Mechanical Properties of Lime Powder Blended Cementitious Composites

Sreenath Sreekumaran, Kaverikalaimani K, Saravana Raja Mohan K.

Abstract*: Cementitious composites are well known for its reasonable strength and high ductility. The recent trends were in developing High Performance Cementitious Composites (HPC) which possesses better strength and durability properties. For achieving high performance, it consumes more cement and the water-binder ratio will be considerably low. That is, only a part of the total cement content will be taking part in hydration and the remaining will be acting as fillers in the mixes. This study aimed to reduce the cost of the mix by replacing this filler part of the cement by locally available lime powder without compromising its strength. Also, accelerated curing such as steam curing is required for the achievement of high strength at the early stages. In this study, normal water curing was adopted to mimic the actual site conditions. The base mix of the composite was developed by replacing 30% of the cement with lime powder. The mix was then reinforced with 0.5%, 1%, 1.5% and 2% crimped fibres by volume. Strength characteristics were studied along with the resistance to damage under low velocity impact test. It was observed that, under the normal water curing, strength development was at low rate and the 28 day strength was considerably less. Addition of fibres helped in improving strength and the better results were shown by the mix reinforced with 2% steel fibres by volume.

***Index Terms*: Cementitious composites, Fibre reinforcement, Lime powder.**

I. INTRODUCTION

Fibre Reinforced Cementitious Composites are special among building materials because of its strength characteristics and ductile nature. The recent researches mainly concentrated on developing Ultra High Performance Composites (UHPC) which possesses high strength as well as better durability characteristics [1]. The effect of proportion is considerable in attaining these characteristics [2]. When reinforced with high volume of fibres, these composites can exhibit high tensile strength. Also these fibre reinforcements will help in improving the strain hardening characteristics of the material. These composites find application in the area of repair and rehabilitation, provision of overlays and joints for bridge decks etc. To achieve Ultra High Performance, the mixes consume high amount of cement (About 900 kg/m^3). Because of low water-binder ratio, only a portion of this cement is taking part in hydration. The remaining cement in the mix will act as a filler material which will strengthen the microstructure of the mix. It will be beneficial if the usage of the cement in the mix can be reduced without compromising the strength characteristics of the composite. In this study, the base mix was chosen referring the previous works in the same area[3]. As cement production is considered as one of the major sources of anthropogenic CO_2 emission, it is desirable to replace the same [3] or at least to reduce the use. The researchers reported that up to 30% of the cement content in the mix can be replaced with suitable alternatives without compromising the strength characteristics. Use of ground quartz as filler is common and it can impart good mechanical properties to the composite [4]. Effective use of lime stone powder for partial replacement of cement was also proven by the previous researchers [5],[6]. The use of locally available materials can help in reducing the cost and energy, thereby attaining sustainability [7]. In this study, locally available hydrated lime powder is used as a replacement for cement. The base mix in this study was developed by replacing 30% of the cement with lime powder. Crimped steel fibres were used to reinforce the matrix. Generally steel fibres are randomly dispersed in the mix which can help in achieving better isotropic behavior [8]. Method of curing is also very important in the case high performance composites. Accelerated curing methods like steam curing will help in achieving high early age strength [9],[10]. Since these methods of curing can be practiced only under controlled conditions, it will be suitable for pre-cast construction [11]. In this study, it was tried to achieve considerable strength with normal water curing. Strength characteristics such as compressive strength, split tensile strength and modulus of rupture were observed. Low velocity impact test was conducted to assess the energy absorption capacity and thereby the capacity to resist the damages.

II. MATERIALS USED

53 grade Ordinary Portland Cement (OPC) conforming to IS 12269 was used in this study. Specific gravity of the cement was 3.15 with an initial setting time of 32 minutes. Fineness test was conducted on the cement conforming to IS 4031. Only 8% of the particles of cement were larger than 90 microns. Silica fume of specific gravity 2.63 acted as a mineral admixture for the mix. The active SiO_2 content in the silica fume was around 99.8%. For the replacement of cement lime powder with active CaO of 68% by mass was used. The particle size of was about 250 microns. Specific gravity was 2.24.

