APPLICABILITY OF STEEL FIBERS TO IMPROVE THE PROPERTIES OF CEMENT STABILIZED AGGREGATE BASES

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DECLARATION

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Supervisor

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ABSTRACT

Stabilized bases are normally designed for the heavy traffic categories or in the absence of base materials which should have the required material properties according to the specifications so that the higher strength category can be achieved.

Bases can be constructed using soil or aggregates. Those are stabilized with various admixtures such as lime, sand or cement. Among them, cement stabilization is a common practice in road construction industry.

The road construction industry has the experiences about the stabilization of dense graded aggregate bases with cement. Even though the content of cement has to be increased to get the higher strength capacity, shrinkage cracks may appear with the increase usage of the cement content and it has a tendency to convert the layer to a rigid pavement too. Hence, another feasible technique should be applied to achieve the required higher strength capacities concurrently to diminish shrinkage cracks and form the base withstand against higher number of heavy load repetitions as well as form the base withstand against higher number of heavy load repetitions without converting the layer into rigid.

To achieve both phenomena, this research was carried out to introduce usage of a reinforcement type such as steel fibers in Dense Graded Aggregate bases.

In this study, it is discussed about the high performance of Steel Fiber Reinforced Cement Stabilized bases over the conventional Cement Stabilized Bases.

Based on the results, a Pavement Design Chart was developed for Steel Fiber Reinforced Cement Stabilized Bases suitable for higher Traffic Classes such as T7 and T8. This can be used in general practice without doing any calculations.

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CHAPTER 1

1.0 INTRODUCTION

Road construction with the use of steel fibers to enhance the strength and reduce maintenance is a new concept in road construction industry. The use of steel fiber improves the strength and an improvement in fatigue life of the pavement together with developing improved resistance to crack and thus being considered as cost effective technology and design of road construction.

Steel fibers have been used in concrete since the early 1900s.The early fibers were round and smooth and the wire was cut or chopped to the required lengths. The use of straight, smooth fibers has largely disappeared and modern fibers have either rough surfaces, hooked ends or are crimped or undulated through their length. Modern commercially available steel fibers are manufactured from drawn steel wire. from slit sheet steel or by the melt-extraction process which produces fibers that have a crescent-shaped cross section.

So far, in the construction industry, steel fibers were used only in traditional concrete rigid pavement types such as concrete slabs to enhance the properties in it. In this study steel fibers were used in Cement Stabilized Dense Graded Aggregate to improve the strength in flexible pavement types and develops the relationship between Crushing strength and Flexural strength, and also to develop a suitable Design Chart relevant to the cement stabilized bases with and without steel fibers.

1.1. PROBLEM STATEMENT

1.1.1 INTRODUCTION

The road construction industry traditionally has two types of pavements called rigid and flexible pavements. The selection of which type to use is often related to the traffic volume, life time and the cost.

The effective pavement design is one of the most important aspects in road design. The pavement life is substantially affected by the number of heavy load repetitions, type of material used, the composition of base material and the strength of the sub grade.

The road pavement can be failed by tribulations in the base itself. Cracks induced due to various reasons are the main problem in base failure. To avoid this situation, base layer can be stabilized to achieve the required strength using cement.

But, another problem will be arising when cement content is increased in to higher level. Then the flexible pavement becomes a rigid pavement and the joints have also to be provided to avoid shrinkage cracks. Hence, to increase the strength of the base layer while keeping the cement content at the minimum level, steel fibers can be used.

Since the steel fibers can control the shrinkage cracks, we can reduce the cement content so that avoiding the shrinkage cracks.

1.1.2 METHODOLOGY

1. Literature review of stabilized bases and steel fibers.
2. Carry out necessary laboratory tests.
3. Analysis of the test results.
4. Conclusion and Recommendation

1.1.3 OBJECTIVES

- ❖ Comparison of flexural and crushing strength in steel fiber reinforced bases over conventional cement stabilized aggregate bases.
- ❖ Develop a co-relation between flexural and crushing strengths of steel fiber reinforced aggregate bases.
- ❖ Develop a Traffic Category Chart for steel fibre reinforced bases in various cement contents and base layer thicknesses.
- ❖ Enhance the Traffic Category Chart for steel fibre reinforced bases in various sub grade strengths.
- ❖ Compare the Cost between road pavement structures with steel fiber reinforced bases and with other bases.
- ❖ Develop a Pavement Design Chart for higher Traffic Classes T7 and T8.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 STABILIZED BASES

Bases are often stabilized to provide serviceable pavements under heavy traffic. The main objective of stabilization is to improve the performance of a material by increasing its strength, stiffness and durability. The performance should be at least equal to, if not better than that of a good quality natural material.

The term 'Stabilization' is the process whereby the natural strength and durability of a soil or granular material is increased by the addition of a stabilizing agent. Furthermore, it may provide a greater resistance to the ingress of water. There are many different reasons for using stabilization, such as lack of good quality materials or desire to reduce aggregate usage for environmental reason or change the layer thickness according to the different flexural capacity of the layer. The main reason for using stabilization will eventually be cost saving as well as time saving. Engineer should try to build a problem free pavement that will last for its intended design life for the most economical price.

Portland cement is most often selected as the stabilizer as it provides a very substantial improvement in shear strength and a stiffness increase of approximately 20 to 30 fold over that of the un-stabilized material. This increase of strength and stiffness considerably enhance the ability of the pavement to support heavy traffic, both in terms of magnitude of wheel load and number of applications of the loads.

The addition of cement to a material, in the presence of moisture, produces hydrated calcium aluminate and silicate gels which crystalize and bond the material particles together. Most of the strength of a cement-stabilized material comes from the physical strength of the matrix of hydrated cement. A chemical reaction also takes place between the material and lime which is released as the cement hydrates leading to a further increase in strength.

Granular materials can be improved by the addition of a small proportion of Portland cement generally less than 10%. The addition of more than 15% cement usually results in conventional concrete. In general the strength of the material will steadily increase with a rise in the cement content. This strength increase is approximately 500 to 1000 KPa for each 1% of cement added. (Lay 1986/88) the elastic modulus of an unbound crushed rock will be in the range 200 – 400 MPa. When stabilized, this will increase to a range of approximately 2,000 to 20,000 MPa.

One of the main problems with stabilizing a material is mixing in the cement. The particle size of ordinary Portland cement is quite well defined with a range of 0.5 – 100 microns and a mean of 20 microns (Ingles & Metcalf, 1972). The larger particles of cement never completely hydrate, and it has been suggested that the larger particles of cement could be replaced with similar particles of inert filler. The greater bulk would aid the distribution process so that the same amount of active cement would be available throughout the material. Thus it will produce an equally effective binder which could be cheaper than ordinary cement.

The use of cement as a stabilizer is more widespread than lime. This is due to many reasons, but the main factors are likely to be the cost and the higher strengths that are attainable using cement. Other factors include availability, past experience and the more hazardous nature of lime. The price of cement is often similar to that of quick lime or hydrated lime, however cement can be used on a wider range of materials and the strengthening effect of cement is much more than that of an equal amount of lime. Hence either higher strength are possible using an equal amount of cement instead of lime or the same specified strength can be achieved using a lower quantity of cement than lime.

Heavily stabilized bases can fail in fatigue due to high tensile stresses induced by traffic if they are too thin. However, it is easy to design against such failures. Most often distress in heavily stabilize bases occurs due to shrinkage cracking in the stabilized bases, thermal movement of the layer or a combination of shrinkage cracking, thermal contraction and load induced stresses.

A cement stabilized granular base directly under an asphalt surfacing will frequent result in reflection cracking as shrinkage cracks in the base propagate through the asphalt surfacing. If cracks are left unsealed, then water penetration can lead to further deterioration, particularly if the underlying the sub base is not stabilized.

2.2 STEEL FIBERS

As per IRC:SP:46-1997 steel fibers have equivalent diameters (*d*) (based on cross-sectional area) of from 0.15 mm to 2 mm and lengths (*l*) from 7 to 75 mm. Aspect ratios (*l/d*) generally range from 20 to 100. (Aspect ratio is defined as the ratio between fiber length and its equivalent diameter, which is the diameter of a circle with an area equal to the cross-sectional area of the fiber). Steel fibers have high tensile strength (0.5 – 2 GPa) and modulus of elasticity (200 GPa), a ductile/plastic stress-strain characteristic and low creep. Concretes which are containing steel fiber have been shown to have substantially improved resistance to impact and greater ductility of failure in compression, flexure and torsion. It has been extensively used for overlay roads, airfield pavements and bridge decks.

2.3 STEEL FIBER REIFORCED CEMENT CONCRETE

It is now well established that one of the important properties of steel fiber reinforced concrete (SFRC) is its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, fiber composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particular under flexural loading; and the fibers are able to hold the matrix together even after extensive cracking. The net result of all these is to impart to the fiber composite pronounced post – cracking ductility which is unheard of in ordinary concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fiber composite and its ability to withstand repeatedly applied, shock or impact loading.

Steel fibers have been used for a long time in construction of rigid pavements in roads and also in floorings, particularly where heavy wear and tear is expected. The bond behaviour in SFRC is through the transmission of forces between fibers and matrix is achieved through interfacial bond. The key bond components are physical and chemical adhesion, friction, mechanical anchorage, fibre to fibre interlock. The tensile behavior according to studies of SFRC shows that it increases tensile concrete strength, improve post-peak tensile concrete behavior, which is dependent on the effective fibre crossing the crack. Flexural tensile tests are more suitable to measure post-cracking capacity. Steel fibers improve shear behavior of concrete as it is randomly distributed at closed spacing, Increase in tensile strength, Increase in shear friction strength. Specifications and nomenclature are important for a material to be used. The pavement design and analysis is carried out as per IRC 58:2002. The flexural strength is directly taken from the bema flexural test for the slab thickness and correspondingly the fatigue life consumed and the stresses needs to be worked out for the design.

From their study, they concluded that Fiber reinforced concrete has advantage over normal concrete particularly in case of cement concrete pavements. Polymeric fibers such as polyester or polypropylene are being used due to their cost effective as well as corrosion resistance though steel fibers also work quite satisfactorily for a long time. It appears that fiber reinforced concrete should be laid on base concrete of lean mix such as 1:4:8 cement concrete rather than over WBM and provided with grooves in panels of about 4m x 4m to avoid expansion / contraction cracks. Grooves can be made after casting of concrete through cutters.

The most significant influence of the incorporation of steel fibers in concrete is to delay and control the tensile cracking of the composite material. This positively influences mechanical properties of concrete. These improved properties resulting SFRC being a feasible material for concrete road pavements.

2.4 STEEL FIBERS USED IN CEMENT STABILIZED BASES (SFRB)

Fiber reinforced concrete (FRC) may be defined as a composite materials made with Portland cement, aggregate, and incorporating discrete discontinuous fibers. In this research, we used Graded Aggregate material instead of single sized aggregates.

Now, why would we wish to add such fibers to Dense Graded Aggregate Base (DGAB)? Mainly, unreinforced DGAB is a brittle material, with a low tensile strength and a low strain capacity. The role of randomly disperse discontinuous fibers is to bridge across the cracks that developed in SFRB and provides some post-cracking "ductility". If the fibers are sufficiently strong, sufficiently bonded to material, and permit the DGAB to carry significant stresses over a relatively large strain capacity in the post-cracking stage.

When the steel fiber reinforcement is in the form of short discrete fibers, they act effectively as rigid inclusions in the concrete matrix. Physically, they have thus the same order of magnitude as aggregate inclusions; steel fiber reinforcement cannot therefore be regarded as a direct replacement of longitudinal reinforcement in reinforced and pre-stressed structural members. However, because of the inherent material properties of fiber concrete, the presence of fibers in the body of the concrete or the provision of a tensile skin of fiber concrete can be expected to improve the resistance of conventionally reinforced structural members to cracking, deflection and other serviceability conditions.

The fiber reinforcement may be used in the form of three – dimensionally randomly distributed fibers throughout the structural member when the added advantages of the fiber to shear resistance and crack control can be further utilized. On the other hand, the fiber concrete may also be used as a tensile skin to cover the steel reinforcement if more efficient two – dimensional orientation of the fibers could be obtained.

2.5 EFFECT OF STEEL FIBERS IN CONVENTIONAL CONCRETE

Steel fiber reinforced concrete (SFRC) is defined as concrete made with hydraulic cement containing fine and single size coarse aggregate and discontinuous discrete fiber. In SFRC, thousands of small fibers are dispersed and distributed randomly in the concrete during mixing, and thus improve concrete properties. SFRC is being increasingly used to improve static and dynamic tensile strength, energy absorbing capacity and better fatigue strength. Janesan, P. V. Indira and S. Rajendra Prasad reported the effect of steel fiber on the strength and behaviour of reinforced concrete is two-way action. They concluded that the addition of steel fiber increases the ultimate strength and ductility. The plain structure cracks into two pieces when the structure is subjected to the peak tensile load and cannot withstand further load or deformation. Steel fibers are generally used to enhance the tensile strength and ductility of concrete. As stated in ACI 544, 3R-08, fiber volume fraction used in producing steel fiber reinforced concrete should be within 0.5% to 1.5% as the addition of fiber may reduce the workability of the mix and will cause balling or mat which will be extremely difficult to separate by vibration. However higher percentage of fiber can be used with special fiber adding techniques and also placement procedures. According to ACI 544, 3R-08, aspect ratio is referred to the ratio of fiber length over the diameter. The normal range of aspect ratio for steel fiber is from 20 to 100. Aspect ratio of steel fiber greater than 100 is not recommended, as it will cause inadequate workability, formation of mat in the mix and also non uniform distribution of fiber in the mix. To avoid any honeycombing, bleeding, segregation and heterogeneous features by improving the workability, use less water and paste. Rui D. Neves and Joao C. O. Fernandes de Almeida varied the percentage of volume of fiber in the concrete up to 1.5%.

Their results indicate that the addition fiber to concrete enhances its toughness and strength and peak stress, but can slightly reduce Young's Modulus. Generally, for structural applications, steel fibers should be used in a role supplementary to reinforcing bars. Steel fibers can reliably inhibit cracking and improve resistance to material deterioration as a result of fatigue, impact, and shrinkage, or thermal stresses.

A conservative but justifiable approach in structural members where flexural or tensile loads occur, such as in beams, columns, or elevated slabs (i.e., roofs, floors, or slabs not on grade), is that reinforcing bars must be used to support the total tensile load. This is because the variability of fibre distribution may be such that low fibre content in critical areas could lead to unacceptable reduction in strength.

In applications where the presence of continuous reinforcement is not essential to the safety and integrity of the structure, e.g., floors on grade, pavements, overlays, and shotcrete linings, the improvements in flexural strength, impact resistance, and fatigue performance associated with the fibres can be used to reduce section thickness, improve performance, or both.

