3.10 Permeability test setup.

The shape of samples was kept cylindrical with height 127mm and diameter 76.2 mm. Arrangement of this test is shown in **Figure 3.9**. Twelve is the total numbers of specimen casted for permeability test.

3.9 DURABILITY PROPERTIES

3.9.1 Abrasion Resistance Test

To calculate the abrasion resistance of no-fines concrete produced with addition of polypropylene, jute and steel fibres, eight specimens of size 70 mm × 70 mm × 25 mm were casted. These specimens are tested after 28 days of curing as per IS 1237: 1980. The specimens are kept in oven at 100^{o}C for 24 hours before testing and are weighed before the test. Aluminium oxide is used as abrasive material in this study. Abrasion resistance test setup is shown in **Figure 3.11.**

Figure 3.10 Abrasion Resistance Test Setup.

The specimens were put in the abrasion testing machine one by one and 300 N load was applied. The machine was then revolved at a rate of 30rpm and 20 grams of aluminium oxide was spread on disk. This abrasive powder is kept on the path of specimen with the help of a paint brush. The number of revolutions given to each specimen is 22 and after that the specimen is rotated by 90^o and fresh aluminium oxide is poured on the disk. This procedure is followed till 10 times that is till 220 revolutions. The weight of specimen is taken after the test and represented as percentage weight loss.

3.10 SUMMARY

Fundamental tests, properties of materials used in making no-fines concrete and procedures of various tests have been explained in this chapter.

To evaluate mechanical and physical properties of no-fines concrete various tests were performed which have been discussed and the results of those tests are discussed in next chapter.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 GENERAL

The results of the tests conducted are examined in this chapter. The consequences of addition of polypropylene and jute fibres on no-fines concrete on properties such as compressive strength, split tensile strength, flexural strength and permeability are talked about.

4.2 SLUMP

Any concrete made should be workable so as to place it on desired place easily. To calculate the workability of freshly mixed no-fines concrete, slump test was conducted. Slump test was conducted in accordance with IS: 1199 – 1959. Slump value is the difference between total height of slump cone and the height of sample left after raising the mould. Slump value in our test is recorded as zero that is no slump. The main reason behind this is the absence of fine aggregate in no-fines concrete. Fine aggregate is the material which is responsible for the workability of concrete.

The important point which is to be noted here is that permeability of no-fines concrete is more critical than its workability. The main purpose of making no-fines concrete i.e. cannot be compromised due to workability. Otherwise, it is also seen that when the no-fines concrete is tightly placed, it gives popcorn like structure with desired strength. Also to use it pavement, the less workable concrete can also be used.

4.3 MECHANICAL PROPERTIES

4.3.1 Compressive Strength

It is the most important property for any type of material. The total of 18 cubes of side 150 mm was casted. Nine of them (three from each batch) were tested after 7 days of curing and twelve of them after 28 days of curing. The compressive strength test results of those specimens are tabulated below in **Table 4.1**. The average compressive strength after 28 days on addition of fibres increases drastically. The average compressive strength of three cube specimens for controlled concrete after 7 days of curing is 9.52 and after 28 days is 11.23 N/mm^2. That is the compressive strength is achieved approximately 85% of 11.23 N/mm^2 in

7 days only. 7 days compressive strength is 13.03 N/mm^2 with addition of polypropylene fibres, 13.16 N/mm^2 with addition of jute fibres and 13.80 N/mm^2 with addition of hooked end steel fibres. These values increase to 17.95 N/mm^2, 20.64 N/mm^2 and 21.44 N/mm^2 in case of polypropylene fibres, jute fibres and steel fibres respectively.

Table 4.1 Compressive strength test results

S. No.	Type	Compressive Strength (N/mm^2)			
		7 Days	Average	28 Days	Average
1	NFC-C	9.19	9.52	11.41	11.23
		9.60		11.86	
		9.78		10.42	
2	NFC-P	12.22	13.03	18.34	17.95
		11.64		18.11	
		15.23		17.40	
3	NFC-J	11.85	13.16	22.52	20.64
		14.34		18.24	
		13.31		21.16	
4	NFC-S	12.64	13.80	23.57	21.44
		14.52		20.19	
		14.25		20.58	

The percentage wise comparison of compressive strength after 7 days and 28 days of curing of different batches of no-fines concrete is shown in **Figure 4.1**. It can be seen from the figure that 37% and 60% increase in compressive strength was recorded after 7 days and 28 days with addition of polypropylene fibres in controlled concrete. With jute fibres the increase was 38% and 83% after 7 days and 28 days respectively. Steel fibres increase the compressive strength up to 45% and 91% on 7 days and 28 days respectively. This increase can be attributed to decrease in void ratio and making the matrix denser. The dense material exhibits more compressive strength. Thus we can conclude that load carrying capacity of no-fines concrete increases drastically with introduction of fibres into it.

