EFFECT OF STEEL FIBRES AND MARBLE DUST ON STRENGTH CHARACTERISITCS OF PAVEMENT QUALITY CONCRETE

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DECLARATION

The author hereby declares that this thesis entitled **"Effect of Steel Fibres and Marble Dust on Strength Characteristics of Pavement Quality Concrete"**, in whole or part, has not been used to obtain any degree in this, or any other, institute. Except where references have been given in text, it is entirely the authors own work.

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CERTIFICATE

This is to certify that the thesis entitled **"Effect of Steel Fibres and Marble Dust on Strength Characteristics of Pavement Quality Concrete"** being submitted by **Mr.Tarunbir Singh, Roll No 801122023** in partial fulfillment for the award of degree of **Masters of Engineering in Structural Engineering** at **Thapar University, Patiala** is a bonafide work carried out by him under our guidance and supervision and that no part of this thesis has been submitted for the award of any other degree

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ABSTRACT

There is growing interest in the construction of concrete pavements, due to its high strength, durability, better serviceability and overall economy in the long run.

The thrust nowadays is to produce thinner and green pavement sections of better quality, which can carry the heavy loads. The high strength steel fibre reinforced concrete is a concrete having compressive strength greater than 40MPa, made of hydraulic cements and containing fine and coarse aggregates; and discontinuous, unconnected, randomly distributed steel fibres.

The present study aims at, developing pavement quality concrete mixtures incorporating marble dust as partial replacement of cement as well as steel fibres. The aim is to the design of slab thickness of PQC pavement using the achieved flexural strength of the concrete mixtures. In this study, the flexural, compressive and split tensile strength for pavement quality concrete mixtures for different percentage of steel fibres and replacement of cement with marble dust are reported. It is found out the maximum increase in flexure strength, compressive strength and split tensile strength is for 0% Marble Dust and 1% Steel fibre. Also it has been possible to achieve savings in cement by replacing it with marble dust and adding fibres.

This study also shows that in view of the high flexural strength, high values of compressive strength and high values of split tensile strength, higher load carrying capacity and higher life expectancy, the combination of 10 to 20% marble dust replacement along with addition of 0.5 to 1% steel fibres is ideal for design of Pavement Quality Concrete (PQC).

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INTRODUCTION

1.1 GENERAL

The word concrete comes from the Latin word "concretus" (meaning compact or condensed), the perfect passive participle of "concrescere", from "con-" (together) and "crescere (to grow). During the Roman Empire, roman concrete (or opus caementicium) was made from quicklime, pozzolana and an aggregate of pumice. Concrete is a composite construction material composed primarily of aggregate, cement and water. There are many formulations that have varied properties. The aggregate is generally coarse gravel or crushed rocks as limestone, or granite, along with a fine aggregate such as sand. The cement, commonly Portland cement and other cementitious materials such as fly ash and slag cement serve as a binder for the aggregate. Various chemical admixtures are also added to achieve varied properties. Water is then mixed with this dry composite which enables it to be shaped (typically poured) and then solidified and hardened into rock-hard strength through a chemical process known as hydration. The water reacts with the cement which bonds the other components together, eventually creating a robust stone like material. Concrete has relatively high compressive strength. For this reason is usually reinforced with materials that are strong in tension (often steel). Concrete can be damaged by many processes, such as the freezing of trapped water.

The environmental impact of concrete is a complex mixture of not entirely negative effects; while concrete is a major contributor to greenhouse gas emissions, recycling of concrete is increasingly common in structures that have reached the end of their life. Structures made of concrete can have a long service life. As concrete has a high thermal mass and very low permeability, it can make for energy efficient housing.

As we know Concrete is a versatile construction material. Firstly it was innovated as protective cover of steel members, after that it was revised and now a day's concrete is used as a structural member and steel is provided to modify its properties and give better strength to the concrete. Concrete has benefits like fire resistance, excellent resistance to water, has ability to mould into various shapes and sizes easily as per requirement, economic and readily available material on the job site. It was observed that the normal concrete have many inadequacy such as low value of strength to weight ratio as compared to steel. So as to overcome this inadequacy resulted in the development of high strength concrete (HSC).

Now a day, with the excessive use of admixtures and widely distributed application of concrete technology, it is easy to attain cylinder strength of 50MPa in 12 to 18 hours and near to 70MPa or above at 28 days. As per economic point of view, it is very important to design a higher proportion of the available strength of concrete with efficiency and effectively rather than a smaller proportion of much higher strength.

1.2 DEFINITION OF HIGH STRENGTH CONCRETE

The definition of high strength concrete (HSC) varies on the geographical basis. In general, HSC may be defined as concrete which attribute the compressive strength properties which is not easy to obtain with the use of local materials and practices. However, the ACI Committee defined HSC of normal weight aggregates having 28 days cylinder compressive strength equal to 41MPa or greater in a uniaxial test (*ACI 363 R-84*). High strengthconcrete is a relative term which can be defined accordingly to requirement, contemporary and technology.

1.3 SELECTION OF MATERIALS

Effective production of high strength concrete should be attainedby carefully inspecting, selecting, controlling and proportioning of all ingredients:

1.3.1 Cement:

The development of HSC will require the utilisation of a Portland cement of optimum quality from workability and strength point of view. Variation in cement will cause the concrete compressive strength to fluctuate more than any other single material.

Following physical properties are required for cement to be used in HSC

Maximum Blaine fineness	: 4000cm^2/gm
Minimum 7 days mortar cube strength	: 28.959 MPa
Mortar air content	: 7 to 10 percent

1.3.2 Other Cementitious Materials:

The cementitious materials other than Ordinary Portland cement, mainly consist of silica fume or fly ash, which has been considered in the production of High Strength concrete (HSC) because as per requirement high cementitious materials content and low W/(C+P) ratio (W = water content, C = cement content, P = pozzolona cement). These materials can help control the temperature rise in concrete at early ages and can reduce the water demand for given workability. On the other hand the early strength gain of concrete may decrease.

1.3.3 Water- cement ratio:

The acceptability of water for High Strength Concrete (HSC) is not major problem if potable type water is used. The evolution of High Strength concrete (HSC) requires a w/c (water-cement) ratio in the range of 0.30 to 0.40.

The following are the maximum w/c (water-cement) ratio is necessary to produce the High Strength Cement (HSC) in the range of 41.38MPa to 62.07MPa.

Strength Specified	Max. W/c ratio
41.38MPa	0.38
51.78MPa	0.36
62.07MPa	0.34

1.3.4 Coarse Aggregate:

Coarse aggregates make up the bulk of a concrete mixture. Sand natural gravel and crushed stone are used mainly for this purpose. Carefully consideration should be adopted at the time of giving proper size, shape, mineralogy and surface texture. High strength aggregate are not suitable for concrete because of their very high modulus of elasticity as compared with the modulus of a cement paste due to this contrary stress concentrations occur which damages the concrete in mechanical behaviour. The presence of aggregate greatly increases the robustness of concrete above that of cement, which otherwise is a brittle material and thus concrete is a true composite material.

It was observed that the size of coarse aggregate regulate the concrete strength apart from W/c ratio. For a given W/c ratio, the strength of concrete is decreased as the maximum size of coarse aggregate is increased. It was also observed that for optimum compressive strength with high cement contents and low water cement ratios, the maximum size of coarse aggregate should be kept minimum at the rate of 12.5 mm or 9.5 mm. “It was suggested that ideal aggregate should be angular, clean, cubical, 100 percent crushed and continuously graded with a minimum of flat and elongated particles”.

1.3.5 Fine Aggregate:

The characteristics property and quality of fine aggregates affect the properties of concrete in fresh as well as in hardened state. Redistribution of aggregates after compaction often creates in homogeneity due to the influence of vibration. This can lead to strength gradients. The presence of aggregate greatly increases the robustness of concrete above that of cement, which otherwise is a brittle material and thus concrete is a true composite material.

The grading of fine aggregate regulate the workability of concrete at a particular water content of the concrete mix as the surface of these fine aggregates is relatively much higher than that of coarse aggregates. Sand which has fineness modulus below 2.5 produced concrete to sticky consistency due to this sticky behaviour it is very difficult to compact. However Sand which has fineness modulus of about 3.0 gave the optimum compressive strength and workability.Fine aggregate with fineness modulus in the range of 2.5 to 3.2 is suitable for production of High Strength concrete (HSC).

1.3.6 Admixtures:

Concreteis essentially made from five materials, namely, air, water, cement, fine aggregate, and coarse aggregates.The first three constituents, when mixed together, form the binder paste; on adding fine aggregates only to the paste forms mortar; whereas, when all the constituents are mixed together, concrete is formed.

An admixtureis a material added to the batch of concrete before or during its mixing to modify its freshly mixed, setting or hardened properties. About 80% of concrete produced in North America have one or more admixtures. About 40% of ready-mix producers use fly ash. About 70% of concrete produced contains a water-reducer admixture. One or more admixtures can be added to a mix to achieve the desired results. The main reasons for using admixtures are as enumerated below:

- Increase slump and workability;
- Retard or accelerate initial setting;
- Reduce or prevent shrinkage;
- Modify the rate or capacity for bleeding;
- Reduce segregation;
- Improve pumpability and finishability;
- Retard or reduce heat evolution during early hardening;
- Accelerate the rate of strength development at early ages;
- Increase strength (compressive, tensile, or flexural);
- Increase durability or resistance to severe conditions of exposure
- Decrease permeability of concrete;
- Control expansion caused by the reaction of alkalis with potentially reactive aggregate constituents;
- Increase bond of concrete to steel reinforcement (bonding);
- Increase bond between existing and new concrete;
- Improve impact and abrasion resistance (hardness);
- Inhibit corrosion of embedded metal;

- Gas-forming;
- Anti-washout;
- Foaming; and
- Produce coloured concrete.

There admixturesare mainly classified into two groups, viz. chemical admixtures and mineral admixtures, respectively.

(i) Chemical admixtures: Chemical admixturesreduce the cost of construction, modify the properties of concrete and improve the quality of concrete during mixing, transportation, placing and curing. In production of High strength concrete, decreasing the W/C by decreasing the total cementitious materials content will usually produce higher compressive strength. Due to this reason, use of chemical admixture should be considered when developing High strength concrete (HSC). The various types of chemical admixtures are classified, based upon their use in concrete, as

1. Air-entrainment
2. Water-reducing
3. Set-retarding
4. Accelerating
5. Super-plasticizers
6. Corrosion-inhibitors
7. Shrinkage-reducers
8. Alkali-silica reactivity reducers

The water reducers which are capable of reducing water content by about 30 percent are popularly known as Super-plasticizers (SPs) or High range water reducers (HRWR). The super-plasticizers are classified into four categories:

(a) Sulphonated melamine-formaldehyde condensates (SMF)
(b) Sulphonated naphthalene-formaldehyde condensates (SNF)
(c) Modified lignosulphonates (MLS)
(d) Other such as sulphonic acid esters, carbohydrate esters etc.

Normal dosage of super-plasticizers in High strength concrete (HSC) is b/w 0.3 % and 1.5% by weight of cement. The potential advantages of HRWR include significant water reduction; reduced cement contents; increased workability;rapid rate of early strength development; increased long-term strength; and reduced permeability. However, with advantages there are some linked disadvantages of using HRWR in concrete, which are enumerated as below:

- Additional admixture cost (the concrete in-place cost may be reduced);
- Slump loss greater than conventional concrete;
- Modification of air-entraining admixture dosage;

- Less responsive with some cement;
- Mild discoloration of light-coloured concrete; and
- Air-void and colour blemishes on exposed and formed finishes.

(ii) Mineral admixtures: Mineral admixtures reduce cost, reduce permeability, increase strength and change other concrete properties. The three main mineral admixtures, which are very frequently used in concrete, are as listed below:

1. Fly ash;
2. Silica fume, and
3. Ground Granulated Blast Furnace Slag.

- ***Fly ash:*** Fly ash is a by-product of electrical coal-fired power plants and can vary widely depending on the source. It should meet the requirements of ASTM C 618. Fly ash particles are usually finer than cement and are mainly made of glassy-spherical particles. Use of fly ash started in the United States about early 1930's. Tests have shown that high-strength concrete can be made by using high volumes of Class C fly ash (about 1/3 of total cement material). Strength levels were obtained in the range of 14,000 psi (100 MPa) at one year of age and beyond. Because of the carbon content of fly ash, air-entraining admixtures may be required. Fly ash inhibits alkali-silica reaction (ASR) in hardened concrete. Fly ash is used in about 40% of ready-mix concrete.

  The two main classes of fly ash specified in ASTM C 618 are Class F and Class C. All fly ashes used in the United States before 1975 were Class F. The Class C fly ash content of concrete generally ranges from 15 to 40 % of the total cementitious material. Class F content usually ranges from 15 to 25%. There is also a Class N; Natural pozzolans from volcanic ash or other materials.

  Class F fly ash is usually obtained from burning anthracite or bituminous coal and has the following effects:

  - Reduces bleeding,
  - Increase time of setting,
  - Improve workability,
  - Reduces segregation in plastic concrete,
  - Increases ultimate strength,
  - Reduces drying shrinkage and permeability,
  - Lowers the heat of hydration, and
  - Reduces creep.

Class C fly ash is usually obtained from burning sub-bituminous coal and ligniteand has the following effects:

- Provides self-hardening characteristics,
- Increase time of setting for most Class C,
- Improves permeability,
- Useful in pre-stressed concrete, and
- Has high early strength.

Fly ash reduces the early age strength of concrete but may increase the strength of the same concrete at age of 90 days. Fly ash was used in several mixtures at replacement rate of 25 to 35 % by weight of cement.

- ***Silica fume:*** Silica fume admixtures are used to meet high strength and low permeability requirements. They have been used to produce concrete with compressive strengths as high as 20,000 psi. They are added in slurry or in dry form at the batching plant. Silica fume is extremely fine. The particles are about 100 times smaller than cement particles. It should meet the requirements of ASTM C 1240.

Benefits are:

- Reduced permeability,
- Improves bonding within the concrete,
- Improves resistance to corrosion,
- Can reduce alkali-silica reactivity (ASR),
- Increased compressive and flexural strengths, and
- Increased durability.

Applications are:

- High-strength structural columns,
- Low permeable parking garage decks, and
- Abrasion resistant hydraulic structures.
- Silica fume dosage is about 8-15% by weight of cement which is added to and not a replacement for the amount of cement.

Dosage:

- High durability / low permeability of bridge decks or parking structures (8-10%)
- High strength structural columns (10-15%)
- Flatwork (10% max)

The higher the percentage of silica fume used, higher is the amount of superplasticizer needed. The mix may become sticky. Generally, 1/3 of the superplasticizer is replaced with a mid-range water reducer to improve workability. Silica fume increases water demand often requiring one pound of water for every pound of silica fume. Silica fume is very expensive and sells for as much as $40 per cubic yard of concrete. It was observed that the optimum replacement of cement by silica fume in high strength concrete 50 to 70MPa at 28 days is 15 percent by weight.

- ***<u>Ground Granulated Blast-furnace Slag (GGBS):</u>***Ground granulated blast-furnace slag is the granular material formed when molten iron blast furnace slag is rapidly chilled (quenched) by immersion in water. It is a granular product with very limited crystal formation, is highly cementitious in nature and, ground to cement fineness, hydrates like portland cement. Since it is a cementitious material, it can be substituted for some of the cement. The optimum is typically 50% of the cement if not exposed to de-icing salts and 25% if exposed to de-icing salts.
  It should meet the requirements of ASTM C 989. The three grades are 80, 100 and 120. The use of grade 80 should be avoided unless warranted in special circumstances. It should not be used in cold conditions.

Effects of slag additives:

- Usually improves workability and decreases water demand,
- Increases setting times,
- Reduces bleeding,
- Increases the air-entrainment required,
- Usually improves flexural strength,
- Reduces permeability, and
- Prevent damage due to ASR.

1.4 DIFFICULTIES IN PRODUCING HSC:

(a)Superlpasticizers are used to attain necessary slump keeping w/c ratio low. But due to diffusive action of superplasticizer, more surface area of cement comes in contact with water. Hence hydration of cement can take place more rapidly, resulting in higher slump loss. Due to this reason, some amount of superplasticizer is added at the mixing plant and remaining portion is added just before concreting at the site.

(b) There is some difficulty in entraining 5 to 7% air in concrete with high cement contents and incorporating 20 to 30% silica fume.

(c) Higher cement contents and lower water contents have produced concrete of higher strengths. By proportioning water demand in the mixture increased due to large amount of cement in the concrete mix. A high percentage of cement could give rise to massive heat generation, with resultant risk of cracking. For this reason cement is replaced 10 to 20% by pozzolona (silica fume, fly ash etc.) to control heat of hydration.

1.5 APPLICATION OF HSC

All over the world Engineers, Architects and Designers have considered the use of higher strength of concrete in their structure from time to time. HSC is very well known about their properties like corrosion resisting property and durable property than the normal concrete. Higher Compressive strength of concrete gives a higher modulus of elasticity. It's maintained a higher tensile stress and has reduced specific creep. HSC used for casting of columns in high rise buildings which is now used for wider range of member types like

(a) Bridges
(b) Monorail piers
(c) Concrete launch pad
(d) Chimney
(e) Prestressed concrete sleeper
(f) Shear walls of high rise building and High-rise building column
(g) Nuclear power plants
(h) Pavement traffic lanes
(i) Airport pavement
(j) Machine foundations
(k) Water tanks etc.

1.6 STEEL FIBRE REINFORCED CONCRETE

1.6.1 Definition

Fibre reinforced concrete represented by combination of four different phases, like cement, water, coarse aggregate, fine aggregate and a dispersion of discontinuous, steel fibre. It can also contain admixtures and pozzolans which are commonly used with the conservative concrete. All admixtures under the ASTM specifications for use in concrete are desirable for use in Steel Fibre Reinforced Concrete (SFRC).

1.6.2 Fibre Content

Various amount of fibre is added in concrete which is generally measured as a fraction of total volume of mortar. Practically four ranges of Volume fractions (V_f) can be identified as shown in Table 1.1

1.6.3 Types of Fibres

Fibre is manufactured from various materials in various shapes and sizes. The numerical parameter representing a fibre is its aspect ratio i.e. l/d ratio which means fibre length divided by diameter. Typical aspect ratio is used which have ranges from 30-150 for length dimensions of 1.0 to 76.2 mm. Various properties of commonly used steel fibres as shown in Table 1.2.

Table 1.1 Typical Practical Ranges of Fibre Reinforcement of Concrete

Approx. Vol. Fraction of Fibre	Matrix	Example
V_f< 0.5%	Concrete	PP in pipe caps
0.5 <V_f< 3%	Concrete (smaller size agg.)	Pavements, Joints
3 <V_f< 8%	Mortar	Cement sheets, repairs
8 <V_f< 20%	Paste, Slurry	Asbestos cement sheets, slurry

Table 1.2: Physical and Mechanical Properties of Fibres

Fibre	Diameter(μm)	Specific Gravity	Young`s Modulus (Kn/mm²)	Tensile Strength (Kn/mm²)	Elongation at break (%)
Asbestos	0.02-20	2.55	165	3-3.5	2-3
Glass	9-15	2.60	70-80	2-4	2-3.5
Steel	5-500	7.84	200	1-3	3-4
Polypropylene	20-200	0.91	6-7	0.5-0.7	20
Rayon	20-200	1.5	7-8	0.4-0.6	10-25
Polyethylene	20-200	0.95	0.14-0.42	0.7	10
Cotton	-	1.5	5	0.42-0.70	3-10

1.6.4 Properties of Fibre Reinforced Concrete

The properties of fibre reinforced concrete is regulate by fibre-matrix bond characteristics, volume fraction, material properties of fibres, type, geometry and matrix proportion in fresh as well as in hardened state.Steel fibres are uniformly distributed throughout the concrete mix as comparison to rebar or welded wire reinforcement, both which are specially located in a single plane. The foremost motive of the use of steel fibre is to modify micro and macro cracking. Steel fibres control the growing of cracks at their initial stages.

a) Workability: As increase the fibre content or the aspect ratio of the fibres, the workability decrease. The balling effect of fibres, segregation of the mix and bleeding during placing and compaction affects the strength and other properties of the concrete. The workability of steel fibre reinforced concrete will totally depend on the percentage of the fibres, size and volume of the aggregates and at last but not least the aspect ratio of fibres.

b) Effect on the size and volume of the aggregate: It has been observed that uniform distribution of fibre is more difficult as the size of aggregate increases from 5 to 10 mm. Fibre interaction will be more if the size and volume of the coarse aggregate is more. A satisfactory fibre concrete should contain a mortar volume of about 70 percent with only about 30 percent consisting of particles between 5 mm to 10 mm.

c) Effect of Aspect Ratio: It is determined that the workability of fibre loading is affected which is directly related to the aspect ratio of the fibres. As increase the aspect ratio of the fibres, the workability decrease for a given fibre content. Normally aspect ratio i.e. l/d ratio ranges from about 20 to 100, while dimension of length ranges from 6.4 to 76 mm.

d) Compressive Strength: Due to the addition of fibres content, the compressive strength increases varyingly ranges from negligible to 20 percent and ranging from 0 to 15 percent for up to 1.5 percent by volume of fibres.

The following formula have been proposed to correlate the cube strength of steel fibre reinforced concrete and cube strength of corresponding plain concrete

$F_{cuf} = F_{cu}(1 + 0.1\,F`)$

Where,

F_{cuf} = Cube strength of SFRC

F_{cu} = Cube strength of corresponding plain concrete

F\` = Fibre factor = $(l/d) \times V_f \times d_f$

Where,

V_f = Volume fraction of fibres

l/d = aspect ratio of fibres

d_f = Bond factor which accounts for the differing bond characteristics of the fibres.

The bond factors for various types of fibres were obtained experimentally by pull out tests. Most of duoform fibres have higher bond value and circular (un-crimped) fibres have less bond value. The following relative values are allotted to different types of fibres.

d_f = 0.5 for un-crimped fibres of circular cross section

d_f = 0.75 for crimped fibres of circular cross section

d_f = 0.9 to 1.2 for duoform fibres depending on the degree of forming, an average value of 1.0 being appropriate in most cases.

e) Flexural strength: It is determined that it is considerable increase with the use of short, small diameter of the steel fibre in the first crack ultimate flexural strength and flexural strength of plain concrete. With the use of steel fibre, the ultimate strength can be increased upto 3 times the strength of plain concrete.

It is found that in the normal third-point bending test, the flexural strength of SFRC is about 50 to 70 percent more than that of the plain concrete mix.

f) Flexural Toughness (energy absorption): The advantage of adding fibre in fibre reinforced concrete(FRC) is that it improves its flexural toughness i.e. the total energy absorbed in breaking a specimen. It is examined that with the addition of 0.5 percent volume fraction of steel fibres in concrete mix is increased the 3.5 times in the number of blows to failure at 28 days as comparison with the plain cement specimens.

g) Tensile Strength: Based on the test observation, the following formula is proposed for correlating the split cylinder strength and compressive strength of steel fibre reinforced concrete.

$F_{spf}= \frac{F_{cuf}}{A} + B + C\sqrt{F}$

Where,

F_{spf} = Split tensile strength of fibre concrete in N/mm^2

F_{cuf} = Cube strength of fibre reinforced concrete in N/mm^2

A = A non-dimensional constant having a value of $2\sqrt{F}$

B = A dimensional constant having a value of 0.7 N/mm^2

C = A dimensional constant having a value of 1 N/mm^2

F = Fibre factor

The following formula is also suggested for the prevision of modulus of rupture of SFRC from its split tensile strength

$F_{spf} = 0.65\ F_r$

Where F_r = modulus of rupture of SFRC

h) Shrinkage and creep: It is determined that as compared to plain concrete, the shrinkage strain is smaller for fibre reinforced concrete. In case of fibre reinforced concrete shrinkage basically stopped at about 500 days but in case of plain concrete it continued up to 600 days.

Fibre does not appear an adverse effect on compressive creep. The value of compressive creep in fibre reinforced concrete increased up to 10 to 20 percent as comparison to plain concrete. Whereas, fibre reinforced concrete can decrease the tensile creep up to 50 to 60 percent.

i) Thermal properties: As the amount of steel fibres increases, the thermal conductivity of fibre reinforced concrete increases. The thermal expansion of steel fibre reinforced concrete is about 10.4×10^{-6} to $11.4 \times 10^{-6}/^{0}C$.

j) Impact strength: It is observed that with the addition of fibre, impact strength of concrete increases. Low modulus fibre like polypropylene and nylon very effective seen as discussed in impact strength. The fibre effectiveness for impact is also related to the bond characteristics, fibre with different shapes can give quite different results. As compared to straight fibres, the hooked or crimped fibres give a better impact resistance to the concrete i.e. up to 500 percent.
k) Fatigue strength: It is determined that an increase percentage of steel fibres, there is remarkable increase in flexural fatigue strength for a given type of fibre. Depending on the concentration and fibre type, a properly designed SFRC mixture have a fatigue strength of about 65 to 90 percent of the static flexural strength at 2 million cycles when non-reversed loading is used, with slightly less fatigue strength when full reversal of load is used.
The improvement in properties of plain concrete with the addition of steel fibre is shown in Table 1.3.