In order to find out effect of steel fiber reinforced in SFRC, it has to be studied the compressive strength and flexural strength parameters. The effect of increase in steel fiber percentage by volume of cement was studied. Workability of steel fiber reinforced concrete mix was observed by the slump cone test. The fig. 2.1 and 2.2 give the observations for 3, 7 and 28 days curing period.

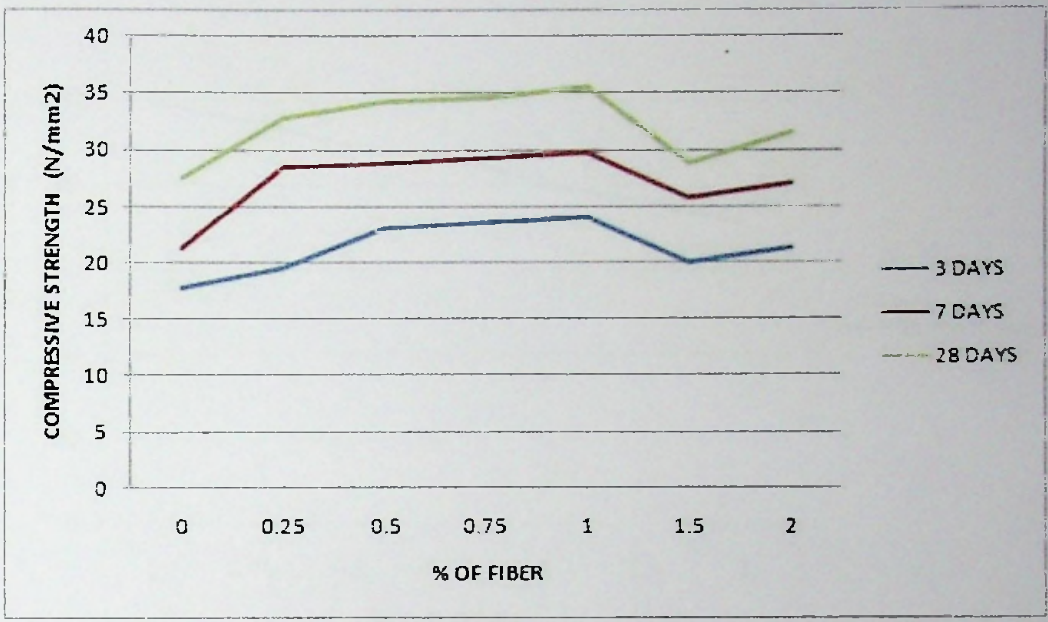


Fig. 2.1: Variation of Compressive strength with respect to % of fiber content

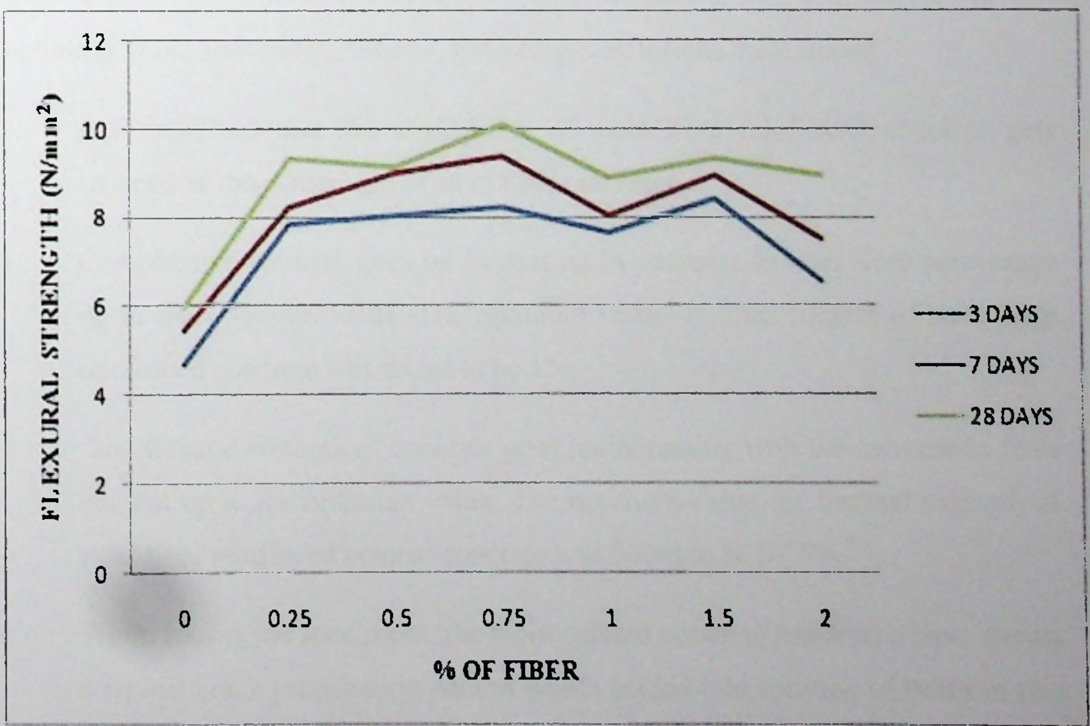


Fig. 2.2: Variation of Flexural strength with respect to % of fiber content

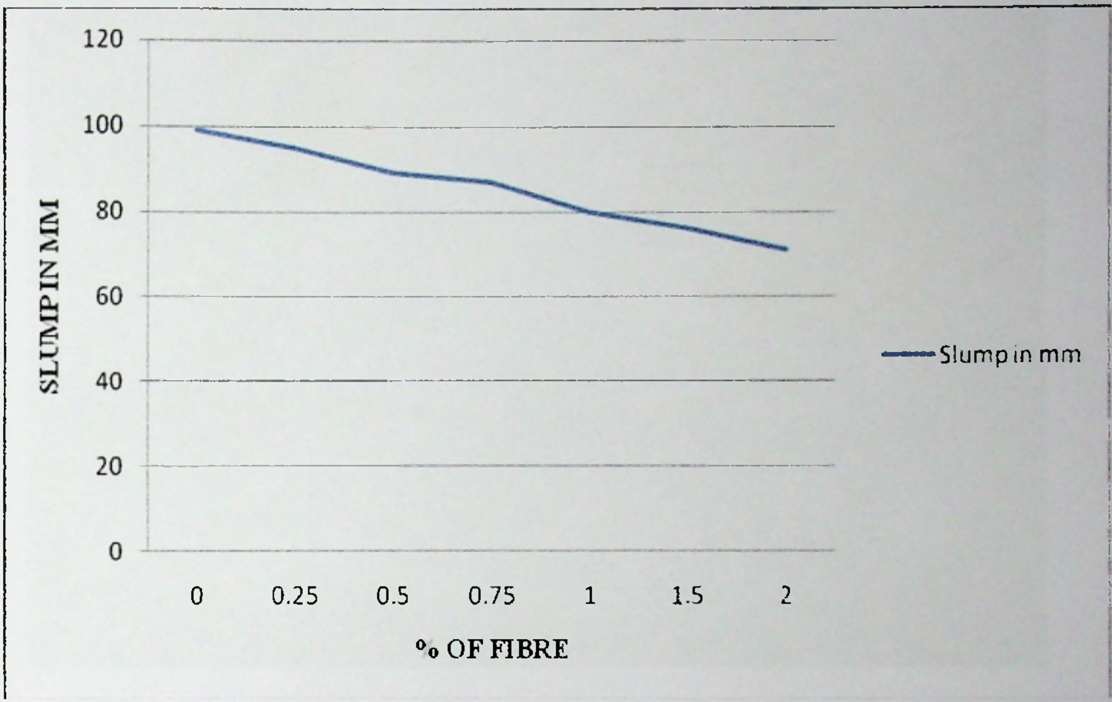


Fig. 2.3: Variation in Slump of concrete with respect to % of fiber content

According to the above observations, following conclusions were drawn.

1) It is observed that the workability of steel fibre reinforced concrete gets reduced as the percentage of steel fibres increases.

2) Compressive strength goes on increasing by increase in steel fibre percentage up to the optimum value. The optimum value of fibre content of steel fibre reinforced concrete was found to be 1%.

3) The flexural strength of concrete goes on increasing with the increase in fibre content up to the optimum value. The optimum value for flexural strength of steel fibre reinforced cement concrete was found to be 0.75%.

4) While testing the specimens, the plain cement concrete specimens have shown a typical crack propagation pattern which leaded into splitting of beam in two piece geometry. But due to addition of steel fibres in concrete, cracks gets ceased which results into the ductile behaviour of SFRC.

Fig.2.4: Steel Fiber Reinforced concrete

Fig.2.5: Crack observed in specimen

2.6 EFFECT OF STEEL FIBER ON FLEXURAL CAPACITY OF REINFORCED CONCRETE BEAM

Steel fibres have been used in concrete since the early 1900s. The early fibres were rounded, smoothed and the wire was cut or chopped to the required lengths. The use of straight, smooth fibres had largely disappeared and modern fibres have either rough surfaces, hooked ends or are crimped or undulated through their length. The use of steel fibre has been well established as complementary reinforcement to improve certain properties of concrete elements. Fibre reinforcement has been shown to improve the ductility, toughness, flexural strength, and shear strength of cementations materials.

Steel fibre reinforced concrete should only be used in a supplementary role to inhibit cracking to improve resistance to impact or dynamic loading and to resist material disintegration. The study concluded that the beneficial effects of steel fibres decrease with increasing bar. Steel fibres uniformly distributed the volume of concrete and rebar much higher shear strength are close to each other. Steel fibres can also provide an adequate internal restraining mechanism when shrinkage-compensating cements are used. The use of steel fibre reinforced concrete beam for structural applications was hindered by the absence of a codified design approach. Therefore there was a need to establish and assess design models for various design aspects on the use of steel fibre reinforced in various structural applications. In order to improve the tensile strength stability and cracking properties in RC beams were used with steel fibres. Amir Hossein Jodeiri, Ronaldo J. Quitalig (2012) investigated the effects of steel fibres on flexural capacity performance, shrinkage and improved resistance cracking mechanical properties of RC beams.

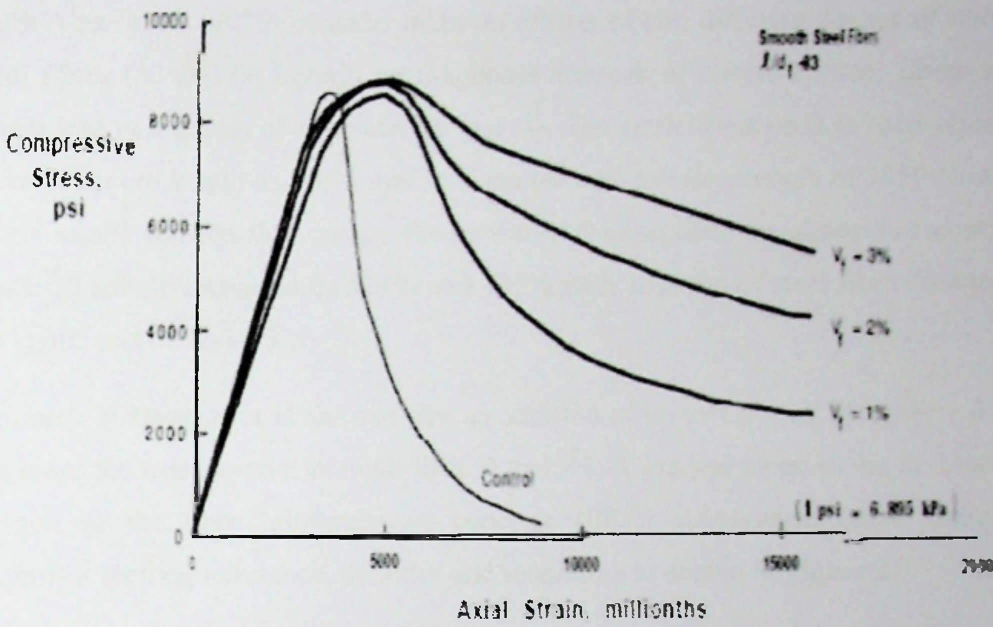


Fig. 2.6: Influence of amount of steel fibres on the compressive stress behavior

The main objective of his study is to determine the effect of Winrad FS7- II steel fibre on flexural capacity of reinforced concrete beams compared with the conventional reinforced concrete beams and concrete beams with bottom rebar. Flexural performance of steel fibre reinforced concrete (SFRC) beams with compressive strength of concrete. This investigation aims to obtain experimental data on the deformation characteristics and strength of reinforced concrete to determine the flexural behaviour of tension- failure RC beams. The most significant improvement imparted by adding fibres to a concrete mix was the substantial increase in the flexural capacity. Composite material which was named as steel fibre concrete has been applied in various applications extensively. In this study, steel fibre reinforced concrete was examined under flexure and its characteristics were determined.

The compressive behaviour of concrete was influenced by properties of its constituent materials. Concrete with a low water-to-cement ratio may display high compressive strength. Normal concrete with high compressive strength usually shows more brittle behaviour. For small amounts of steel fibres added to concrete, the compressive strength in concrete does not significantly improve. However, post-cracking ductility of the composite may be improved with the addition of steel fibres.

Fatih Altun et al, (2005) consider addition effects of two different dosage of hooked steel fibres (30 and 60 kg/m3) on toughness strength of concrete. Steel fibres were added into two grades of concrete, 20 and 30. The steel fibres used in their research were 60 mm in length and 0.75 mm in diameter with tensile strength of 1050 N/mm2. Their results showed that energy absorption of 2 capacities (toughness) of concrete grade 20 and 30 increased by 121% and 135% with addition of steel fibre dosages of 30 kg/m3 and 60 kg/m^3.

Research of Darwish et al showed that an addition of up to 1.5% of fibres by volume increases the compressive strength from 0 to 15%. A gradual slope in the descending portion of the fibre reinforcement concrete (FRC) stress-strain curve indicates improved spelling resistance, ductility and toughness as shown in Figure 2.7.

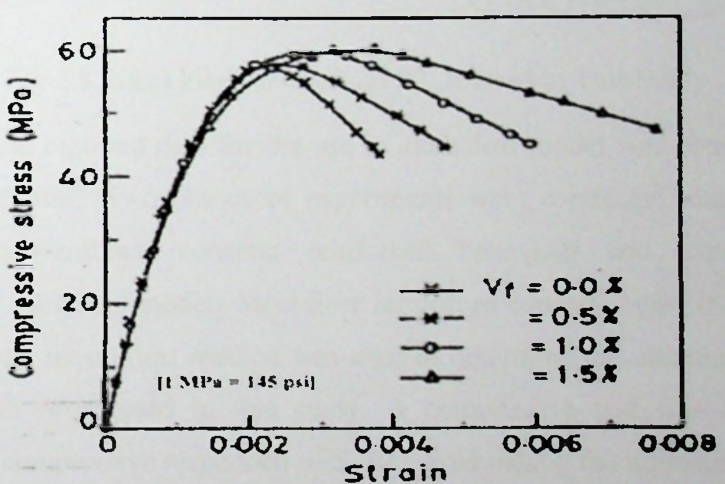


Fig. 2.7: Effects of Steel Fibres Content on Compressive Stress-Strain Curve of FRC (Padmarajaiah and Ramaswamy, 2002)

The influence of steel fibres on the flexural strength of concrete is much greater than for direct tension and compression .The flexural strength of fibre reinforcement concrete increased by about 55% with a $V_f = 2\%$ as reported.