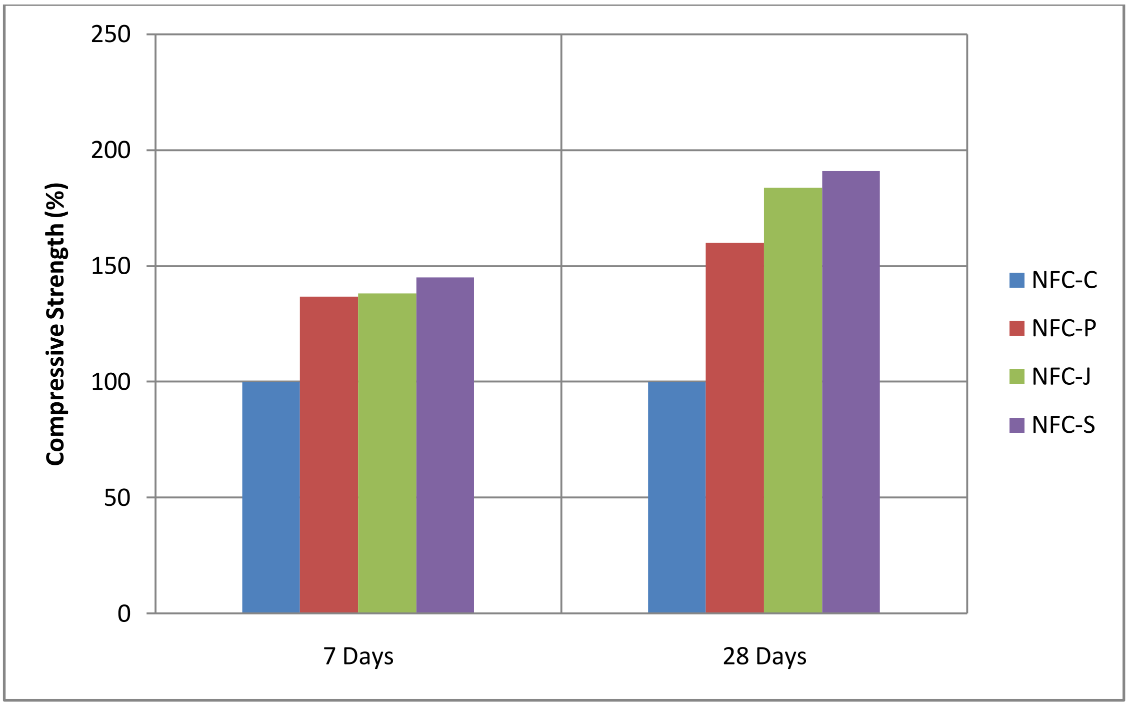

Figure 4.1 Compressive Strength Comparisons

Figure 4.2 Failed Sample in Compressive strength test.

If we compare only the fibrous concrete batches, the concrete with steel fibre exhibits maximum compressive strength both at 7 days as well as 28 days. After 7 days steel exhibits 6% and 5% increase with respect to NFC-P and NFC-J respectively. After 28 days the increase in compressive strength can be observed as 19% and 4% with respect to NFC-P and NFC-J respectively. This can be due to high strength steel fibres having higher elastic modulus as compare to polypropylene and jute fibres i.e. steel fibres are having higher ability in delaying cracks. Failed sample under Compressive Strength test is shown in **Figure 4.2**.

4.3.2 Stress Strain Graphs

The stress vs. strains graphs for four different types of samples are shown in **Figure 4.3**. These graphs were made from load applied and deflection data for first cube of all the four batches after 28 days when tested under compression. It can be seen from the graphs that the ultimate stress increases with addition of fibres. NFC-S gave the maximum ultimate stress of 23.57 N/mm^2. The value of strain also increases with addition of fibres. Controlled sample gave the strain value of 2.13%. The strain value increases with addition of polypropylene fibres and jute fibres up to 3.26% and 4.07%. NFC-S gave the strain value of 4.93%. Hence, the brittleness of no-fines concrete reduces with addition of fibres making it more ductile. The toughness of no-fines concrete increases with addition of fibres as the area under stress strain curve increases.