Table 1.3 Improvementsin Properties of Plain Concrete by Use of Steel Fibre Reinforced Concrete

Property	**Fibre reinforced concrete**	**Advantage over plain concrete**
Compressive strength	Up to 90 N/mm^2	Remarkable increase
Flexural strength (proportional limit)	Up to 12.5 N/mm^2	Can be more than 2 times
Ductility	Very higher	Very higher
Flexural strength (ultimate limit)	Up to 17.5 N/mm^2	Can be more than 3 times
Fatigue endurance limit ratio	0.80-0.95	More than 70%
Impact resistance	1367	3 times higher
Freeze-thaw damage	1.9	90% greater resistance
Deflection	Very less	Very less
Abrasion resistance index	2	Twice

1.7 APPLICATION OF FIBRE REINFORCED CONCRETE

Steel fibre reinforced concrete (SFRC) is concrete containing dispersed steel fibres. The most important regulation of steel fibres in concrete is to control and retard the tensile cracking of the composite material. The steel fibre reinforced concrete improves the strength characteristics like flexural strength, split tensile strength, strain capacity, flexural toughness, compressive strength and crack arrest properties which lead to use in highway and airfield pavements, overlays and bridge deck slabs. Some of the practical applications of steel fibre reinforced concrete include usage in thin shells and walls, concrete pipes, highway pavements, partially prestressed composite concrete beams, airport runways, high velocity passages, blast resistance structures, water retaining structures, marine structures etc.

1.8 USE OF MARBLE DUST AS REPLACEMENT MATERIAL IN CONCRETE

In building industry, Marble has been commonly used as a building material since the ancient times. The disposal of the marble powder material, consisting of very fine powder, constitutes one of the environmental problems around the world. Marble blocks are cut into smaller blocks in order to give them the desired smooth shape. In India, marble dust is settled by sedimentation and then dumped away which results in environmental pollution, in addition to forming dust in summer and threatening both agriculture and public health. Therefore, utilization of the marble dust in various industrial sectors especially the construction, agriculture, glass and paper industries would help to protect the environment. For instance, certain residues such as marble sludge from stony material manufacturing and cement kiln dust are characterized by an average diameter. This important characteristic makes them potentially candidates for use in the production of self-levelling mortars (SLMs) and self-compacting concretes (SCCs). They can be compacted under their self-weight, with no external action, providing a considerable saving in time and energy. The feasibility of the waste material recovery process is particularly influenced by the simultaneous satisfaction of the economic, technical and normative aspects for each field of use. Once the economic convenience has been assessed, the experimentation must verify that the physicochemical characteristics attained after treatment are suitable to the specific project solutions for which they are intended (Shahul and Sekar 2009).

1.9 OBJECTIVES OF THE PROPOSED WORK

The main objective of the proposed work is to study the effect of steel fibres on strength characteristics of Pavement Quality Concrete. Additionally, the effect of partial replacement of cement by marble dust had also been proposed to be studied

The relevant literature pertaining to the use of marble dust, steel fibre and super-plasticizer in concrete carried out in India and abroad has been reviewed and presented as under:-

2.1 STEEL FIBRE REINFORCED CONCRETE

Steel fibre reinforced concrete (SFRC) is concrete containing dispersed steel fibres. The most important regulation of steel fibres in concrete is to control and retard the tensile cracking of the composite material. The steel fibre reinforced concrete improves the strength characteristics like flexural strength, split tensile strength, strain capacity, flexural toughness, compressive strength and crack arrest properties which lead to use in highway and airfield pavements, overlays and bridge deck slabs.

Wang et al. (1996), investigated the fibre reinforced concrete beams under impact loading. Impact tests were carried out on small concrete beams reinforced with different volumes of both polypropylene and steel fibres. The drop height of the instrumented drop weight impact machine was so chosen that some specimens failed completely under a single drop of the hammer, while others required two blows to bring about complete failure. It was found that, at volume fractions less than 0.5%, polypropylene fibres gave only a modest increase in fracture energy. Steel fibres could bring about much greater increases in fracture energy, with a transition in failure modes occurring between steel fibre volumes of 0.5% and 0.75%. Below 0.5%, fibre breaking was the primary failure mechanism and the increase in fracture energy was also modest; above 0.75% fibre pull-out was the primary mechanism with a large increase in fracture energy.

Furlan and Bento (1997),analyzed the influence of fibres on the structural performance in situations of different ratios of shear reinforcement, some aspects of the properties of fresh and hardened concrete are introduced. The main alterations resulting from the use of fibres were increased shear strength, stiffness (particularly after first cracking stage) and ductility. Other parameters used in analyzing performance were the properties of the hardened concrete (compressive strength, tensile strength, and modulus of elasticity), and stresses in the stirrups, in the longitudinal reinforcement and in the concrete (at the web and compression zone).

Chunxiang and Patnaikuni (1998), studied on the Properties of high-strength steel fibre-reinforced concrete beams in bending. They investigated that the flexural rigidity before yield stage and the displacement at 80% ultimate load in the descending curve are improved and crack number and length at comparable loads is reduced after the addition of steel fibres. The descending part of the load-displacement curve of the concrete beams without steel fibres is much steeper than that with steel fibres, which shows that the addition of steel fibres makes the high strength concrete beams more ductile. The research results of ten high-strength reinforced concrete beams and steel fibre-reinforced high strength concrete beams, with steel fibre content of 1% by volume. The enlarged ends of mild carbon steel fibres with three different dimensions were selected.

Natarajaet al.(1999),carried out an investigation on Stress-strain curves for steel-fibre reinforced concrete under compression. The complete stress-strain curve of the material in compression is needed for the analysis and design of structures. In this experimental investigation, an attempt has been made to generate the complete stress-strain curve experimentally for steel-fibre reinforced concrete for compressive strength ranging from 30 to 50 MPa. Round crimped fibres with three volume fractions of 0.5%, 0.75% and 1.0% (39, 59, and 78 kg/m^3) and for two aspect ratios of 55 and 82 are considered. The effect of fibre addition to concrete on some of the major parameters namely peak stress, strain at peak stress, the toughness of concrete and the nature of the stress-strain curve is studied. A simple analytical model is proposed to generate both the ascending and descending portions of the stress-strain curve. There exists a good correlation between the experimental results and those calculated based on the analytical model. Equations are also proposed to quantify the effect of fibre on compressive strength, strain at peak stress and the toughness of concrete in terms of fibre reinforcing parameter.

Elsaigh et al. (2005),carried out investigation on steel fibre reinforced concrete for road pavement applications. In this paper, they established that the use of SFRC for road pavements and compare its execution with plain concrete under traffic loading. The determining of SFRC properties on performance and design aspects of concrete roads are discussed. Results coming out from road trial sections, tested under in-service traffic, are used to validate the use of the material in roads.

Wegian et al. (2011), studied on the influences of fly ash on behaviour of fibre reinforced concrete structures. The aim of this study was to measure the tensile and compressive strength of concrete with different steel fibre and fly ash percentage. Concrete specimens with different fibre contents like 0.50%, 1% and 1.5% by volume were tested. Fly ash contents in mixes ranged b/w 0 and 30% by weight. Sixteen concrete mixes were prepared. The result of this study confirmed that the addition of steel fibre has a negligible effect on the compressive strength of concrete but it improves the flexural strength.

Neophytou et al. (2011),studied on the proportioning of steel fibre reinforced concrete mixes for pavement construction and their impact on environment and cost. The innovative concept of the project is the use of recycled steel tyre-cord wire as concrete fibre reinforcement, which provides additional environmental benefits for tyre recycling over landfilling. Within the project framework a demonstration of a steel-fibre-reinforced roller-compacted concrete (SFR-RCC) pavement was constructed in a rural area in Cyprus. In order to assess the economic and environmental picture of the demonstration pavement, life cycle cost analysis (LCCA) and life cycle assessment (LCA) studies were undertaken, which also compared the under study pavement design with four conventional alternatives. The main output of the studies is that SFR-RCC is more environmentally and economically sustainable than others.

The proposed SFR-RCC pavement design is well sustainable alternative to SFRC for use in road construction industry both in economic and environmental terms. Given available design methodology, existing laying and material production equipment, SFR-RCC pavement may be the ideal new approach in road construction.

However, further work can be done towards a more environmental and economic pavement design. Most importantly, the life cycle studies showed that the steel fibre type and dosage can greatly influence the environmental (emissions and energy consumption) and economic indicators of concrete pavement layer. This is because the pavement layer depth, required to support the traffic load, is affected by the mechanical properties of SFRC which in turn are influenced by fibre type and dosage. On the other hand, recycled concrete aggregates may replace natural aggregates used in concrete mix, achieving only a small reduction in air emissions. But, it is more environmentally sustainable to recycle wastes than to extract natural resources.

Soulioti(2011), carried out investigation on effect of fibre geometry and volume fraction on the flexural behaviour of steel fibre reinforced concrete. In this paper the effect of fibre geometry and fibre volume fraction has been investigated for steel fibre reinforced concretes. Specifically the compression strength, the flexural strength and toughness were studied as a function of the above parameters and compared to unreinforced concrete. The effect of the fibre inclusion on the slump and air content properties of fresh concrete has been also evaluated.

The test results led to the conclusion that the fibres play an important role, not only in the fresh state of the concrete, but also in the mechanical properties of hardened concrete specimens. Concerning fresh concrete, the addition of steel fibres in the concrete mixture reduced the slump in the range of 65–90 mm, compared to plain concrete.

The air content increased with the raising of fibre volume fraction. Mixtures with high fibre volume fraction (1 and 1.5% by concrete volume) presented higher air content than mixtures with smaller fibre volume fraction (0.5% by concrete volume).

Plain concrete specimens failed catastrophically by a single crack, and separation into two pieces. On the contrary, the fibre-reinforced concrete specimens, even those with small fibre volume fraction (0.5%), retained post-cracking ability to carry out loads.

Vardhan et al. (2012), carried out laboratory investigation on the influence of steel fibre on concrete at a dosage of 0.8% volume of concrete. Experimental investigation was done using

M20 mix and tests were carried out as per recommended procedures by relevant codes. The study parameters of this investigation included compressive strength, split tensile strength and flexural strength of conventional and fibre reinforced concrete. The results indicated that the compressive, split tensile and flexural strength of fibre reinforced concrete is increased by 32.14%, 52.38%, 12.68% respectively when compared to the conventional concrete.

Patel et al. (2012), investigated thatthe shear strength of Steel Fibre Reinforced Concrete (SFRC) moderate deep beams without stirrups having span to depth ratio 2.0, 2.4, 3.0, 4.0. The 12 numbers of beams were tested. 12 numbers of beams were tested to failure under two point symmetrical loading. A complete shear deformational behaviour along with load-deflection response, crack patterns and modes of failure is studied experimentally. Shear strength is evaluated using empirical equations proposed here in this work for estimation of ultimate shear strength of moderate deep beams without stirrups. Experimental results of ultimate shear strength are compared with theoretical results calculated from proposed equation proposed. The comparison shows that the equation proposed here provides the most accurate estimates of shear strength. In addition to concrete strength, the influence of other variation such as fibre factor, span to depth ratio, longitudinal steel ratio and size effect is considered.

*Khan et al. (2013),*performed on steel fibres to increase the load carrying capacity of concrete members. Fibres substantially reduce the brittleness of concrete and improve its engineering properties, such as tensile, flexural, impact resistance, fatigue, load bearing capacity after cracking and toughness. It shows a review of research performed on Steel Fibre reinforced concrete. The performance of the Steel Fibre Reinforced Concrete (SFRC) has shown a significant improvement in flexural strength and overall toughness compared against Conventional Reinforced Concrete.

2.2. MARBLE DUST

It is white in colour, in powdered form andair dried. Different percentages of marble dust are replaced with concrete which isdiscussed as follows:

Aukour (2009), studied that the marble sludge is very useful in house building materials. The main objectives of using marble sludge are to save natural resources and to reduce the dumping problem of industrial waste materials quantity. The experimental results and their theoretical interpretation shows suitable incorporation of marble sludge results in building blocks of 15 cm with superior properties in terms of water absorption (7%). The compressive strength at age of 28 days only reached 7.8 N/mm^2.

Sekar et al. (2009), carried out investigation on the properties of green concrete containing quarry rock dust and marble sludge powder as fine aggregate. In this paper, they accomplished that feasibility of the usage of quarry rock dust and marble sludge powder as hundred percent substitutes for natural sand in concrete. An attempt has been made to durability studies on green concrete compared with the natural sand concrete. It is found that the compressive, split tensile strength and durability studies of concrete made of quarry rock dust are nearly 14 % more than the conventional concrete. The concrete resistance to sulphate attack was enhanced greatly. Application of green concrete is an effective way to reduce environment pollution and improve durability of concrete under severe conditions.

Demirel (2010), performed the effects of using waste marble dust (WMD) as a fine material on the mechanical properties of the concrete. Four different series of concrete-mixtures were prepared by replacing the fine sand (passing 0.25 mm sieve) with WMD at proportions of 0, 25, 50 and 100% by weight. The effect of the WMD on the compressive strength with respect to the curing age, compressive strengths of the samples were recorded at the curing ages of 3, 7, 28 and 90 days. In addition, the porosity values, ultrasonic pulse velocity (UPV), dynamic modulus of elasticity (Edin) and the unit weights of the series were determined and all data were compared with each other. It was observed that the addition of WMD such that would replace the fine material passing through a 0.25 mm sieve at particular proportions has displayed an enhancing effect on compressive strength. Marble dust is a by-product of marble production facilities and also creates large scale environmental pollution. Therefore, it could be possible to prevent the environmental pollution especially in the regions with excessive marble production and to consume fewer natural resources as well through its utilization in normal strength concretes as a substitute for the very fine aggregate.

Moriconi et al. (2010), carried out investigation on characterization of marble powder for its use in mortar and concrete. In this paper, they established that with the replacement of 10% of marble powder with sand gives a maximum compressive strength at about the same workability,comparable to that of the reference mixture after 28 days of curing. Mixtures were evaluated based upon cement or sand substitution by the marble powder.

Reddy (2010), carried out investigations on stone dust and ceramic scrap as aggregate replacement in concrete. In this research paper, he accomplished that stone dust has been tried as fine aggregate in place of sand and ceramic scrap has been used as partial/full substitute to conventional coarse aggregate in concrete making. Cubes, cylinders and prisms were cast and tested for compressive strength, split tensile strength and modulus of rupture after a curing period of 28 days. The results indicated effectiveness of stone dust as fine aggregate and partial replacement of conventional coarse aggregate by ceramic scrap upto 20 percent, without affecting the design strength

Brostowet al. (2011), carried out investigation on the properties of concrete paving blocks made with waste marble. In this research paper, they resulted that the cement type turns out to be an important factor. Mechanical strength decreases with increasing marble content while freeze-thaw durability and abrasive wear resistance increase. Waste marble is well usable instead of the usual aggregate in the concrete paving block production. Incorporation of marble waste provides concrete paving blocks of sufficient quality.

Rai et al.(2011),concluded the effect of using marble powder and granules as constituents of fines in mortar or concrete by partially reducing quantities of cement as well as other conventional fines has been studied in terms of the relative workability & compressive as well as flexural strengths. Partial replacement of cement and usual fine aggregates by varying percentage of marble powder and marble granules reveals that increased waste marble powder (WMP) or waste marble granule (WMG) ratio result in increased workability and compressive strengths of the mortar and concrete.

Gupta et al. (2012), carried out investigation on the Partial replacement of cement with marble dust powder. In this research, they resulted that with the replacement of 10% of marble dust with cement, the compressive strength increases and further any replacement of marble dust with concrete the compressive strength decreases. Same case in the split tensile strength of cylinder, As 10% replacement of marble dust with cement the split tensile strength increases and further any replacement of marble dust the split tensile strengthdecreases. Thus they found that the optimum percentage for replacement of marble powder with cement and it is almost 10% cement for both cubes and cylinders.

2.3 SUPERPLASTICIZER

Manjrekar (1994), carried out the investigation that the super-plasticizers are in use in concrete for nearly one and a half decades, there are still some bad in certain quarters in using them. The researcher also tried to give answer some questions that arise in the minds of practicing engineers, consultants and others users.

Park and Seung (1999), studied that the properties of super-plasticized concrete have an appreciable fludifying action in fresh concrete. They permitted a significant water reduction while maintaining the same workability. Bleeding of super-plasticized concrete was much lower than that of conventional concrete of the same consistency. Hence, they concluded that super-plasticizer did not affect the tendency of segregation of fresh concrete. The compressive, tensile and flexural strength of super-plasticized concrete were significantly higher than those of conventional concrete.

Kim et al. (2000),investigated the adsorption behaviour of a polynaphthalenesulfonate (PNS) super-plasticizer and its relation to the fluidity of cement paste for six cements at a given dosage of PNS super-plasticizer. The incompatible cements have a higher adsorption capacity of PNS super-plasticizer because of a lack of soluble alkali sulphates. There is an inverse relationship between the amount of PNS adsorbed and the mini-slump area value of the cement pastes at 30 min, i.e. the higher the amount of PNS adsorbed, the lower the initial slump value, and the higher the slump loss. The addition of some Na_2SO_4 contributes to increase the slump area by reducing the amount of PNS adsorbed. Moreover, it has been found that additional calcium sulphate does not prevent the adsorption of PNS on cement particles as sodium sulphate does in cement pastes having W/C = 0.35. The contribution of alkali sulphate on dispersing mechanism of PNS super-plasticized cement pastes is explained in relation with initial slump and its loss.

Percheet al. (2003), concluded that the adsorption of super-plasticizers onto cement particles is a key factor in the rheology of cement and concrete. The adsorbed amount is generally measured as the difference between the amount of polymer present in the aqueous phase before and after contact with cement(depletion method).Adsorption isotherms of well characterized lignosulfonate and polycarboxylate admixtures have been measured on a model powder (MgO) using the depletion method and on an ultrafine cement by using an electroacoustic method. The method allowed us to follow the variation of zeta potential of the same suspensions as a function of increasing amounts of super-plasticizers. It was found that the influence of the adsorption of super-plasticizers on zeta potential measured by electroacoustic technique are significantly lower than those measured earlier with preceding instruments. The electroacoustic method is useful for studying the adsorption of super-plasticizers. It measures zeta potential values necessary for inter-particle force calculations. Differences in polymer structures and the effect of different ions on polymer adsorption can be observed.

Veronezet al. (2006), concluded that the kind of chemical and mineral admixture can influence on the fresh and hardened properties of the concretes and mainly on high-performance concretes (HPC), where great amounts of super-plasticizers and cementitious materials are required. The physical and mechanical properties of an experimental investigation of the effect of the use of different kinds of super-plasticizers and mineral admixtures to produce an 80 MPa at 28 days high performance concrete. Metakaolin and silica fume HPC are produced using naphthalene or polycarboxylate based super-plasticizers (or mixture of them) as chemical admixture to lead the concrete mixtures to 100 ± 20 mm slump consistence. Different kinds of super-plasticizers have not great meaning on the mechanical properties at 28 days for silica fume and metakaolin HPC, when maintaining the same physical properties in fresh state. But at the first 7 days, the behaviours are little different.

Rashid and Mansur (2009), investigated that the use of quality materials, smaller water-binder ratio, larger ratio of coarse aggregate (CA) to fine aggregate (FA), smaller size of coarse aggregate and suitable admixtures with their optimum dosages are found necessary to produce HSC. The targeted strengths of concretes were from 60 MPa to 130 MPa. A larger ratio of CA to FA (1.81 except one mix of 1.60) was considered while the variables considered were the water-binder ratio (from 0.34 to as low as 0.20) and the super-plasticizer binder ratio (from 0.73% to 2.95%). Test results are found to support the reviewed information on HSC production, the water binder ratio and the suitable admixtures with their optimum dosages are found to be the most important parameters for producing HSC.

Bhikshmaet al. (2009),reported that high performance concrete are being widely used all over the world. Most applications of high strength concrete have been in high rise buildings, long span bridges and in some special applications in structures. In high strength concrete, it is necessary to reduce the water/cement ratio and which in general increases the cement content. To overcome low workability problem, different kinds of pozzolanic mineral admixtures fly ash, rice husk ash, metakaoline, etc. and chemical admixtures are used to achieve the required workability. They revealed that the use of waste material like silica fume improved the mechanical properties of high strength concrete with partial replacement of cement.

Nuruddinet al. (2010), concluded that the increase production of Portland cement causes great concern on the environment because of high carbon footprint. Besides CO_2 emission, quarrying of raw materials (limestone and clay) for the production of cement is becoming the source of environmental degradation. On the other hand, waste disposal is also becoming a global issue because of its costly disposal. The complete elimination of Portland cement for production of concrete that can achieve 90 days cube strength in the range of 40-50 MPa with the emphasis on the curing techniques applicable for in-situ construction; namely hot gunny sacks, ambient and external exposure curing. The fly ash acts as a base source material and silica fume as replacements of fly ash by 3%, 5% and 7%. Sodium hydroxide and sodium silicate solution used as activators of silica (Si) and aluminium (Al) in source material and sugar based material is incorporated in the mix to increase the setting time of concrete. Compressive strength and Scanning Electron Microscopy (SEM) tests are conducted on the specimens at 3, 7, 28, 56and 90 days the fly ash along with silica fume are good replacements of cement. Compressive strength of external exposure curing for the polymeric concrete reaches up to 51.36 MPa at 90 days.

Mazloom and Ranjbar (2010), determined the results of an experimental research on the workability and compressive strength of self-compacting concrete. The concrete mixes having water/binder ratios of 0.35 and 0.45, which contained constant total binder contents of 500 kg/m^3 and 400 kg/m^3, respectively. The concrete mixes contained four different dosages of a super-plasticizer based on carboxylic with and without silica fume. 10% silica fume was replaced by the cement. The workability tests utilized were the slump flow, V-funnel, L-box, and J-ring, which can be used to evaluate the passing ability of self-compacting concrete. Based upon the experimental results, the relation between the compressive strength and workability of concrete mixes were linear when the w/c ratio and other mix proportions were constant. The effects of silica fume and the dosage of the super-plasticizer were higher on improving the compressive strength when the w/c ratio was lower.

Ramli and Dawood (2011), studied the comparison between high strength flowing concrete (HSFC) and high strength flowing mortar (HSFM) from the view of density, compressive strength and flexural strength at the age of 7 and 28 days. The use of silica fume (10% as a partial replacement of cement) and super-plasticizer (1.6-2.2% of cementitious materials) give the properties of high flow ability with the high strength for each of concrete and mortar mixes. Besides, the compressive strength and flexural strength for each of mortar and concrete have been enhanced by the inclusion of silica fume.

Katzer(2011),concluded the results of steel fibre reinforced cement composites (SFRCC) modified by super-plasticizers based on different chemical substances. The SFRCC were made on the basis of fine aggregate cement matrix modified by steel fibres of an aspect ratio l/d= 50. Fine aggregate matrix composed of waste aggregate (obtained during hydro classification) was modified by an addition from 0% to 2.8% (by volume) of hooked steel fibres and 1% of super-plasticizer. After establishing basic parameters of fresh mix and hardened fibre reinforced composites, the main tests were a drop-weight test of the SFRCC plates and dynamic harmonic loading of beams. The results specify the influence of the specific super-plasticizer on the behaviour of SFRCC subjected to a dynamic force. Super-plasticizers based on polycarboxylate (PC3), Super-plasticizers based on polyether (PE) and Super-plasticizers based on silica fume (CRSP) admixtures; represent three groups of most frequently used Super-plasticizers. The number of impact loading until the appearance of first crack n_{crack} is the same for all three super-plasticizers. The total number of dynamic loading of all SFRCC plates modified by the CRSP admixture is the highest one. It is nearly four and five times higher than number of dynamic loading of plates modified by the PE and PC3 admixtures, respectively. The total duration of dynamic loading of all SFRCC beams modified by PC3 admixture is the highest one. It is nearly 13% and 24% higher than the duration of a dynamic loading of all the beams modified by the CRSP and PE admixtures, respectively.

3.1 GENERAL

The present chapter deals with the presentation of results obtained from various tests conducted on material used for developing pavement quality concrete. In order to achieve the objectives of present study, an experimental program was planned to investigate the effect of marble dust and steel fibre on compressive strength, split tensile strength and flexure strength of concrete.

3.2 MATERIALS

The properties of material used for making concrete mix are determined in laboratory as per relevant codes of practice. Different materials used in present study were cement, coarse aggregates, fine aggregates, and super-plasticizer, in addition to marble dust and steel fibres. The aim of studying of various properties of material is used to check the appearance with codal requirements and to enable an engineer to design a concrete mix for a particular strength. The description of various materials which were used in this study is given below:

3.2.1 Portland Cement

Although all materials that go into concrete mix are essential, cement is very often the most important because it is usually the delicate link in the chain. The function of cement is first of all to bind the sand and stone together and second to fill up the voids in between sand and stone particles to form a compact mass. It constitutes only about 20 percent of the total volume of concrete mix; it is the active portion of binding medium and is the only scientifically controlled ingredient of concrete. Any variation in its quantity affects the compressive strength of the concrete mix. Portland cement referred as (Ordinary Portland Cement) is the most important type of cement and is a fine powder produced by grinding Portland cement clinker. The OPC is classified into three grades, namely 33 Grade, 43 Grade, 53 Grade depending upon the strength of 28 days. It has been possible to upgrade the qualities of cement by using high quality limestone, modern equipments, maintaining better particle size distribution, finer grinding and better packing. Generally use of high grade cement offers many advantages for making stronger concrete. Although they are little costlier than low grade cement, they offer 10-20% saving in cement consumption and also they offer many hidden benefits. One of the most important benefits is the faster rate of development of strength.