The observation in this research was concentrated on determining the flexural capacity of RC beams with the addition of 1% steel fibre FS7- II was 23.77 kg/m3 in concrete. Furthermore, the research wanted to study how well the steel fibres would improve the flexural capacity of the concrete beams with the conventional steel bar reinforcement. In this study, steel fibre reinforced concrete (SFRC) was a composite material made of hydraulic cements, water, fine and coarse aggregate and a dispersion of discontinuous, small fibres. All admixtures meeting ASTM specifications for use in concrete are suitable for use in steel fibre reinforced concrete SFRC which was shown in Table 2.1.

Table 2.1: Specification of Steel Fibers which Used in This Study

Diameter(D) (mm)	Length (L)(mm)	D/L	Specific Gravity (Kg/m3)	Tensile Strength (MPa)	Strain at Failure
0.55	33	60	7850	800	2%

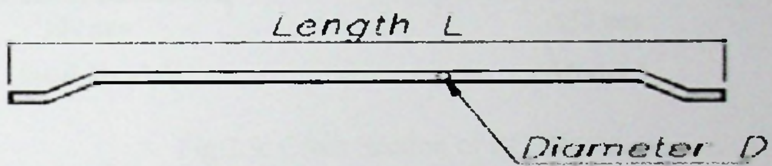


Fig 2.8: Steel Fiber Winrad @FS7_II Used in This Study

In this study the required data for the use in analytical model was obtained through experimental testing. Two phases of experiments were conducted: experiments for preliminary conventional concrete reinforced behaviour and experiments for verification of analytical models Steel fibre reinforced concrete beam (SFRC). In this study an indirect tensile test method was used to determine the ultimate (maximum) tensile strength rebar used in this study. A compressive test was conducted to determine the compressive responded of SFRC, establishing the ultimate compressive strength yield compressive strain was used in cylinder of concrete. In this study two samples for conventional concrete cylinder was used and two samples was used for concrete cylinder with 1% steel fibre.

This study included three models; model one conventional concrete beam two samples, model two concrete beam with steel fibre two samples and model three concrete beam without top steel reinforced but with steel fibre two sample in 28 days. The overall dimensions of the beam are 200 mm thickness, 150 mm width and 940 mm lower support as shown in Figure 2.9. The size of main reinforcement used in the concrete beam was 12 mm in diameter and the link reinforcement was made of hot rolled mild steel with 6 mm in diameter arranged at 100 mm centre to centre. In this study utilized three models of beams, with steel fibre and without steel fibre.

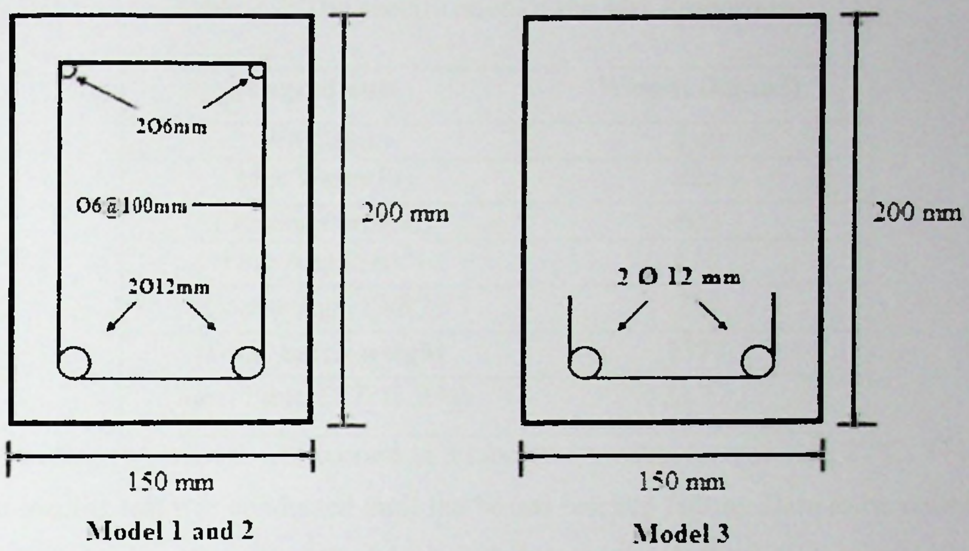


Fig 2.9: Cross Section of RC Beams

Rebar testing was a basic tensile test where an escalating tensile load was applied to a rebar specimen until it yields or breaks revealing important data about the specimen's strength. This load frame features a top-mounted hydraulic actuator which was place in the loading area at ground level. This significantly reduced our lifting requirements for loading the heavy rebar specimens. The strength of main reinforcement 12mm in diameter f_y was 502.33 N/mm2 and strength of 6mm in diameter f_y was 427.18 N/mm2. In this study for the tensile strength test (I) 2 rebar was used to reinforce 12mm and 6mm and length for testing 500mm. the elongation of rebar 12mm in diameter was 100mm while rebar 6mm in diameter was 50mm.

Materials used for the concrete includes Ordinary Portland cement; the cement was keep on an airtight container and stored in the humidity controlled room to prevent cement from being exposed to moisture, fine aggregate (sand) and coarse aggregate; The sand was use natural river sand and the coarse aggregate was 3/8'' crushed granite. Water; Water was needed for the hydration of cement and to provide workability during mixing and placing. The study, normal tap water was used. Steel fibres; the steel fibre used in this study was hooked end shape. The specification mix proportioning of the concrete used in the study was shown in Table 2.2.

Table 2.2: The specification of the Mix Proportion

Ingredients	Weight (kg/m3)
W/C Ratio	0.40
Mix Water(lit)	225
Cement(Portland)	600
Fine Agg.(Sand)	816
Coarse Agg. (3/8")	736
Total batch weight	**2377**
Steel Fibre FS7_II (1%)	23.77

The pouring of concrete was carried in a laboratory with a temperature 27ºC. Third - point loading test was conducted until the beams reached failure. Data to be collected includes: ultimate strength of the beams at failure, load – deflection characteristics of the beams, location and shape of cracks occur on the beams and mode of structural failure of the concrete beams.

The study was used ASTM C1609 / C1609M, standard test method for flexural performance of fibre reinforced concrete (Using Beam with Third-Point Loading). This test method evaluates the flexural performance of fibre reinforced concrete using parameters derived from the load deflection curve obtained by testing a simply supported beam under third-point loading using a closed-loop servo-controlled testing system. It also requires determination of residual loads at specified deflections, the corresponding residual strengths calculated by inserting them in the formula for modulus of rupture given in Equation (1).

f = PL/bd2 Eq.......... (1)

Where: f = the strength,

MPa (psi), P = the load,

N (lbf), L= the span length, mm (in),

b = the average width of the specimen at the fracture, as oriented for testing, mm (in), d = the average depth of the specimen at the fracture, as oriented for testing, mm (in).

Fig. 2.10: Concrete with 1% Steel Fiber FS7 _II

The results of compressive strength test of concrete cylinder with 1% steel fiber FS7_II (23.77 kg/m3) and conventional concrete cylinder at 7, 14 and 28 days were shown in Table 2.3.

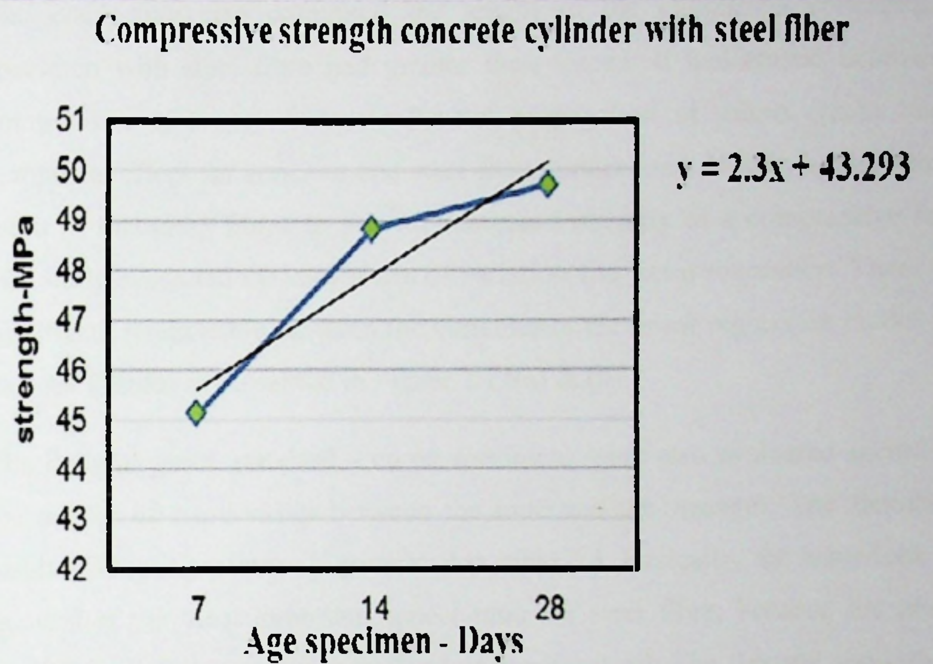
Table 2.3: Compressive Strength of Normal and Steel Fiber added Concrete cylinder

Sample	Strength 7 day (MPa)	Strength 14 day (MPa)	Strength 28 day (MPa)
Conventional Cylinder	40.15	43.71	46.68
		44.73	47.50
Mean		44.22	47.09
Standard Deviation of the Mean		0.72	0.57
Cv %		1.63	1.23
Concrete cylinder with 1% steel fiber	45.15	48.79	48.53
		48.89	50.92
Mean		48.84	49.72
Standard Deviation of the Mean		0.070	1.68
Cv %		0.144	3.39
Cv Allowable		< 4	< 4

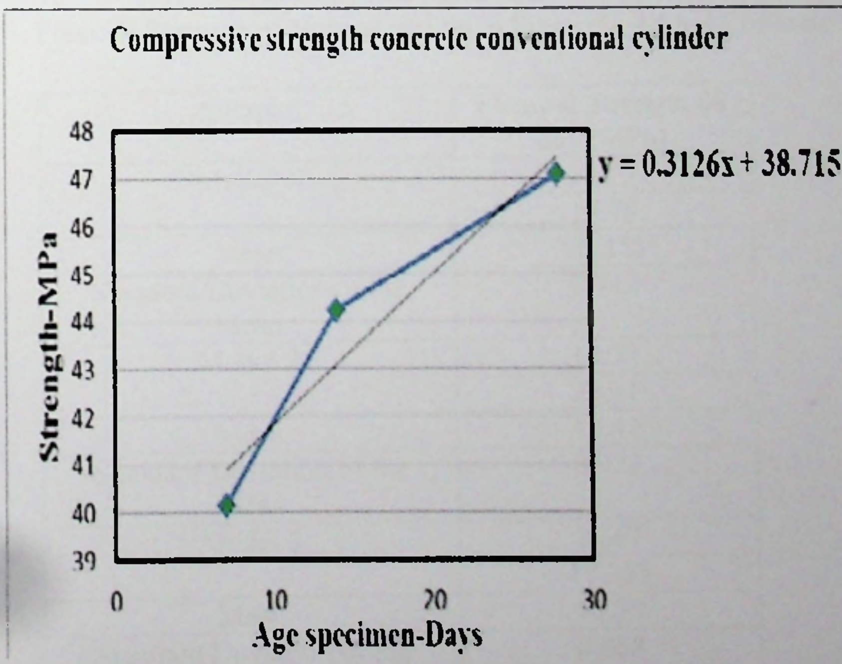
It can be seen that the addition of 1% Vf steel fibres had the most increase in compressive strength. This enhancement in uniaxial strength was due to the internal passive confinement of the matrix by steel fibres which also delays the crack spreading and propagation. In comparison with control concrete, the maximum increased in the compressive strength with1% steel fibre was 12.37% at 7 days, 10.44 % at 14 days and 5.58% at 28 days.

The addition of steel fibre to volume fraction of 1% caused an increase in compressive strength of concrete at early ages. In general, the increase in compressive strength of high performance steel fibre concrete was attributed to the capability of steel fibre to delay the unstable development of micro-cracks as well as to limit the propagation of these micro-cracks and the composite was affected for concrete and steel fibres under load. However, there must be merit in including fibres to provide increased ductility in a compressive failure.

Fig. 2.11: Failure of cylinder in compressive test at 28th days



(a) Linear Regression of Sample Concrete Cylinder with 1% Steel Fiber FS7-II



(b) Linear Regression Conventional Concrete Cylinder

Fig 2.12: Linear Regression

The experimental investigation also observed two type of failure for the cylindrical specimen. During the splitting strength test for conventional concrete, the cylindrical specimens were completely split but for steel fibre there was only a single crack line that occurred on the cross- section from the top loading plate.

The crack line also continued the length of the cylindrical specimen. The specimen with steel fibre had greater than forced. It had elastic behaviour in compressive test as well as to limited propagation of micro cracks and the composite effect for concrete and steel fibres under load. However, there may be merit in including fibres to provide increased ductility in a compressive failure. The study evaluated the coefficient of variation and linear regression. There was a significant relationship between the variables in the linear regression model of the data set faithful as presented in Figure 2.12(a) & (b).

The flexural group standard – cured specimens were also evaluated according to the degree of relationship between the time and the strength. The flexural test result of these specimens is presented in table 2.4. Basically, the behaviour under flexural is the most important aspect ratio for steel fibre, because the practical application is subjected to some kind of bending load. The flexural strength trend on all samples with 1% steel fibres increased.

Table 2.4: Flexural Strength of Normal and Steel Fibre 1% Added Concrete Beam

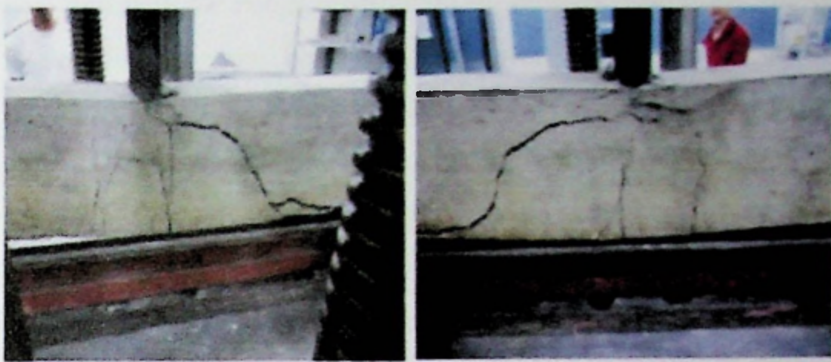
Sample	Flexural Strength 28 day (MPa)
Model 1	15.73
	16.78
Mean	16.255
Standard Deviation of the Mean	0.742
Model 2	18.73
	20.11
Mean	19.42
Standard Deviation of the Mean	0.975
Model 3	16.67
	17.355
Mean	15.73
Standard Deviation of the Mean	0.968

In comparison with controlled concrete, the maximum increased in the flexural strength with 1% steel fibre was 19.42% for model two at 28 days and 6.76% for model three at 28 days. Furthermore compressions model two and model three increased the flexural strength 11.89% at 28 days. In general, the significant improvement in various strengths was observed with the inclusion of 1% steel fibres in the conventional concrete. However it can be shown that there was an increase for model three because this model removed the reinforced rebar at the top.