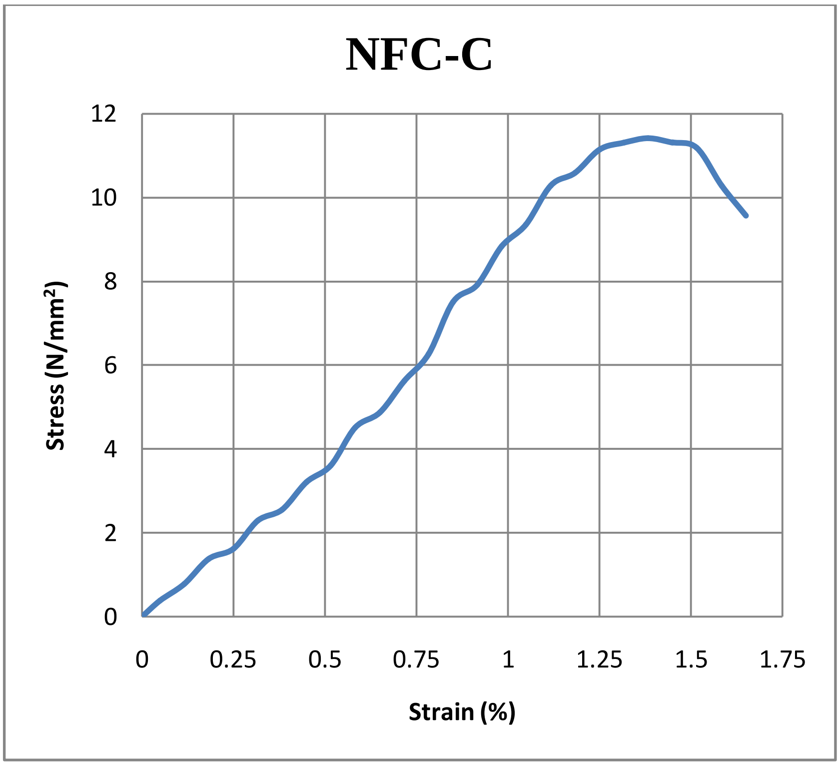

Figure 4.3 (a) Stress vs. Strain graph for NFC-C

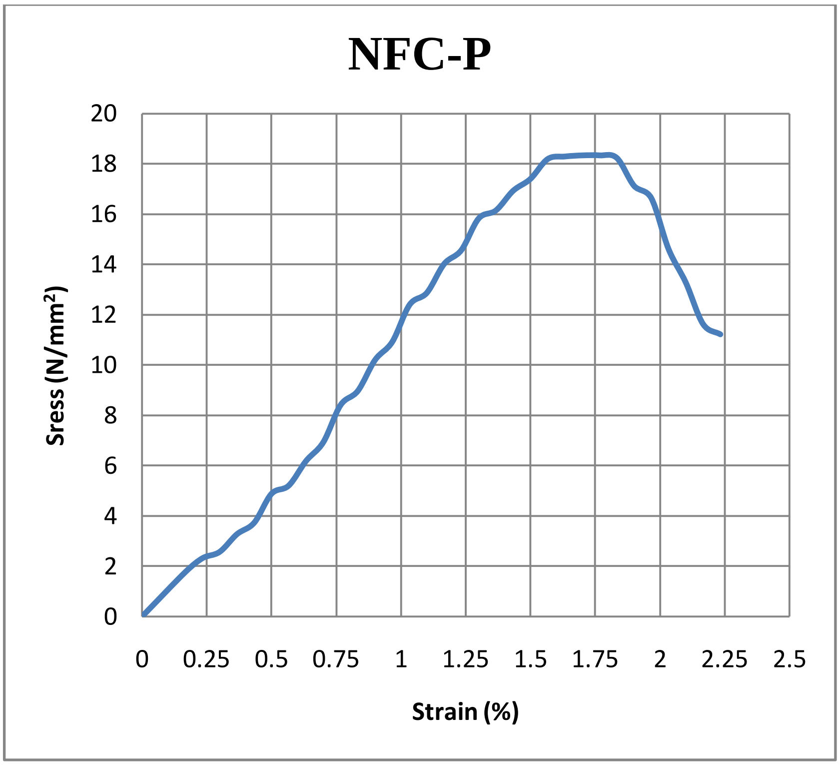

Figure 4.3 (b) Stress vs. Strain graph for NFC-P

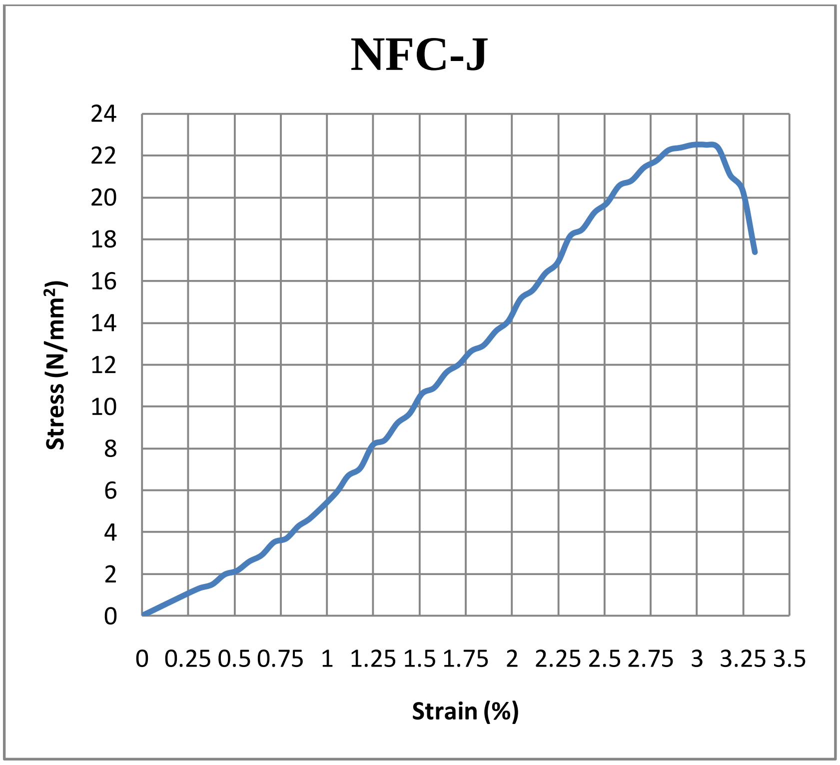

Figure 4.3 (c) Stress vs. Strain graph for NFC-J

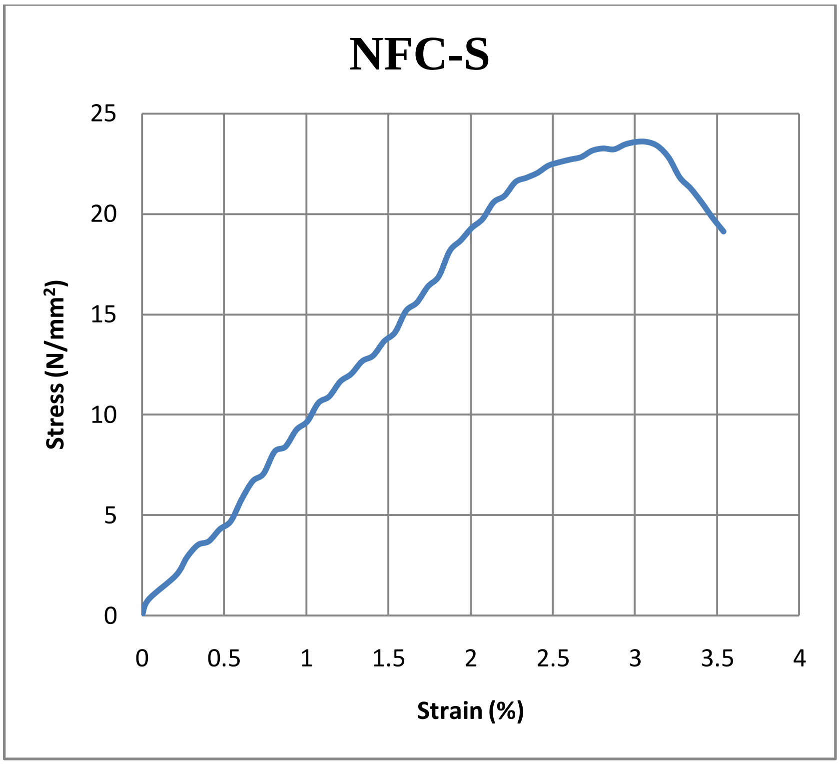

Figure 4.3 (d) Stress vs. Strain graph for NFC-S.

Figure 4.4 shows the comparison of strain in different samples of no-fines concrete. The increase in strain is 53%, 91% and 131% in case of NFC-P, NFC-J and NFC-S respectively. This increase in strain value is due to cement paste made with addition of polypropylene and jute fibres. These two fibres add up to the quantity of cement paste. NFC-S gives the highest value of strain.

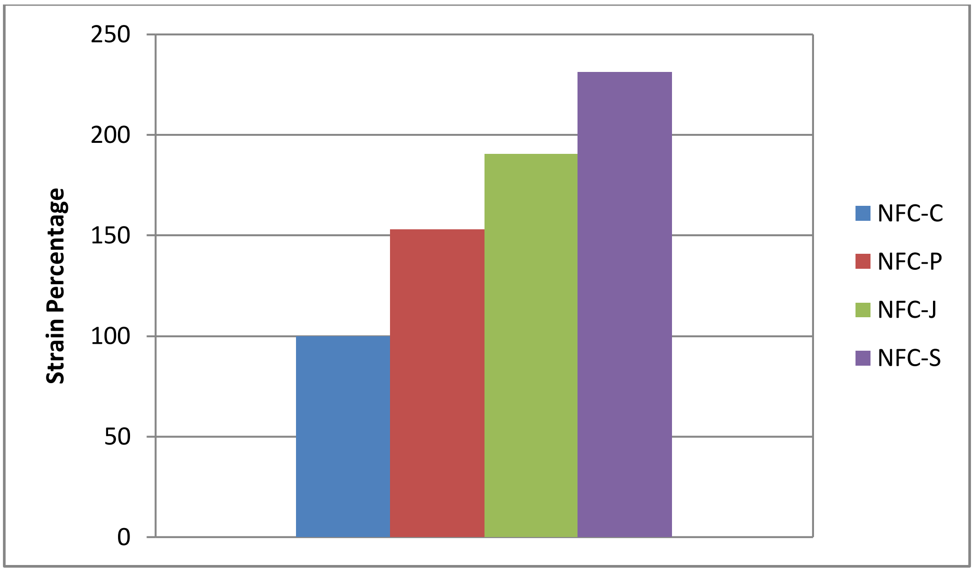

Figure 4.4 Comparison of Strain value for different samples.

4.3.3 Split Tensile Strength

The split tensile strength results after 7 days and 28 days of different no-fines concrete batches are given in **Table 4.2**. It can be seen from the table that the split tensile strength results follows the same trend as that of compressive strength test results. It increases with addition of fibres in no-fines concrete. This increase is as high as 20% in case of NFC-S. The percentage increase in split tensile strength is less as compare to compressive strength and flexure strength.

Table 4.2 Split Tensile strength results

S. No.	Type	Split Tensile Strength (N/mm^2)			
		7 Days	Average	28 Days	Average
1	NFC-C	1.24	1.39	1.74	1.72
		1.42		1.78	
		1.52		1.65	
2	NFC-P	1.53	1.62	1.87	1.85
		1.58		1.90	
		1.77		1.77	
3	NFC-J	1.55	1.64	1.84	1.85
		1.59		1.90	
		1.79		1.81	
4	NFC-S	1.69	1.78	2.16	2.06
		1.87		1.97	
		1.78		2.05	

The percentage increase in split tensile strength of various samples is shown in **Figure 4.5**. After 28 days the increase in split tensile strength is 7.5% in case of NFC-P and NFC-J and 20% in case of NFC-S. The increase is due to the decrease in void ratio. Voids of controlled concrete are filled up by fibres. It can be observed that increase in split tensile strength is significant with steel fibres as compare to polypropylene and jute fibres. This is due high strength and high elastic modulus of steel fibres. Also the hooked end steel fibres hold the material till its ends gets straightened.

