The Study of Effect of Steel Fibres and Marble Dust on Strength Characteristics of Pavement Quality Concrete

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Abstract— **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 fibres.

Index Terms— Marble Dust, Concrete, Steel fibre, fly ash

Sub area : Construction Technology

Broad Area: Construction Technology & Management

I. INTRODUCTION

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.

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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

Ground Granulated Blast-furnace Slag (GGBS):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.

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 u	159	15.9	55.6	44.4
5	300 u	316.5	31.65	23.95	76.05
6	150 u	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 u	8	8	92	8
5	300 v.	11	11	81	19
6	150 u.	81	81	0	100

7	PAN	0	0	SUM = 127	F.M. = 1.27

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

d) Steel Fibre

Mild steel fibres having 30 mm thickness and 60 mm length i.e. aspect ratio (lid) 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 "strayed" 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 "GLENIUMTM 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
	Type	Polycarboxylic ether (PCE)
	Form	Liquid
	Colour	Light Brown
	Specific Gravity	1.09
	Relative density	1.09 ± 0.01 at 25^0C
	pH Content	> 6
	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.

METHODOLOGY

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

$Fcuf = F_{c\cdot u}(1 + 0.1\,F')$

Where,
Fcuf = Cube strength of SFRC
^{F}cu = Cube strength of corresponding plain concrete
F' = Fibre factor = (1/d) x Vf x df
Where,
Vf= Volume fraction of fibres
l/d = aspect ratio of fibres
df = 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.
df= 0.5 for un-crimped fibres of circular cross section
df= 0.75 for crimped fibres of circular cross section
df= 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.

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.

B **LA/** *r*

Where,
Fspf = Split tensile strength of fibre concrete in N/mm^2
Fcuf=Cube strength of fibre reinforced concrete in N/mm^2
A = A non-dimensional constant having a value of 2-g'
A dimensional constant having a value of 0.7 N/mm^2
C = A dimensional constant having a value of 1 N/mm^2
Fibre factor
The following formula is also suggested for the prevision of modulus of rupture of SFRC from its split tensile strength
$Fspf = 0.65\,F_r$
Where F_r = modulus of rupture of SFRC/

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

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).

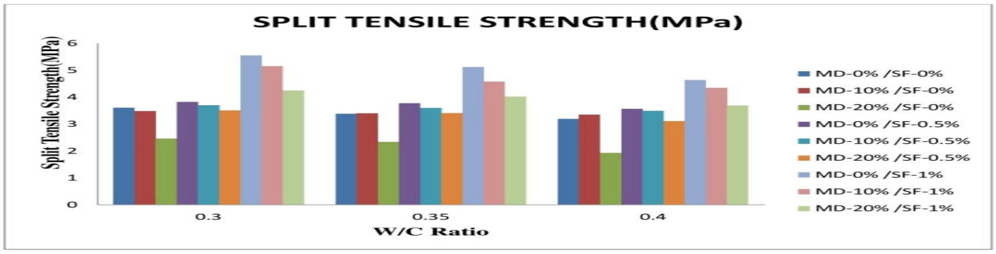

Fig. 4.21 Variation of split strength of concrete Vs W/C with different percentage of S.F and different percentage of M.D.

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%

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.

Table -M 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%

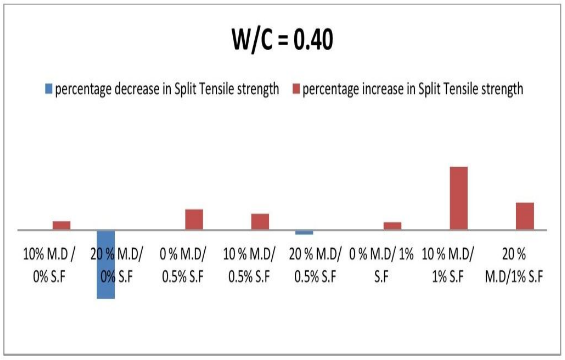

Fig. 4.27 Variation of Split Tensile Strength at W/C Ratio = 0.40

Tables M and Above Figures 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

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.

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.

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.

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