The behaviour of cracks propagated on the conventional beam groups under bending showed comparability in figure 2.14 and 2.15 the crack started from the extreme flexure substrate and gradually inclined to finally approach the near point loading. The cracking patterns in all beams were almost symmetrical and characterized by the load induced that created the flexural – shear cracks visible enough. Since the initial cracks on the concrete beams model two specimens were not visible until such time as the maximum load reached the increase in the propagation of the cracks was visible enough.

For the concrete beam with steel fibre 1% model two fine vertical flexural cracks were formed first, usually the bottom face of the beam close to mid span. The width of these initial cracks was very small. In fact, the steel fibres can sustain the stress after cracking at strain beyond the normal for the failure of conventional concrete beam. Some sort of stress distribution was promoted which approached the full plastic condition in the tension zone, while remaining elastic in the compression zone. This mechanism caused the neutral axis of the section to move up, thus the moment of resistance and ultimate load was increased significantly.

This behaviour was mainly attributed to the role of steel fibre in releasing fracture energy around crack tips which was required to extent crack growing by transferring stress from one side to another side. Also this behaviour was due to the increase in crack resistance of the composite and the ability of fibres to resist forces after the concrete matrix had cracked.



Conventional Beam tested to destruction 28th day specimen

Concrete Beam with steel fiber Model 2 tested to destruction 28th day specimen

Figure 2.13: Schematic of Typical Fracture Patterns under Bending

Concrete Beam with Steel fiber Model 3 tested to destruction 28th day specimen

Figure 2.14: Schematic of Typical Fracture Patterns under Bending

Conventional concrete can be seen by its post cracking effects, ductility and energy absorption. The steel fibres when uniformly dispersed throughout the specimens act as reinforcement and help for better distribution of stresses. Therefore, the cracks that occurred in steel fibre concrete beam specimens were smaller in size compared with the conventional concrete and even more did break up at ultimate load. Alternatively, the toughness may be defined as the area under the load-deflection curve out to some particular deflection or out to the point at which the load had fallen back to some fixed percentage of the peak load. Table 2.5 was showed the summary of the independent t- test for the determining significant difference of the strength between the conventional beam and concrete beam with 1% steel fibre at 28 days of flexural strength.

$$t = (X - \mu) /(S/\sqrt{N}) \text{ .... Eq.(2)}$$

Where: X is the respective means of the sample.

S is the respective standard deviation of the sample.

N is the respective number of sample.

The degrees of freedom used in this test was (n1 + n2) – 2.

Table 2.5: Compression of t-test Flexural Strength at 28 day

H_0	$\mu1=\mu2$	
H_1	$\mu1>\mu2$	
n	2	
df	(n1 + n2) – 2 = 2	
α	A = 0.05	
NAME	S	X
Conventional Concrete Beam Model 1	0.742	16.255
Concrete Beam with 1% Steel Fiber Fs7_II Model 2	0.975	19.42
t_{actual}	3.65	
$t_{critical}$	2.92	

The result showed that the mean difference on the strength reached 3.65 with standard deviation of 0.74 and 0.97 respectively from the conventional beams strengths and concrete beam with 1% steel fiber strengths. When the mean difference was tested for significance a computed actual t value of 3.65 was generated. It was relatively higher than the critical t value of 2.92 to the idea that the difference was significant. The enormous increase 1% steel fiber was an affirmation that the present study effect of Winrad FS7- II steel fiber on flexural capacity of reinforced concrete beam was effective at the 0.05 level of significance under flexural.

The first crack load (P_{cr} in Table 2.6) was determined from the curve. All the SFRC beams showed significant increase in the first crack load over reinforced concrete beams. It also required determination of residual loads at specified deflections, the corresponding residual strengths calculated by inserting them in the formula Equation (1). The first-peak strength characterizes the flexural behaviour of the fiber-reinforced concrete up to the onset of cracking, while residual strengths at specified deflections characterize the residual capacity after cracking.

Table 2.6: Comparison the Flexural Strength and First crack, Model 1, Model2, Model3

Specimen	Flexural strength MPa	First crack KN	Peak load KN	Deflection mm
Conventional Concrete Beam Model 1	10.48 11.18	55 52	66.92 71.42	9.33 26.89
MEAN	10.83	53.5	69.17	18.11
Concrete Beam with Steel fiber 1% Model 2	12.48 13.40	55 62	79.68 85.56	14.21 11.91
MEAN	12.94	58.5	82.62	13.06
Beam with Steel fiber 1% Model 3	11.11 12.02	66 54	76.78 70.92	7.05 24.64
MEAN	11.56	60	73.85	15.84

The increase in the flexural modulus of rupture was about model two with 19.48% and model three with 6.7% in case beams containing 1% steel fibres. The SFRC beams with 1% volume fraction of fibres, showed an average increase of model two with 19.44 % and model three 6.76 % in ultimate load (P_u) when compared to RC beams. Hence, it can be said that the addition of steel fibres caused the increase of both ultimate load and first crack load. This increase can be due to the crack arresting mechanism of the closely spaced fibres.

In other cases, fibres may significantly increase the first-peak and peak strengths while affecting a relatively small increase in residual load capacity and specimen toughness at specified deflections. The first-peak strength, peak strength and residual strength determined by this test method reflect the behaviour of fibre reinforced concrete under static flexural loading. First peak deflection for third point loading was estimated assuming linear elastic behaviour up to first peak from equation (3):

$\delta = 23PL3/1296EI^* \{1+[(216D2 *(1+\mu))/115L2]\}$ .... Eq. (3)

Where; P is the first-crack load.

L is the span,

E is the estimated modulus of elasticity of the concrete.

I is the cross-sectional moment of inertia.

D is the specimen depth, and

μ is Poisson's ratio.

Table 2.7: First peak load, Net deflection at First peak load

At 28 day	First peak load KN	peak load KN	δ_1 mm	δ_P mm	δ L/600 mm
MODEL 1	52	66.92	0.24	0.31	1.485
	57	71.49	0.27	0.34	1.32
MODEL 2	55	79.68	0.26	0.37	1.595
	62	85.56	0.29	0.40	1.43

Table 2.8: Residual load at net deflection

At 28 day	P^D600 N
MODEL 1	311877.3566
	277224.3169
MODEL 2	334979.383
	300326.3433

The first peak strength characterizes the flexural behaviour of the fibre-reinforced concrete up to the onset of cracking while residual strengths at specified deflections characterize the residual capacity after cracking.

The area under the load deflection graph showed the ductility of the beams. It can be seen that the area under the beams containing steel fibres was more than the beams with conventional concrete. So, SFRC beams had more ductile behaviour than normal concrete beams.

It can be seen in Table 6 that although the addition of 1% steel fibres increased the ultimate load the deflection at ultimate load was less than conventional concrete beams. Hence, it can be said that the SFRC beams were stiffer than conventional concrete beams. The reason can be due to the effects of steel fibres and good bonding between steel fibres with the surrounding concrete which was act as confinement to the concrete.

When the specimens were loaded in bending setup, the maximum tension stress occurs at the bottom and the first crack develops. In the case without fibre, crack develops at near the centre and suddenly collapse. On the other hand, ductility was enhanced with the addition of fibres. Specimens with fibre never collapse suddenly and steel fibre holds crack parts together which was good for making reliable building.

High Performance steel fibre concrete exhibited increasing flexural strength with increasing in steel fibres compared with conventional concrete. This behaviour was mainly attributed to the role of steel fibre in releasing fracture energy around crack tips which was required to extent crack growing by transferring stress from one side to another side. Also this behaviour was due to the increase in crack resistance of the composite and the ability of fibres to resist forces after the concrete matrix has cracked. As recommended by ACI Committee 544, 'when used in structural applications, steel fibre reinforced concrete should only be used in a supplementary role to inhibit cracking to improved resistance impact or dynamic loading and to resist material disintegration.

Addition of steel fibres in the concrete mix significantly influenced the cracking behaviour and ultimate strength of beams. On the other hand, inclined cracks went through a slow process of widening and extension in beams of model two and model three with 1% of fibre content and without web reinforcement. In the study the main reason for incorporating steel fibres in concrete was to impart ductility to an otherwise brittle material. They enable concrete to continue to carry load after cracking has occurred, the so called post crack behaviour or toughness.

The aim of this study was to provide determination effect of Winrad FS7- II steel fibre on flexural capacity of reinforced concrete beams compared with conventional reinforced concrete beams and concrete beams with bottom rebar. It was anchored to the based information that greater volume of steel fibre has to conventional concrete. Generally, this study showed that the addition of 1% steel fibre FS7_II improved the mechanical properties of concrete and RC beams.

Based on the finding of this study, the following conclusions were drawn: addition of steel fibres increases flexural and compressive strength of concrete. In comparison with control concrete the maximum increase in the compressive strength with 1% steel fibre was 12.37% at 7 days, 10.44 % at 14 days and 5.58% at 28 days. The increase in compressive strength of high performance steel fibre concrete was attributed to the capability of steel fibre to delay the unstable development of micro cracks as well as to limitation the propagation of these micro cracks and the composite effect for concrete and steel fibres under load. Increase in the flexural strength with 1% steel fibre was 19.42 % at 28 days for model two and 6.76% at 28 days for model three. In general, the significant improvement in various strengths was observed with the inclusion 1% of steel fibres in the conventional concrete. However it can be showed increase for model three because the model removed the reinforced rebar at the top. The initial cracks on the concrete beams model two specimens were not visible until such time the maximum load was reached, the increase in the propagation of the cracks was visible enough. Addition of steel fibres in the concrete mix significantly influenced the cracking behaviour and ultimate strength of beams. In the study the main reason for incorporating steel fibres in concrete was to impart ductility to an otherwise brittle material. They enable concrete to continue carry load after cracking had occurred called post crack behaviour, or toughness. The most remarkable changes in increasing strength by the used of short fibres to concrete occurs in bending. These changes included the increasing of flexural strength in pre-cracking stage and ductility of the concrete in post-cracking stage. It showed that the increasing amount of short fibres increase the load bearing capacity of the concrete. The first crack load P_{cr} in Table 2.6 was determined from the curve. All the SFRC beams showed significant increase in first crack load over reinforced concrete beams. This increase flexural modulus of rupture was model two with 19.48% and model three with 6.7 % in case beams containing 1% steel fibres. The SFRC beams with 1% volume fraction of fibres, showed an average increase of model two with 19.44 % and model three with 6.76% in ultimate load (P_u) when compared to RC beams. The addition of 1% steel fibres increased the ultimate load but the deflection at ultimate load was less than the conventional concrete beams. Hence, it can be said that the SFRC beams were stiffer than conventional concrete beams. The reason can be due to the effects of steel fibres and good bonding between steel fibres with the surrounding concrete which was act as confinement to the concrete and also energy absorption under flexural loading which was greatly enhanced with steel fibre reinforcement.

CHAPTER 3

3.0 METHODOLOGY

3.1 OVERVIEW

This research was carried out as a laboratory test series according to the pavement design procedure in OVERSEAS ROAD NOTE 31.

As with any other type of concrete, the mix proportions for Steel Fibre Reinforced Cement Stabilized Bases (SFRB) depend upon the requirements for a particular job, in terms of strength, workability, and so on. Several procedures for proportioning SFRB mixes are available, which emphasize the workability and strength of the resulting mix.

SFRB can, in general, be produced using conventional concrete practice, though there are obviously some important differences. The basic problem is to introduce a sufficient volume of uniformly dispersed to achieve the desired improvements in mechanical behaviour, while retaining sufficient workability in the fresh mix to permit proper mixing, placing and finishing. The performance of the hardened concrete is enhanced more by fibers with a higher aspect ratio, since this improves the fiber-matrix bond. On the other hand, a high aspect ratio adversely affects the workability of the fresh mix. In general, the problems of both workability and uniform distribution increase with increasing fiber length and volume.

One of the main difficulties in obtaining a uniform fibre distribution is the tendency for steel fibres to ball or clump together. Clumping may be caused by a number of factors:

i. The fibres may already be clumped together before they are added to the mix; normal mixing action will not break down these clumps.

ii. Fibres may be added too quickly to allow them to disperse in the mixer.

iii. Too high a volume of fibres may be added.

iv. The mixer itself may be too worn or inefficient to disperse the fibres.

v. Introducing the fibres to the mixer before the other concrete ingredients will cause them to clump together.

In view of this, care must be taken in the mixing procedures. Most commonly, when using a revolving drum mixer, the fibres should be added last to the wet concrete. Of course, the fibres should be added free of clumps, usually by first passing them through an appropriate screen. Once the fibres are all in the mixer, about 30-40 revolutions at mixing speed should properly disperse the fibres. Alternatively, when the mixture is produced in mass scale at the site, the fibres may be added to the fine aggregate on a conveyor belt during the addition of aggregate to the mix. The use of collated fibres held together by a water-soluble adhesive which dissolves during mixing largely eliminates the problem of clumping.

SFRB can be placed adequately using normal concrete equipment. It appears to be very stiff because the fibres tend to inhibit flow; however when vibrated, the material will flow readily into the forms. It should be noted that water should be added to SFRB mixes to improve the workability only with great care.

3.2 MIX DESIGN

As to any other mix design, this follows the guide lines given by the Overseas Road Note 31.

Stabilization can enhance the properties of road materials and pavement layers in the following ways:

- A substantial proportion of their strength is retained when they become saturated with water.
- Surface deflections are reduced.
- Resistance to erosion is increased.
- Materials in the supporting layer cannot contaminate the stabilized layer.
- The effective elastic moduli of granular layers constructed above stabilized layers are increased.

• Lime-stabilized material is suitable for use as a capping layer or working platform when the in situ material is excessively wet or weak and removal is not economical.

Associated with these desirable qualities are several possible problems:

• Traffic, thermal and shrinkage stresses can cause stabilized layers to crack.

• Cracks can reflect through the surfacing and allow water to enter the pavement structure.

• If carbon dioxide has access to the material, the stabilization reactions are reversible and the strength of the layers can decrease.

• The construction operations require more skill and control than for the equivalent un-stabilized material.