Ordinary Portland Cement (OPC) of 43 Grade (UltraTech cement) from a single lot was used throughout the course of the investigation. It was fresh and without any lumps. The physical properties of the cement as determined from various tests conforming to Indian Standard IS: 8112:1989 are listed in Table 3.1. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture

Table 3.1 Properties of OPC 43 Grade Concrete

Sr.No.	Characteristics	Values Obtained Experimentally	Values Specified By IS 8112:1989
1.	Specific Gravity	3.10	-
2.	Standard Consistency, percent	27	-
3.	Initial Setting Time, minutes	149	30 (minimum)
4.	Final Setting Time, minutes	257	600 (maximum)
5.	Compressive Strength 3 days 7 days 28 days	 27.8 N/mm^2 36.5 N/mm^2 48.6 N/mm^2	 23 N/mm^2(minimum) 33 N/mm^2(minimum) 43 N/mm^2(minimum)

3.2.2 Aggregate

Aggregates constitute the bulk of a concrete mixture and give dimensional stability to concrete. To increase the density of resulting mix, the aggregates are frequently used in two or more sizes. The most important function of the fine aggregate is to assist in producing workability and uniformity in mixture. The fine aggregate assist the cement paste to hold the coarse aggregate particles in suspension. This action promotes plasticity in the mixture and prevents the possible segregation of paste and coarse aggregate, particularly when it is necessary to transport the concrete some distance from the mixing plant to placement. The aggregates provide about 75% of the body of the concrete and hence its influence is extremely important. They should therefore meet certain requirements if the concrete is to be workable, strong, durable and economical. The aggregates must be proper shape, clean, hard, strong and well graded.

a) Coarse Aggregates: The aggregate which is retained over IS Sieve 4.75 mm is termed as coarse aggregate. The coarse aggregates may be of following types:-

i) Crushed graves or stone obtained by crushing of gravel or hard stone.

ii) Uncrushed gravel or stone resulting from the natural disintegration of rocks.

iii) Partially crushed gravel or stone obtained as product of blending of above two types.

The normal maximum size is gradually 10-20 mm; however particle sizes up to 40 mm or more have been used in Self Compacting Concrete. Gap graded aggregates are frequently better than those continuously graded, which might expensive grader internal friction and give reduced flow. Regarding the characteristics of different types of aggregate, crushed aggregates tend to improve the strength because of interlocking of angular particles, while rounded aggregates improved the flow because of lower internal friction.

The coarse aggregate used were a mixture of two locally available crushed stone of 20 mm and 10 mm size in 70:30 proportion. The aggregates were washed to remove dirt, dust and then dried to surface dry condition.

Specific gravity and other properties of coarse aggregates are given in Table 3.2. The sieve analysis of coarse aggregate was done. Table 3.3& Table 3.4 show the result of sieve analysis. Proportioning of coarse aggregates was done and fineness modulus was obtained.

Table 3.2 Properties of Coarse Aggregates

Characteristics	Value
Colour	Grey
Shape	Angular
Maximum Size	20 mm/10mm
Specific Gravity	2.73/2.72
Water Absorption	0.20%/0.35%

Table 3.3 Sieve Analysis of Coarse Aggregate (20 mm) .

Weight of sample taken = 3000gm					
Sr. No	**IS-Sieve (mm)**	**Wt. Retained (gm)**	**%age retained**	**%age passing**	**Cumulative % retained**
1	80	0.00	0.00	100.00	0.00
2	40	0.00	0.00	100.00	0.00
3	20	53.00	1.77	98.23	1.77
4	10	2938.50	97.95	0.28	99.72
5	4.75	5.50	0.18	0.10	99.90
6	Pan	3.00	0.10	0.00	
	Total	**3000.00**		**SUM**	**201.38 + 500 = 701.38**
				FM =	*7.01*

TABLE 3.4 Sieve Analysis of Coarse Aggregate (10 mm)

Weight of sample taken = 3000gm.					
Sr. No	**IS-Sieve (mm)**	**Wt. Retained (gm)**	**%age retained**	**%age passing**	**Cumulative % retained**
1	100	0.00	0.00	100.00	0.00
2	80	0.00	0.00	100.00	0.00
3	40	0.00	0.00	100.00	0.00
4	20	0.00	0.00	100.00	0.00
5	10	2012.00	67.07	32.93	67.07
6	4.75	958.00	31.93	1.00	99.00
7	Pan	30.00	1.00	0.00	
	Total	**3000.00**		**SUM**	**166.07 + 500 = 666.07**
				FM =	*6.66*

b) Fine Aggregates: The aggregates most of which pass through 4.75 mm IS sieve are termed as fine aggregates. The fine aggregate may be of following types:

i) Natural sand, i.e. the fine aggregate resulting from natural disintegration of rocks.

ii) Crushed stone sand, i.e. the fine aggregate produced by crushing hard stone.

iii) Crushed gravel sand, i.e. the fine aggregate produced by crushing natural gravel.

According to size, the fine aggregate may be described as coarse, medium and fine sands. Depending upon the particle size distribution IS: 383-1970 has divided the fine aggregate into four grading zones (Grade I to IV). The grading zones become progressively finer from grading zone I to IV.

In this experimental program**,** fine aggregates (stone dust) were collected from Jhelum Stone Crusher, Mirthal, Pathankot and conforming to grading zone II. It was coarse sand light brown in colour. The sand was sieved through 4.75 mm sieve to remove particles greater than 4.75 mm size. Sieve analysis and physical properties of fine aggregate are tested as per IS: 383-1970 and results are shown in Table 3.5. Specific gravity of fine aggregates was experimentally determined as 2.49. Sieve analysis of fine aggregates was performed to get Fineness Modulus.

c) Marble Dust

Marble dust was collected from Ashoka Marbles, ITI Chowk, Bathinda. It was white in colour and it was air dried and powder in form. It was sieved through 4.75 mm sieve so as to find the percentage fineness as shown in Table 3.6. The specific gravity of marble powder was experimentally determined as 2.47.

Table 3.5 Sieve Analysis of Fine Aggregate

Weight of sample taken =1000 gm.					
Sr. No.	**IS-Sieve (mm)**	**Wt. Retained (gm)**	**%age retained**	**%age passing**	**Cumulative % retained**
1	4.75	6	0.6	99.4	0.6
2	2.36	59	5.9	93.5	6.5
3	1.18	220	22	71.5	28.5
4	600 µ	159	15.9	55.6	44.4
5	300 µ	316.5	31.65	23.95	76.05
6	150 µ	196.5	19.65	4.3	95.70
7	Pan	43	4.3	0.0	
	Total	**1000.00**		**SUM**	**251.75**
				FM =	*2.51*

Table 3.6 Sieve Analysis of Marble Dust

Weight of sample taken =100 gm.					
Sr. No	**IS-Sieve**	**Wt. Retained (gm)**	**%age Wt. Retained**	**% age passing**	**Cumulative % retained**
1	4.75 mm	0	0	100	0
2	2.36 mm	0	0	100	0
3	1.18 mm	0	0	100	0
4	600 µ	8	8	92	8
5	300 µ	11	11	81	19
6	150 µ	81	81	0	100
7	PAN	0	0	SUM = 127	F.M. = 1.27

The 90 % particle size of marble powder ranges between 150µ to 600µ

d) Steel Fibre

Mild steel fibres having 30 mm thickness and 60 mm length i.e. aspect ratio (l/d) 50 which are corrugated and obtained through cutting of steel wires have been used. The fibres have been cut by fibre cutting machine to an accurate size. Three different proportions of fibres i.e. 0%, 0.5% and 1% have been used. Properties of steel fibre used are tabulated in 3.7.

Table 3.7 Properties of Steel Fibres

Average Thickness	30 mm
Length	60 mm
Density	7850 kg/m^3
Tensile Strength	8500 kg/m^3
Shape	Crimped steel fibre

3.2.3 SUPERPLASTICIZER

Super-plasticizers constitute a relatively new category and improved version of plasticizer. They are chemically different from normal plasticizers. Use of super-plasticizer permits the reduction of water to the extent up to 30 percent without reducing workability in contrast to possible reduction up to 15 percent in case of plasticizers. The mechanism of action of super-plasticizer is more or less same as in case of ordinary plasticizer. The super-plasticizers are more powerful as dispersing agents and they are high water reducers. It is use of super-plasticizer which has made it possible to use w/c as low as 0.25 or even lower and yet to make flowing concrete to obtain compressive strength of the order of 120 MPa or more (Shetty 2005). It is the use of super-plasticizer which has made it possible to use fly ash, slag and particularly silica fume to make high performance concrete.

Super-plasticizers are also often used when pozzolanic ash is added to concrete to improve strength. This method of mix proportioning is especially popular when producing high-strength concrete and fibre reinforced concrete. Adding 1-2% super-plasticizer per unit weight of cement is usually sufficient. However, note that most commercially available super-plasticizers come dissolved in water, so the extra water added has to be accounted for in mix proportioning. Adding an excessive amount of super-plasticizer will result in excessive segregation of concrete and is not advisable. Some studies also show that too much super-plasticizer will result in a retarding effect (Shetty, 2005).

Super-plasticizers are chemical admixtures that can be added to concrete mixtures to improve workability. Unless the mix is “straved” of water, the strength of concrete is inversely proportional to amount of water added or water-cement (w/c) ratio. In order to produce stronger concrete, less water is added which makes the concrete mixture very unworkable and difficult to mix, necessitating the use of plasticizers, water reducers, super-plasticizer or dispersants.

The superplasticizer “GLENIUM™ B233” procured from SIKA India Pvt. Limited was used in present study. The technical data provided by manufacturer is given in Table 3.8

Table 3.8 Properties of Superplasticizer

Sr. No.	Characteristics	Value
1.	Type	Polycarboxylic ether (PCE)
2.	Form	Liquid
3.	Colour	Light Brown
4.	Specific Gravity	1.09
5.	Relative density	1.09 ± 0.01 at 25^0C
6.	pH Content	> 6
7.	Setting Time	There may be mild extension of initial or final set

The dosage of superplasticizer recommended is 0.6% to 2% by weight of cementitous material. 1% superplasticizer by weight of cementitious material was selected in this study to get the medium range of workability.

3.2.4 WATER

The potable water is generally considered satisfactory for mixing and curing of concrete. Accordingly potable water was used for making concrete available in Material Testing laboratory. This was free from any detrimental contaminants and was good potable quality.

3.3TEST METHODS

The procedure of methods used for testing cement, coarse aggregates, fine aggregate and concrete are given below:

3.3.1 Specific Gravity

Specific gravity is ratio of the weight of a given volume of a substance to the weight of an equal volume of some reference substance, or equivalently the ratio of the masses of equal volumes of two substances.

3.3.2 Sieve Analysis for Coarse and Fine Aggregates as per IS: 2386 (Part I) – 1963

The sieve analysis is used for the determination of particle size distribution of fine and coarse aggregates by sieving or screening.

3.3.3 Compressive Strength of Concrete:

Cube specimens of size 150 mm x 150 mm x 150 mm were taken out form the curing tank at the ages of 28 days and tested immediately on removal from the water (while they were still in the wet condition). Surface water was wiped off, the specimens were tested. The position of cube when tested was at right angle to that as cast. The load as applied gradually without shock till the failure of the specimen occurs and thus the compressive strength was found.

The quantities of cement, coarse aggregate (20 mm and 10 mm), fine aggregate, marble dust and water for each batch i.e. for different percentage of marble dust replacement was weighed separately. The cement and marble dust were mixed dry to a uniform colour separately. The coarse aggregates were mixed to get uniform distribution throughout the batch. Water added to the mix and then super-plasticizer was added. Firstly, 50 to 70% of water was added to the mix and then mixed thoroughly for 3 to 4 minutes in mixer. Super-plasticizer was added in the remaining was and stirred to have uniform mix, added to the mix and then thoroughly mixed for further 2 to 3 minutes in mixer. Then the concrete was filled into the cube moulds and then get vibrated to ensure proper compaction. The surface of the concrete was finished level with the top of the mould using trowel. The finished specimens were left to harden in air for 24 hours. The specimens were removed from the moulds after 24 hours of casting and were placed in the water tank, filled with potable water in the laboratory.

3.3.4 Split Tensile Strength of Concrete:

The split tensile strength of concrete is determined by casting cylindersof size 150 mm X 300 mm. The cylinders were tested by placing them uniformly. Specimens were taken out from curing tank at age of 28 days of moist curing and tested after surface water dipped down from specimens. This test was performed on Universal Testing Machine (UTM). The magnitude of tensile stress (T) acting uniformly to the line of action of applied loading is given by formula

$$T= 0.637P/dl$$

Where,

T = Split Tensile Strength in MPa

P = Applied load,

D = Diameter of Concrete cylinder sample in mm.

L =Length of Concrete cylinder sample in mm.

The quantities of cement, coarse aggregate (20 mm and 10 mm), fine aggregate, marble dust and water for each batch i.e. for different percentage of marble dust replacement was weighed separately. The cement and marble dust were mixed dry to a uniform colour separately. Fine aggregate was mixed to this mixture in dry form. The coarse aggregates were mixed to get uniform distribution throughout the batch. Water added to the mix and then super-plasticizer was added. Firstly, 50 to 70% of water was added to the mix and then mixed thoroughly for 3 to 4 minutes in mixer. Super-plasticizer was added in the remaining mix and stirred for further 2 to 3 minutes in mixer to have uniform mix. Then the concrete was filled into the cylindrical moulds and then get vibrated to ensure proper compaction. The surface of the concrete was finished level with the top of the mould using trowel. The finished specimens were left to harden in air for 24 hours. The specimens were removed from the moulds after 24 hours of casting and were placed in the water tank, filled with potable water in the laboratory.

3.4 MIX DESIGN OF PAVEMENT QUALITY CONCRETE (PQC)

Step 1: As per clause **602** of MORTH Specification

- Cement – 43 grade OPC as per **IS 8112** as per **602.2.2**
- Coarse aggregate – 20 mm and 10 mm as per **602.2.4**
  Los angles Abrasion value not greater than 35%
  Impact value not greater than 30%
- Fine aggregate – Natural sand as per **IS 383**
- Admixture – Conplast AEA (if required)
  Air entrained concrete 5% maximum (optional)

Step 2: Design Parameter:

1. Characteristics flexural strength required at 28 days = 4.5 N/mm^2
2. Maximum water cement ratio = 0.40 as per clause **602.3.3.1**
3. Maximum size of coarse aggregate = 25 mm
4. Degree of quality control = Good
5. Minimum cement content = 350 kg/m^3 as per clause **602.3.2**
6. Maximum cement content = 425 kg/m^3 as per clause **602.3.2**

Step 3: Calculation of fine aggregate content:

After determining the weight per cubic meter of cement, water, coarse aggregate and percentage of air content, the fine aggregate is calculated so as to produce one cubic meter of concrete using absolute volume method. On converting the weight per cubic meter into volume, we have

(a) Volume of cement = $\dfrac{Weight\ of\ cement}{Specific\ gravity\ of\ cement\ X\ 1000}$

(b) Volume of coarse aggregate = $\dfrac{Weight\ of\ coarse\ aggregate}{Specific\ gravity\ of\ coarse\ aggregate\ X\ 1000}$

(c) Volume of water = $\dfrac{Weight\ of\ water}{1000}$

(d) Volume of fine aggregate = 1 – {Volume of cement + coarse aggregate + water + Air content}

(e) Weight of fine aggregate = Volume of fine aggregate × specific gravity ×1000

Now by following the above steps for mix design, the mix proportion for different compressive strengths are calculated by using the following data:

Specific gravity of cement = 3.10

Specific gravity of fine aggregate = 2.49

Specific gravity of coarse aggregate, 20mm= 2.73

Specific gravity of coarse aggregate, 10mm= 2.72

Slump value = 50 to 70 mm

The proportions for different pavement quality concrete mixtures are tabulated in Table 3.9

Table 3.9 Proportions for Pavement Quality Concrete Mixtures

Mean Target Flexure strength (MPa)	**Max. Size of Aggregate, (mm)**	**Mix proportions (C:FA:CAI:CAII)**	**W/C Ratio**	**Materials for 1 m³ in kg**				
				Water	*Cement*	*F.A*	*C.AI(20)*	*C.AII(10)*
4.5	20	1:1.828:1.936:0.83	0.4	156	390	713	755.30	323.70
5	20	1:1.815:1.921:0.82	0.35	140	400	726	768.60	329.40
5.5	20	1:1.805:1.908:0.82	0.3	123	410	740	782.60	335.40
The estimated values of the steel fibre contents are = 40 kg/m³ (for 0.5%) and 80 kg/m³ (for 1%)								

Step 4: Estimation of fibre content:

The fibre content is taking as 0.5 percent by volume. Therefore

0.5% by volume = $\frac{0.005 X\ Unit\ weight\ of\ fibre}{0.995\ X\ Unit\ weight\ of\ concrete} \times 100$= % by weight

We have, Unit weight of fibre = 7860 kg/m³

Unit weight of concrete = 2300 kg/m³

0.5% by volume = $\frac{0.005 \times 7860}{0.995 \times 2300} \times 100$ = 1.7173% by weight

0.5% fibre by volume = $\frac{\%\ by\ weight}{100} \times Unit\ weight\ of\ concrete\ in\ kg/m^3$

0.5% fibre by volume = $\frac{1.7173 \times 2300}{100}$ = 39.4979 kg/m^3 = 40 kg/m^3(approx.)

Fibre content = 40 kg/m^3

CHAPTER-4
RESULTS AND DISCUSSION

4.1 GENERAL

This chapter deals with the presentation of results obtained from various tests conducted on material used for developing pavement quality concrete. In order to achieve the objectives of present study, an experimental program was planned to investigate the effect of marble dust and steel fibre on flexural strength, compressive strength and split tensile strength of concrete so as to assess its feasibility for use in highway pavement. The experimental program consists of casting, curing and testing of controlled and marble dust-steel fibre concrete specimen at different ages.

The experimental program included the following:

- Testing of properties of materials used for making concrete.
- Design of mixes for pavement quality concrete and steel fibre reinforced concrete by making trials.
- Casting and curing of specimens.
- Tests to determine the flexural strength, compressive strength and Split Tensile strength of high strength steel fibre reinforced concrete.

4.2 COMPRESSIVE STRENGTH

4.2.1 General

In most structural applications, concrete is employed primarily to resist compressive stresses.When a plain concrete member is subjected to compression, the failure of the member takes place, in its vertical plane along the diagonal. The vertical crack occurs due to lateral tensile strains. A flow in the concrete, which is in the form of micro crack along the vertical axis of the member will take place on the application of axial compression load and propagate further due to the lateral tensile strains. If the concrete contains steel fibres, the crack propagation gets effectively arrested by the fibres oriented at the right angle to the axis of loading. The lateral tensile strain is resisted by the fibres and hence the compressive strength of the member is increased.

4.2.2 Test Procedure and Results

Test specimens of size $150 \times 150 \times 150$ mm were prepared for testing the compressive strength of both controlled as well as marble dust-steel fibre reinforced pavement quality concrete. The modified concrete mixtures with varying percentages of steel fibres and partial replacement of cement with marble dust were prepared and cast into cubes.

In this study, the mix was done by manually. The cement and fine aggregate were first mixed dry to uniform colour and then coarse aggregate was added and mixed with the mixture of cement and fine aggregates. Water was then added and the whole mass mixed. In case of SFRC the fibres were added just before adding water and mixed dry thoroughly. Same in the case of marble dust, cement in different percentages was replaced with marble dust and added before adding water. The interior surface of the moulds and the base plate were oiled before concrete was placed. After 24 hours the specimens were removed from the moulds and placed in clean fresh water at a temperature of $27^0 \pm 2^0$C for 28 days curing. For testing in compression, no cushioning material was placed between the specimen and the plates of the machine. The load was applied axially without shock till the specimen was crushed. Test results of compressive strength test at the age of 28 days are given in the Table 4.1. The cube strength results of concrete mix are also shown graphically.

4.3 FLEXURAL STRENGTH

4.3.1 General

The most common concrete structure subjected to flexure is a highway or airway pavement and strength of concrete for pavements is commonly evaluated by means of bending tests. When concrete is subjected to bending, then tensile and compressive stresses and in many cases direct shear stresses are developed.

When fibre reinforced concrete and composite beams are loaded in pure bending, then the tensile strains develop. The load at first crack would increase with respect to steel fibre reinforced concrete due to crack arresting mechanism of the closely spaced fibres. After the concrete matrix cracks, the fibres continue to take higher load which is provided. Thus the ultimate flexural strength is increased.

4.3.2 Test Procedure and Results

Test specimens of beam size 150 mm $\times$ 150 mm $\times$ 700 mm were prepared for testing the flexural strength of steel fibre reinforced concrete and replacement of cement with marble dust in different percentages.

The beam moulds containing the test specimens were placed in moist air (at least 90% relative humidity) and a temperature of $27^0 \pm 2^0$ C for 24 hours $\pm$ 1/2hour from the time of addition of water to the dry ingredients. After this the specimens were removed from the moulds and placed in clean fresh water at a temperature of $27^0 \pm 2^0$ C for the remaining curing period. After 28 days of curing the specimens were tested in flexure on a Universal Testing Machine. Loads were applied at the one third points at a constant rate of 30 kg/minute. The distance between the centres of two rollers was kept 20 cm.

If the fracture occurred within the central one-third of the beam, the flexural strength was calculated on the basis of ordinary elastic theory using the following equations:

$F_b = \frac{PL}{BD^2}$, when 'a' is greater than 20 cm for 15 cm specimen

$F_b = \frac{3Pa}{BD^2}$, when 'a' is less than 20 cm but greater than 17 cm for 15 cm specimen

Where,

F_b = Flexural Strength of the specimen in N/mm^2

B = Width of the specimen (= 150 mm)

D = Depth of the specimen (= 150 mm)

L = Span of the specimen (= 700 mm)

P = Maximum load in Newton (N) applied to the specimen

a = Distance b/w the line of fracture and nearer support, measured on the centre line of thetensile side of the specimen in cm, shall be calculated to the nearest 0.5 kg/cm^2.

If 'a' is less than 17 cm the results of a test shall be discarded. Test results of flexural test at the age of 28 days curing are given in Table 4.2. The flexural strength results of concrete mix are also shown graphically.

4.4SPLIT TENSILE STRENGTH

The split tensile strength of all the mixes was determined at the ages 28 days for various replacement levels of marble dust and additional percentages of steel fibres in concrete mix. The results of split tensile strength of concrete are reported in Table 4.3. Table 4.3 shows the gain in split tensile strength for different levels of marble dust replacement with concrete and addition of steel fibre at different time. The split tensile strength results of individual concrete mix are also shown graphically. The maximum values of split tensile strength of concrete with addition of 1% steel fibre and 0% marble dust replacement for pavement quality concrete designed for flexural strength of 4.5 N/mm^2, 5N/mm^2, 5.5 N/mm^2, respectively, at 28 days are 4.64 N/mm^2, 5.12 N/mm^2 and 5.55 N/mm^2.