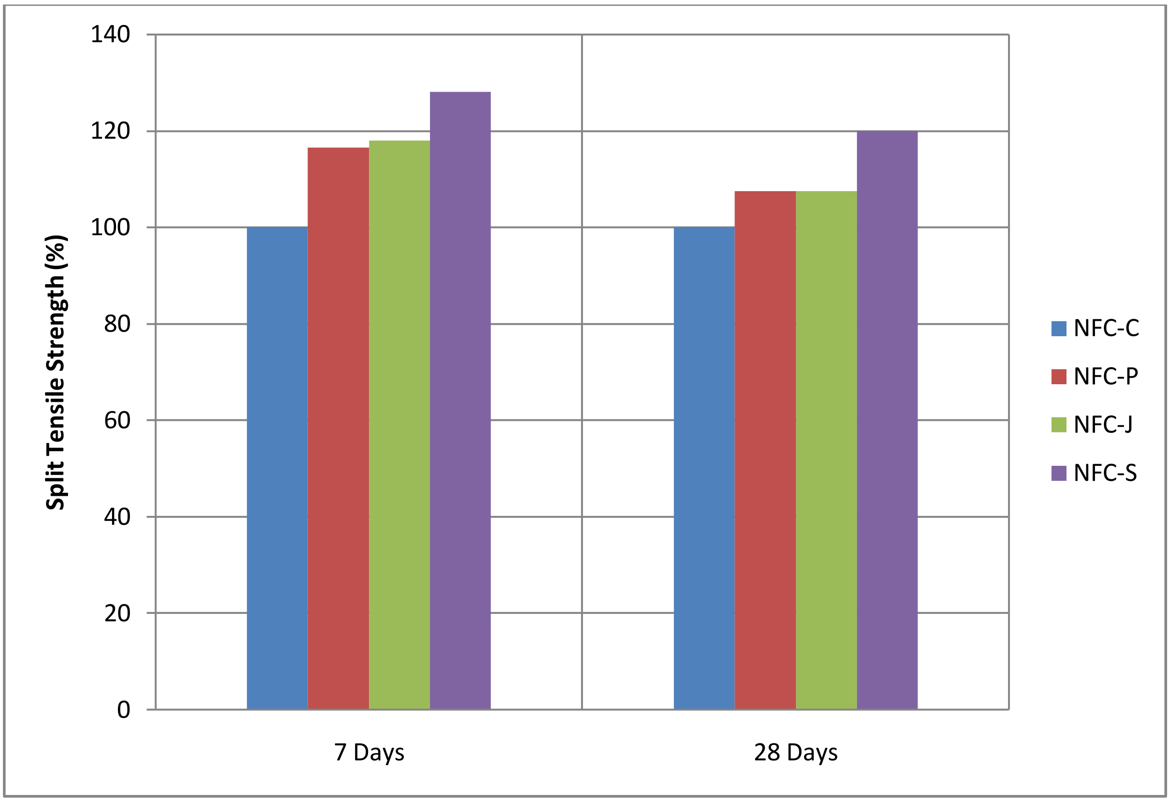

Figure 4.5 Comparison of Split tensile strength of different batches.

4.3.4 Flexural Strength

Flexure Strength is the important criterion to judge the class of pavement. All pavements are subjected to bending stresses due to wheel load and temperature changes. Hence the pavement constructed should bear these stresses. Therefore to increase the flexural strength of pavement, fibres are added. The flexural strength test results of different batches of no-fines concrete are tabulated below in **Table 4.3**. Flexural strength values follow the same trend as that of compressive strength and split tensile strength. The value of Modulus of rupture increases with addition of fibres.

From the given table it can be observed that addition of fibres increases the flexural strength. In case of no-fines concrete without fibres the beam is kind of a brittle material, hence cracks at a lesser load. But after the addition of fibres the deflection capacity of a beam increases due to the high tensile values of fibres. Also the gaps which were generated by the bending load were bridged by the fibres.

Table 4.3 Flexural Strength test results

S. No.	Material	Modulus of Rupture (N/mm^2)	
		28 Days	Average
1	NFC-C	2.27	2.32
		2.39	
		2.30	
2	NFC-P	3.15	3.04
		3.05	
		2.92	
3	NFC-J	3.00	3.08
		3.16	
		3.08	
4	NFC-S	3.26	3.34
		3.30	
		3.45	

The percentage wise comparison of flexure strength with addition of fibres into no-fines concrete is shown in **Figure 4.6**. After 28 days the increase in Flexure strength is 31% and 32.75% in case of NFC-P and NFC-J respectively and 44% in case of NFC-S. The peak bending load increases with addition of fibres. This can be attributed to their higher tensile values and ability to bridge the cracks developed. The highest value of modulus of rupture is obtained in case of NFC-S. This is due to hooked end of steel fibres which require more energy to straighten their ends and has higher tensile strength.