The minimum acceptable strength of a stabilized material depends on its position in the pavement structure and the level of traffic. It must be sufficiently strong to resist traffic stresses but upper limits of strength are usually set to minimize the risk of reflection cracking. Three types of stabilized layer have been used in the structural design catalogue and the strengths required for each are defined in Table 3.1.

Table 3.1: Properties of Cement Stabilized materials

Code	Description	Unconfined Compressive Strength (M Pa)
CB1	Stabilized Road Base	3.0 – 6.0
CB2	Stabilized Road Base	1.5 – 3.0
CS	Stabilized sub Base	0.75 – 1.5

(Source: Road Note 31)

The quality of the material to be stabilized should meet the minimum standards set out in Table 3.2. Materials which do not comply with Table 3.2, the cost and the risk from cracking and carbonation will increase.

Some aspects of construction must also be considered in selecting the stabilizer. It is not always possible to divert traffic during construction and the work must then be carried out in half widths. The rate of gain of strength in the pavement layer may sometimes need to be rapid so that traffic can be routed over the completed pavement as soon as possible. Under these circumstances, cement stabilization, with a faster curing period, is likely to be more suitable than lime stabilization.

Table 3.2: Desirable properties of Dense Graded aggregate material before stabilization

BS test sieve (mm)	% by mass of total aggregate passing test sieve		
	CB1	CB2	CS
53	100	100	-
37.5	85 – 100	80 – 100	-
20	60 – 90	55 – 90	-
5	30 – 65	25 – 65	-
2	20 – 50	15 – 50	-
0.425	10 – 30	10 – 30	-
0.075	5 - 15	5 - 15	-
Maximum Allowable Value			
LL	25	30	-
PI	6	10	20
LS	3	5	-

(Source: Road Note 31)

3.3 TEST PROCEDURE

3.3.1 SELECTION OF CEMENT CONTENT

The Code was selected as CB1 since we need the Unconfined Compressive Strength in the range of 3.0 – 6.0 MPa.

The cement contents were selected in the range of 3% – 8% and it was very careful not to go beyond 8% because it is needed to confine in the flexible pavement type.

The cement content determines whether the characteristics of the mixture are dominated by the properties of aggregate or by the hydration products. As the proportion of cement in the mixture increases, so the strength increases. Strength also increases with time. During the first one or two days after construction this increase is rapid. Thereafter, the rate slows down although strength gain continues provided the layer is well cured. The choice of cement content depends on the strength required, the durability of the mixture, and the soundness of the aggregate.

The minimum cement content, expressed as a percentage of the dry weight of aggregate, should exceed the quantity consumed in the initial ion exchange reactions. The durability of the stabilized mixture which satisfies the strength requirements for the particular layer should also be assessed. Mixtures produced from sound materials complying with the minimum requirements of Table 3.2 can be assumed to be durable if they achieve the design strength.

3.3.2 SELECTION OF WATER CONTENT

The water content was calculated for different cement content using the Proctor Compaction Test according to BS 1924-2:1990.

3.3.3 SELECTION OF STEEL FIBER CONTENT

RC – 80/60 – BN Dramix steel fibers were used to increase the flexural capacity of the SFRB layer. The Dramix fibers are filaments of wire, deformed and cut to lengths, for reinforcement of concrete, mortar and other composite materials. Dramix RC-80/60-BN is a cold drawn wire fiber, with hooked ends, and glued in bundles. As per the manufacturer's practical experiences, dosage of 10 kg/m3 was used in this research.

Fig.3.1: Dramix Steel Fibres

3.3.4 PREPERATION OF SPECIMEN AND TESTS CARRIED OUT

The Optimum Moisture Content and the Maximum Dry Density of the mixtures of dense graded aggregate plus cement were determined according BS 1924-2:1990 by additions of 3 to 8 per cent of cement. According to the study, two types of beams were casted such as with steel fibers and without steel fibers so that a comparison could be achieved. All the specimens were compacted at the optimum moisture content as soon as the mixing is completed. The correct amounts of steel fibers were added to the mix at the final stage. Samples for the strength tests were mixed and compacted into 150x150x750mm steel moulds for the flexural strength (BS 1881-118:1983) and 150 mm cubes for crushing strength (BS 1924-2:1990). These samples were then moist cured for 7 days and soaked for 7 days before tests were carried out.

Two methods of moist curing are described in Road Note 31. The preferred method was to seal the specimens in wax but as this was not possible, they were wrapped with a gunny bags and moistened. The specimens were maintained at 25°C during the whole curing and soaking period. When the soaking phase is completed, the samples were crushed and the strength was measured. The Flexural strength and Crushing strengths were measured for both with steel fibers and without steel fibers in different cement contents.

Fig.3.2: Casted Beam specimen.

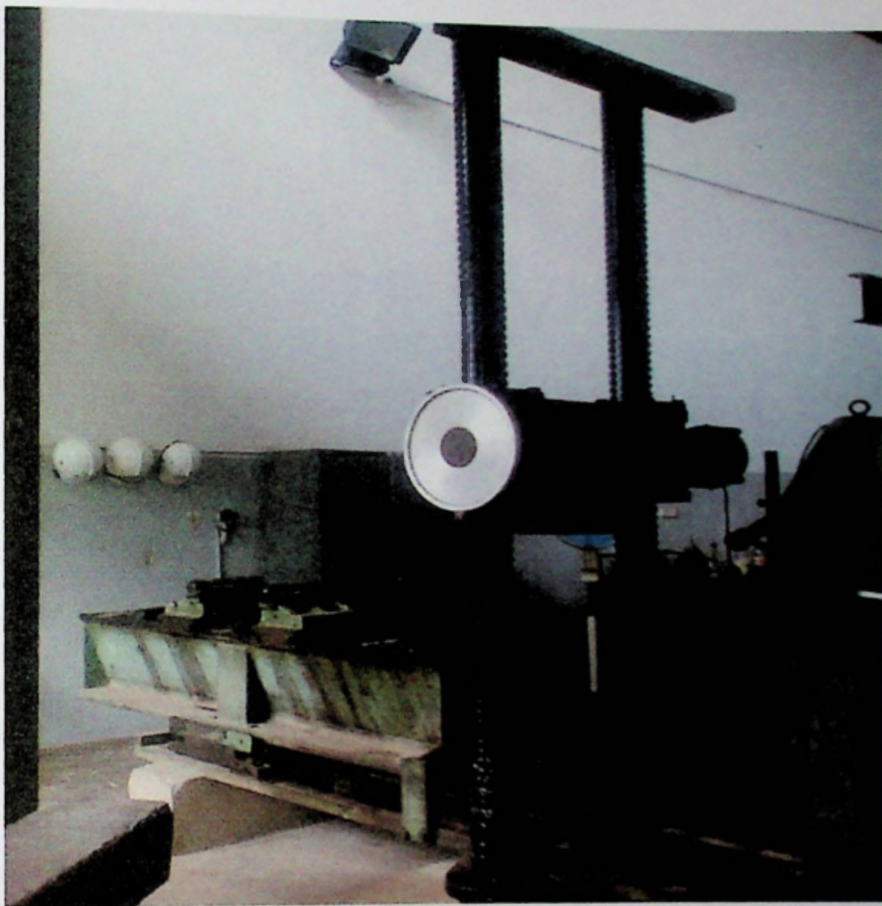


Fig.3.3: Testing Machine

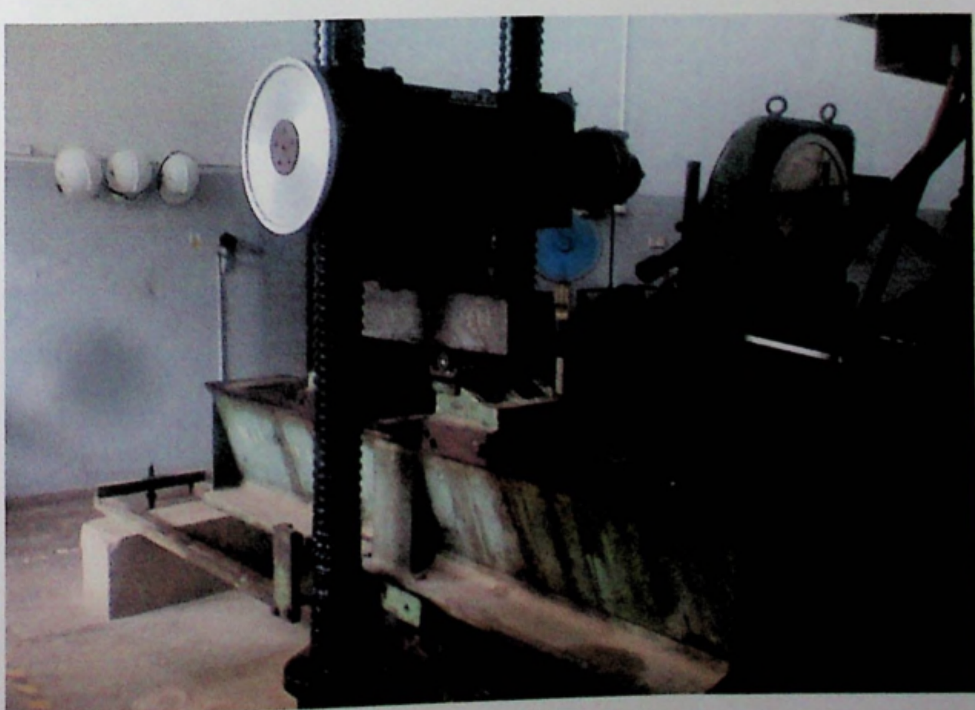


Fig.3.4: Beam to be tested is positioned on the machine

Fig.3.5: The crack was initiated at the bottom and propagated upwards

Fig.3.6: The cracked surface of the tested beam

3.3.5 OBSERVATIONS

The following observations were made after the tests carried out.

Table 3.3: Desirable properties of Dense Graded aggregate material before stabilization

% CEMENT CONTENT	FLEXURAL STRENGTH (N/mm^2)		CRUSHING STRENGTH (MT)	
	WITH STEEL FIBERS	WITHOUT STEEL FIBERS	WITH STEEL FIBERS	WITHOUT STEEL FIBERS
3	0.8	0.5	13	8.8
4	1.3	0.7	15	9.5
5	1.5	0.8	17	11.2
6	2.0	1.4	22	11.3
7	2.6	1.4	23.2	11.8
8	2.9	2.1	35.8	12.2

4.0 DATA ANALYSIS & RESULTS

4.1 COMPARISION OF FLEXURAL STRENGTH OF THE BEAMS WITH AND WITHOUT STEEL FIBERS

The values in Table 4.1 were received after the tests were carried out for the beams for Flexural strengths.

Table 4.1: Flexural Strengths of beams with and without Steel Fibres

CC %	FLEXURAL STRENGTH (N/mm^2)		INCREMENT (N/mm^2)
	WITH SF	WITHOUT SF	
3	0.8	0.5	1.6
4	1.3	0.7	1.8
5	1.5	0.8	1.8
6	2.0	1.4	1.4
7	2.6	1.4	1.8
8	2.9	2.1	1.4

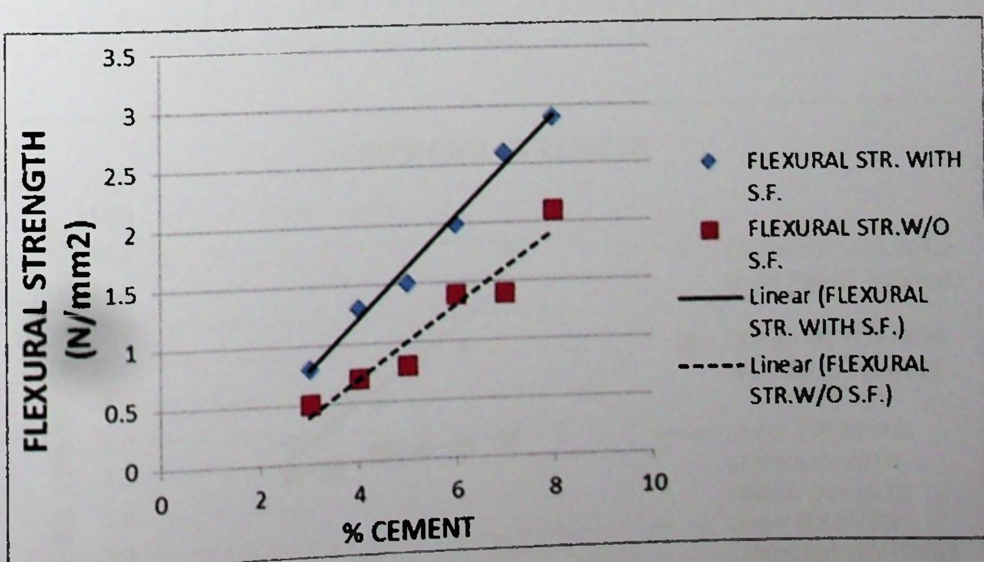


Fig. 4.1: Flexural Strength Vs Cement Content

Hence, it can easily be shown that the steel fibers causing increment the flexural capacity in stabilized aggregate blend. According to the laboratory test results, it shows the increment is around 1.5 times as shown in Table 4.1.

4.2 COMPARISION OF CRUSHING STRENGTH OF THE CUBES WITH AND WITHOUT STEEL FIBERS:

The values in Table 4.2 were obtained after the tests were carried out for the cubes for Crushing strengths.

Table 4.2: Crushing Strengths of Cubes with and without Steel Fibres

% CEMENT	CRUSHING STRENGTH		INCREMENT (N/mm2)
	WITH STEEL FIBRES (N/mm2)	WITHOUT STEEL FIBRES (N/mm2)	
3	5.7	3.8	1.5
4	6.5	4.1	1.6
5	7.4	4.9	1.5
6	9.6	4.9	1.9
7	10.1	5.1	1.9
8	15.6	5.3	2.9

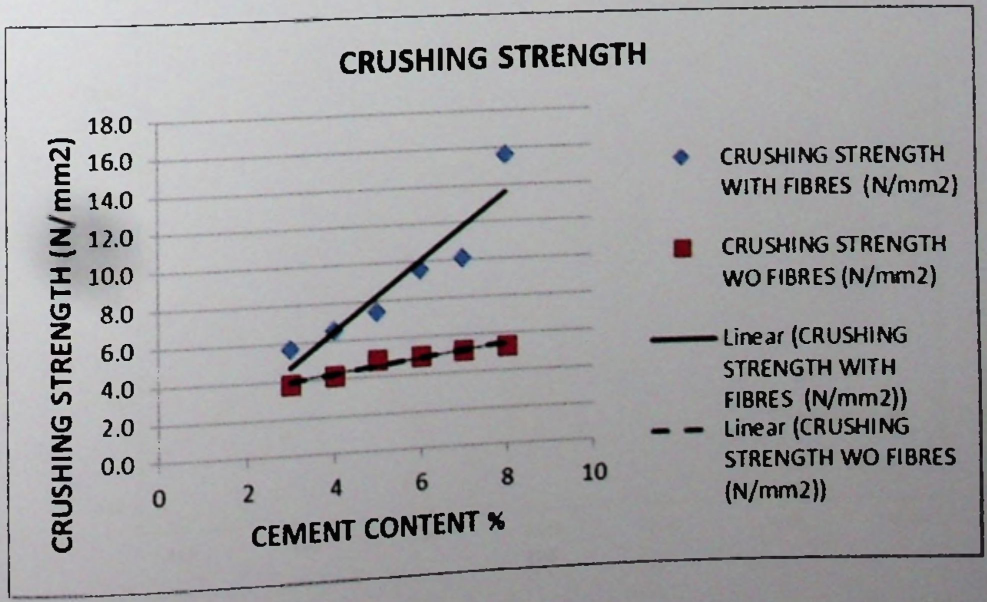


Fig. 4.2: Crushing Strength Vs Cement Content

According to the laboratory tests, the steel fibers causing the increment in crushing strength in stabilized aggregate blend more than 1.5 times as shown in Table 4.2.