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Table I. Chemical Composition of the Constituents

Constituent	Chemical Composition (% by mass)						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI
OPC	20.49	5.91	4.07	62.90	1.13	1.87	2.29
LP	2.94	3.08	3.94	91.57	1.68		
SF	92.5	0.72	0.96	0.48	1.78	0.2	1.5
MS	99.5	0.08	0.04	0.01	0.01		0.28

Sand used was with an average particle size 2 mm and fineness modulus 2.55. The bulk density of the sand was 1.50. For ensuring better packing micro sand was also used for the study. The particle size of micro sand was in the range of 0.1 mm to 1 mm. Active SiO_2 content in the micro sand was 99.5%. Specific gravity of micro sand was about 2.6. Normal potable water was used for the hydration of cementitious materials. Polycarboxylate ether based super plasticizer was used. Crimped steel fibres of aspect ratio 27.77 were used in the study. Length of the fibres was 12.5 mm and diameter was 0.45 mm. The chemical composition of cement, silica fume, micro sand and lime stone powder are given in the Table I.

III. METHODOLOGY

A. Mix Proportion

Mix proportion for the high performance composites is usually fixed to attain maximum dense particle packing. From the research articles studied, it was observed that the optimum packing of constituents was done based on the Linear Packing Density Model. A mix presented by Yu et. Al, in which OPC was optimally replaced with Lime Powder, was taken as a reference mix proportion for this study [3]. 30% of OPC was replaced with Lime Powder. The detailed mix proportion is given in the following table. Since the water to binder ratio is 0.33, Super Plasticizer content was as high as 7.5 % by mass of cement to achieve the required workability of mix. Mix proportion is detailed in the Table II.

Table II. Mix Proportion

S.No.	Constituent	Ratio
1	Cement	1
2	Lime Powder	0.42
3	Micro sand	0.357
4	Sand	1.72
5	Silica Fume	0.07
6	W/B Ratio	0.33
7	Super Plasticizer	0.075

Maximum dosage of fibres was taken as 2 % by volume of the mix. Various mixes were prepared with 0%, 0.5%, 1%, 1.5% and 2% fibre by volume of the mix to compare the fresh and hardened properties. The mixes are designated based on the fibre volume as M0, M0.5, M1, M1.5 and M2 respectively in the following parts of this article. The prepared mixes were tested for their fresh and hardened properties. The following are the tests conducted on the samples/specimens.

B. Study on Rheology of mixes

Workability of the mix is an important factor as the composite is to be reinforced with closely spaced rods in most of the cases. Flow table test was conducted conforming to IS 1199. The flow value was considered as a measure of workability which is defined as the average of the diameter of the flow in two mutually perpendicular directions.

C. Compressive Strength Test

Standard 100 mm cube specimens were used to determine the compressive strength of the composite. The test was conducted based on the recommendations of the standard code IS 516. The specimens were cast for each mix proportions and tested after 28 days of normal water curing.
Three specimens were tested per mix after the above mentioned curing age and the average strength was reported. Standard cylinder specimens were also tested under compression on Universal Testing Machine to assess the stress strain behavior of the mixes.

D. Split Tensile Strength Test

To assess the tensile strength of the mixes, split tensile strength test was conducted conforming to IS 5816. Standard cylinder specimens of diameter 100 mm and height 200 mm were cast and tested after 28 days of normal water curing. Three specimens were tested per mix and the average results were reported.

E. Modulus of Rupture

To assess the flexural strength of the mixes, modulus of rupture was found conforming to IS 516. Standard prism specimens of cross section 100 mm × 100 mm and length 500 mm were cast and tested after 28 days of normal water curing. Three specimens were tested per mix and the average results were reported.

F. Low Velocity Impact Test

Drop hammer impact test was conducted conforming to ACI Committee 544. Standard disc specimens of diameter 150 mm and depth 50 mm were prepared and tested under low velocity impact loads after 28 days of curing. A steel ball of weight 2.86 kg was used as the hammer. The specimens were kept on a rigid platform and the ball was dropped from a height of 730 mm. The number of blows required for making the first crack was noted as designated as N1 and the same for complete failure was noted as designated as N2. The energy absorbed by the specimens were calculated as,
Impact Energy, $E = m \times g \times h \times N$
Where 'm' is the mass of the ball, 'g' is the acceleration due to gravity, 'h' is the drop height and 'N' is the number of blows.