From the results, it is observed that the optimum value of split tensile strength is achieved with addition of 1% of steel fibre in controlled concrete mix. Test results of split tensile strength at the age of 28 days curing are given in Table 4.3

Table 4.1 Compressive Strength Test Results

CUBE SRENGTH (MPa)									
w/c ratio	MD-0% / SF-0%(MF00)	MD-10% /SF-0%(MF10)	MD-20%/SF-0%(MF20)	MD-0%/SF-0.5% (MF01)	MD-10%/SF-0.5%(MF11)	MD-20%/SF-0.5%(MF21)	MD-0%/SF-1%(MF02)	MD-10%/ SF-1%(MF12)	MD-20%/SF-1%(MF22)
0.3	52.13	48.44	24.21	58.37	54.76	49.28	93.15	85.16	72.25
0.35	45.70	46.24	21.90	56.85	51.84	46.51	72.56	68.57	64.64
0.4	40.70	44.89	14.90	50.98	48.72	38.89	64.12	59.86	54.46

Table 4.2 Flexural Strength Results

FLEXURE SRENGTH (MPa)									
w/c ratio	MD-0% / SF-0%(MF00)	MD-10% /SF-0%(MF10)	MD-20%/SF-0%(MF20)	MD-0%/SF-0.5% (MF01)	MD-10%/SF-0.5%(MF11)	MD-20%/SF-0.5%(MF21)	MD-0%/SF-1%(MF02)	MD-10%/ SF-1%(MF12)	MD-20%/SF-1%(MF22)
0.3	6.10	5.89	5.45	6.14	6.30	5.86	7.27	6.73	6.14
0.35	5.70	5.69	4.78	6.00	5.88	5.67	6.68	6.21	5.89
0.4	4.90	4.60	4.18	5.87	5.16	4.89	6.10	5.69	5.45

Table 4.3 Split Tensile Strength Results

SPLIT TENSILE SRENGTH (MPa)									
w/c ratio	MD-0% /SF-0%	MD-10% /SF-0%	MD-20%/SF-0%	MD-0%/SF-0.5%	MD-10%/SF-0.5%	MD-20%/SF-0.5%	MD-0%/SF-1%	MD-10%/ SF-1%	MD-20%/SF-1%
0.3	3.61	3.48	2.46	3.82	3.70	3.51	5.55	5.15	4.25
0.35	3.38	3.40	2.34	3.77	3.60	3.41	5.12	4.58	4.02
0.4	3.19	3.35	1.93	3.57	3.49	3.11	4.64	4.35	3.69

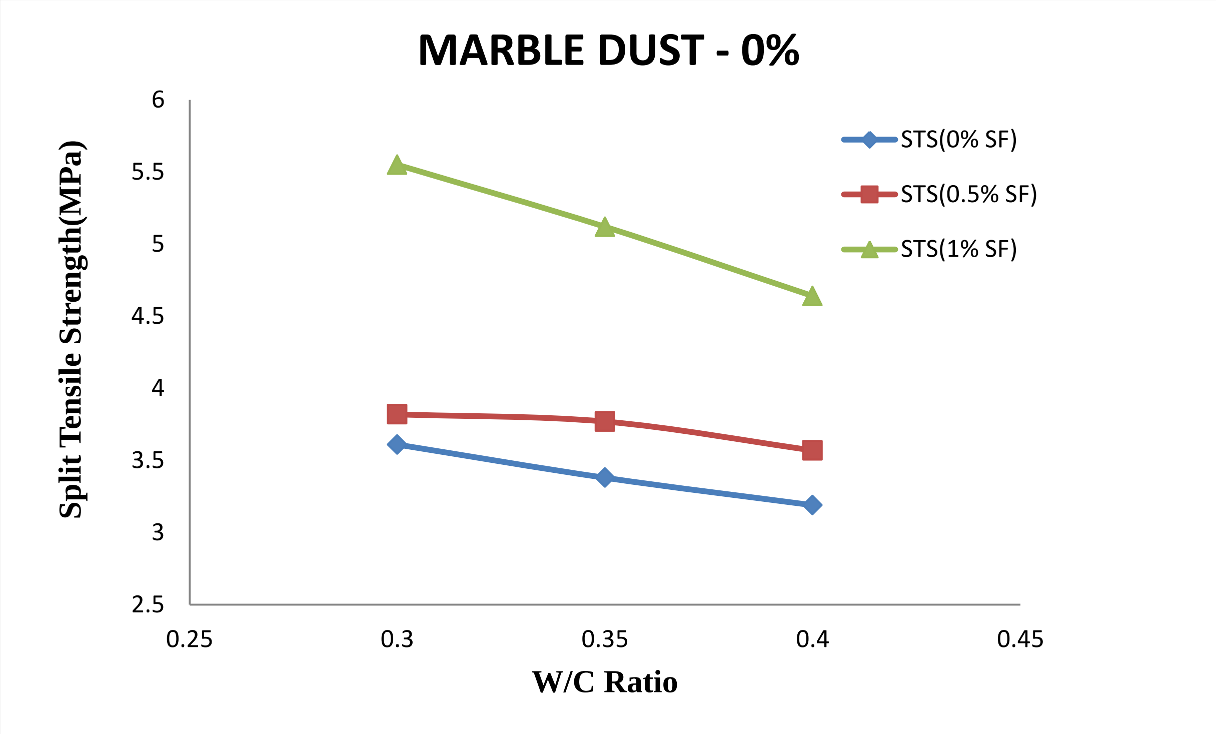


Fig. 4.1 Variation of split tensile strength of concrete with different W/C for 0% M.D and different percentage of S.F.

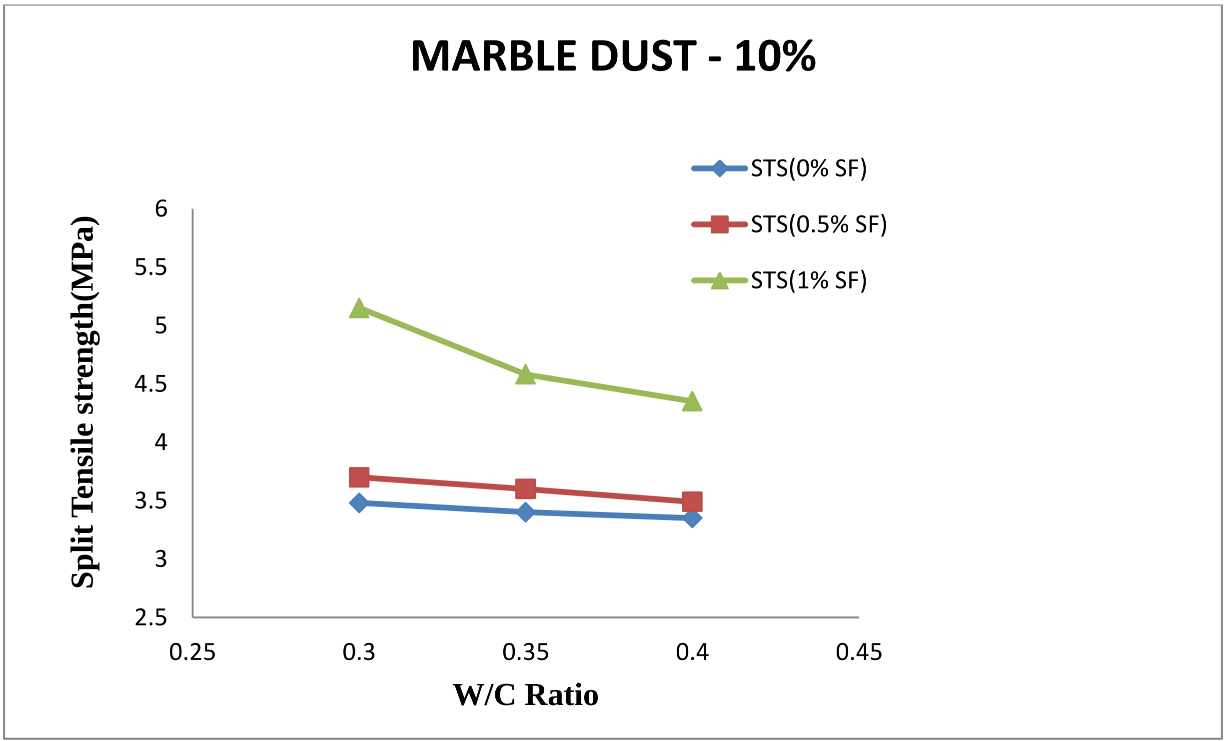


Fig. 4.2 Variation of split tensile strength of concrete with different W/C for 10% M.D and different percentage of S.F.

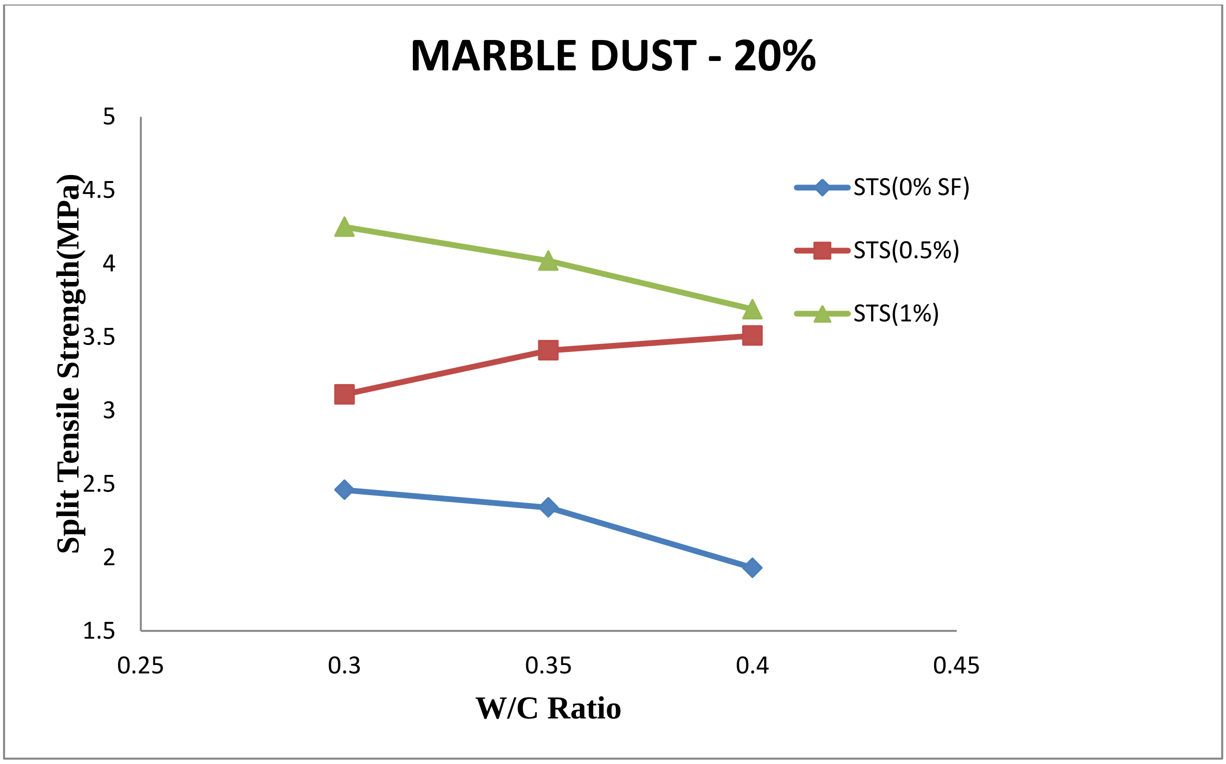


Fig. 4.3 Variation of split tensile strength of concrete with different W/C for 20% M.D and different percentage of S.F.

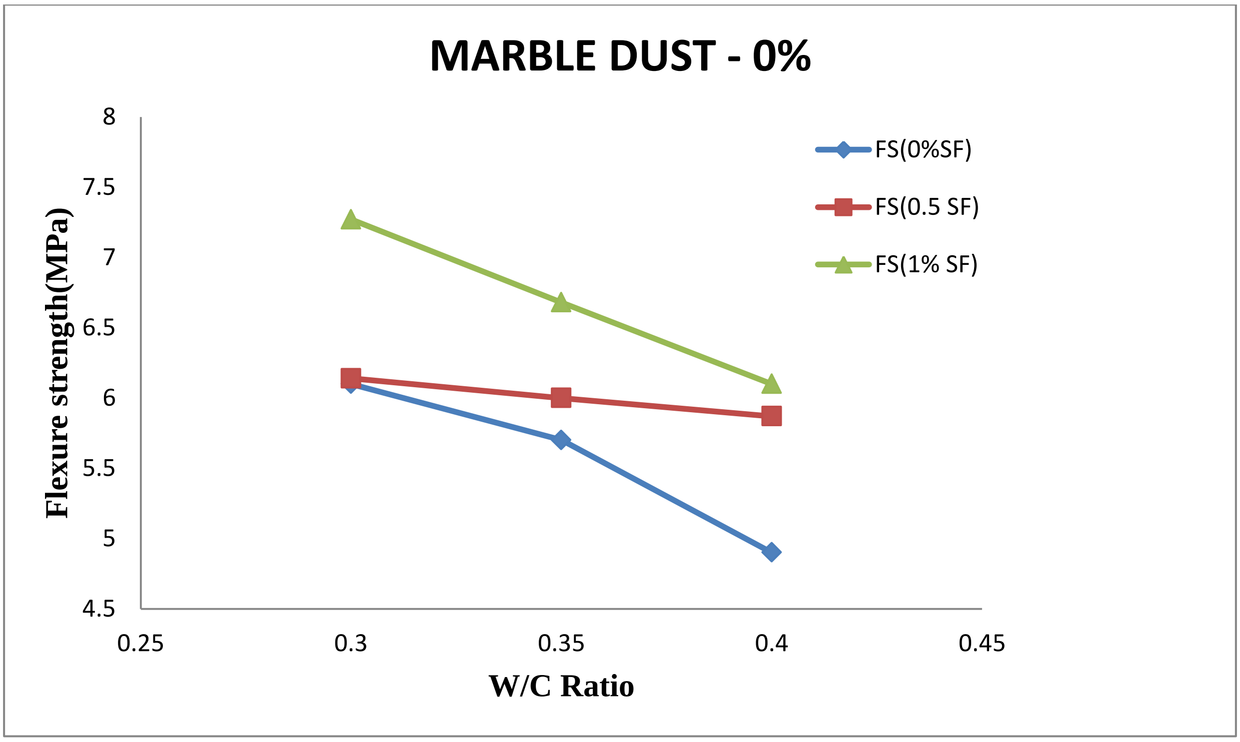


Fig. 4.4 Variation of flexure strength of concrete with different W/C for 0% M.D and different percentage of S.F.

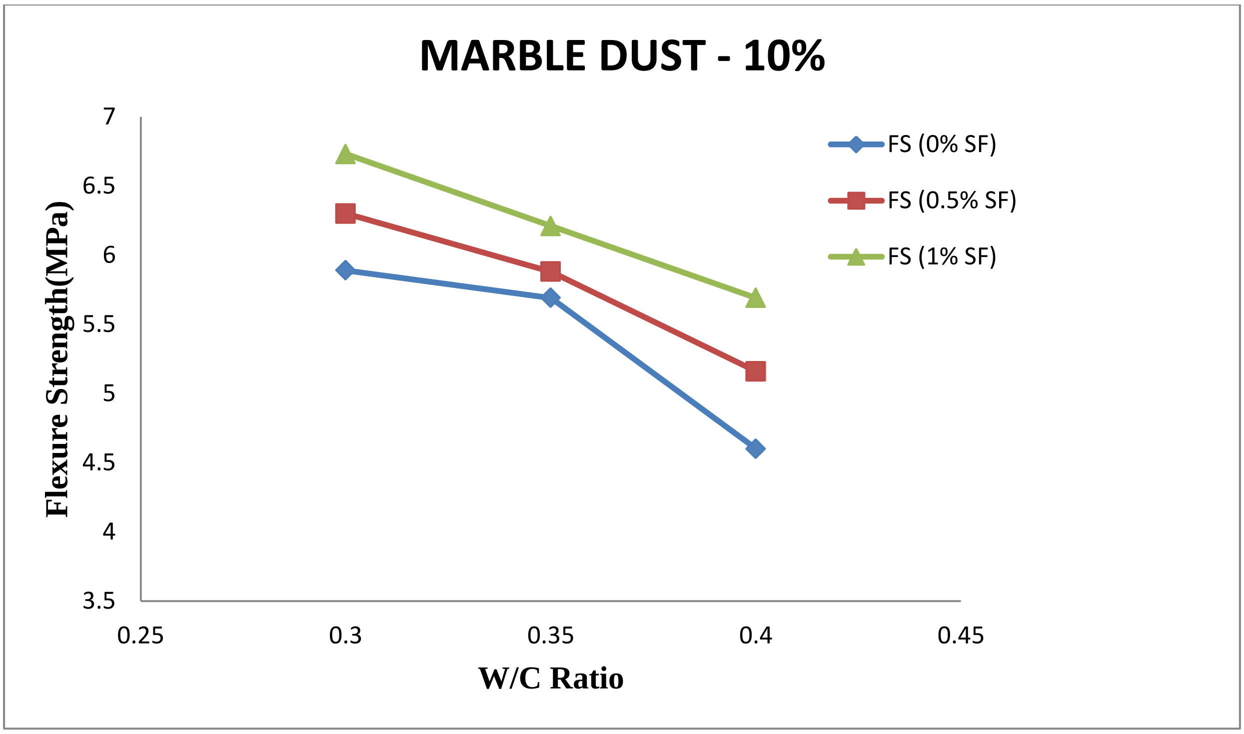


Fig. 4.5 Variation of flexure strength of concrete with different W/C for 10% M.D and different percentage of S.F.

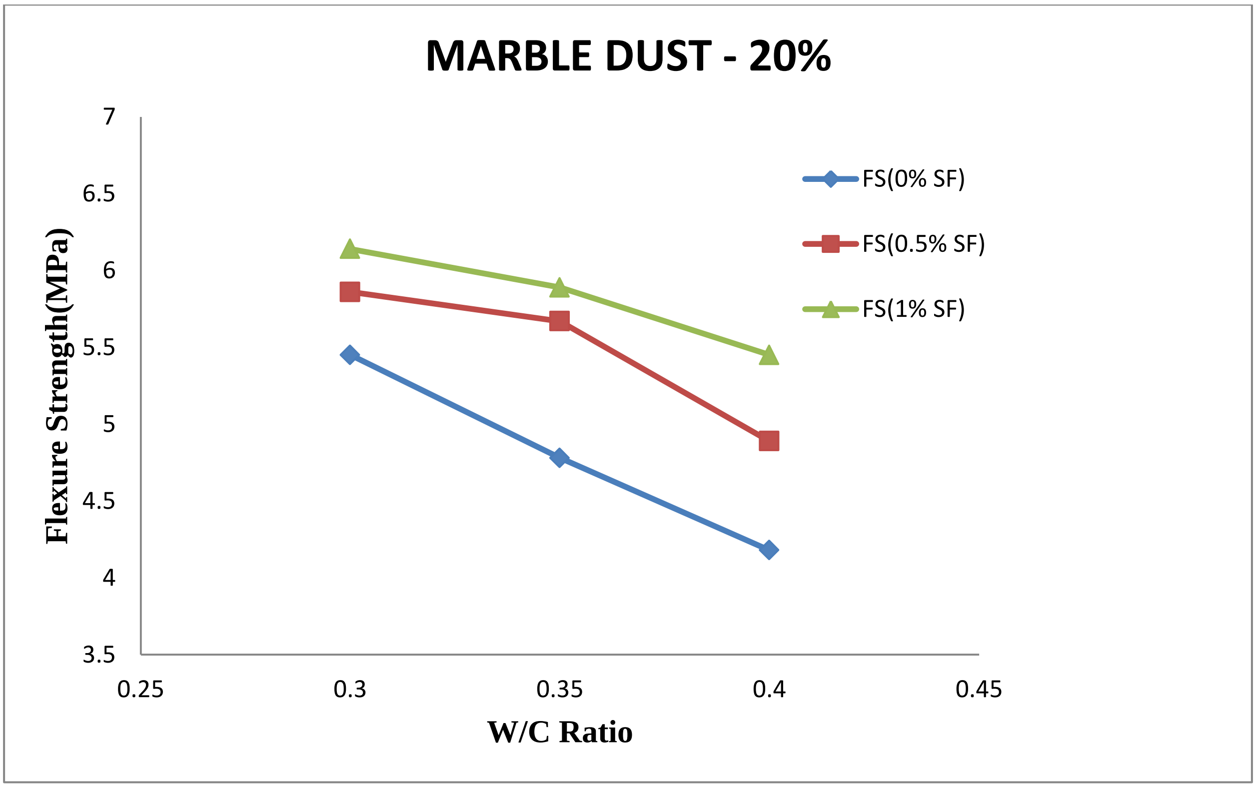


Fig. 4.6 Variation of flexure strength of concrete with different W/C for 20% M.D and different percentage of S.F.

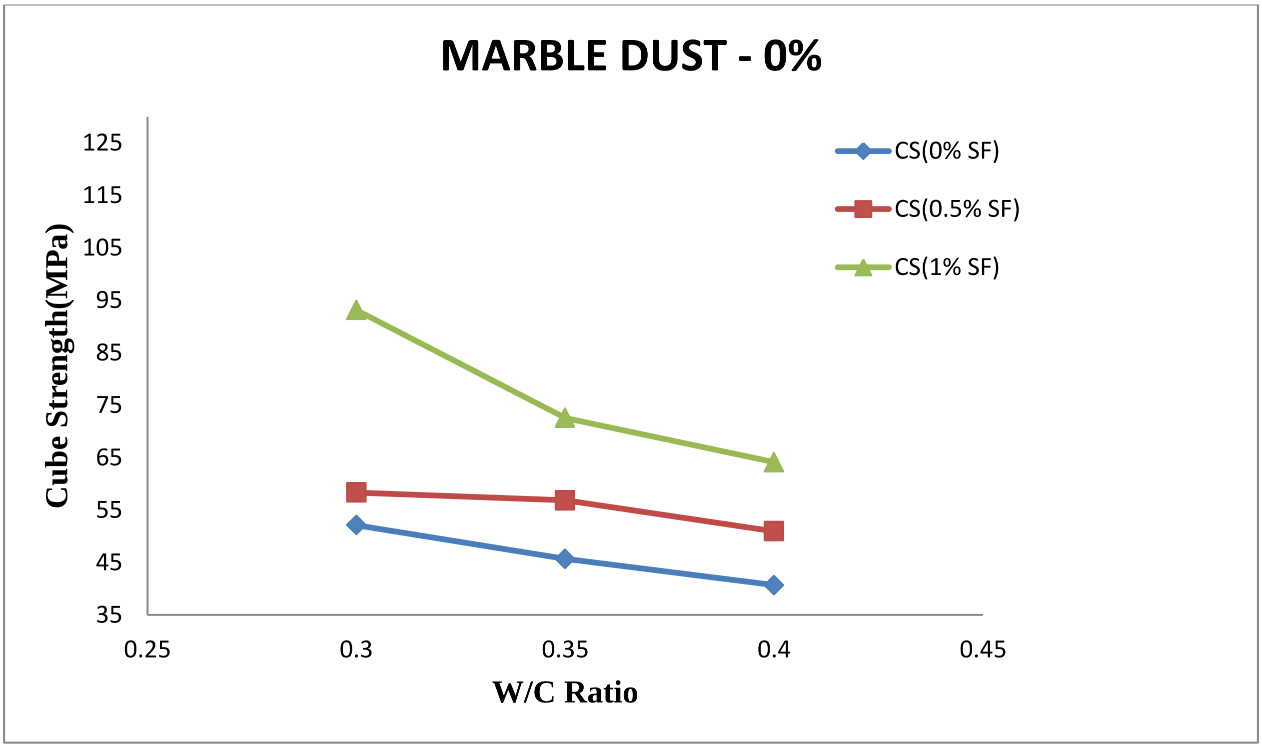


Fig. 4.7 Variation of compressive strength of concrete with different W/C for 0% M.D and different percentage of S.F.

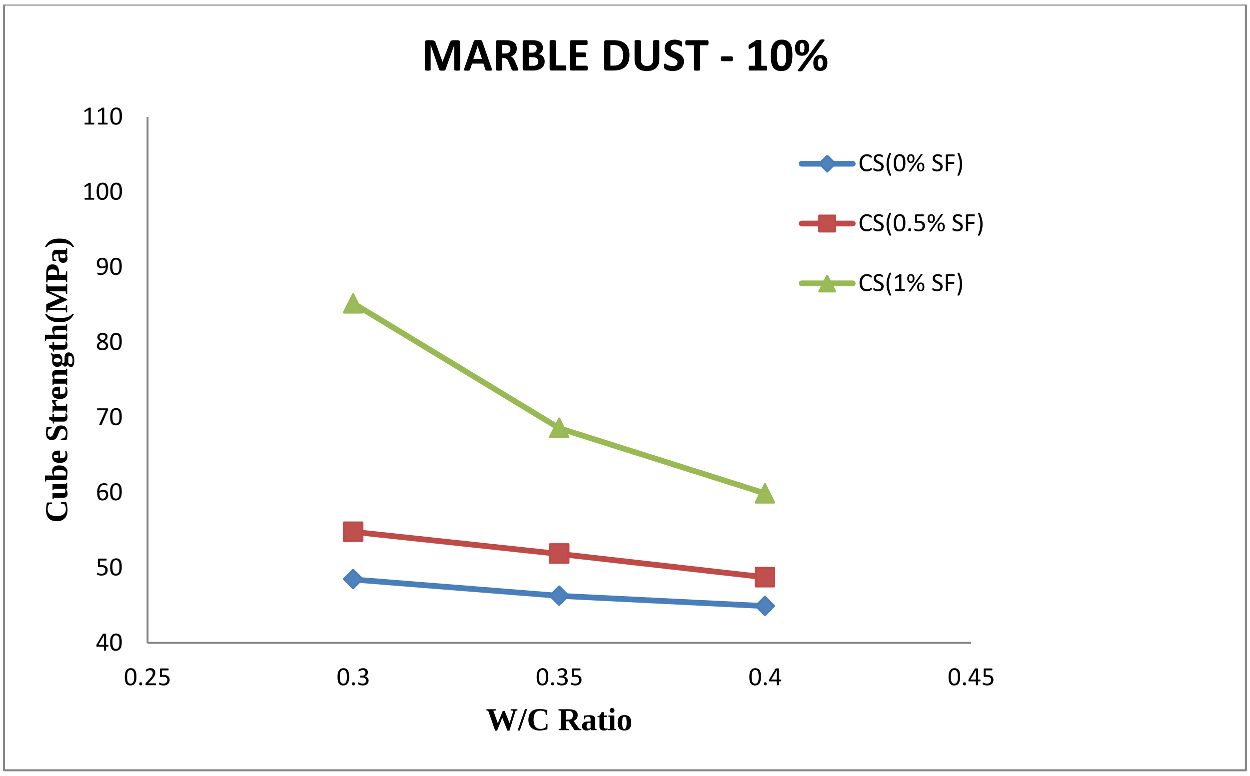


Fig. 4.8 Variation of compressive strength of concrete with different W/C for 10% M.D and different percentage of S.F.