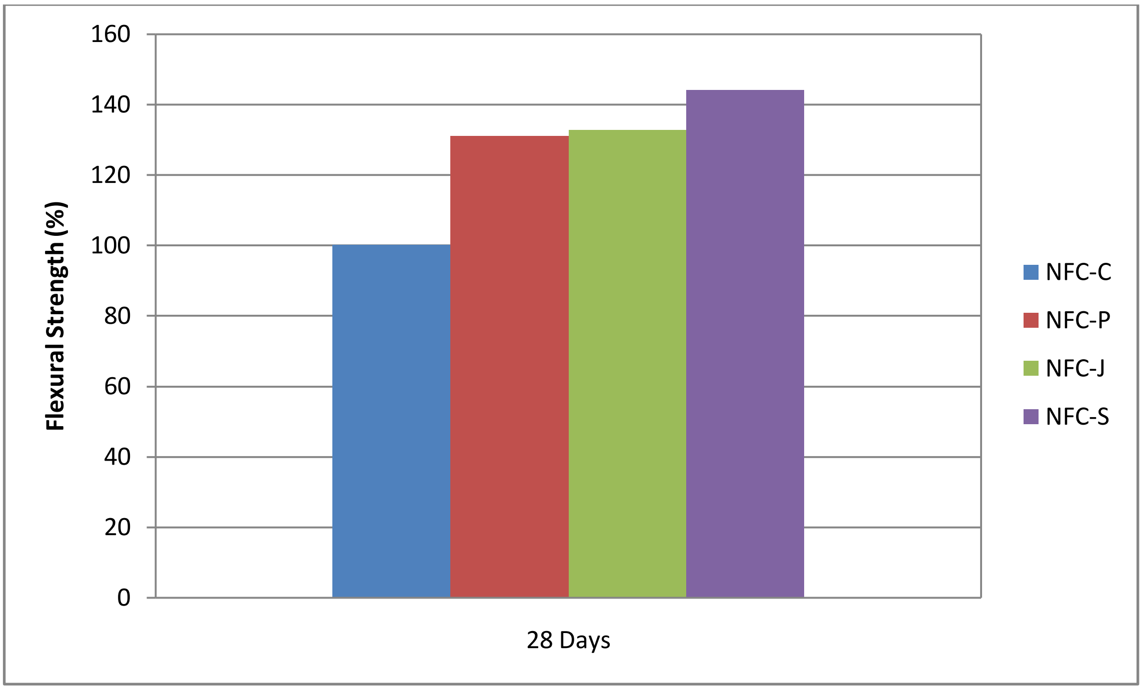

Figure 4.6 Comparison of flexure strength

The load versus displacement graphs of different batches of no-fines concrete are given below in **Figure 4.7**. The peak load is also shown in this graph. Peak load is least in case of NFC-C and maximum peak load is attained with NFC-S. There is a small increase observed in case of NFC-P.

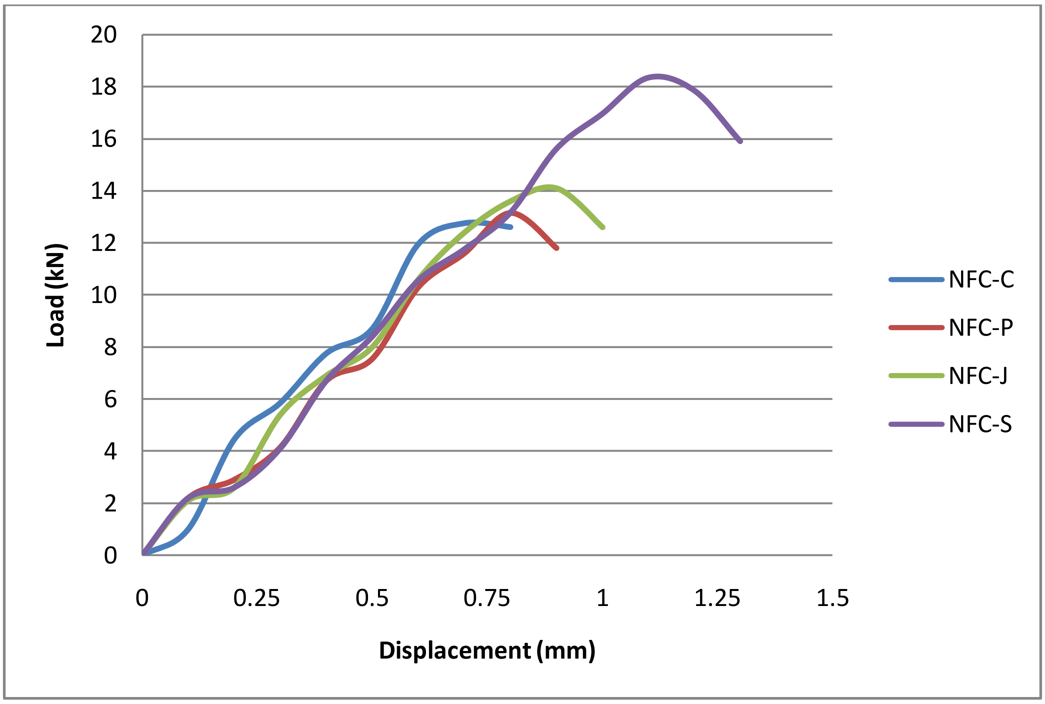

Figure 4.7 Loads vs. Displacement Graph

4.4 PERMEABILITY

It is most essential property of no-fines concrete pavements. It is the basic principle behind the design of permeable pavement. The permeability of different batches of concrete after 28 days is given below in **Table 4.4.**

Table 4.4 Permeability test results

S. No.	Material	Permeability (cm/sec)	
		28 Days	Average
1	NFC-C	0.189	0.183
		0.178	
2	NFC-P	0.160	0.158
		0.156	
3	NFC-J	0.147	0.151
		0.155	
4	NFC-S	0.164	0.168
		0.172	

The decrement in permeability of no-fines concrete on addition of fibres is discussed in this section. Permeability of control mix is 0.183 cm/sec. The no-fines concrete exhibits lowest permeability in case NFC-J i.e. 0.151 cm/sec whereas permeability of NFC-P and NFC-S is 0.158 cm/sec and 0.168 cm/sec respectively. This is due to the decrease in porosity of concrete with addition of fibres.

The permeability results according to percentage decrease are further illustrated in bar diagrams shown in **Figure 4.8**. Out of the three batches of fibrous concrete NFC-J exhibits the minimum permeability than NFC-S and NFC-P. The percentage decrease in permeability is maximum in case of NFC-J i.e. 17.49% whereas NFC-S experiences minimum percentage decrease with 8.19%. 13.67% is the percentage decrease of permeability in NFC-P samples. Jute fibres and polypropylene fibres add up to the quantity of cement paste and hence decrease the void present in concrete.