IV. RESULTS AND DISCUSSIONS

A. Flow of the mixes

It was observed that the addition of fibres in the mix lead to the reduction in the flow of mixes. Though, the reduction in flow was negligible and hence it won't be affecting the passing and filling ability of the mixes. Table III presents the flow values of different mixes.

Table III. Average Flow Diameter

Mix	Average Flow Diameter (mm)
M0	244
M0.5	243
M1	241
M1.5	239
M2	236

B. Compressive Strength

The compressive strength test results are given in the Fig.1. The percentage increase in the compressive strength is illustrated in the Fig.2. It was observed that the compressive strength of the control mix is inferior among all the mixes prepared. This is due to the absence of coarse aggregate in the mix. It was also observed that the compressive strength was increasing as the fibre content in the mix was increasing. The increment in the strength for the minimum volume of fibre (that is 0.5%) was observed as 12.82% and the same for maximum volume of fibre (that is 2%) was observed as 39.53% with reference to the control mix with 0% fibre in it. The improvement in the strength is happening in a passive way because of the confining effect of the fibres added.

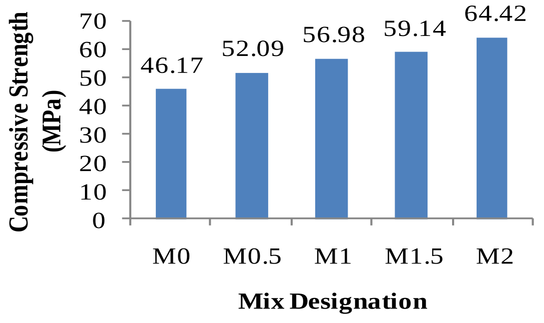

Fig. 1. Compressive Strength of the mixes

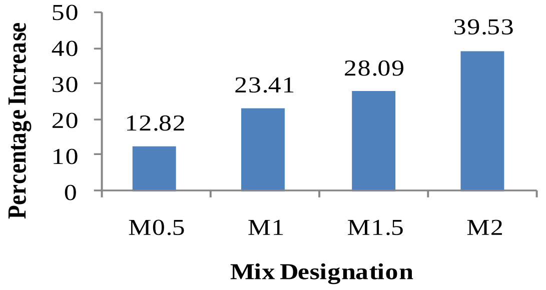

Fig. 2. Percentage Increase in the Compressive Strength due to the addition of fibres

C. Stress-Strain Relationship

The relationship between stress and strain is plotted from the load-deformation characteristics of the cylinder specimens under compression. Fig.3 gives the plot. From the comparative plot of stress-strain relationships of various mixes, it is clear that addition of fibres improved the ductility of the mixes. Even a smaller addition of fibre as in the mix M0.5 showed a sudden change in the nature of the mix from brittle to ductile. Mixes M1.5 and M2 showed better and almost same strain hardening nature.

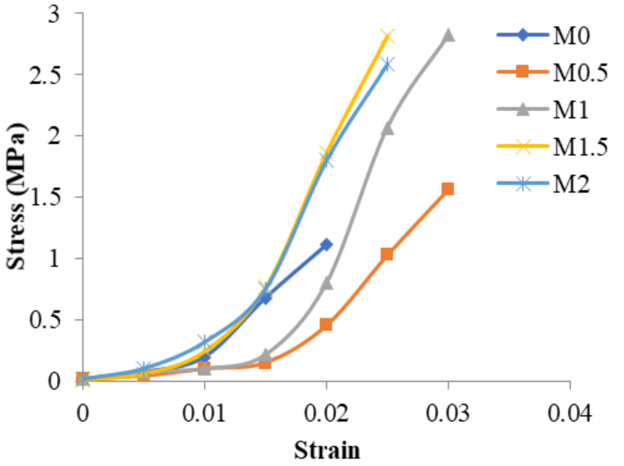

Fig. 3. Stress-Strain Relationship of Mixes

D. Split Tensile Strength

The Split Tensile test results are given in the Fig.4. The percentage increase in the spit tensile strength is illustrated in the Fig.5. It was observed that the split tensile strength of the control mix was considerably less compared to the other mixes. A brittle failure was observed on the control mix specimens. This is due to the absence of fibres. It was noted that the split tensile strength was increased considerably as the volume of fibres increased in the mix. The mix with 0.5% volume of fibres in it showed an increase in strength of 19.14% while the same showed by the mix with 2% fibres was 65.74%. The improvement in split tensile strength observed is due to the improvement in the ductility due to the addition of fibres.