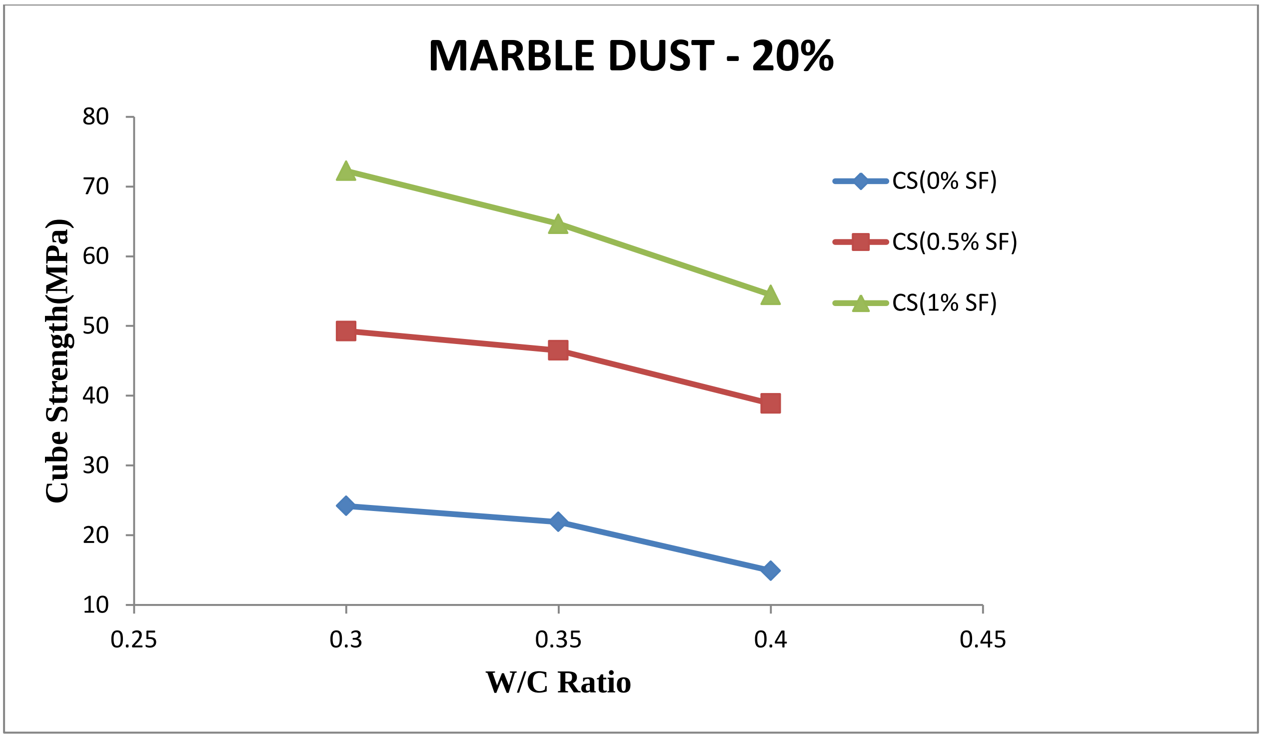


Fig. 4.9 Variation of compressive strength of concrete with different W/C for 20% M.D and different percentage of S.F.

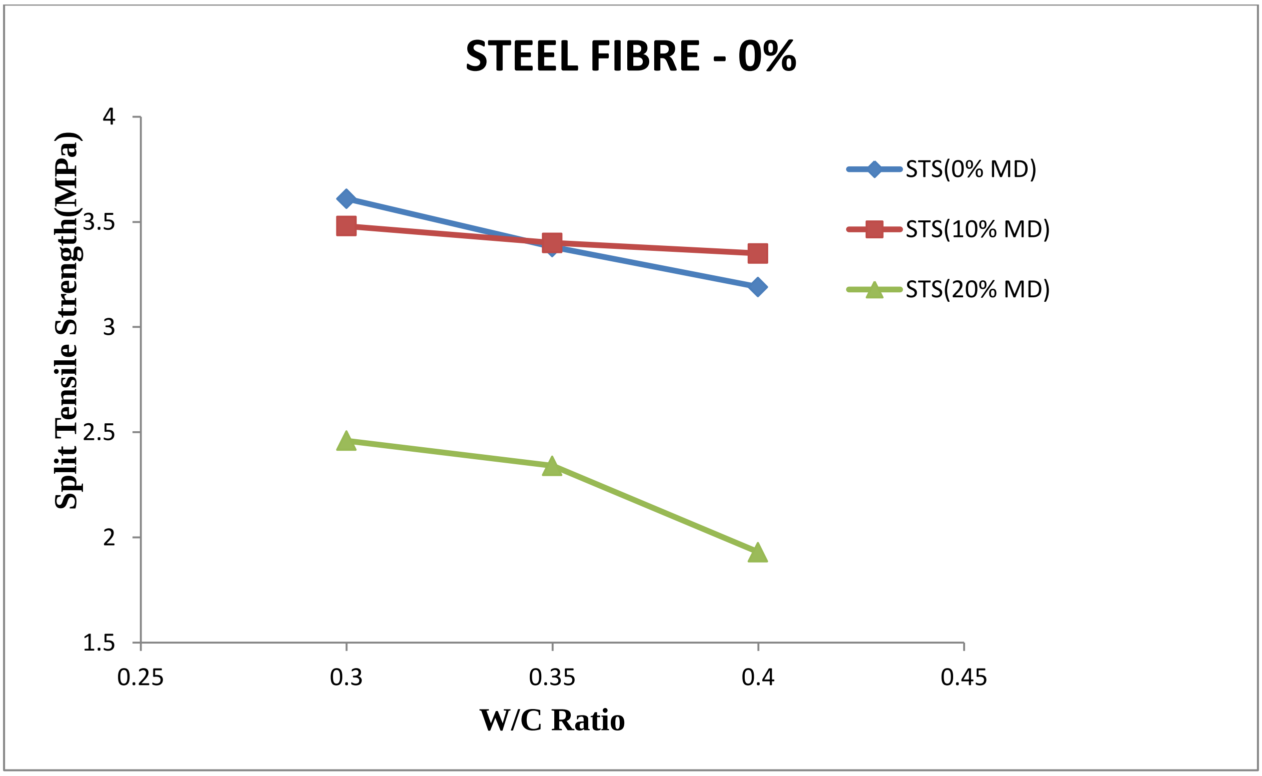


Fig. 4.10 Variation of split strength of concrete with different W/C for 0% S.F and different percentage of M.D.

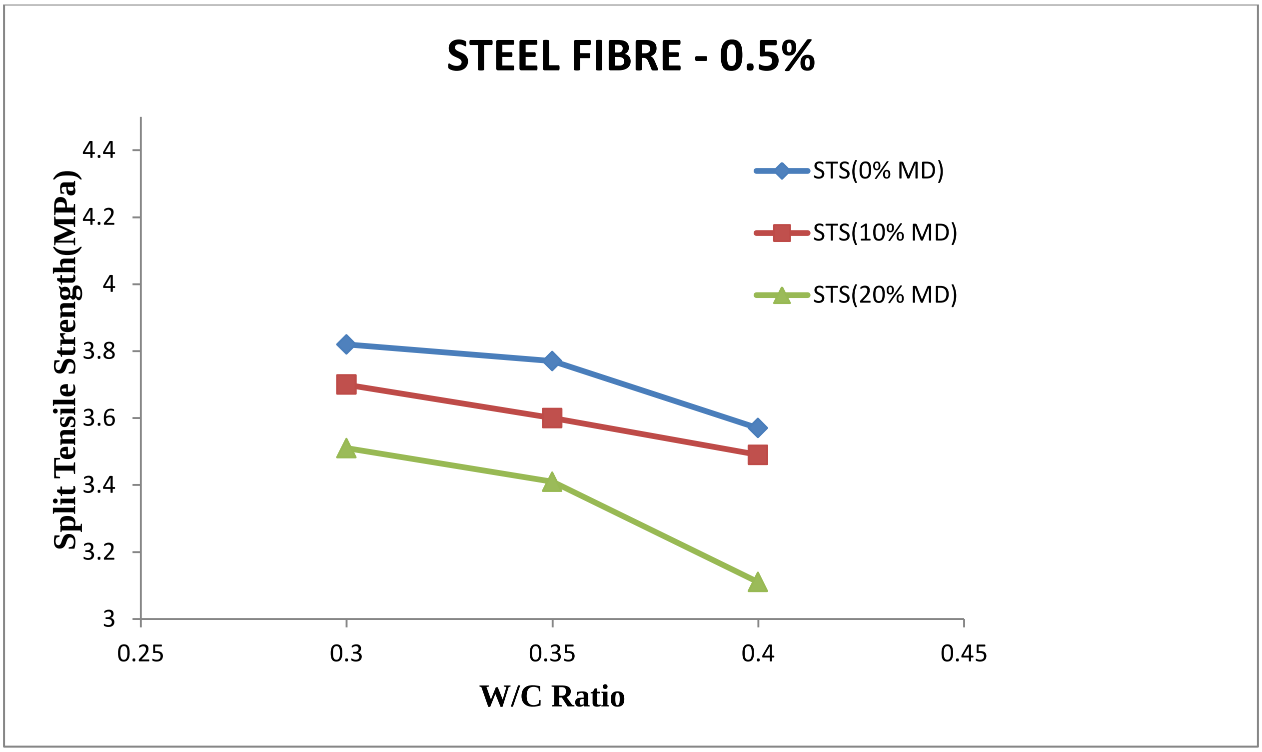


Fig. 4.11 Variation of split strength of concrete with different W/C for 0.5% S.F and different percentage of M.D.

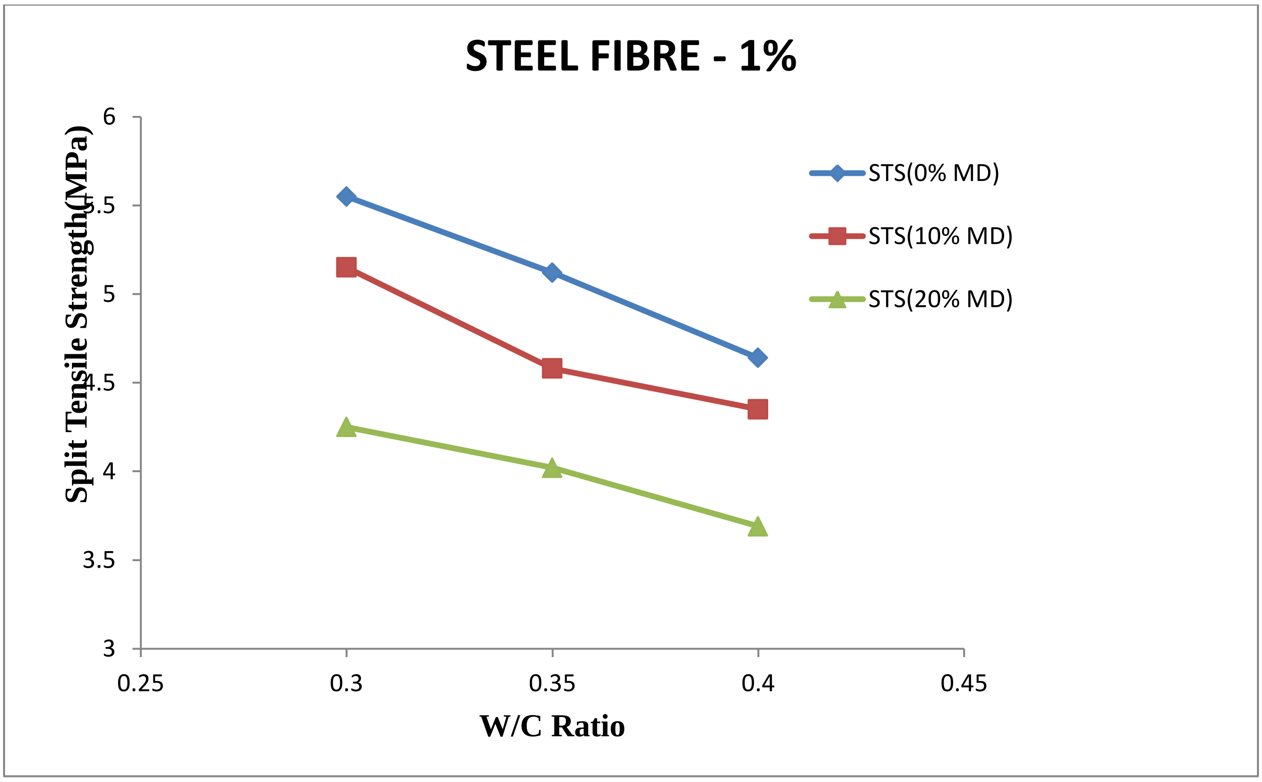


Fig. 4.12 Variation of split strength of concrete with different W/C for 1% S.F and different percentage of M.D.

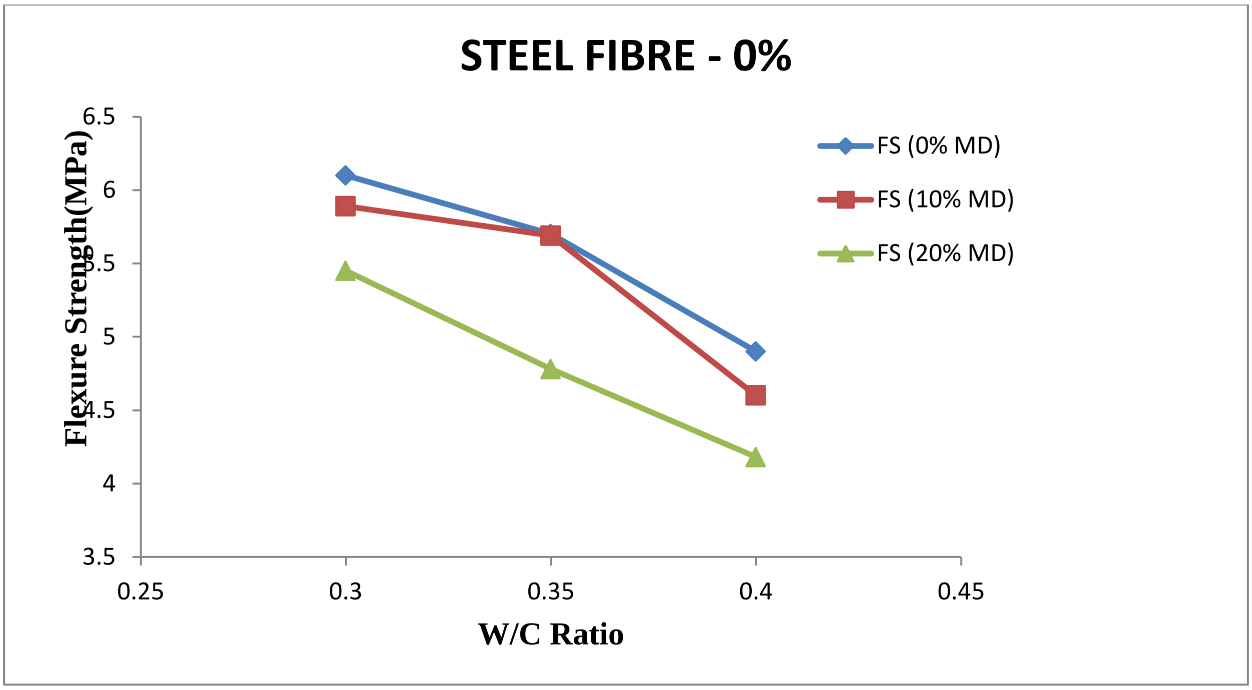


Fig. 4.13 Variation of flexure strength of concrete with different W/C for 0% S.F and different percentage of M.D.

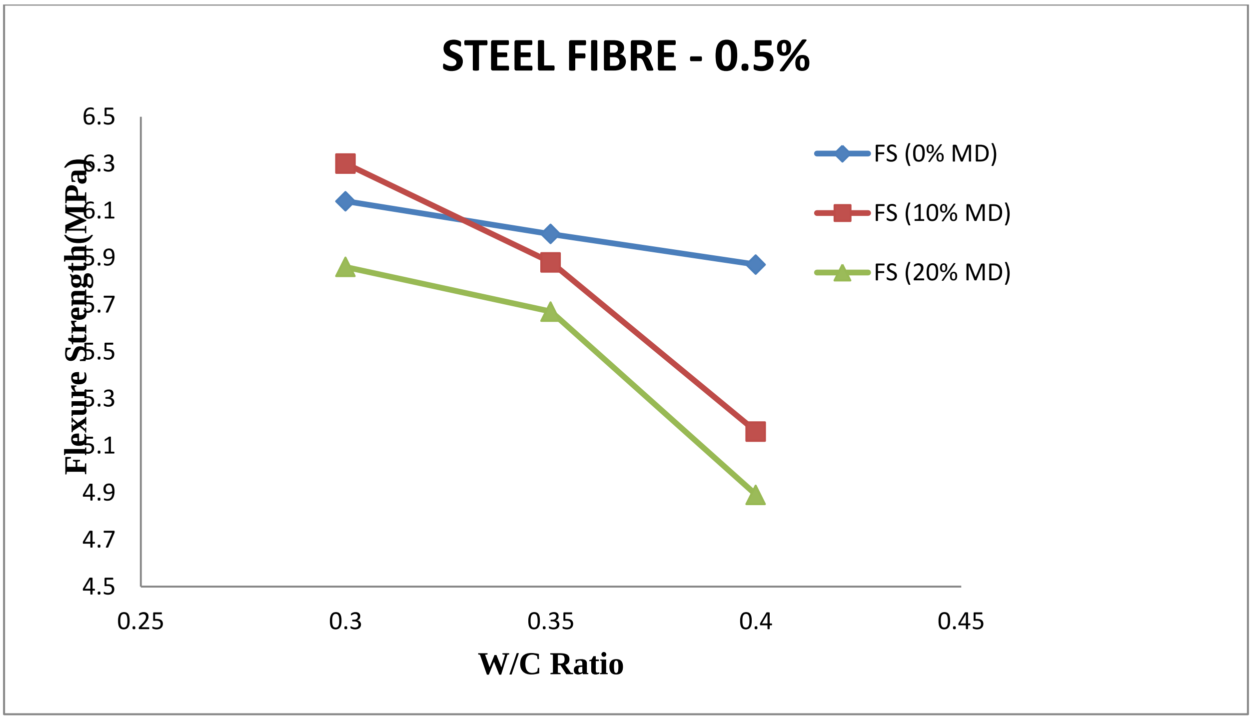


Fig. 4.14 Variation of flexure strength of concrete with different W/C for 0.5% S.F and different percentage of M.D.

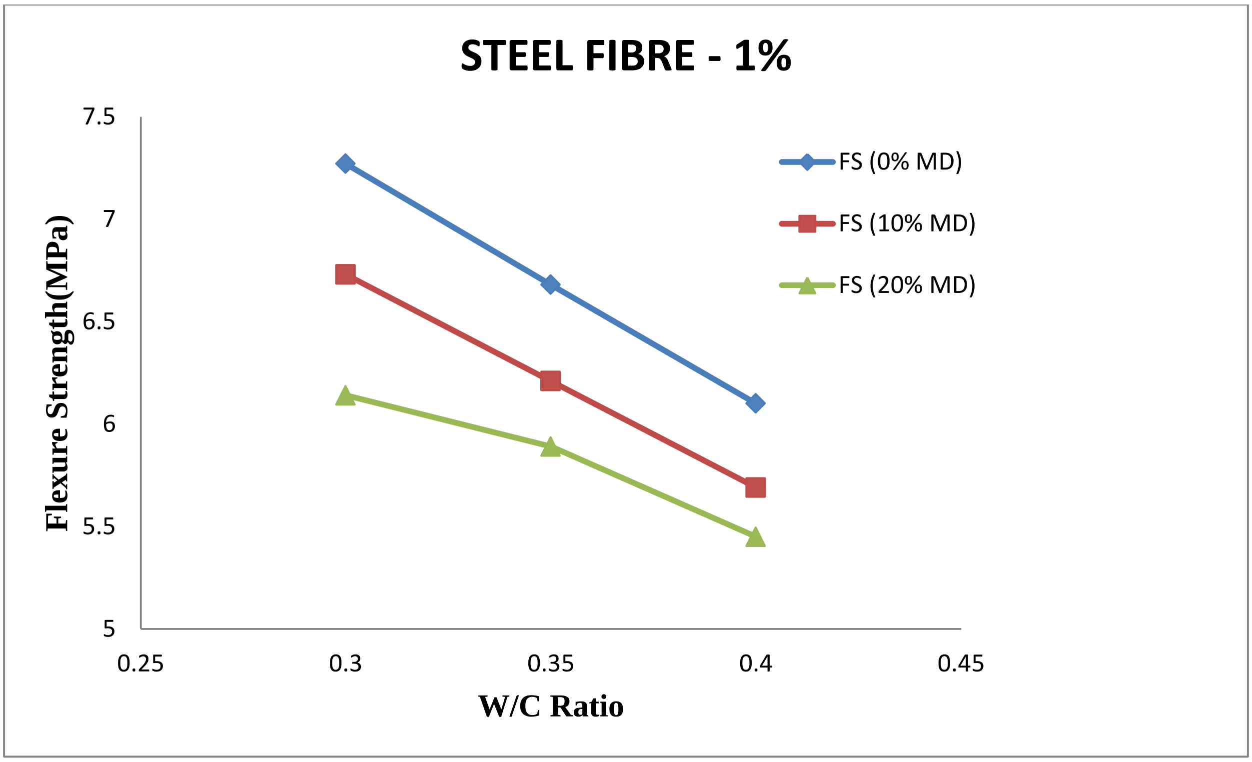


Fig. 4.15 Variation of flexure strength of concrete with different W/C for 1% S.F and different percentage of M.D.

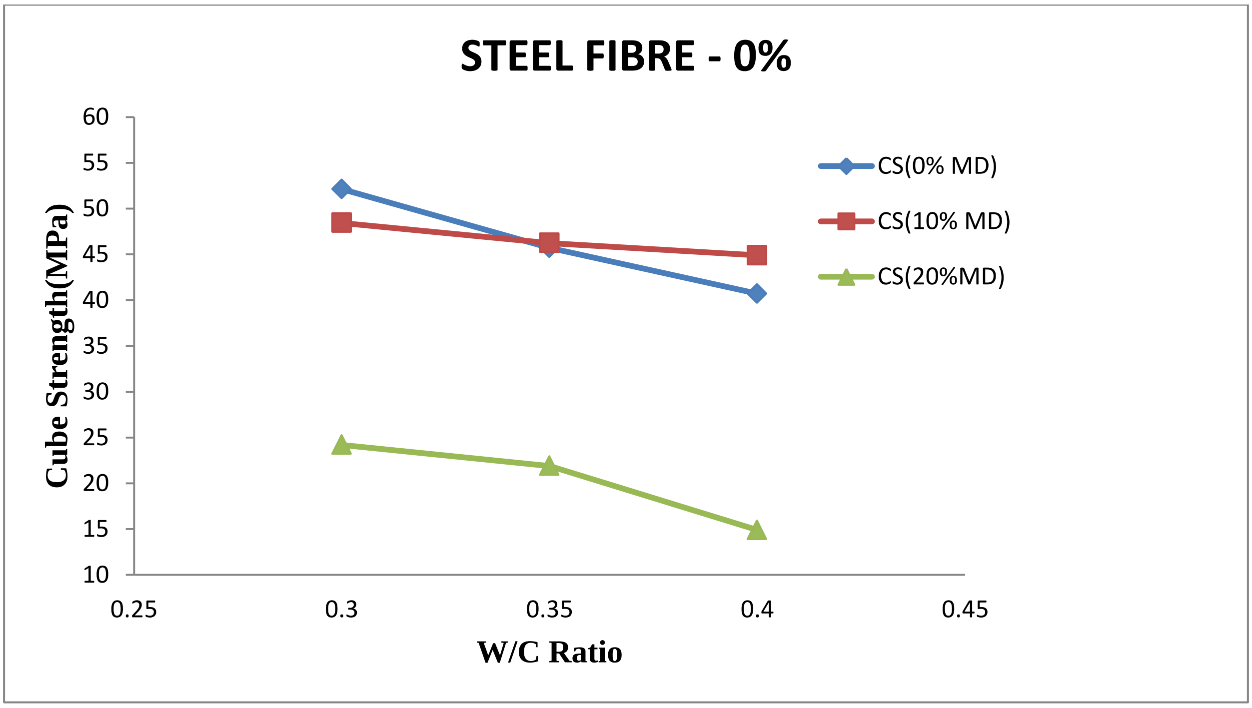


Fig. 4.16 Variation of compressive strength of concrete with different W/C for 0% S.F and different percentage of M.D.