4.3 DEVELOPING A RELATIONSHIP BETWEEN FLEXURAL STRENGTH AND CRUSHING STRENGTH:

The results which were obtained from the tests carried out were tabulated in Table3.3.

Table 4.3: Flexural Strength and Crushing Strength in N/mm2

% OF CEMENT CONTENT	FLEXURAL STRENGTH WITH S.F. (f_f) in N/mm2	CRUSHING STRENGTH WITH S.F.(f_c) in N/mm2
3	0.8	5.7
4	1.3	6.5
5	1.5	7.4
6	2.0	9.6
7	2.6	10.1
8	2.9	15.6

The SPSS software was used to analyze the relationship between the Flexural Strength and Crushing Strength as shown in fig.4.3.

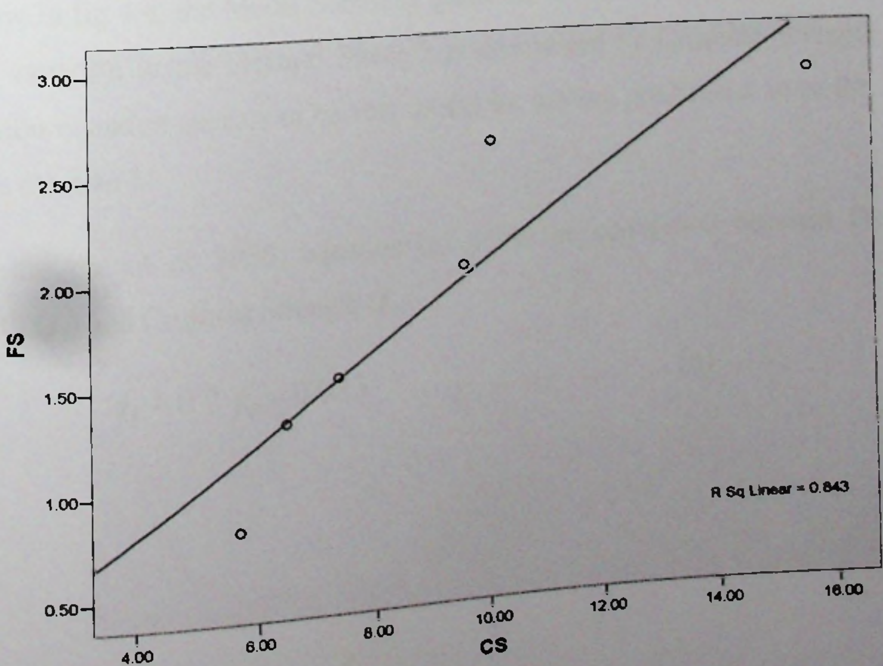


Fig. 4.3: The Graph of Flexural Strength Vs Crushing Strength using SPSS

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.918[a]	.843	.804	.35474

a. Predictors: (Constant), CS

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.023	.429		-.054	.959
	CS	.205	.044	.918	4.642	.010

a. Dependent Variable: FS

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.712	1	2.712	21.549	.010[a]
	Residual	.503	4	.126		
	Total	3.215	5			

a. Predictors: (Constant), CS

b. Dependent Variable: FS

Fig. 4.4: The Model Summery and coefficients given by SPSS software

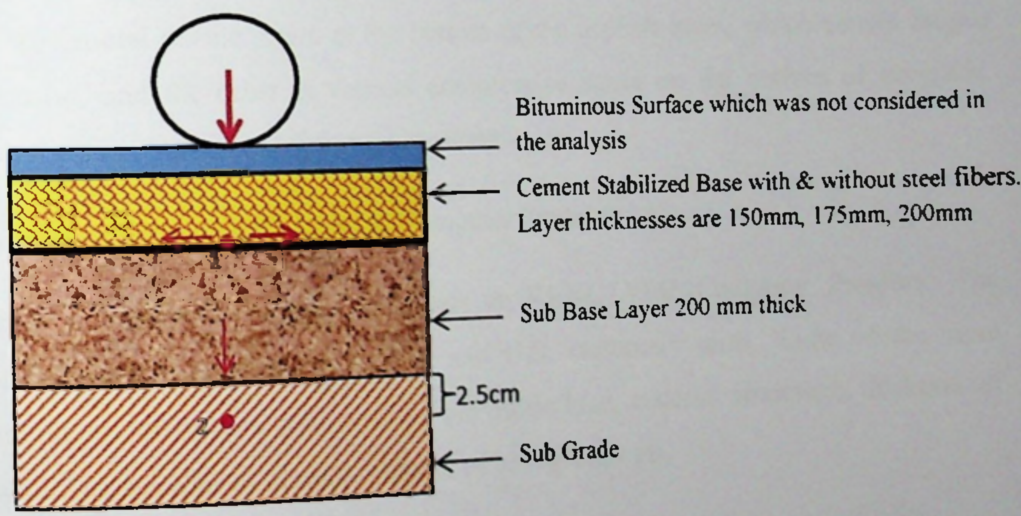
As show in fig 4.4, the Model Summery gives the R^2=0.843; therefore, about 84.3% of the variation in the Flexural Strength is determined by Crushing Strength. The regression equation appears to be very useful for making predictions since the value of R^2 is close to 1.

Using the output of SPSS, equation (a) gives the co-relation between Flexural Strength (f_f) and Crushing Strength (f_c).

$$f_f = 0.2\, f_c - 0.025 \quad \text{.......................(a)}$$

4.4 DEVELOP A TRAFFIC CATEGORY FOR STEEL FIBRE REINFORCED BASES IN VARIOUS CEMENT CONTENTS

The third part of the study is to develop a relevant "Traffic Category" for the steel fibre reinforced concrete base. The "KENLAYER" design software and "Austroads Pavement Design Guide (2004)" were used to do the damage analysis. Damage analysis is being carried out to find out both fatigue cracking and permanent deformation (rutting). Fatigue analysis is based on horizontal tensile strain at the bottom of specified layers, usually the hot-mix asphalt (HMA) or cemented layers while rutting analysis is based on the vertical tensile strain at the top of specified layers, usually the sub grade or lowest layer.



Location 1: Underneath the Cement Stabilized layer where subjected to Tension.
(Fatigue failure)

Location 2: 2.5 cm below the Sub Base layer where subjected to Compression.
(Rutting)

Fig. 4.5: Critical Locations in Pavement Analysis

KENLAYER Computer Program for Flexible Pavement Modeling

KENLAYER Computer Program has been used for determining the damage ratio using distress models in flexible pavements with no joints. Design life in years has been determined using two distress models in KENLAYER Computer Program. The KENLAYER gives the solution for an elastic multilayer system under a circular loaded area. The solutions are superimposed for multiple wheels, applied iteratively for non-linear layers. As a result, KENLAYER can be applied to layer systems under different axle load arrangements with each layer behaving differently, linear elastic, and nonlinear elastic.

Distress models in KENLAYER are cracking and rutting. Strains due to cracking and rutting have been considered most critical for the design of asphalt pavements. One is the horizontal tensile strain at the bottom of the asphalt layer, which causes fatigue cracking, and the other is vertical compressive strain on the surface of subgrade, which causes permanent deformation or rutting.

Input Parameters in KENLAYER Computer Program:

There are so many input parameters in KENLAYER Computer Program. The parameters can be used both in SI and U.S. customary units. Some of the input parameters for linear elastic analysis are traffic load, material properties, thickness of each layer, number of periods, number of load groups etc.

Output Parameters of KENLAYER:

For a single and multiple load groups, a maximum of nine and ten responses can be obtained, respectively. Only the vertical compressive strain on the surface of subgrade and the radial (tangential) tensile strain at the bottom of Cement Stabilized Layer are used for damage analysis.

CALCULATION PROCEDURE:

1. 150mm thick Cement Stabilized base without steel fibers

Using "KENPAVE", the Compressive and Tensile strain were obtained as follows.

POINT NO.	VERTICAL COORDINATE	VERTICAL DISPL. (HORIZONTAL P. STRAIN)	VERTICAL STRESS (STRAIN)	MAJOR PRINCIPAL STRESS (STRAIN)	MINOR PRINCIPAL STRESS (STRAIN)	INTERMEDIATE PRINCIPAL STRESS (STRAIN)
1	15.00000	0.07604	27.712	27.747	-1593.235	-1320.979
	(STRAIN)	-9.479E-05	4.336E-05	4.337E-05	-9.479E-05	-7.158E-05
1	37.50000	0.07145	9.788	9.916	2.277	2.512
	(STRAIN)	-1.658E-04	3.788E-04	3.881E-04	-1.658E-04	-1.487E-04
2	15.00000	0.07713	25.372	25.372	-1571.313	-1120.848
	(STRAIN)	-9.604E-05	4.004E-05	4.004E-05	-9.604E-05	-5.765E-05
2	37.50000	0.07242	10.142	10.155	2.302	2.585
	(STRAIN)	-1.715E-04	3.968E-04	3.978E-04	-1.715E-04	-1.510E-04
3	15.00000	0.07723	24.245	24.245	-1543.135	-1035.072
	(STRAIN)	-9.524E-05	3.834E-05	3.834E-05	-9.524E-05	-5.194E-05
3	37.50000	0.07255	10.167	10.167	2.302	2.592
	(STRAIN)	-1.720E-04	3.982E-04	3.982E-04	-1.720E-04	-1.509E-04

Fatigue Analysis

The failure criterion for fatigue cracking is expressed as the allowable number of load repetition (N) to prevent fatigue cracking. Allowable number of load repetition (N) for Cemented Material layer is given in Austroads Pavement Design Guide (2004).

From the Austroads Pavement Design Guide (2004), the Subgrade Fatigue model is;

$$N = \{K / (\mu\square)\}^{12}$$

Where; N = No. of repetitions

K = Constant depend on Modulus of stiffness of the materials in MPa

μ□ = Tensile strain of bottom of Cement Stabilized Base (in micro strain)

The values of Flexural Strength with and without steel fibres were taken from the graphs in Fig 4.1 and tabulated in Table 4.4.

Table 4.4: Flexural Strength of the beams with and without Steel fibres for various Cement Contents

CEMENT CONTENT %	FLEXURAL STRENGTH WITH SF (N/mm2 or MPa)	FLEXURAL STRENGTH WITHOUT SF (N/mm2 or MPa)
3	0.8	0.4
4	1.2	0.7
5	1.6	1.0
6	2.1	1.3
7	2.5	1.6
8	2.9	1.9

Detailed calculation was carried out for 6% cement content as follows.

For this case, it was assumed that;

- Subgrade CBR = 2%
- Poison ratio = 0.2
- Thickness of Sub base = 200mm

Flexural strength with steel fibers @ 6% cement content = 2.1 MPa

Flexural strength without steel fibers @ 6% cement content = 1.3 MPa

From the Austroads Pavement Design Guide (2004),

$E_b = 8.15\,\sigma_b + 3485$ ……………..(1)

Where; E_b = Flexural (Bending) Stiffness in MPa

σ_b = Flexural (Bending) Strength in KPa

From (1); $E_b = 8.15*2100 + 3485$

$= 20,600$ MPa (with steel fibers)

From (1); $E_b = 8.15*1300 + 3485$

$= 14,080$ MPa (without steel fibers)

From the Austroads Pavement Design Guide (2004), the Subgrade Fatigue model is;

$N = \{K / (\mu□)\}^{12}$ ………… (2)

Modulus of Cemented Material (MPa)	Value of K
2.000	440
3.500	350
5.000	310
10.000	260
15.000	240

(Source: Austroads Pavement Design Guide -2004)

Substitute $\mu□ = 96.04\times10^{-6}$ and K = 240 in eq. (2)

Hence; **N = 0.06 Million**

2. <u>150mm thick Cement Stabilized base with steel fibers</u>

As above in Section 1, taking $E_b = 14,080$ MPa ;

N = 1.5 Million

Similarly KENLAYER Computer Programme was used to obtain the Tensile strain of the Cement Stabilized Base with and without steel fibers for the cement content of 3%, 4%, 5%, 6%, 7% and 8% using above E_b values. The Cement stabilized Base layer thicknesses were taken as 150mm, 175mm and 200mm and Sub Base layer thickness was taken as 200mm for both cases and the no. of Repetitions and the increments were tabulated as in Table 4.6.

Rutting analysis of sub grade

From the Austroads Pavement Design Guide (2004), the failure criterion for permanent deformation (rutting) is expressed as:

$$N_d = f_4(\varepsilon_c)^{-f_5}$$

Where;

N_d - the allowable number of load repetitions to limit permanent deformation

ε_c - the compressive strain on the top of sub grade

f_4 , f_5 - constants determined from road tests or field performance. Values of f_4 and f_5 are suggested as 1.365 x 10-9 and 4.477 respectively by the Asphalt Institute (AI, 1982).

$$N_d = 1.365x10^{-9} \{172x10^{-6}\}^{-4.477}$$

$$= 97.6x10^{6}$$

Table 4.5: Fatigue and Rutting Analysis

Tensile Strain at Bottom of the CSB	Load Repetitions at Fatigue	Compressive strain at top of the SG	Load Repetitions at Rutting
9.604x10-5	0.06 Million	1.72x10-4	97.6 Million

According to the KENLAYER analysis, allowable number of load repetitions for rutting is greater than that of fatigue, hence the fatigue cracking is critical than rutting in Cement Stabilized Base pavement. According to that, in this study, it is authenticated that the failure mode in Cement Stabilized Base is taken placed by Fatigue.