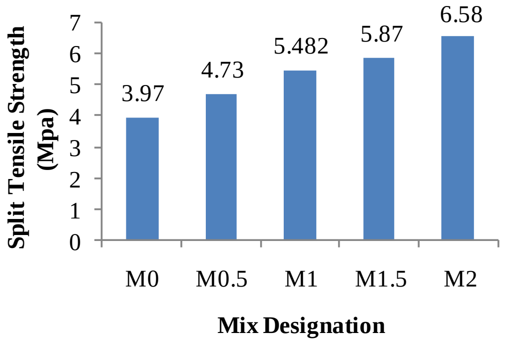

Fig. 4. Split Tensile Strength of the mixes

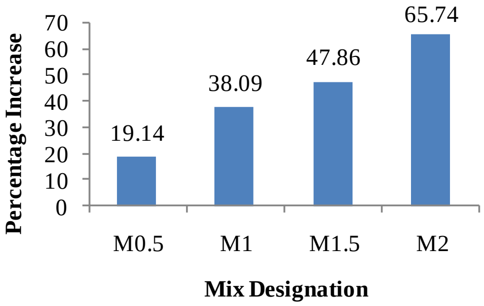

Fig. 5. Percentage Increase in the Split Tensile Strength due to the addition of fibres

E. Flexural Strength

The Modulus of Rupture for the mixes were found and are given in the Fig.6. The percentage variation in the flexural strength is illustrated in the Fig.7.

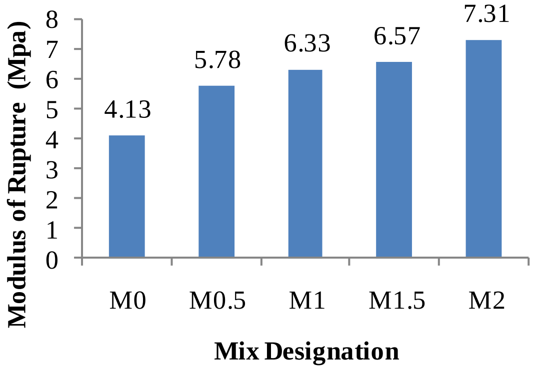

Fig. 6. Flexural Strength of the mixes

Control mix with zero fibre content showed poor flexural properties. This is also due to the absence of fibres. Addition of fibres helped in improving the modulus of rupture considerably. Addition of 0.5% of fibres improved the strength by 39.95% while the addition of 2% fibres improved the strength by 77% with reference to the control mix. This is also due to conversion from the brittle nature to the ductile due to the addition of fibres.

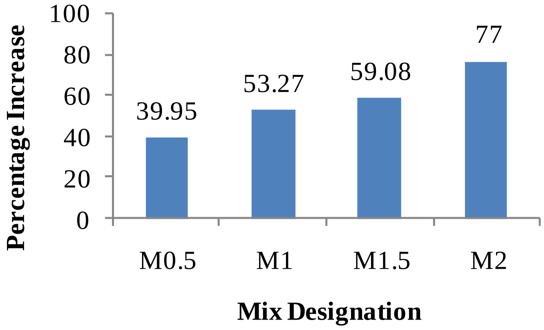

Fig. 7. Percentage Increase in the Flexural Strength due to the addition of fibres

F. Impact Energy Absorption

The number of blows observed to make the first crack and for the complete failure is given in the Table IV. The energy absorbed is also given in the table. The variation in the energy absorbed is plotted in the Fig. 8. The percentage variation in the energy absorption is given in the Fig. 9.