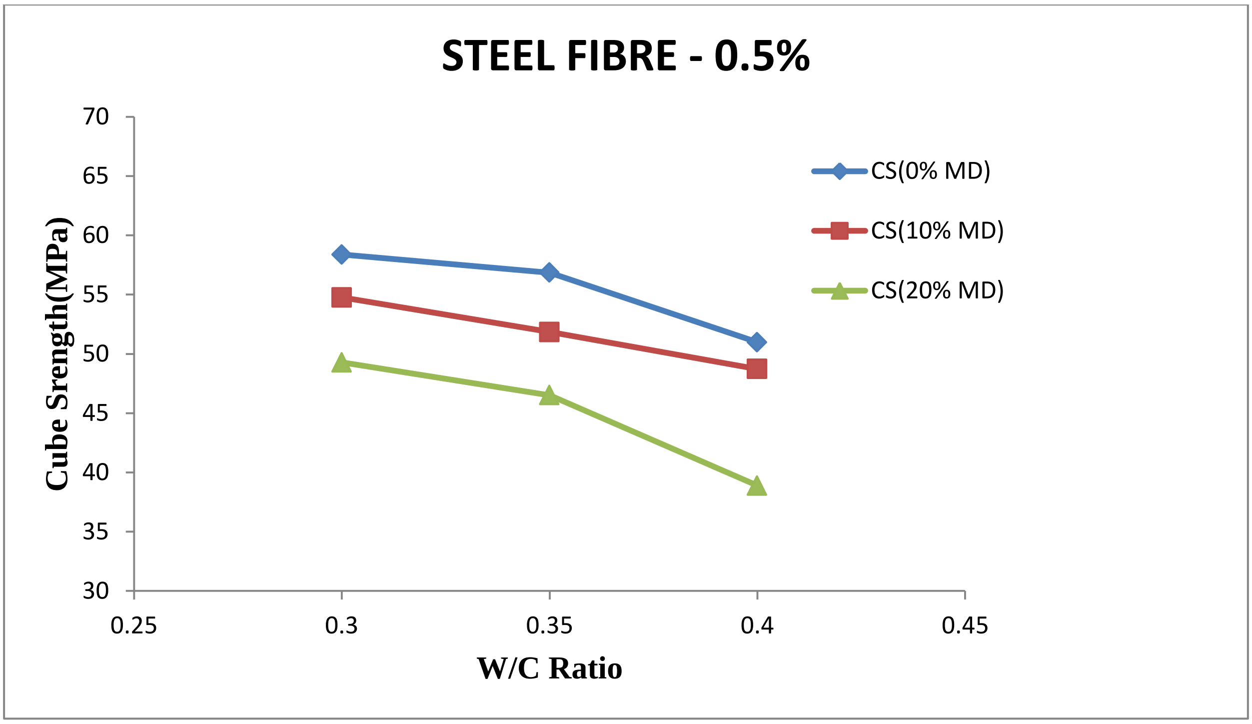


Fig. 4.17 Variation of compressive strength of concrete with different W/C for 0.5% S.F and different percentage of M.D.

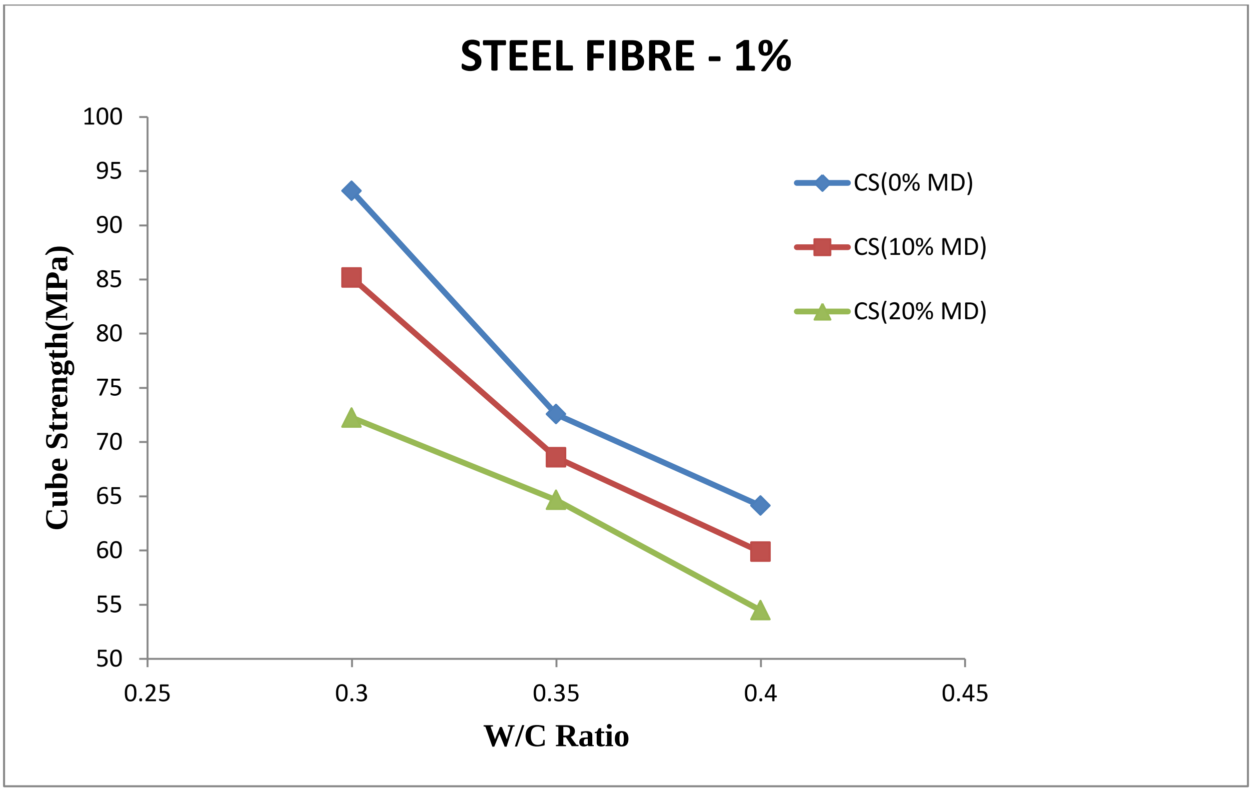


Fig. 4.18 Variation of compressive strength of concrete with different W/C for 1% S.F and different percentage of M.D.

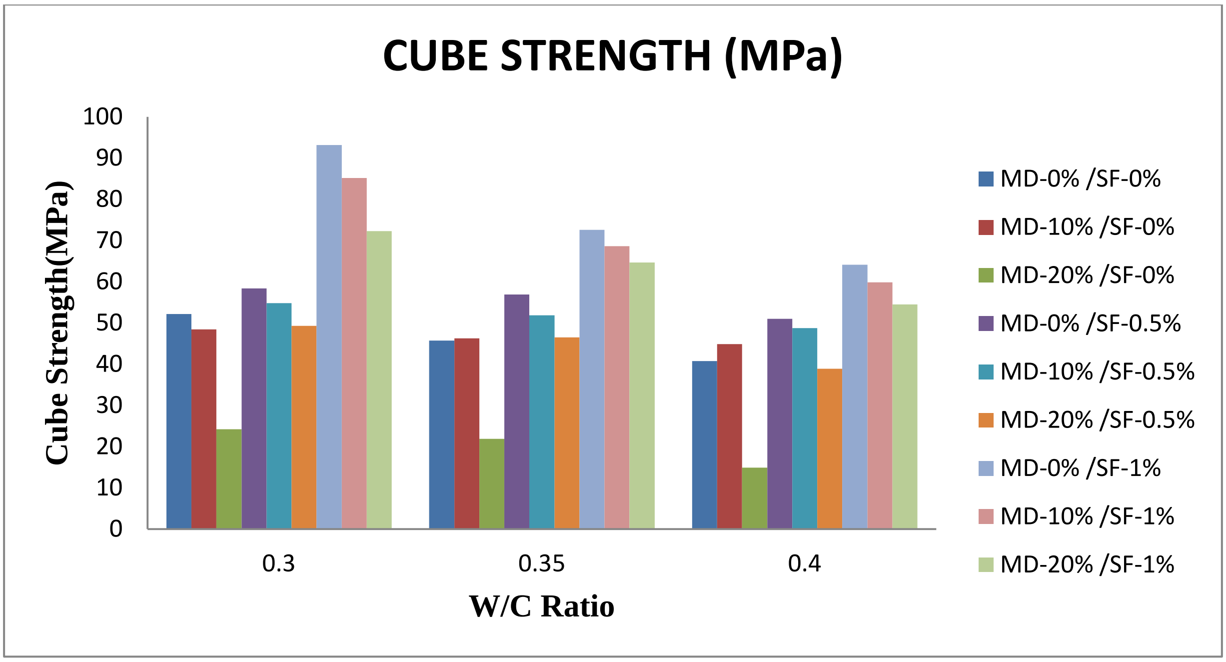


Fig. 4.19 Variation of compressive strength of concrete Vs W/C with different percentages of S.F and different percentage of M.D.

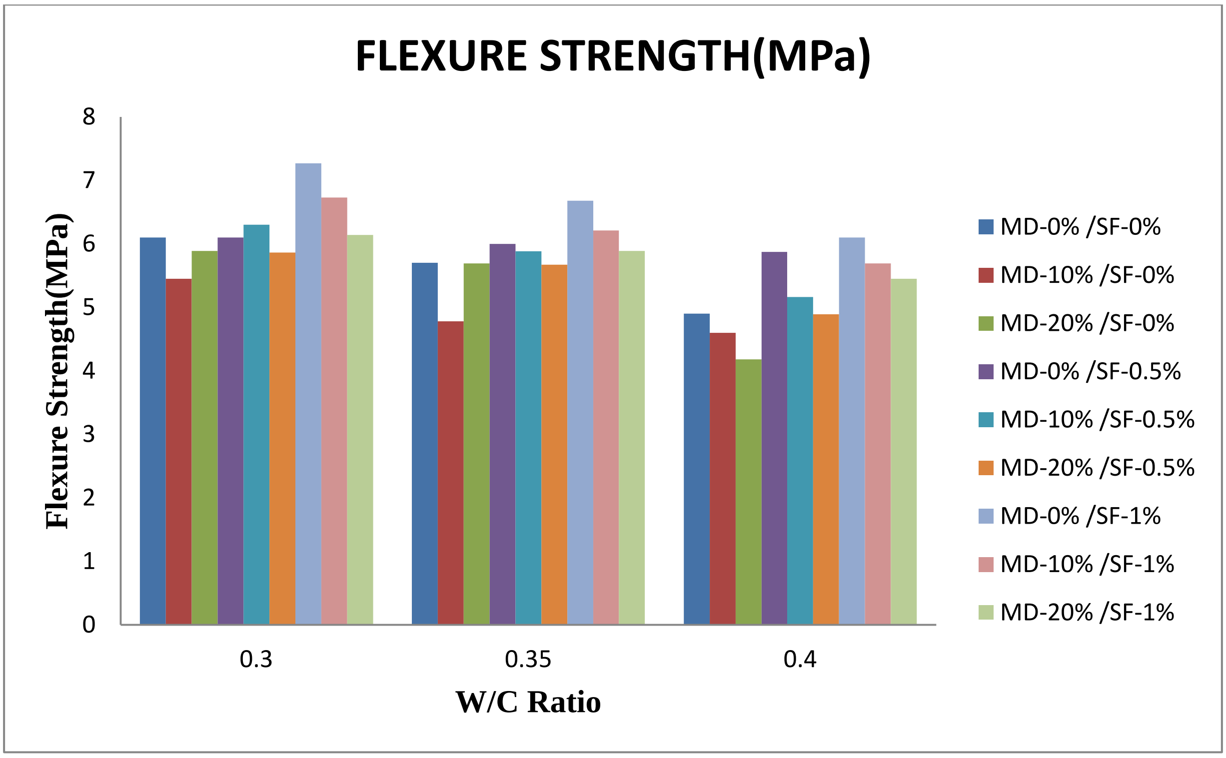


Fig. 4.20 Variation of flexure strength of concrete Vs W/C with different percentage of S.F and different percentage of M.D.

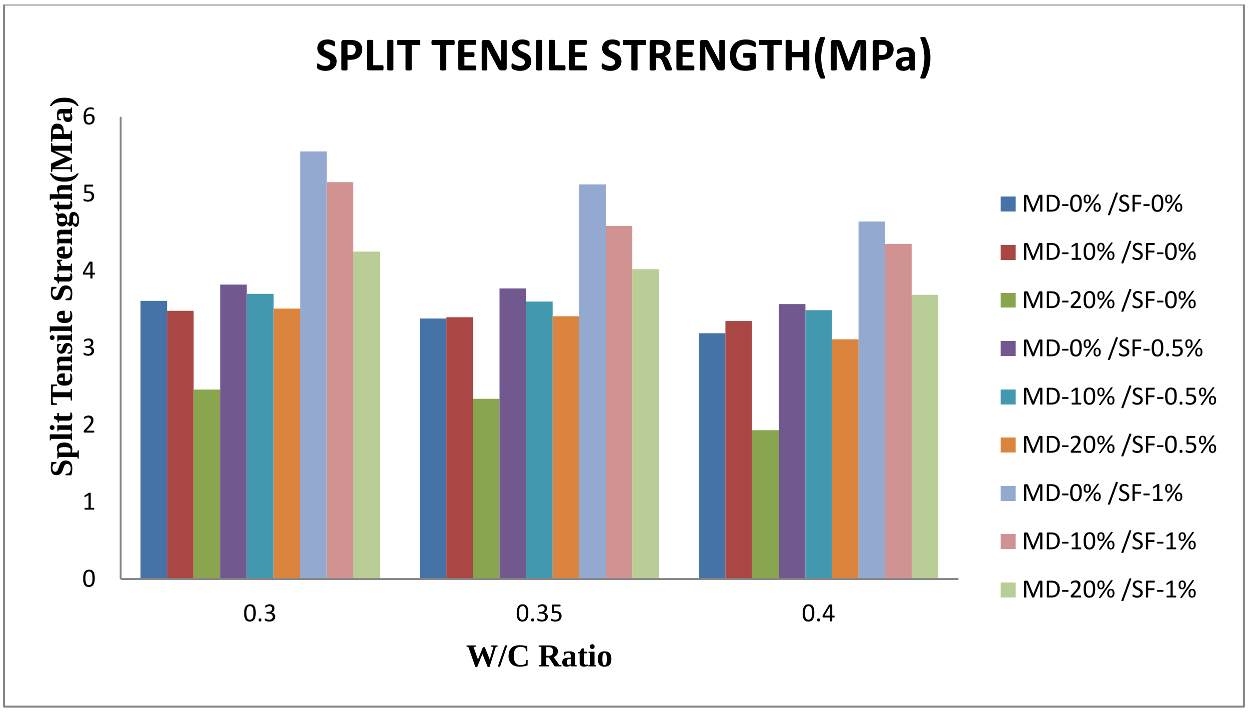


Fig. 4.21 Variation of split strength of concrete Vs W/C with different percentage of S.F and different percentage of M.D.

4.5 DISCUSSION OF RESULTS

4.5.1 Effect of Marble Dust Replacement on Strength Characteristics;

Figures 4.1 to4.9 show the effect of marble dust replacement on strength characteristics of pavement quality concrete. The effect on each strength parameter is discussed in succeeding sub-sections.

a) Effect on compressive strength:

Table 4.4 Test Results of Compressive Strength vs. W/C Ratio

	Compressive strength W/C = 0.3	
Sample ID	**Percentage decrease in compressive strength**	**Percentage increase in compressive strength**
10% M.D / 0% S.F	-7.08%	
20% M.D / 0% S.F	-53.56%	
0% M.D / 0.5% S.F		11.97%
10% M.D / 0.5% S.F		5.05%
20% M.D / 0.5% S.F	-5.47%	
0% M.D / 1% S.F		78.70%
10% M.D / 1% S.F		63.30%
20% M.D / 1% S.F		38.60%

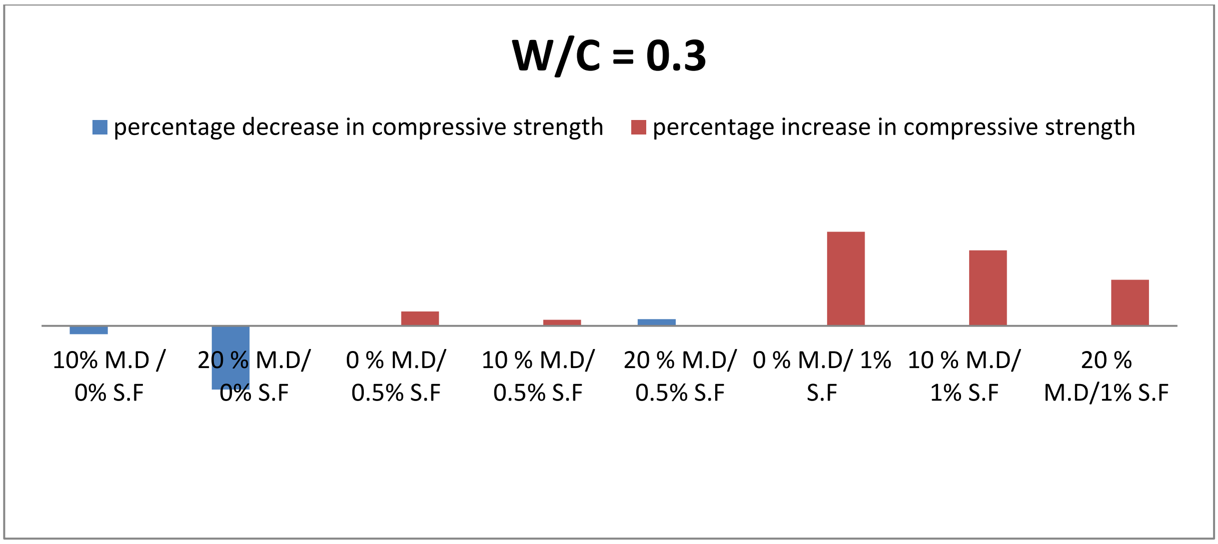


Fig. 4.22 Variation of Compressive Strength at W/C Ratio = 0.3

Table 4.5 Test Results of Compressive Strength vs. W/C Ratio

Compressive strength W/C = 0.35		
Sample ID	**Percentage decrease in compressive strength**	**Percentage increase in compressive strength**
10% M.D / 0% S.F		1.18%
20% M.D / 0% S.F	-52.07%	
0% M.D / 0.5% S.F		24.40%
10% M.D / 0.5% S.F		13.44%
20% M.D / 0.5% S.F		1.77%
0% M.D / 1% S.F		58.70%
10% M.D / 1% S.F		50.00%
20% M.D / 1% S.F		41.44%

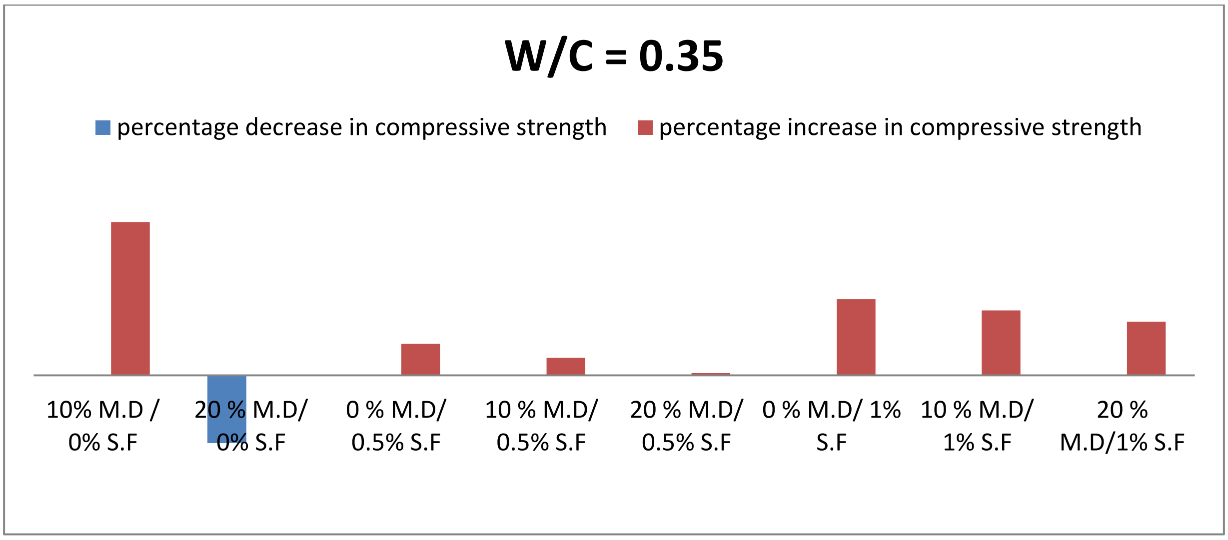


Fig. 4.23 Variation of Compressive Strength at W/C Ratio = 0.35

Table 4.6 Test Results of Compressive Strength vs. W/C Ratio

Compressive strength W/C = 0.40		
Sample ID	**Percentage decrease in compressive strength**	**Percentage increase in compressive strength**
10% M.D / 0% S.F		10.29%
20% M.D / 0% S.F	-63.39%	
0% M.D / 0.5% S.F		25.26%
10% M.D / 0.5% S.F		19.71%
20% M.D / 0.5% S.F	-4.45%	
0% M.D / 1% S.F		57.54%
10% M.D / 1% S.F		47.07%
20% M.D / 1% S.F		33.81%

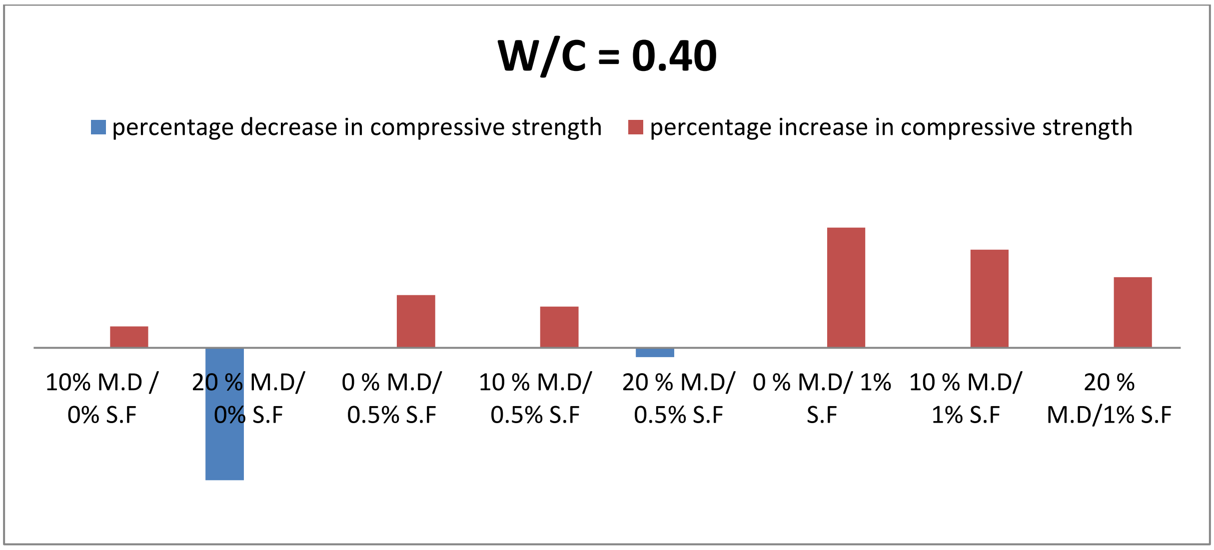


Fig. 4.24 Variation of Compressive Strength at W/C Ratio = 0.40

From the Tables 4.4 to 4.6 and Figs. 4.22 to 4.24, showing the variation of compressive strength with water cement ratios, it is observed here that with the increase in percentage of marble dust (replacing cement) the strength reduces for lower water cement ratio of 0.3 but a slight increase is observed for water-cement ratios of 0.35 and 0.40. This trend of a minor increase in the compressive strength as compared to the controlled concrete is observed when cement has been replaced by 10% marble dust. This trend can be attributed to the fact that marble granules possess some cementing properties but cannot replace cement to a large extent. On increasing the percentage replacement beyond 10%, there is a significant decrease in the compressive strength value. The reduction in the strength of the concrete may be attributed to the pozzolanic activity and pore structure of the cementitious materials. Since, the replacement of the cement by waste materials reduces clinker content of the cement, the amount of cementitious gelformed from pozzolanic reaction decreases. Hence, the strength contribution from this process is lower than that of the control mix without waste material. It is generally accepted that the strength of concrete is fundamentally a function of the distribution of the void space and porosity in it. On the other hand, when the steel fibre is adding in the concrete mix, there is widely increase in compressive strength as compared to nominal mix. Maximum compressive strength of pavement quality concrete incorporating marble dust and steel fibres both is achieved for 10% Marble Dust and 1% steel fibres. However, if the marble dust content is increased to 20%, even with 1% steel fibre, the increase is not very significant.

b) Effect on split tensile strength:

Table 4.7 Test Results of Split Tensile Strength vs. W/C Ratio

Split Tensile Strength W/C = 0.30		
Sample ID	**Percentage decrease in Tensile strength**	**Percentage increase in Tensile strength**
10% M.D / 0% S.F	-3.74%	
20% M.D / 0% S.F	-31.86%	
0% M.D / 0.5% S.F		5.82%
10% M.D / 0.5% S.F		2.49%
20% M.D / 0.5% S.F	-2.77%	
0% M.D / 1% S.F		53.74%
10% M.D / 1% S.F		42.66%
20% M.D / 1% S.F		17.73%