Table 4.6: No. of Repetitions at Fatigue Failure in Millions for 2% Sub grade CBR obtained from 'KENLAYER' Software

2% SUB GRADE CBR								
	CC%	μ□		μ□ * (10^-6)		N = {K/(μ□)}^{12} in Million		Increment
		with SF	without SF	with SF	without SF	with SF	without SF	
150	3	-1.197E-04	-1.501E-04	119.70	150.10	0.0042	0.0003	15.1
	4	-9.998E-05	-1.261E-04	99.98	126.10	0.04	0.002	16.2
	5	-8.598E-05	-1.090E-04	85.98	109.00	0.22	0.01	17.2
	6	-7.338E-05	-9.604E-05	73.38	96.04	1.50	0.06	25.3
	7	-6.580E-05	-8.598E-05	65.80	85.98	5.54	0.22	24.8
	8	-5.972E-05	-7.792E-05	59.72	77.92	17.75	0.73	24.3
175	3	-1.005E-04	-1.290E-04	100.50	129.00	0.03	0.002	20.0
	4	-8.256E-05	-1.063E-04	82.56	106.30	0.36	0.02	20.8
	5	-7.030E-05	-9.059E-05	70.30	90.59	2.51	0.12	21.0
	6	-5.949E-05	-7.909E-05	59.49	79.09	18.59	0.61	30.5
	7	-5.308E-05	-7.030E-05	53.08	70.30	73.01	2.51	29.1
	8	-4.797E-05	-6.337E-05	47.97	63.30	245.98	8.82	27.9
200	3	-8.472E-05	-1.109E-04	84.72	110.90	0.27	0.01	25.3
	4	-6.891E-05	-8.997E-05	68.91	89.97	3.19	0.13	24.5
	5	-5.828E-05	-7.595E-05	58.28	75.95	23.78	0.99	24.0
	6	-4.902E-05	-6.588E-05	49.02	65.88	189.69	5.46	34.7
	7	-4.357E-05	-5.828E-05	43.57	58.28	780.34	23.78	32.8
	8	-3.927E-05	-5.232E-05	39.27	52.32	2715.21	86.80	31.3

Based on the Road Note 31, the relevant Traffic Classes were determined using Table 4.6 as follows in Table 4.7 for the Sub grade strength 2%.

Table 4.7: The Traffic Classes obtained for various Layer Thicknesses

2% Subgrade CBR					
Layer Thickness	Cement Content %	No. of Repetitions in Millions		Traffic Class	
		with SF	without SF	with SF	without SF
150 mm	3	0.0042	0.0003	T1	T1
	4	0.04	0.002	T1	T1
	5	0.22	0.01	T1	T1
	6	1.50	0.06	T3	T1
	7	5.54	0.22	T5	T1
	8	17.75	0.73	T8	T3
175 mm	3	0.03	0.002	T1	T1
	4	0.36	0.02	T2	T1

	5	2.51	0.12	T4	T1
	6	18.59	0.61	T8	T2
	7	73.01	2.51	> T8	T4
	8	245.98	8.82	>T8	T6
200 mm	3	0.27	0.01	T1	T1
	4	3.19	0.13	T5	T1
	5	23.78	0.99	T8	T3
	6	189.69	5.46	>T8	T5
	7	780.34	23.78	>T8	T8
	8	2715.21	86.80	>T8	>T8

4.5 ANALYSIS OF NUMBER OF REPITITIONS AT FATIGUE FAILURE FOR DIFFERENT SUB GRADE STRENGTHS

When a road section is considered, different sub grade strengths could be found. For the different sub grade strengths, the Number of Repetitions at Fatigue Failure could be obtained using the "KENLAYER" software. The analysis was further carried out for the sub grade strengths of 3%, 5% and 8%.

Table 4.8: No. of Repetitions for different layer thicknesses for Sub grade CBR values of 3%, 5% and 8%

3% SUB GRADE CBR					
Layer Thickness	CC%	μ□ * (10^-6)		N = {K/(μ□)}[12] in Million	
		with SF	without SF	with SF	without SF
150	3	111.4	139.3	0.01	0.0007
	4	93.12	117.2	0.09	0.01
	5	80.23	101.4	0.51	0.03
	6	68.61	89.5	3.36	0.14
	7	61.6	80.23	12.23	0.51
	8	55.97	72.8	38.64	1.65
175	3	93.67	120	0.08	0.00
	4	77.17	99.05	0.82	0.04
	5	65.85	84.57	5.49	0.27
	6	55.83	73.96	39.82	1.36
	7	49.88	65.85	153.96	5.49

	8	45.14	59.42	510.27	18.85
200	3	79.22	103.3	0.60	0.02
	4	64.61	84.06	6.90	0.29
	5	54.76	71.13	50.23	2.18
	6	46.16	61.81	390.25	11.74
	7	41.1	54.76	1571.93	50.23
	8	37.09	49.24	5388.31	179.77

5% SUB GRADE CBR					
Layer Thickness	CC%	μ□ * (10^-6)		N = {K/(μ□)}^{12} in Million	
		with SF	without SF	with SF	without SF
150	3	101.2	126.2	0.03	0.002
	4	84.86	106.5	0.26	0.02
	5	73.29	92.28	1.52	0.10
	6	62.83	81.61	9.65	0.42
	7	56.5	73.29	34.51	1.52
	8	51.41	66.6	107.14	4.80
175	3	85.46	109	0.24	0.01
	4	70.64	90.29	2.37	0.12
	5	60.42	77.3	15.43	0.80
	6	51.36	67.75	108.40	3.91
	7	45.97	60.42	410.05	15.43
	8	41.66	54.61	1336.30	51.91
200	3	72.55	94.12	1.72	0.08
	4	59.37	76.9	19.04	0.85
	5	50.45	65.25	134.34	6.13
	6	42.64	56.83	1010.95	32.18
	7	38.02	50.45	4003.04	134.34
	8	34.37	45.43	13439.42	472.52

8% SUB GRADE CBR					
Layer Thickness	CC%	μ□ * (10^-6)		N = {K/(μ□)}^{12} in Million	
		with SF	without SF	with SF	without SF
150	3	92.5	115	0.09	0.01
	4	77.73	97.2	0.75	0.05
	5	67.27	84.42	4.25	0.28
	6	57.8	74.8	26.27	1.19

	7	52.06	67.27	92.15	4.25
	8	47.43	61.22	281.77	13.18
175	3	78.36	99.59	0.68	0.04
	4	64.96	82.71	6.47	0.36
	5	55.7	70.99	40.95	2.23
	6	47.46	62.34	279.64	10.60
	7	42.53	55.7	1042.77	40.95
	8	38.6	50.42	3338.01	135.30
200	3	66.74	86.21	4.68	0.22
	4	54.78	70.67	50.01	2.35
	5	46.66	60.13	342.92	16.35
	6	39.53	52.48	2508.49	83.68
	7	35.3	46.66	9755.25	342.92
	8	31.95	42.08	32276.36	1184.75

4.6 DEVELOP A PAVEMENT DESIGN STRUCTURES WITH SFCSB FOR MEDIUM AND HIGHER TRAFFIC CATAGORIES

Table 4.9 was derived from the section 4.6. As per the literature review the shrinkage cracks can appear beyond 5% CC. Hence, the cement content was confined up to 5%.

Table 4.9: No of Repetitions in millions at different sub grade strengths

Layer thickness	CC%	SUB GRADE STRENGTHS			
		2%	3%	5%	8%
150	3	0.004	0.01	0.03	0.09
	4	0.04	0.09	0.26	0.75
	5	0.22	0.51	1.52	4.25
175	3	0.03	0.08	0.24	0.68
	4	0.36	0.82	2.37	6.47
	5	2.51	5.49	15.43	40.95
200	3	0.27	0.60	1.72	4.68
	4	3.19	6.90	19.04	50.01
	5	23.78	50.23	134.34	342.92

Using table 4.9, below Pavement Design Chart was developed.

Table 4.10: Pavement Design Details for different Traffic Classes

Traffic Class in Millions	SUB GRADE STRENGTHS			
	2%	3%	5%	8%
< 1.5 (T3)			150mm, 5%	150mm, 5%
	175mm, 5%	175mm, 5%	175mm, 4%	175mm, 4%
	200mm, 4%	200mm, 4%	200mm, 3%	200mm, 3%
1.5 - 3.0 (T4)		175mm, 5%	175mm, 5%	175mm, 4%
	200mm, 4%	200mm, 4%	200mm, 4%	200mm, 3%
3.0 - 6.0 (T5)			175mm, 5%	175mm, 4%
	200mm, 5%	200mm, 4%	200mm, 4%	200mm, 4%
6.0 - 10.0 (T6)			175mm, 5%	175mm, 5%
	200mm, 5%	200mm, 5%	200mm, 4%	200mm, 4%
10.0 - 17.0 (T7)				175mm, 5%
	200mm, 5%	200mm, 5%	200mm, 4%	200mm, 4%
17.0 - 30.0 (T8)		200mm, 5%	200mm, 5%	200mm, 4%

Using Table 4.10, the following chart can be derived to obtain most suitable design details for steel fiber reinforced cement stabilized bases.

Table 4.11: Design details of SFCS Bases

TRAFFIC CLASS IN MILLIONS	SUBGRADE STRENGTHS			
	S1 (2%)	S2 (3%,4%)	S3 (5% - 7%)	S4 (8% - 14%)
< 1.5 (T3)	175 mm, 5% CC	175mm, 5% CC	150mm, 5% CC	150mm, 5% CC
1.5 - 3.0 (T4)	200mm, 4% CC	175mm, 5% CC	175mm, 5% CC	175mm, 4% CC
3.0 - 6.0 (T5)	200mm, 5% CC	200mm, 4% CC	175mm, 5% CC	175mm, 4% CC
6.0 - 10.0 (T6)	200mm, 5% CC	200mm, 5% CC	175mm, 5% CC	175mm, 5% CC
10.0 - 17.0 (T7)	200mm, 5% CC	200mm, 5% CC	200mm, 4% CC	175mm, 5% CC
17.0 - 30.0 (T8)	-	200mm, 5% CC	200mm, 5% CC	200mm, 4% CC

4.7 ECONOMICAL ANALYSIS

4.7.1 GENERAL

Cost is a main factor which affect to the popularity of a technology. That means the quality and cost of the final product should be within the acceptable limits. Therefore when introduce a new method or new technology, it is a important to do a cost analysis. This chapter focus on comparison of the cost between road pavement structures with steel fiber reinforced cement stabilized bases and road pavement structures with conventional bases in Chart 3 in Road Note 31. It was considered that the soil and aggregate borrow pits are located within 20 km distances from the job site. Further rates used for the analysis are taken from the Highway Schedule Rates (HSR) 2013.

4.7.2 COST ANALYSIS FOR ROAD PAVEMENT STRUCTURES WITH STEEL FIBER REINFORCED CEMENT TREATED BASE

<u>For 1m^2 Area</u>

1. **Asphalt Surface of 50 mm thickness:**

Volume of Asphalt = 1 x1 x 0.05 = 0.05 m^3

Asphalt compacted density = 2.35 MT/m^3

Weight of asphalt = 2.35 x 0.05 = 0.117 MT

Cost of Asphalt material = 0.117 x 4271.90 = **Rs. 499.81**

Lay and compact Asphalt using paver = Rs. 755.10/ MT

Lay and compact for 0.112MT = Rs. 755.10 x 0.117 = **Rs. 88.34**

Transport cost per m^3 per 1km = Rs. 15.90

Transport cost of $0.05m^3$ for 20km =15.9 x 20 x 0.05 = **Rs. 15.90**

Total cost of Asphalt for $1m^2$ = Rs. 499.81 + 88.34 +15.90 = Rs. 604.05

2. **Steel Fiber Reinforced Cement stabilized Base (200mm thick):**

Volume of base = 1 x 1 x 0.2 = 0.2 m^3

Steel fiber dosage = $10kg/m^3$

Weight of steel fiber = 10 x 0.2 = 2.0 kg

Cost of steel fiber = Rs. 300.00/kg = Rs. 300 x 2.0 = **Rs. 600.00**

DGAB laying, watering and compacting = Rs. 2370.90/ m^3

Cost of DGAB laying, watering and compacting = 2370.90 x 0.2 x 1.4

= **Rs. 663.85**

Transport cost for 20km = Rs. 0.2 x 1.4 x 20 x 15.9 = **Rs. 89.04**

Cost of cement = Rs. 675.00 / 50kg

Weight of base section = 0.2 x 2400 = 480kg

3% Cement Content = Rs. (675.00/50) x [(480 x 3)/97] = **Rs. 200.41**

4% Cement Content = **Rs. 270.00**

5% Cement Content = **Rs. 341.05**

Cost of Rotary Mixer = Rs. 800.00 x (3/60)

= **Rs. 40.00**

3. **30 CBR Gravel sub Base (200mm thick):**

Volume of sub base (loose) = 1 x 1 x 0.2 x 1.4 = 0.28 m^3

Approved soil including piling = Rs. 200.50 $/m^3$

Laying and compaction = Rs. 132.70/ m^3

Transport cost for 20 km = Rs. 20 x 15.9 = Rs. 318.00 /m^3

Total cost = Rs. (200.50 + 132.70 + 318.00) x 0.28

= **Rs. 182.33**

4. Preparation of Sub Grade:

Trimming, levelling and compaction of original ground, subgrade to 95% STD Density = **Rs. 40.20**

With the help of above details, the summary of cost for all SFCS Bases can be obtained as follows.

Table 4.12: Cost analysis for Road Pavement structures with SFCS bases in Rupees/m^2

BASE THICKNESS	150 MM			175 MM			200 MM		
CEMENT CONTENT	**3%**	**4%**	**5%**	**3%**	**4%**	**5%**	**3%**	**4%**	**5%**
COST OF CEMENT	200.41	270.00	341.05	200.41	270.00	341.05	200.41	270.00	341.05
ROTARY MIXING	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
COST OF STEEL FIBER	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00
ASPHALT SURFACE	604.05	604.05	604.05	604.05	604.05	604.05	604.05	604.05	604.05
PRIMING	47.00	47.00	47.00	47.00	47.00	47.00	47.00	47.00	47.00
CONSTRUCTION OF DGAB	497.88	497.88	497.88	580.87	580.87	580.87	663.85	663.85	663.85
TRANSPORT COST OF DGAB	66.78	66.78	66.78	77.91	77.91	77.91	89.04	89.04	89.04
30 CBR SUB BASE 200MM THK	182.33	182.33	182.33	182.33	182.33	182.33	182.33	182.33	182.33
PREPERATION OF SUB GRADE	40.20	40.20	40.20	40.20	40.20	40.20	40.20	40.20	40.20
TOTAL WITHOUT CAPPING	**2278.65**	**2348.24**	**2419.29**	**2372.77**	**2442.36**	**2513.41**	**2466.88**	**2536.47**	**2607.52**
CAPPING LAYER 300MM	209.87	209.87	209.87	209.87	209.87	209.87	209.87	209.87	209.87
TOTAL WITH CAPPING LAYER	**2488.52**	**2558.11**	**2629.16**	**2582.64**	**2652.23**	**2723.28**	**2676.75**	**2746.34**	**2817.39**

4.7.3 COST ANALYSIS FOR ROAD PAVEMENT STRUCTURES IN CHARTS 3 & 5 IN ROAD NOTE 31

In this section, the cost analysis was carried out for road pavement structures in Chart 3 and Chart 5 of ROAD NOTE 31 in order to do the cost comparison with SFCS bases.