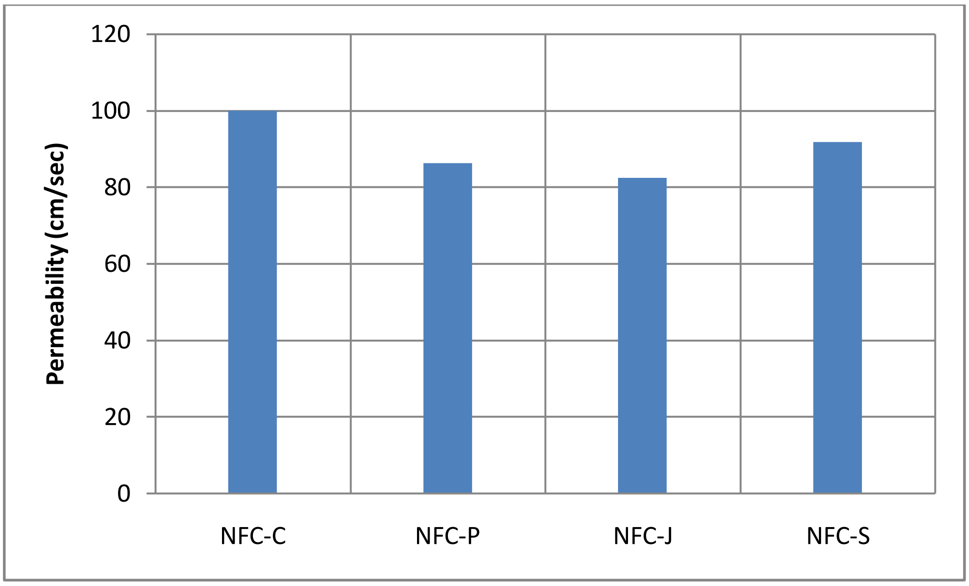

Figure 4.8 Comparison of Permeability results

4.5 DURABILITY PROPERTIES

4.5.1 Abrasion Resistance

The abrasion resistance test results of various mixes of concrete, performed after 28 days, are given below in **Table 4.5**.

Table 4.5 Abrasion resistance test results

S. No.	Mix	Initial Weight (g)		Final Weight (g)		Percentage weight loss (%)
		28 Days	Average	After Test	Average	
1	NFC-C	291.25	291.00	288.95	288.91	0.71
		290.76		288.87		
2	NFC-P	302.40	305.27	299.77	302.84	0.79
		308.14		305.91		
3	NFC-J	299.61	299.88	297.23	297.35	0.84
		300.16		297.47		
4	NFC-S	324.52	326.94	322.29	324.53	0.73
		329.36		326.77		

Figure 4.9 shows the comparison of percentage weight loss of different no-fines concrete mixes after the abrasion test with the control mix. It can be seen from the figure that with addition of fibres, the percentage weight loss due to abrasion increases with a small amount i.e. the resistance to abrasion decreases with addition of fibres in no-fines concrete. The change in abrasion resistance value is not very significant on addition of fibres. Out of three fibre reinforced pervious concrete mixes, steel fibre gives the maximum resistance to abrasion.

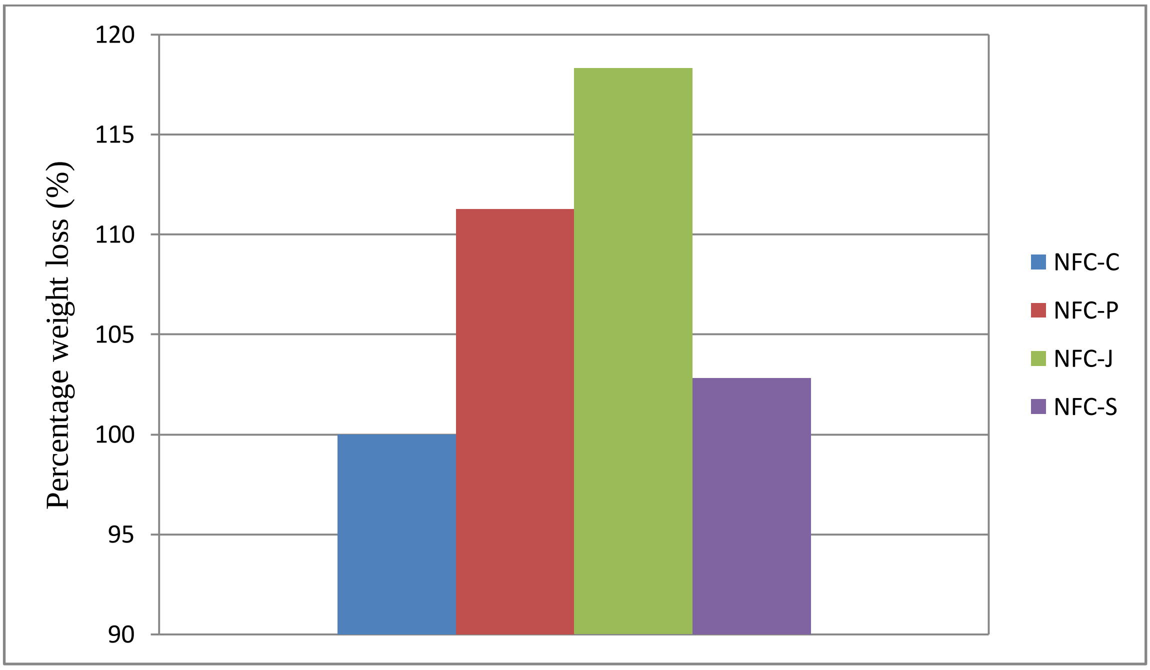

Figure 4.9 Percentage weight losses after Abrasion Resistance test.