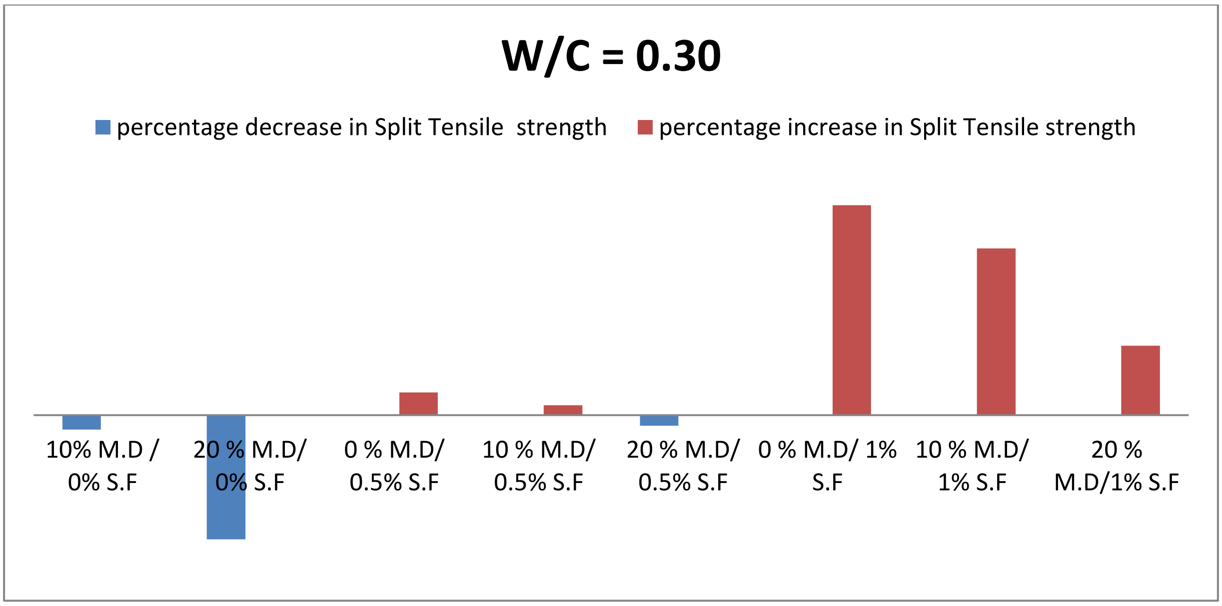


Fig. 4.25 Variation of Split Tensile Strength at W/C Ratio = 0.30

Table 4.8 Test Results of Split Tensile Strength vs. W/C Ratio

Split Tensile Strength W/C = 0.35		
Sample ID	**Percentage decrease in Tensile strength**	**Percentage increase in Tensile strength**
10% M.D / 0% S.F		0.59%
20% M.D / 0% S.F	-30.77%	
0% M.D / 0.5% S.F		11.54%
10% M.D / 0.5% S.F		6.51%
20% M.D / 0.5% S.F		0.89%
0% M.D / 1% S.F		51.48%
10% M.D / 1% S.F		35.50%
20% M.D / 1% S.F		18.93%

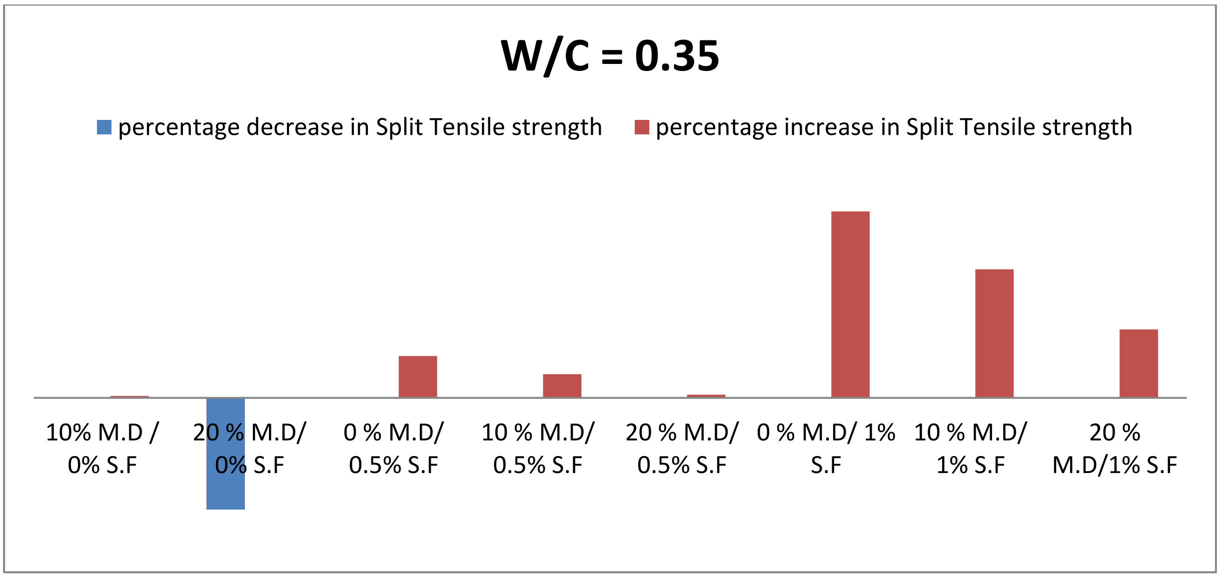


Fig. 4.26 Variation of Split Tensile Strength at W/C Ratio = 0.35

Table 4.9 Test Results of Split Tensile Strength vs. W/C Ratio

Split Tensile Strength W/C = 0.40		
Sample ID	Percentage decrease in Tensile strength	Percentage increase in Tensile strength
10% M.D / 0% S.F		5.01%
20% M.D / 0% S.F	-39.50%	
0% M.D / 0.5% S.F		11.91%
10% M.D / 0.5% S.F		9.40%
20% M.D / 0.5% S.F	-2.51%	
0% M.D / 1% S.F		4.45%
10% M.D / 1% S.F		36.36%
20% M.D / 1% S.F		15.67%

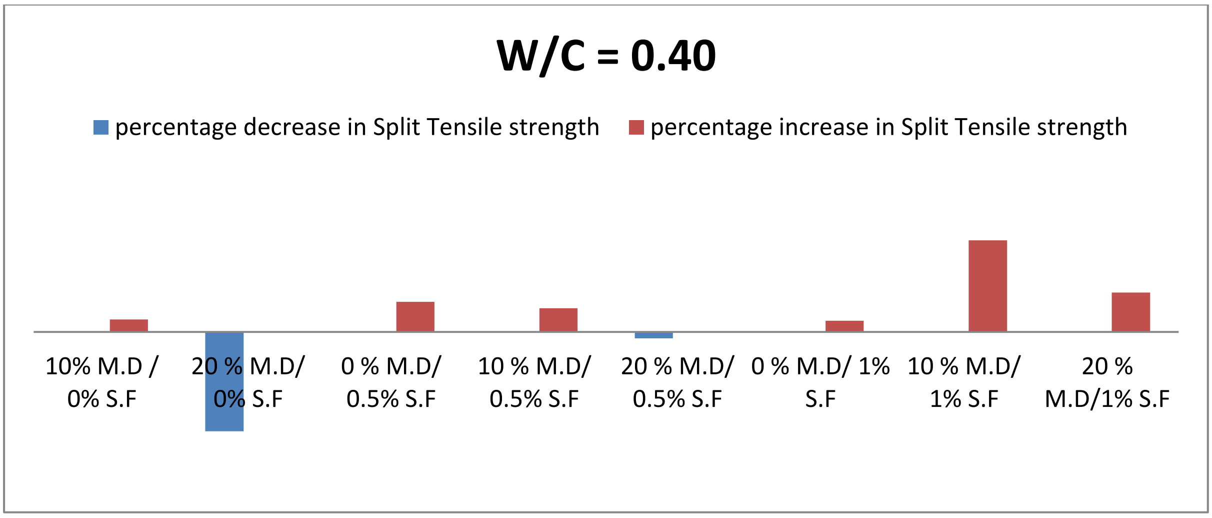


Fig. 4.27 Variation of Split Tensile Strength at W/C Ratio = 0.40

Tables 4.7 to 4.9 and Figures 4.25 to 4.27 have been plotted between split tensile strength and water cement ratios for each specimen. It is observed here that with the increase percentage of marble dust (replacing cement) the split tensile strength follows a pattern similar to that of compressive strength. When the cement has been replacedwith 10% marble dust a slight increase in split tensile strength is observed for higher w/c ratios. This trend, as stated earlier, can be attributed to the fact that marble granules do possess cementing properties. It is also as much effective in enhancing cohesiveness due to lower fineness modulus of the marble powder or granules both. However, on increasing the percentage replacement beyond 10%, there is a slight reduction in the tensile strength value. On the other hand, when the steel fibre is added in the concrete mix, there is significant increase in tensile strength as compared to controlled mix. Maximum split tensile strength of pavement quality concrete incorporating marble dust and steel fibres both is achieved for 10% Marble Dust and 1% steel fibres. However, if the marble dust content is increased to 20%, even with 1% steel fibre, the increase is not very significant.

c) Effect on flexural strength:

Table 4.10 Test Results of Flexure Strength vs. W/C Ratio

	Flexure Strength W/C = 0.30	
Sample ID	Percentage decrease in Flexure strength	Percentage increase in Flexure strength
10% M.D / 0% S.F	-3.44%	
20% M.D / 0% S.F	-10.66%	
0% M.D / 0.5% S.F		0.66%
10% M.D / 0.5% S.F		3.28%
20% M.D / 0.5% S.F	-3.93%	
0% M.D / 1% S.F		19.18%
10% M.D / 1% S.F		10.33%
20% M.D / 1% S.F		0.65%

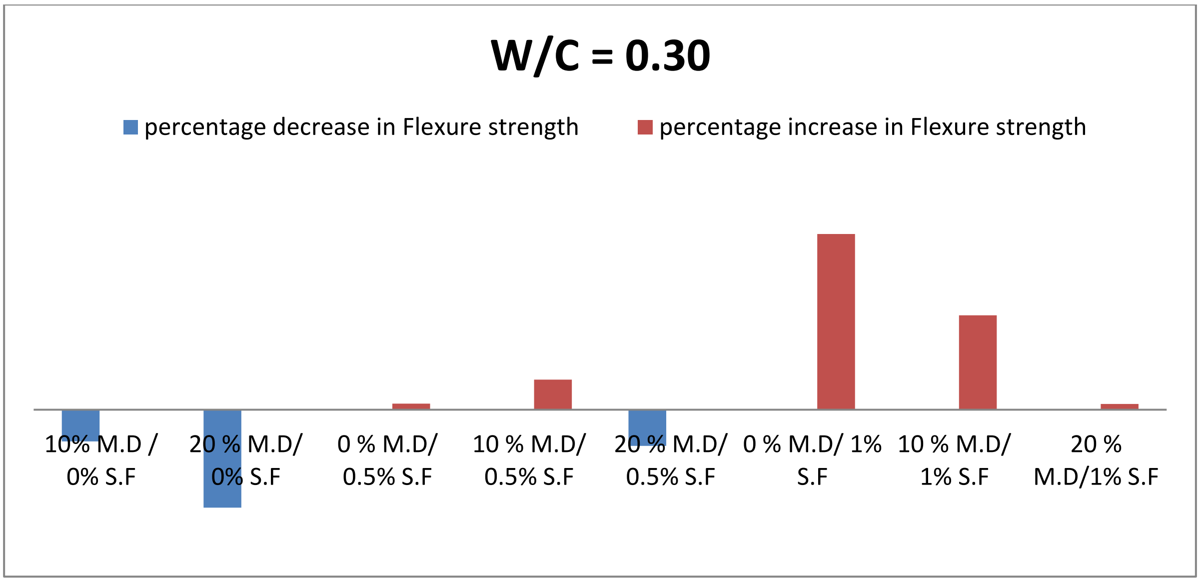


Fig. 4.28 Variation of Flexure Strength at W/C Ratio = 0.30

Table 4.11 Test Results of Flexure Strength vs. W/C Ratio

	Flexure Strength W/C = 0.35	
Sample ID	Percentage decrease in Flexure strength	Percentage increase in Flexure strength
10% M.D / 0% S.F	-0.18%	
20% M.D / 0% S.F	-16.14%	
0% M.D / 0.5% S.F		5.00%
10% M.D / 0.5% S.F		3.16%
20% M.D / 0.5% S.F	-0.53%	
0% M.D / 1% S.F		17.19%
10% M.D / 1% S.F		8.95%
20% M.D / 1% S.F		3.33%

Table 4.12 Test Results of Flexure Strength vs. W/C Ratio

	Flexure Strength W/C = 0.40	
Sample ID	Percentage decrease in Flexure strength	Percentage increase in Flexure strength
10% M.D / 0% S.F	-6.52%	
20% M.D / 0% S.F	-14.69%	
0% M.D / 0.5% S.F		19.80%
10% M.D / 0.5% S.F		5.31%
20% M.D / 0.5% S.F	-0.20%	
0% M.D / 1% S.F		24.49%
10% M.D / 1% S.F		16.12%
20% M.D / 1% S.F		11.22%

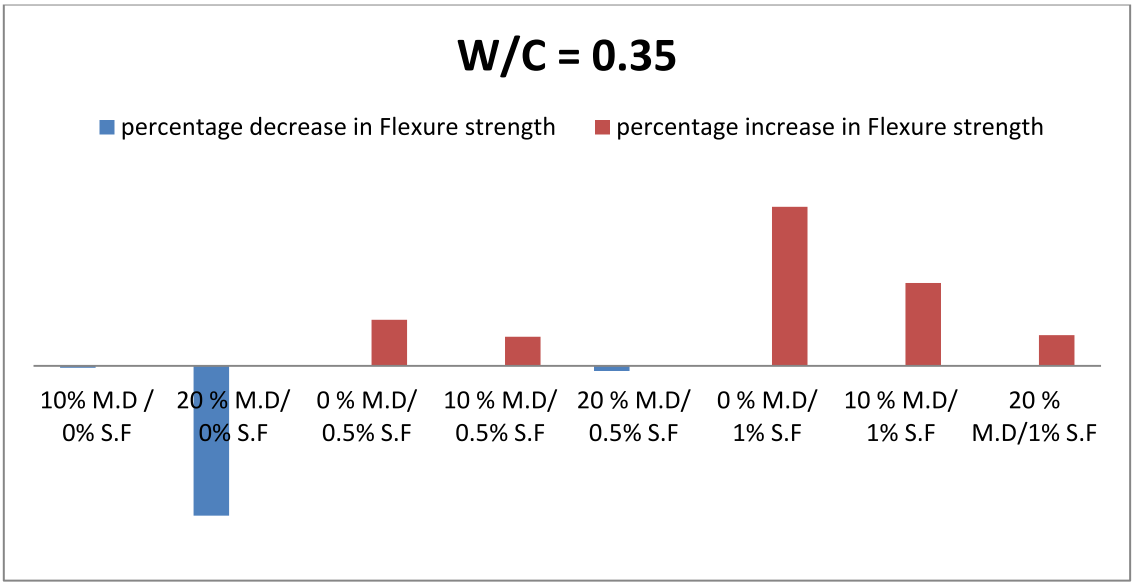


Fig. 4.29 Variation of Flexure Strength at W/C Ratio = 0.35

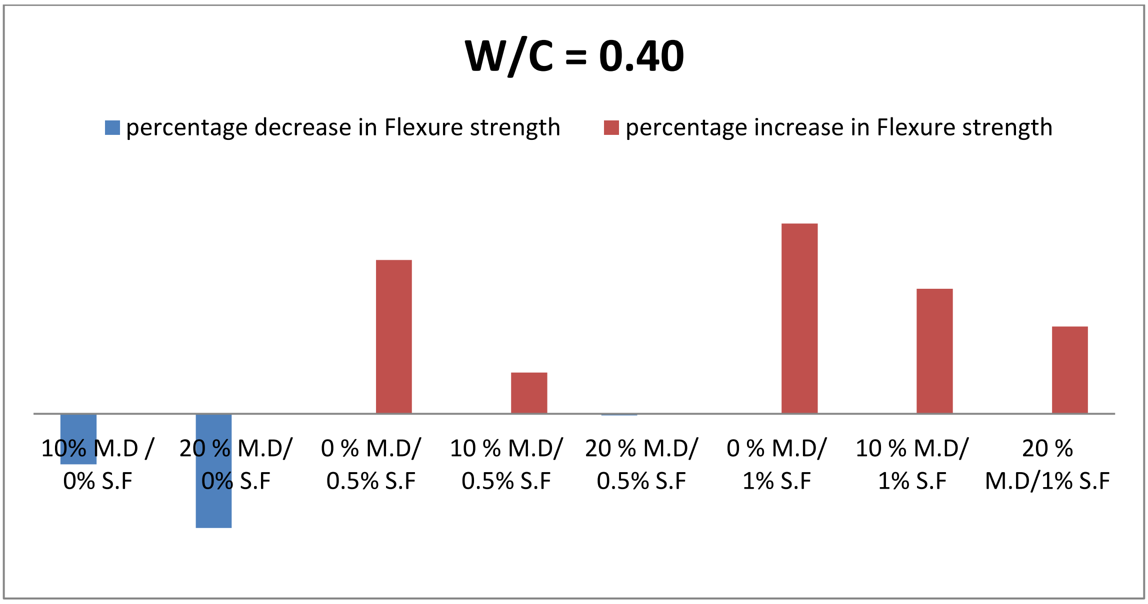


Fig. 4.30 Variation of Flexure Strength at W/C Ratio = 0.40

Tables 4.10 to 4.12 and Figures 4.28 to 4.30 have been plotted between Flexure strength and water cement ratios for each specimen. It is observed here that with the increase percentage of marble dust (replacing cement) the flexure strength follows a pattern similar tothat of compressive strength and split tensile strength. When the cement has been replacedwith 10% and 20% marble dust flexure strength is decreased continuouslywhich is observed for higher w/c ratios. This trend, as stated earlier, can be attributed to the fact that marble granules do possess cementing properties. It is also as much effective in enhancing cohesiveness due to lower fineness modulus of the marble powder or granules both. However, on increasing the percentage replacement beyond 10%, the value of flexure strength is decreased. On the other hand, when the steel fibre is added in the concrete mix, there is significant increase in flexure strength as compared to controlled mix. Maximum flexure strength of pavement quality concrete incorporating marble dust and steel fibres both is achieved for 0% Marble Dust and 1% steel fibres. However, if the marble dust content is increased to 20%, even with 1% steel fibre, the increase is not very significant.

4.5.2 Effect of Steel Fibres on Strength Characteristics

Figures 4.10 to 4.18 show the effect of addition of steel fibres on strength characteristics of pavement quality concrete. The effect on each strength parameter is discussed in succeeding sub-sections.

a) Effect on compressive strength:

From the Tables 4.4 to 4.6 and Figs. 4.22 to 4.24, showing the variation of compressive strength with water cement ratios, it is observed that with the increase in percentage of steel fibre the strength increases. This happens becausewhen the steel fibre was added to the concrete, the propagation of cracks was restrained due to the bonding of fibres into the concrete (ductile failure). Also it is observed that one of the most desirable benefits of adding fibres to concrete is to increase its energy absorbing capability or saying more precisely ductility. Referring to graph above shown, it is observed that for addition of 1% steel fibre and replacement of cement with 0% marble dust, the compressive strength increases is the most when compared to nominal mix.

b) Effect on split tensile strength:

From the Tables 4.7 to 4.9 and Figs. 4.25 to 4.27, showing the variation of split tensile strength with water cement ratios, it is observed here that with the increase in percentage of steel fibre the split tensile strength increases as similar to compressive strength. This trend can attributed to the addition of steel fibre in concrete and same reason, as for compressive strength increase, can be attributed to this increase as well.When the cement has been replacedwith 10% marble dust a slight increase in split tensile strength is observed for higher w/c ratios.This trend, as stated earlier, can be attributed to the fact that marble granules do possess cementing properties. It is also as much effective in enhancing cohesiveness due to lower fineness modulus of the marble powder or granules both. However, on increasing the percentage replacement beyond 10%, there is a slight reduction in the tensile strength value. On the other hand, when the steel fibre is added in the concrete mix, there is significant increase in tensile strength as compared to controlled mix.

c) Effect on flexural strength:

From the Tables 4.10 to 4.12 and Figs. 4.28 to 4.30, have been plotted between flexure strength and water cement ratios for each specimen, It is observed here that with the increase percentage of steel fibre the flexure strength follows a pattern similar to that of compressive strength and split tensile strength**.** This happens because when the steel fibre was added to the concrete, the propagation of cracks was restrained due to the bonding of fibres into the concrete (ductile failure).However, on increasing the percentage replacement beyond 10%, the value of flexure strength is decreased. On the other hand, when the steel fibre is added in the concrete mix, there is significant increase in flexure strength, as well, when compared to controlled mix

5.1DESIGN OF PAVEMENT QUALITY CONCRETE (PQC) FOR INDIAN HIGHWAYS

5.1.1 Introduction

Guidelines for the design of rigid pavements for highways were first approved by the Cement Concrete Road Surfacing Committee in March 1973 and published subsequently in the IRC: 58-2002 editions.In view of the recent upward revision of the legal limit on the maximum laden axle loads of commercial vehicle from 8160 kg to 10200 kg, appropriate modifications have become necessary in some sections of the Guidelines of IRC:58-1988, which resulted in the publication of IRC:58-2002, "Guidelines for the Design of Plain Jointed Rigid Pavements for Highways". The early approach to the Design of Rigid Pavement was based on Westergaard`s analysis. Recent advance in knowledge have led to vast changes in the design methodology.

5.1.2 Factor Governing Design

a) Factor Governing Design: It considers single andtandem axle loads, their repetition, tyre pressure and lateral placement characteristics of commercial vehicles.

b) Wheel Load: The legal axle load limits in India have been fixed as 10.2, 19 and 24 tonnes for single axles, tandem axles and tridem axles respectively, a large number of axles operating on National Highways carry much higher loads than the legal limits. Data on axle load distribution of the commercial vehicles is required to compute the number of repetitions of single and tandem axles of different weights expected during the design period. For most of the commercial highways vehicles, the tyre pressure ranges from 0.7 to 1.0 MPa but it is found that stresses in concrete pavements having thickness of 20 cm or more are not affected significantly by the variation of tyre pressure in the range mentioned earlier. A tyre pressure of 0.8 MPa may be adopted for design.

For computation of stresses in the pavements, the magnitude of axle loads should be multiplied by Load Safety Factor(LSF). For important roads, like, Expressways, National Highways and other roads where there will be uninterrupted traffic flow and high volume of truck traffic, the value of LSF is taken as 1.2. For roads of lesser importance having lower proportion of truck traffic, LSF may be taken as 1.1. For residential and other streets that carry small number of commercial traffic, the LSF may be taken as 1.0.

c) Design Period: Normally, cement concrete pavements have a life span of 30 years and should be designed for this period. When the traffic intensity cannot be predicted accurately for a long period of time, and for low volume roads, a design period of twenty years may be considered. However, the design engineer should use his judgement about the design life taking into consideration the factors, like, traffic volume, the traffic growth rate, the capacity of the road.

d) Design Traffic: Assessment of average traffic should normally be based on 7×24 hours count made in accordance with IRC: 9 "Traffic Census on Non-Urban Roads". The actual value of growth rate 'r' of heavy commercial vehicles should bedetermined. However, if actual data is not available, an average annual growth rate of 7.5 percent may be adopted.

The cumulative number of repetitions of axles during the design period may be adopted from the following formula:

$$C = \frac{365 \times A\{(1+r)^n - 1\}}{r}$$

Where

C = Cumulative number of axles during the design period.

A = Initial number of axles per day in the year when the road is operational.

r =Annual rate of growth of commercial traffic (expressed in decimals).

n = Design period in years.

In most of design problems, it is expected that the weights and number of trucks travelling in each direction are fairly equal. This may not be true for roads, like, Haul roads in mine areas where many of the trucks haul full loads in one direction and return empty in the other direction. In such cases, a suitable adjustment should be made.

e) Temperature Differential: Temperature differential between the top and the bottom of concrete pavements causes the concrete slab to wrap, giving rise to stresses. The temperature differential is a function of solar radiation received by the pavement surface at the location, losses due to wind velocity and thermal diffusivity of concrete and is thus affected by geographical features of the pavement location. As far as possible, values of actually anticipated temperature differentials at the location of the pavement should be adopted for pavement design.

5.2 CHARACTERISTICS OF SUBGRADE AND SUB BASE

5.2.1 Strength

The strength of subgrade is expressed in terms of modulus of subgrade reaction k, which is defined as pressure per unit deflection of the foundation as determined by plate bearing tests. As the limiting design deflection for cement concrete pavements is taken as 1.25 mm, the k-value is determined from the pressure sustained at this deflection. As k-value is carried out by test plate diameter, the standard test is to be carried out with a 75 cm diameter plate. IS:9214-1974, "Method of Determination of Modulus of Subgrade Reaction of Soil in the field" may be referred. A frequency of one test per km per lane is recommended for assessment of k-value, unless the foundation changes with respect of subgrade soil, type of sub-base or the nature of formation i.e. cut or fill when additional tests may be conducted. An approximate idea of k-value of a homogenous soil subgrade may be obtained from its soaked CBR value using Table 5.1. It is advisable to have a filter layer above the subgrade for drainage of water to prevent (i) excessive softening of subgrade and (ii) erosion of the subgrade particularly under adverse moisture condition.

The approximate increases in k-values of subgrade due to different thickness of sub-bases made up of untreated granular, cement treated granular and dry lean concrete (DLC) layers may be taken from Table 5.2. 7-day unconfined compressive strength of cement treated granular soil should be a minimum of 2.1 MPa. Dry Lean Concrete should have a minimum compressive strength of 7 MPa at 7 days.