Table IV. Low Velocity Impact Test Results

Mix	N1	N2	E1 (Nm)	E2 (Nm)
M0	4	9	81.93	184.33
M0.5	7	25	143.37	512.03
M1	9	31	184.33	634.92
M1.5	12	45	245.78	921.66
M2	15	120	307.22	2457.76

N1 is the number for blows to make the first crack, N2 is the number of blows required for the complete failure, E1 is the energy absorbed when the first crack was observed on the specimen and E2 is the energy absorbed when the specimen failed completely.

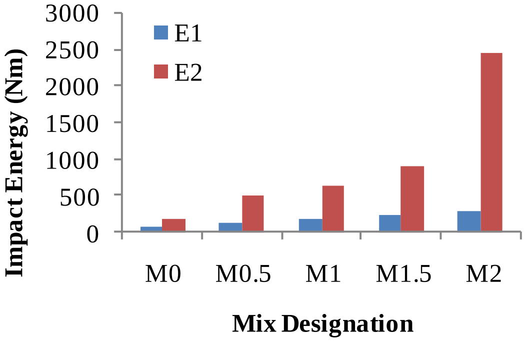

Fig. 8. Energy Absorbed by the specimens

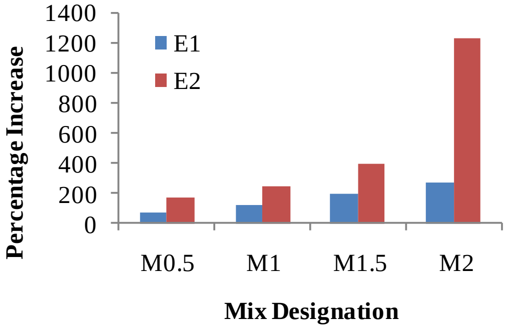

Fig. 9. Percentage Increase in the Impact Enegy Absorption by the Specimens

The number of blows required to make the first crack on the control specimen was 4 and the specimen got failed at the 9th blow. The energy absorbed by the specimen at failure was less compared to the other mixes. This is due to the absence of fibres in it. In increase in energy absorption capacity of the specimens was increase greatly as the fibre volume in the mix was increased. The energy absorbed by the specimen with mix M0 at failure was 178% more than the reference mix while the increase in energy absorption capacity for the specimens with mix M2 at failure was about 1233%. This improvement in energy absorption capacity can be attributed to the improved ductility of the mixes. The images of failed specimens under impact load from which the failure pattern can be observed are given as Fig. 10.

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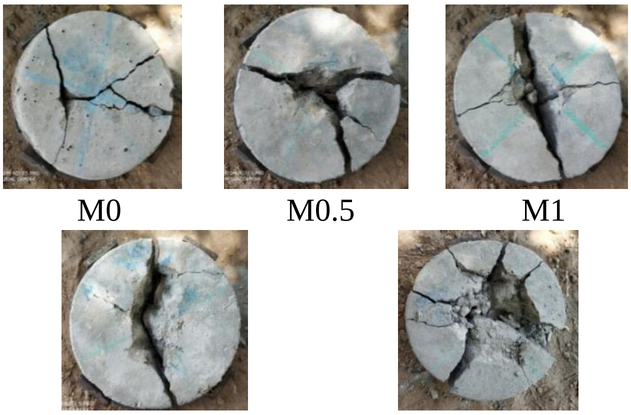

M0 M0.5 M1

M1.5 M2

Fig. 10. Failure Pattern of Specimens

V. SUMMARY AND CONCLUSIONS

It was observed that the strength attainment of lime powder based composite was less compared to the Ultra High Performance Composite mixes discussed in various articles referred. The possible reason can be the curing method followed in this study. As the consumption of cement is more and the resulting strength is low compared to the proven UHPC mix proportions, the presented mix proportion is not economically viable. Further, studies can be done, by improving the packing and by trying different curing regime, to prove the viability of lime powder as a replacement for cement in UHPC mixes. Addition of fibres helped in improving the compressive strength, split tensile strength and flexural strength of the composite mixes. Impact energy absorption capacity got considerably increased due to the addition of fibres and it was very high for the mix with 2% fibres in it. Further studies can be done to optimize the usage of fibres and to optimize the replacement of cement by other locally available fillers.

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