4.6 SUMMARY

It can be concluded from the test results that various mechanical properties such as Compressive Strength, split tensile strength and flexural strength increases with addition of fibres. The permeability of fibrous mixes decreases with addition of fibres into the control mix.

The following chapter deals with the conclusions obtained from the test results discussed in this chapter. It also discusses the future scope of work in the area of no-fines concrete.

CHAPTER 5
CONCLUSIONS

5.1 GENERAL

This study is done to find out the effect of addition of polypropylene fibres, jute fibres and steel fibres on mechanical and durability properties of no-fines concrete. Various properties are studied such as compressive strength, split tensile strength, flexural strength and permeability. Polypropylene fibres, jute fibres and steel fibres were added equal to 0.2%, 0.1% and 1% of the volume fraction of concrete respectively.

5.2 CONCLUSIONS

Following conclusions are made based upon the test results:

- Compressive Strength
  - i) The compressive strength after 28 days increases with addition of polypropylene fibres by 60% i.e. from 11.23 N/mm^2 to 17.95 N/mm^2.
  - ii) The 28 day compressive strength increases with addition of jute fibres from 11.23 N/mm^2 to 20.64 N/mm^2 i.e. by 84%.
  - iii) This increase was recorded as high as 91% for steel fibres. The compressive strength for NFC-S is calculated as 21.44 N/mm^2 as compare to 11.23 N/mm^2 for control mix.
  - iv) Thus it can be conclude that with addition of fibre in no-fines concrete, the compressive strength increases significantly.
- Split tensile Strength
  - i) The Split tensile strength after 28 days increases with addition of polypropylene fibres by 7.5 % i.e. from 1.72 N/mm^2 to 1.85 N/mm^2.
  - ii) The 28 day Split tensile strength increases with addition of jute fibres by the same value as that of polypropylene fibres.
  - iii) The highest increase was recorded in case of steel fibres i.e. 20%. The Split tensile strength for NFC-S is calculated as 2.06 N/mm^2 as compare to 1.72 N/mm^2 for control mix.
  - iv) Thus, we can say that the increase in split tensile strength with addition of fibres is satisfactory in case of steel fibres but a bit low in case of polypropylene and jute fibres.

- Flexural Strength
  i) The flexural strength after 28 days increases with addition of polypropylene fibres by 31 % i.e. from 2.32 N/mm^2 to 3.04 N/mm^2.
  ii) The 28 day flexural strength increases with addition of jute fibres by 32.75 % than the control mix. The value increases from 2.32 N/mm^2 to 3.08 N/mm^2.
  iii) The highest increase was recorded in case of steel fibres i.e. 44 %. The flexural strength for NFC-S is calculated as 3.34 N/mm^2 as compare to 2.32 N/mm^2 for control mix.
  iv) Thus, it can be said that the increase in flexural strength with addition of fibres is significant.
- Permeability
  i) The permeability decreases with addition of fibres. In case of NFC-P this decrease was recorded as 13.67 % i.e. from 0.183 cm/sec to 0.158 cm/sec.
  ii) This decrease further increase with jute fibres to 17.49 %. In case of NFC-J the value of permeability is calculated as 0.151 cm/sec as compare to 0.183 cm/sec of control mix.
  iii) The decrease in permeability in case of NFC-S is least than the other two fibre reinforced concretes. The value of permeability recorded in this case is 0.168 cm/sec.
  iv) Therefore we can say that the permeability value obtained in all three cases is significant.
- Abrasion Resistance
  i) The resistance of no-fines concrete to abrasion decreases with addition of fibres. In case of NFC-P the percentage loss in weight after abrasion resistance test is 0.79% which is 11.26% more than that of control mix
  ii) NFC-J gives the least resistance of all three of the fibre reinforced concretes. the percentage loss in weight in case of NFC-J is 18.30% more than control mix.
  iii) There is a slight decrease in weight loss in NFC-S as compare to control mix. Also it provides the maximum resistance out of three fibre reinforced concrete mixes. The percentage weight loss obtained in case of NFC-S is 0.73% i.e. 2.82% more than control mix.

iv) Therefore, it can be concluded that value of abrasion resistance obtained are comparable and these fibres can be effectively added to pervious concrete without any significant decrease in abrasion resistance.

It can be concluded from the above results that steel fibre reinforced no-fines concrete gives the significant values in mechanical as well as durability properties. But the results obtained with addition of polypropylene and jute fibres are also good enough. From the obtained results it can be said that addition of steel fibres is better than the other two. But as the foremost use of this pavement is to pass water through it, steel fibres can decay easily due to corrosion. This can be taken care of either by treatment of steel fibres with some chemicals before addition or finding an alternate fibre. The treatment process may prove costly. On the other hand jute fibre reinforced no-fines concrete can be a good alternative as there is a slight difference in strength properties of these two.

5.3 FURTHER SCOPE OF WORK

i) There is very little work done on fibre reinforcement of no-fines concrete. All three fibres gave significant strength results. Effect of various mix fractions of these fibres can be studied.

ii) Effect of various admixture to obtain a high strength no-fines concrete can be studied.

iii) There is no recommended method to design no-fines concrete pavement, this is the area where there is a lot of work to be done.

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