Table 5.1 Approximate K-Value Corresponding to CBR Values For Homogenous Soil Subgrade

Soaked CBR value %	2	3	4	5	7	10	15	20	50	100
k-value ($kg/cm^2/cm$)	2.1	2.8	3.5	4.2	4.8	5.5	6.2	6.9	14.0	22.2

Table 5.2 K-Values with Dry Lean Concrete Sub-Base

k-value of subgrade $kg/cm^2/cm$	2.1	2.8	4.2	4.8	5.5	6.2
Effective k over 100 mm DLC, $kg/cm^2/cm$	5.6	9.7	16.6	20.8	27.8	38.9
Effective k over 150 mm DLC, $kg/cm^2/cm$	9.7	13.8	20.8	27.7	41.7	----

The maximum value of effective k will be 38.9 $kg/cm^2/cm$ for 100 mm of DLC and 41.7 $kg/cm^2/cm$ for 150 mm of DLC.

5.2.2 Separation layer between sub-base and pavement:

Foundation layer below concrete slabs should be smooth to reduce the inter layer friction. A separation membrane of minimum thickness of 125 micron polythene is recommended to reduce the friction between concrete slabs and dry lean concrete slab-base (DLC).

5.3 CHARACTERISTICS OF CONCRETE:

5.3.1 Design Strength:

The concrete pavements fail due to bending stresses, it is necessary that their design is based on the flexural strength of concrete. The relationship b/w the flexural strength and compressive strength may be worked out. The mix should be so designed that the minimum structural strength requirement in the field is met at the desired level. Thus,

S^1 = Characteristics flexural strength at 28 days.

S = Target average flexural strength at 28 days.

Z_a = Tolerance factor for the desired confidence level, known as the standard normal variate (Table 4)

σ=Expected standard deviation of field test samples; if it is not known, it may be initially Assumed as per IS: 456-2000

Then the target average flexural strength is given as:

$$S = S^1 + Z_a\sigma$$

For pavement construction, the concrete mix should preferably be designed and controlled on the basis of flexural strength. Flexural strength should be determined by modulus of rupture tests under third point loading. The preferred size of the beam should be 15 cm × 15 cm × 70 cm when the size of the aggregate is more than 19 mm. When the maximum size of aggregate is less than 19 mm, 10 cm × 10 cm × 50 cm beams may be used. IS: 516 should be referred for the test procedure.

5.3.2 Fatigue behaviour of cement concrete:

Due to repeated application of flexural stresses by the traffic loads, progressive fatigue damage takes place in the cement concrete slab in the form of gradual development of micro-cracks especially when the applied stress in terms of flexural strength of concrete is high. The ratio b/w the flexural stress due to the load and the flexural strength of the concrete is known as stress ratio (SR). If the stress ratio is less than 0.45, the concrete is expected to sustain infinite number of repetitions. As the stress ratio increases, the number of load repetitions required to cause cracking decreases. The relation b/w fatigue life (N) and stress ratio is given as:

N = unlimited for SR < 0.45

$$N = \left(\frac{4.2577}{SR-0.4325}\right)^{3.268} \qquad \text{When } 0.45 \leq SR \leq 0.55$$

$$\log_{10} N = \frac{0.9716-SR}{0.0828} \text{ for SR > 0.55}$$

The values of fatigue life for different values of stress ratio are given in Table 5.3.

5.4 DESIGN OF SLAB THICKNESS

Step by step procedure of Design of Slab Thickness Pavement as per IRC 58-2002.

Step 1.As Per IRC 58:2002, Axle load (AL) in Single Axle and Tandem Axle (Tonnes) is given.

Step 2. From the given data, cumulative repetition in 20 yrs. can be calculated from the formula which is given below:

$$C = \frac{365 \times A\{(1+r)^n - 1\}}{r}$$

Where,

C = Cumulative number of axles during the design period.

A = Initial number of axles per day in the year when the road is operational.

r =Annual rate of growth of commercial traffic (expressed in decimals).

n = Design period in years.

Step 3.After calculating cumulative repetition, Design traffic can be calculated by 25% of cumulative repetition.

Step 4.The Single and Tandem Axle load is multiplied with a factor of 1.2 respectively.

Step 5. Stress(kg/cm^2)is calculated from the given graphs as mentioned in IRC 58: 2002 (Graph between slab thickness and flexure strength).

Step 6. Stress Ratio is calculated from$\frac{Stress}{Flexure\ Strngth}$.

Step 7. Expected Repetition is calculated from the Design Traffic which is multiplied with a percentage of respective Axle loads.

Step 8. Allowable Repetition is calculated from the Table which is mentioned in IRC 58:2002 which is also shown below Table 5.3.

Step 9.Fatigue life consumed is calculated which is the ratio of fatigue life (N) and expected repetition (n). The design is unsafe if the cumulative fatigue life consumed is less than 1.0.

The slab design process as per IRC 58-2002 for the pavement quality concrete tested in the laboratory is presented in Tables 5.5. The Table 5.4 contains the input traffic data in terms of the expected repetitions for the single and tandem axles, for which the slab thicknesses have been calculated. The other input parameters are as below:

Road category: Two-lane Two way National Highway Cement Concrete Pavement

Modulus of sub-grade reaction with 150mm DLC: 8kg/cm^3

Elastic Modulus of Concrete: 3 x 10^5 kg/cm^2

Tyre Pressure: 8kg/cm^2

Rate of increase of traffic: 7.5%

The Tables 5.5 to 5.13 present the design of slab thickness by calculating the fatigue life consumed for the given axle load traffic (Table 5.4) & flexural strength of PQC achieved in the laboratory. Table 5.5 presents the calculations for the minimum flexural strength, as per IRC specifications, of 4.5MPa. Subsequent tables present the design for flexural strengths achieved by varying the percentages of Marble dust and steel fibres in the concrete mix.

Table 5.3 Stress Ratio and Allowable Repetitions in Cement Concrete

Stress Ratio	Allowable Repetitions	Stress Ratio	Allowable Repetitions
0.45	6.279×10^7	0.66	5.83×10^3
0.46	1.4335×10^7	0.67	4.41×10^3
0.47	5.2×10^6	0.68	3.34×10^3
0.48	2.4×10^6	0.69	2531
0.49	1.287×10^6	0.70	1970
0.50	7.62×10^5	0.71	1451
0.51	4.85×10^5	0.72	1099
0.52	3.26×10^5	0.73	832
0.53	2.29×10^5	0.74	630
0.54	1.66×10^5	0.75	477
0.55	1.24×10^5	0.76	361
0.56	9.41×10^4	0.77	274
0.57	7.12×10^4	0.78	207
0.58	5.4×10^4	0.79	157
0.59	4.08×10^4	0.80	119
0.60	3.09×10^4	0.81	90
0.61	2.34×10^4	0.82	68
0.62	1.77×10^4	0.83	52
0.63	1.34×10^4	0.84	39
0.64	1.02×10^4	0.85	30
0.65	7.7×10^3		

Table 5.4 Input Traffic Data for Slab Design

Flexure Strength= 45 kg/cm^{2}Assumed Slab thickness = 33 cm			
Single Axle Load		**Tandem Axles**	
Load in Tonnes	*Expected Repetitions*	*Load in Tonnes*	*Expectedrepetitions*
20	71127	36	35564
18	177820	32	35564
16	569023	28	71128
14	1280303	24	213384
12	2608024	20	177820
10	27622135	16	59274
<10	3556397	< 16	237093

Table 5.5 Slab Design for Minimum Flexural Strength of 4.5MPa as per IRC Specifications

Axle load(AL), tonnes	A.L × 1.2	Stress kg/cm²	Stress Ratio	Expected repetition, n	Allowable Repetitions, N	Fatigue life consumed
Single Axle						
20	24	24.10	0.53	71127	2.16×10^5	0.33
18	21.6	21.98	0.49	177820	1.29×10^5	0.14
16	19.2	19.98	0.44	569023	∞	0.00
14	16.8	17.64	0.39	1280303	∞	0.00
Tandem Axle						
36	43.2	19.38	0.43	35564	∞	0.00
						= 0.47

Table 5.6 Slab Design for Mix MF00

Flexure Strength = 49 kg/cm² Slab thickness = 31 cm						
Axle load(AL), tonnes	**A.L × 1.2**	**Stress kg/cm²**	**Stress Ratio**	**Expected repetition, n**	**Allowable Repetitions, N**	**Fatigue life consumed**
Single Axle						
20	24	26	0.53	71127	2.29×10^5	0.31
18	21.6	24.8	0.51	177820	4.85×10^5	0.37
16	19.2	22	0.45	569023	6.279×10^7	0.01
14	16.8	20	0.41	1280303	∞	0.00
Tandem Axle						
36	43.2	20.7	0.42	35564	∞	0.00
						= 0.68

Table 5.7 Slab Design for Mix MF10

Flexure Strength = 46 kg/cm² Slab thickness = 32 cm						
Axle load(AL), tonnes	**A.L × 1.2**	**Stress kg/cm²**	**Stress Ratio**	**Expected repetition, n**	**Allowable Repetitions, N**	**Fatigue life consumed**
Single Axle						
20	24	25.19	0.55	71127	1.24×10^5	0.57
18	21.6	22.98	0.50	177820	7.62×10^5	0.23
16	19.2	20.73	0.45	569023	6.279×10^7	0.01
14	16.8	18.45	0.40	1280303	∞	0.00
Tandem Axle						
36	43.2	20.07	0.44	35564	∞	0.00
						= 0.81

Table 5.8 Slab Design for Mix MF20

Flexure Strength = 41.8 kg/cm² Slab thickness = 34 cm						
Axle load(AL), tonnes	**A.L × 1.2**	**Stress kg/cm²**	**Stress Ratio**	**Expected repetition, n**	**Allowable Repetitions, N**	**Fatigue life consumed**
Single Axle						
20	24	23	0.55	71127	1.24×10^5	0.57
18	21.6	20	0.49	177820	1.287×10^6	0.14
16	19.2	18.4	0.44	569023	∞	0.00
14	16.8	16.5	0.39	1280303	∞	0.00
Tandem Axle						
36	43.2	18	0.43	35564	∞	0.00
						= 0.71

Table 5.9 Slab Design for Mix MF01

Flexure Strength = 58.7 kg/cm² Slab thickness = 27 cm						
Axle load(AL), tonnes	**A.L × 1.2**	**Stress kg/cm²**	**Stress Ratio**	**Expected repetition, n**	**Allowable Repetitions, N**	**Fatigue life consumed**
Single Axle						
20	24	32.5	0.55	71127	1.24×10^5	0.57
18	21.6	29.7	0.51	177820	4.85×10^5	0.37
16	19.2	27	0.46	569023	1.4335×10^7	0.04
14	16.8	22.5	0.38	1280303	∞	0.00
Tandem Axle						
36	43.2	25	0.43	35564	∞	0.00
						= 0.98

Table 5.10 Slab Design for Mix MF11

Flexure Strength = 51.6 kg/cm² Slab thickness = 30 cm						
Axle load(AL), tonnes	**A.L × 1.2**	**Stress kg/cm²**	**Stress Ratio**	**Expected repetition, n**	**Allowable Repetitions, N**	**Fatigue life consumed**
Single Axle						
20	24	28	0.54	71127	1.66×10^5	0.43
18	21.6	25.5	0.49	177820	1.287×10^6	0.14
16	19.2	23.2	0.45	569023	6.279×10^7	0.01
14	16.8	19.8	0.38	1280303	∞	0.00
Tandem Axle						
36	43.2	20.07	0.39	35564	∞	0.00
						= 0.58

Table 5.11 Slab Design for Mix MF21

Flexure Strength = 48.9 kg/cm² Slab thickness = 31 cm						
Axle load(AL), tonnes	**A.L × 1.2**	**Stress kg/cm²**	**Stress Ratio**	**Expected repetition, n**	**Allowable Repetitions, N**	**Fatigue life consumed**
Single Axle						
20	24	26	0.53	71127	2.29×10^5	0.31
18	21.6	24.8	0.51	177820	4.85×10^5	0.37
16	19.2	22	0.45	569023	6.279×10^7	0.01
14	16.8	20	0.41	1280303	∞	0.00
Tandem Axle						
36	43.2	20.7	0.42	35564	∞	0.00
						= 0.68

Table 5.12 Slab Design for Mix MF02

Flexure Strength = 61 kg/cm² Slab thickness = 26 cm						
Axle load(AL), tonnes	**A.L × 1.2**	**Stress kg/cm²**	**Stress Ratio**	**Expected repetition, n**	**Allowable Repetitions, N**	**Fatigue life consumed**
Single Axle						
20	24	32.5	0.53	71127	2.29×10^5	0.31
18	21.6	29.7	0.49	177820	1.287×10^6	0.14
16	19.2	27	0.44	569023	∞	0.00
14	16.8	22.5	0.37	1280303	∞	0.00
Tandem Axle						
36	43.2	25	0.41	35564	∞	0.00
						= 0.44

Table 5.13 Slab Design for Mix MF12

Flexure Strength = 56.9 kg/cm² Slab thickness = 28 cm						
Axle load(AL), tonnes	**A.L × 1.2**	**Stress kg/cm²**	**Stress Ratio**	**Expected repetition, n**	**Allowable Repetitions, N**	**Fatigue life consumed**
Single Axle						
20	24	30.5	0.54	71127	1.66×10^5	0.43
18	21.6	28.4	0.50	177820	7.62×10^5	0.23
16	19.2	25.6	0.45	569023	6.279×10^7	0.01
14	16.8	22.2	0.39	1280303	∞	0.00
Tandem Axle						
36	43.2	23	0.40	35564	∞	0.00
						= 0.67

Table 5.14 Slab Design for Mix MF22

Flexure Strength = 54.5 kg/cm² Slab thickness = 29 cm						
Axle load(AL), tonnes	**A.L × 1.2**	**Stress kg/cm²**	**Stress Ratio**	**Expected repetition, n**	**Allowable Repetitions, N**	**Fatigue life consumed**
Single Axle						
20	24	29	0.53	71127	1.66×10^5	0.43
18	21.6	26.7	0.49	177820	7.62×10^5	0.23
16	19.2	24.4	0.45	569023	6.279×10^7	0.01
14	16.8	20.8	0.38	1280303	∞	0.00
Tandem Axle						
36	43.2	22.3	0.41	35564	∞	0.00
						= 0.67

CHAPTER –6
CONCLUSION AND RECOMMENDATIONS FOR FURTHER STUDY

6.1 GENERAL

The present study was undertaken to investigate the flexure strength, compressive strength and split tensile strength of concrete with different level of replacement of cement with marble dust and addition of steel fibre in concrete mix. Cement was partially replaced by marble dust at three different levels of replacement i.e. 0%, 10% and 20% and steel fibre is added in concrete mix at different percentage i.e. 0%, 0.5% and 1%. Tests were performed after 28 days of curing of concrete. 27 samples of reference mix i.e. with 0% marble dust and 0% steel fibre and 216 samples of marble dust and steel fibre in concrete with different percentage were prepared for determining flexure strength, compressive strength and split tensile strength of concrete with different water-cement ratio as 0.30 for 5.5 N/mm^2, 0.35 for 5 N/mm^2 and 0.40 for 4.5N/mm^2 (Target Mean Flexure Strength). Super-plasticizer was used in all the mixes at 1% level by weight of cementious material.

6.2 CONCLUSIONS

From the experimental results, the following conclusion can be drawn:

Strength Characteristics

- Concrete mix with 10 percent marble dust as replacement of cement is the optimum level as it has been observed to show a significant increase in compressive strength at 28 days when compared with nominal mix.
- Concrete mixes when reinforced with steel fibre show an increased compressive strength as compared to nominal mix.
- The split tensile strength also tends to increase with increase percentages of steel fibres in the mix.
- On increasing the percentage replacement of cement with marble dust beyond 10%, there is a slight reduction in the tensile strength value.
- The flexure strength also tends to increase with the increase percentages of steel fibres, a trend similar to increase in split tensile strength and compressive strength.
- On increasing the percentage replacement of cement with marble dust beyond 10%, there is decrease in the flexure strength value.
- Maximum strength (flexure, compressive as well as split tensile) of pavement quality concrete incorporating marble dust and steel fibres, both, is achieved for 10% marble dust replacement and 1% steel fibres. However, if the marble dust content is increased to 20%, even with 1% steel fibre, the increase is not very significant.

6.3 SAVING OF MATERIALS IN DESIGN OF SLAB THICKNESS PAVEMENT

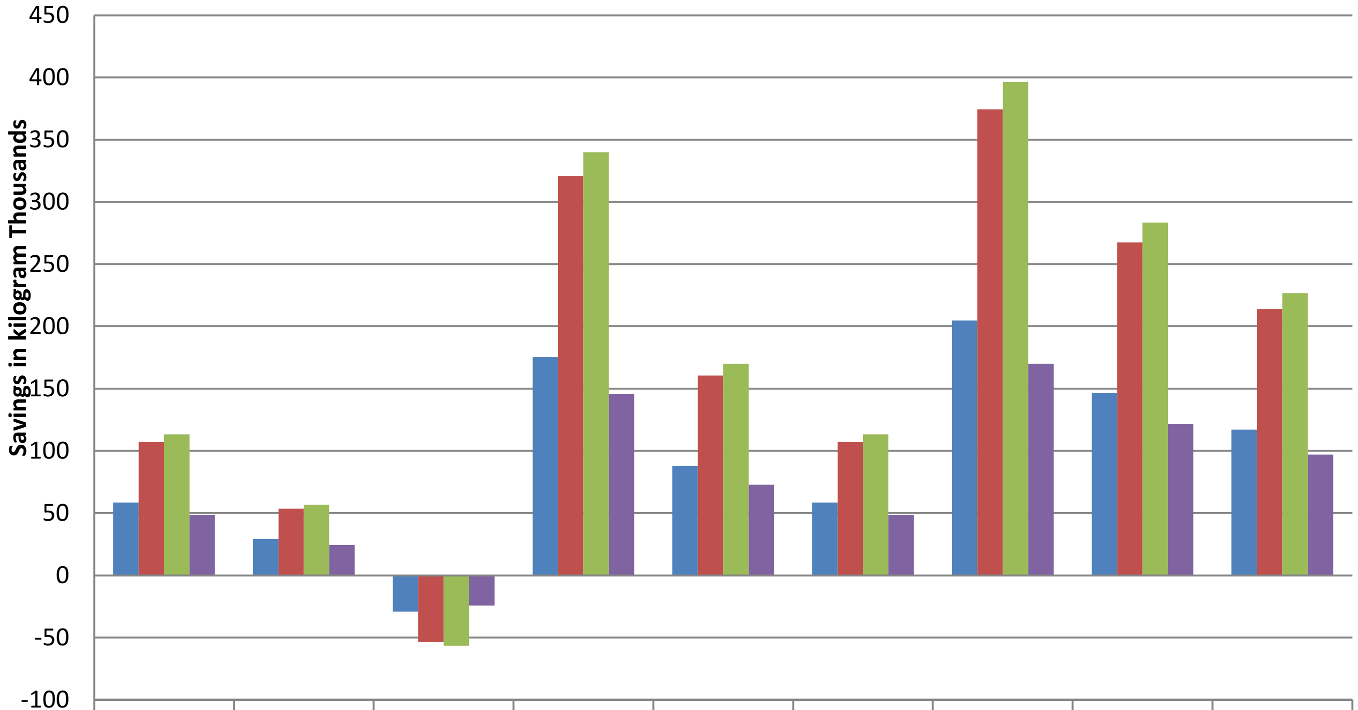
According to the results of the study, compiled for different mixes incorporating marble dust and steel fibres in the Table below, other than nominal mix, there is a noticeable change (i.e. decrease in material usage or saving of materials on economical basis) of following materials:

- Concrete Pavement Thickness
- Volume of concrete (m^3) used for 1 km Two Lane Highway
- Cement content (kg)
- Fine Aggregate (kg)
- Coarse Aggregate 10mm (kg)
- Coarse Aggregate 20mm (kg)

A 20 to 30mm saving in the thickness of PQC slab containing 10 to 20% marble dust as cement replacement is achieved with addition of 0.5% steel fibres where as with addition 1% steel fibres a reduction of 40 to 50mm is achieved. This indicates that the cost of using steel fibres can be offset by using 10 to 20% marble dust and thus considerable savings in materials can also be achieved. This leads to developing sustainable and green concrete pavements.

Table 6.1 Saving in Concrete Ingredientswith use of Marble Dust and Steel Fibres

Mix ID	Slab Pavement Thickness (mm)	Saving in PQC slab Thickness (mm)	Saving in m^3 of Concrete for 1 km Two Lane Highway	Saving in Cement Content (kg)	Saving in Fine Aggregate (kg)	Saving in Coarse Aggregate (20mm) (kg)	Saving in Coarse Aggregate (10mm) (kg)
MF00 (Min.)	330						
MF00	310	20	150	58500	106950	113295	48555
MF10	320	10	75	29250	53475	56647.5	24277.5
MF20	340	-10	-75	-29250	-53475	-56647.5	-24277.5
MF01	270	60	450	175500	320850	339885	145665
MF11	300	30	225	87750	160425	169942.5	72832.5
MF21	310	20	150	58500	106950	113295	48555
MF02	260	70	525	204750	374325	396532.5	169942.5
MF12	280	50	375	146250	267375	283237.5	121387.5
MF22	290	40	300	117000	213900	226590	97110



	150 m3 20 310 MF00	75 m3 10 320 MF10	75 m3 -10 340 MF20	450 m3 60 270 MF01	225 m3 30 300 MF11	150 m3 20 310 MF21	525 m3 70 260 MF02	375 m3 50 280 MF12	300 m3 40 290 MF22
Saving in Cement, kg	58500	29250	-29250	175500	87750	58500	204750	146250	117000
Saving in Fine aggregates, kg	106950	53475	-53475	320850	160425	106950	374325	267375	213900
Saving in Coarse Aggregates (20mm), kg	113295	56647.5	-56647.5	339885	169942.5	113295	396532.5	283237.5	226590
Saving in coarse aggregate(10mm), kg	48555	24277.5	-24277.5	145665	72832.5	48555	169942.5	121387.5	97110

Fig. 6.1 Saving of Materials in Slab Thickness Pavement

Table 6.2 Saving in Concrete Pavement Thickness (mm)

Mix ID	Saving in concrete pavement thickness (mm)
MF00 (Min)	
MF00	20
MF10	10
MF20	-10
MF01	60
MF11	30
MF21	20
MF02	70
MF12	50
MF22	40

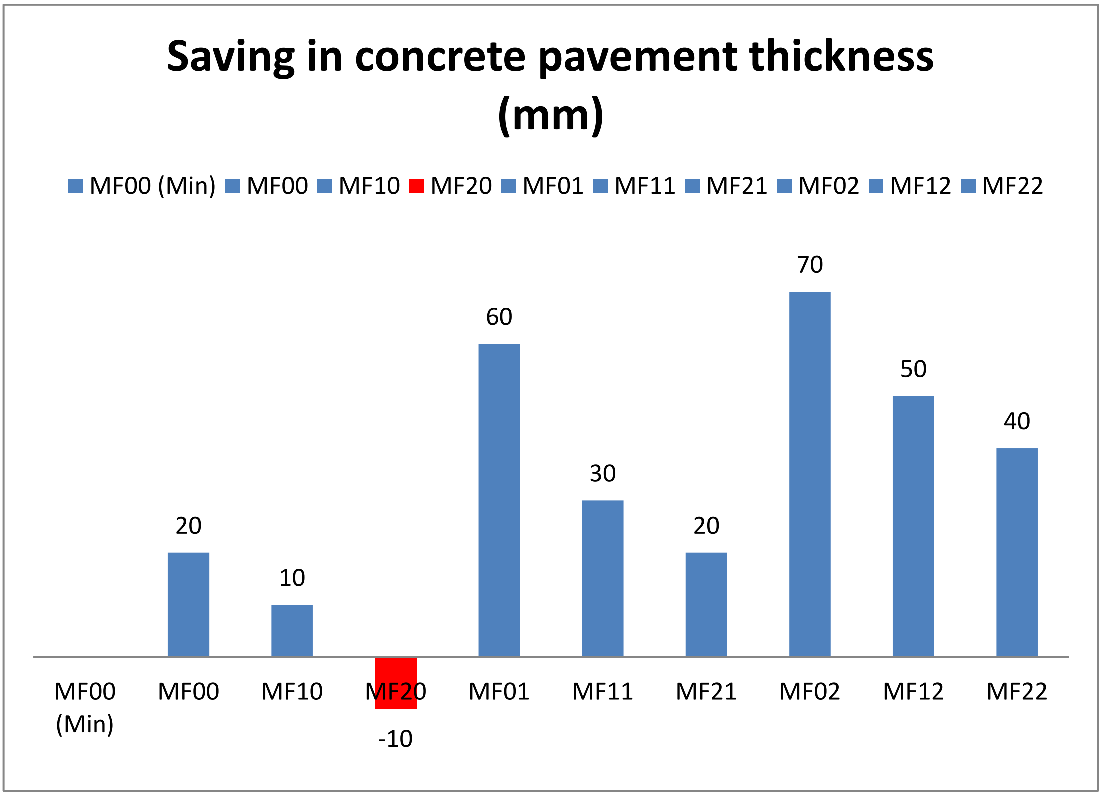


Fig. 6.2 Saving in Concrete Pavement Thickness

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