Table 4.13: Cost Analysis of Road Pavement structures in Road Note 31 in Rs/m^2

			TRAFFIC CLASSES					
			CHART 3 in RN 31			CHART 5 in RN 31		
			T3	T4	T5	T6	T7	T8
SUBGRADE STRENGT	S1	RN31	1705.08	1741.38	1777.67	2461.42	2858.81	3274.35
	S2	RN31	1616.98	1653.27	1689.57	2356.49	2753.88	3169.42
	S3	RN31	1513.36	1549.65	1585.95	2234.72	2632.11	3047.65
	S4	RN31	1458.92	1495.21	1531.51	2180.27	2577.67	2975.06

5.0 CONCLUTUION:

5.1 COMPARISON OF FLEXURAL AND CRUSHING STRENGTH IN STEEL FIBER REINFORCED BASES OVER CONVENTIONAL CEMENT STABILIZED BASES:

This study included two models; model one was conventional stabilized aggregate beam samples and model two was stabilized aggregate beam with steel fibers. The overall dimensions of the beam are 150 mm thick, 150 mm width and 750 mm long. The Aspect Ratio (*l/d*) of steel fiber used in the concrete beam was 80. In this study it was utilized two types of beams and cubes such as with steel fibre and without steel fibre.

When the specimens were loaded in bending setup, the maximum tension stress occurs at the bottom and the first crack develops. In the case without fibre, crack develops at near the centre and suddenly collapse. Specimens with fibre never collapse suddenly and steel fibre holds crack parts together which was good for making reliable bending. On the other hand, ductility was enhanced with the addition of fibres.

High Performance steel fibre reinforced stabilized bases exhibited increasing flexural strength adding steel fibres compared with conventional cement stabilized bases. This behaviour was mainly attributed to the role of steel fibre in releasing fracture energy around crack tips which was required to extent crack growing by transferring stress from one side to another side.

All the steel fiber reinforced stabilized beams showed significant increase in first crack load over conventional stabilized beams. According to the research outcome, it can be understand that the increase of flexural strength was 1.5 times over conventional stabilized beams (Table 4.1). Hence, it can be said that the steel fiber reinforced stabilized beams were flexible than conventional stabilized beams. The reason can be due to the effects of steel fibres and good bonding between steel fibres with the surrounding cementeous materials which was act as confinement to the stabilized mix and also energy absorption under flexural loading which was greatly enhanced with steel fibre reinforcement.

Furthermore, according to the study, it can be seen that the crushing strength increased by 1.5 times with the use of steel fibers as well (Table 4.2).

5.2 DEVELOPMENT OF A CO-RELATION BETWEEN FLEXURAL AND CRUSHING STRENGTHS OF STEEL FIBER REINFORCED BASES.

The second part of the study was to develop a co-relation between the Flexural strength and the Crushing strength of steel fiber reinforced bases. The advantage of this relationship is; if the Flexural testing machine is not available at the working sites, crushing strength can be used to determine the Flexural strength as the crushing machines are normally available at construction sites.

As per the research outcome it was found that the relationship between the Flexural strength and Crushing Strength as follows;

$$f_f = 0.2\, f_c - 0.025$$

5.3 COMPARISION OF THE INCREMENT PATTERNS OF NO. OF REPETITIONS OBTAINED FROM THE BASES WITH AND WITHOUT STEEL FIBRES

The third part of the study is to compare the increment patterns of number of Repetitions of the Bases with and without steel fibres. The "KENLAYER" design software and "Austroads Design Manual" were used to analyze the data. The results were tabulated in Table 4.5. Within the layer which with and without steel fibers were considered for the various cement contents. The variation pattern could be observed for different layer thicknesses are shown in Fig. 5.1, 5.2 and 5.3.

At the presence of steel fibres, the increment of the no. of Repetitions of the layer is significant. The reason can be the improvement of ability of withstand against the stresses of cement stabilized material when introducing the steel fibres.

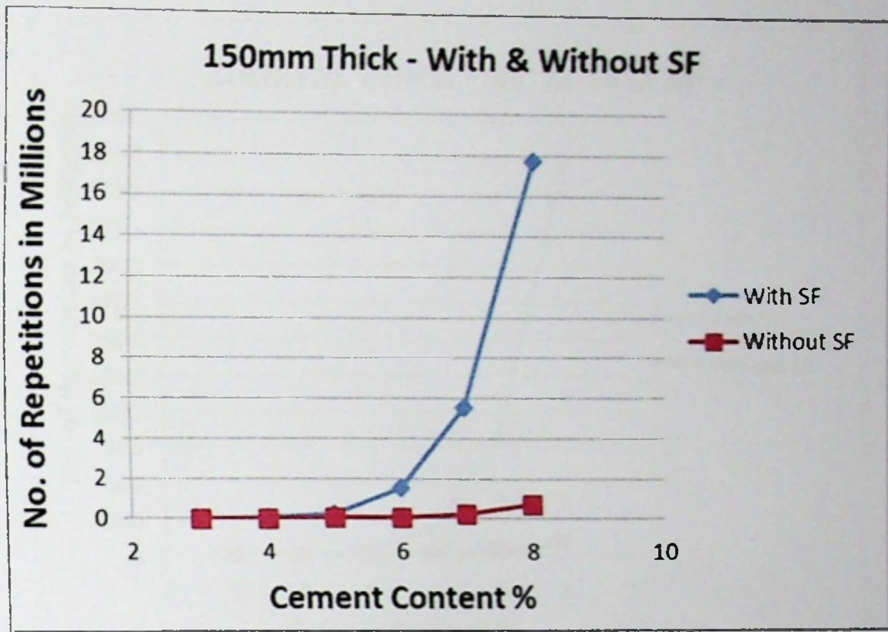


Fig. 5.1: No. of Repetitions Vs Cement content (150mm thick)

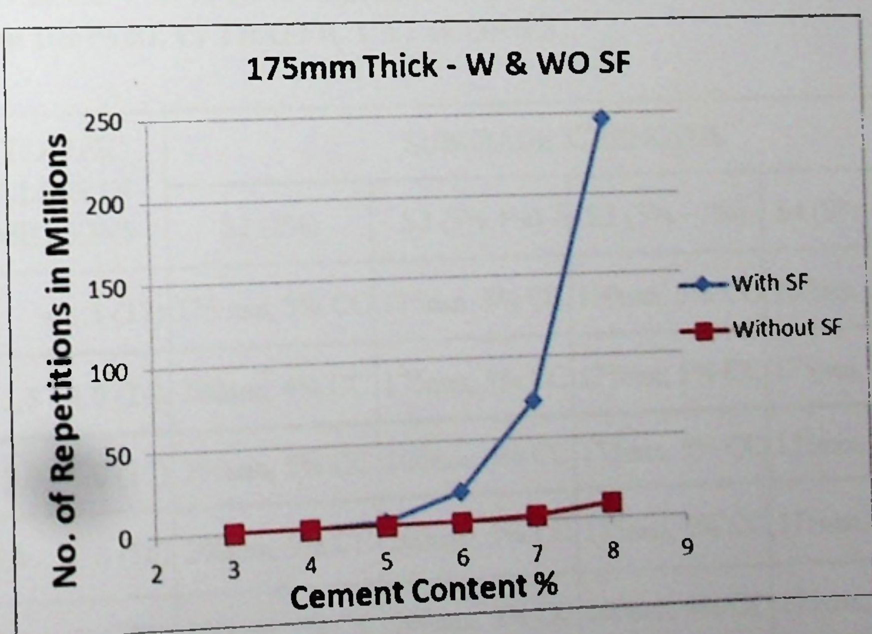


Fig. 5.2: No. of Repetitions Vs Cement content (175mm thick)

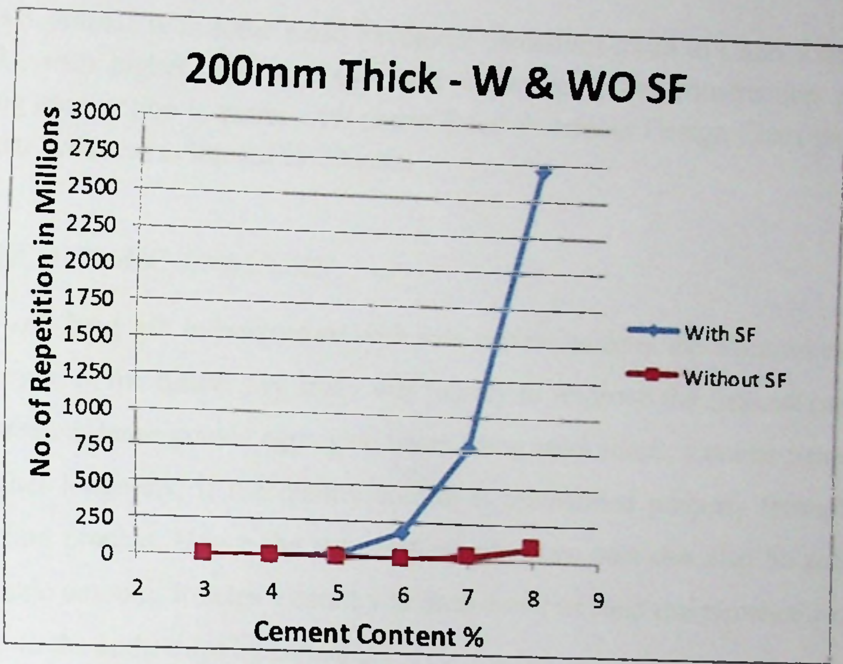


Fig. 5.3: No. of Repetitions Vs Cement content (200mm thick)

5.4 DEVELOP PAVEMENT DESIGN STRUCTURES WITH SFCS BASES FOR DIFFERENT TRAFFIC CATAGORIES

TRAFFIC CLASS IN MILLIONS	SUBGRADE STRENGTHS			
	S1 (2%)	S2 (3%,4%)	S3 (5% - 7%)	S4 (8% - 14%)
< 1.5 (T3)	175 mm, 5% CC	175mm, 5% CC	150mm, 5% CC	150mm, 5% CC
1.5 - 3.0 (T4)	200mm, 4% CC	175mm, 5% CC	175mm, 5% CC	175mm, 4% CC
3.0 - 6.0 (T5)	200mm, 5% CC	200mm, 4% CC	175mm, 5% CC	175mm, 4% CC
6.0 - 10.0 (T6)	200mm, 5% CC	200mm, 5% CC	175mm, 5% CC	175mm, 5% CC
10.0 - 17.0 (T7)	200mm, 5% CC	200mm, 5% CC	200mm, 4% CC	175mm, 5% CC
17.0 - 30.0 (T8)	-	200mm, 5% CC	200mm, 5% CC	200mm, 4% CC

The above pavement design chart gives the design details of Steel Fiber reinforced cement stabilized bases obtained from the analysis of research outcome. In this research the thicknesses of SFCS base were taken in 150mm, 175mm and 200mm sections. Compare with some Road Pavement Structures given in Chart 3 and Chart 5 of RN31 with higher base and sub base thicknesses, the construction procedure including compaction is easier with above Road Pavement Design Chart because the maximum thickness is limited to 200mm.

5.5 ECONOMIC ANALYSIS

Durable and long life infrastructure with low maintenance is the solution to reliable infrastructure in the future. My study was mainly to improve the flexural capacity of cement treated dense graded aggregate bases using steel fibers. Cement treated bases have higher longevity, if the quality control is maintained properly throughout the construction process. Hence the recurrent maintenance cost can also be reduced by considerable amount. It helps a country to drop down its road maintenance cost which troubling to the authorities by annually.

Table 5.1: Cost comparison in Rs./ m^2 between Road Note 31 and Research outcome

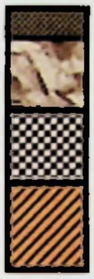
		CHART 3			CHART 5		
		T3	T4	T5	T6	T7	T8
S1	RESEARCH	2723.28	2746.34	2817.39	2817.39	2817.39	-
	RN31	1705.08	1741.38	1777.67	2461.42	2858.81	3274.35
S2	RESEARCH	2723.28	2723.28	2746.34	2817.39	2817.39	2817.39
	RN31	1616.98	1653.27	1689.57	2356.49	2753.88	3169.42
S3	RESEARCH	2419.29	2513.41	2513.41	2513.41	2536.47	2607.52
	RN31	1513.36	1549.65	1585.95	2234.72	2632.11	3047.65
S4	RESEARCH	2419.29	2442.36	2442.36	2513.41	2513.41	2536.47
	RN31	1458.92	1495.21	1531.51	2180.27	2577.67	2975.06

Table 5.1 reveals that for low and medium traffic classes such as T3, T4, T5 and T6, road pavement designs which developed from the Research outcome become cost ineffective and for higher Traffic classes such as T7 and T8, the Research outcome become cost effective. Here for the lower sub grade strengths S1 and S2, cost of 300mm high capping layer was added in addition to the sub base and base layers to increase the quality and durability of the work.

The above cost analysis provided a high chance to screen the most suitable cost effective road pavement structures. Hence for all road pavement structures up to subgrade strength S4 corresponding to higher traffic classes in T7 and T8 except S2/T7 and S1/T8 can be recommended.

The recommended Road Pavement Design Structures are shown below.

PAVEMENT DESIGN CHART		
SUBGRADE STRENGTH	TRAFFIC CLASS T7	TRAFFIC CLASS T8
S1	 50MM ASPHALT SURFACE 200MM, 5% CC SFCS BASE 200MM SUB BASE 300MM CAPPING LAYER SUB GRADE	-
S2	-	 50MM ASPHALT SURFACE 200MM, 5% CC SFCS BASE 200MM SUB BASE 300MM CAPPING LAYER SUB GRADE
S3	 50MM ASPHALT SURFCE 200MM, 4% CC SFCS BASE 200MM SUB BASE SUB GRADE	 50MM ASPHALT SURFCE 200MM, 5% CC SFCS BASE 200MM SUB BASE SUB GRADE

S4	 50MM ASPHALT SURFCE 175MM, 5% CC SFCS BASE 200MM SUB BASE SUB GRADE	 50MM ASPHALT SURFCE 200MM, 4% CC SFCS BASE 200MM SUB BASE SUB GRADE

REFERANCES

Amir Hossein Jodeiri, Ronaldo J. Quitalig. (2012) *Effect of Wirand FS7-II Steel Wire Fibre on Flexural Capacity of Reinforced Concrete Beam*

Milind V. Mohod, Assistant Professor, Department of Civil Engineering, P.R.M.I.T.& R., Badnera. (2012) *Performance of Steel Fiber Reinforced Concrete*

Ravindra V. Solanki, Prof. Mishra C. B., Dr. Umrigar F. S., Prof. Sinha D. A., *USE OF STEEL FIBER IN CONCRETE PAVEMENT: A REVIEW*

Technical Basis of Austroads Pavement Design Guide: Part 1

OVERSEASE ROAD NOTE 31