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Influence of Lime and Marble powder Waste on the Strength Activity Index of Self Compacting Mortar and Concrete

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Abstract: ***Void free mass, congested reinforcement, reduced section, and surface finishes are the present demand in the construction sector that can be fulfilled using Self Compacting Concrete (SCC). It flows under self-weight and develops a homogeneous dense mass of concrete without external energy (Vibration). The research described in this research examined the making of SCC with readily available materials. The most crucial distinction is the presence of filler material and small aggregate size in the SCC mixture. To obtain the benefit of filler material, reduced cement content, improve workability and strength in SCC, two fillers selected from a group of natural inert by-product, limestone powder (LP), and marble powder (MP). For this purpose, mortar cube prepared as per BS 3892 with two fillers, LP and MP by 10%, 15%, and 20% of replacement with a different combination. Present work also investigates the pozzolanic and filler effect of partial replacement in mortars by strength activity index (SAI), also tried to develop the relationship between fresh SCC slump flow and V-flow spread time. The observed value in the SAI test for the sixteen samples of a mineral filler of 10%,15%, and 20% replacement compared with a normal mix, all samples have the value lower than the control mix of 80% as per BS 3892. It is due to the effect of the filler on the microstructure and the presence of superplasticizer. From these results, it is concluded that filler, LP, and MP does not contribute to pozzolanic reaction, and it is still unhydrated at the age of 28 days.***

Keywords: ***Lime powder, Marble powder, Self-compacting concrete, Strength activity index, Superplasticizer, Pozzolanic material.***

I. INTRODUCTION

Self-Compacting Concrete (SCC) is one of the most current applications of high-performance concrete available on the market today. SCC is a strong material that matches a unique blend of performance and uniformity requirements that cannot ever be obtained using traditional constituents and common construction practices. It can flow quickly into place and self-consolidate under its self-weight without displaying any notable separation of constituents[1-2].

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These features transpose into a significant reduction in labor cost and construction time and better working conditions by excluding the influence of vibration.This new technology can support the building industry to optimize material usage, produce economic advantages, and develop stable structures environmentally and economically. In the late 1980s, the making of SCC, produced at the University of Tokyo needs higher cement content and expensive chemical admixtures [1]. Despite its high primary cost, this type of SCCis used for several important purposes in Japan and Europe [3-4].

It is vitally essential for the future use of such concrete in the construction industry to develop a cost-effective SCC with excellent fresh and hardened properties. Modern research efforts head to developing new types of SCC by substituting a high percentage of cement in the mix with recyclable industry waste.

SCCis manufacturedby integrating either pozzolanic or non-pozzolanic supplementary cementitious materials, such as fly ash, silica fume, lime, and slag cement with viscosity-modifying agents[2, 5]. The application of such industrial by-products can assure high flowability, improves the workability and durability property of SCC at a reasonable cost. Additionally, the use of such waste by-product reduces the carbon footprint by decreasing cement content in the mix and save the environment.

Domone et al.[6] stated that the use of natural and industrial waste products allows unlimited advantages from the viewpoint of conserving natural resources, saving of materials, cost-effectiveness, worksite productivity, and overall development of sustainable construction.

The most productive step to make the building construction industry sustainable is to encourage and admit the application of SCC, which can match appropriate combinations of production and uniformity demands that cannot ever be performed routinely using regular concrete.

In the present situation, reducing the consumption of cement in the construction industry is of prime importance to decreasing greenhouse gases and energy consumption. SCC used fillers produced by industries as a substitute for cement lead to sustainable construction[7-8].

Recent research has revealed that these materials can be employed as relevant inorganic and organic resources to generate various profitable value-added products. The solid disposal of a waste by-product of the industry creates many problems in the soil and the environment. To promote and use of by-product is the only way for sustainable development.

For this reason, the construction industry is continually examining additional cementitious supply to overcome the solid waste disposal problem.The economy in production cost, abundant energy, and cost-saving can occur when secondary industrial products are employed as partial replacements for reducing the carbon footprint in the production of Portland cement.

Due to the high production cost and continued extraction of natural material from mines, the good-quality materials are limited; hence, partially replacing cement with the secondary industrial product conceivably satisfied the raised requirements for cement and concrete products [9].

The present research attempts to study the probability of using regionally available marble powder and lime powder as partial replacements for cement for the production of high-quality SCC mix and explores the strength behavior of SCC mixes with MP and LP. Different replacement levels were attempted during the development of mixes.The influence of mineral admixtures on admixture demands is significantly dependent on the shape of the particle, particle size distribution, and surface properties.

II. PROPERTY OF MATERIALS

The purpose of the present experimental work was to study the effect of non-pozzolanic filler types on workability and hardened property of SCC with different types of replacement levels and also to compare a different combination of replacement with the SCC (0%) without filler. For this experimental program, two fillers of the same group (mineral type) were selected; Limestone powder (LP) and Marble powder (MP), as shown in fig.1. The mixed design of Self-compacting mortar (SCM) adopted for testing and casting the specimen has shown in Table 3.

A. Cement

Cement is one of the powder contents, and binders in SCChave used to provide higher paste with a binary or ternary blend. In this experimental study, all the mixture includes ordinary Portland cement (OPC), which meets an IS 12269 [10], and ASTM C-150[11] specification was used.

Fig.1. Ingredients of SCM and SCC.

B. Aggregate

For obtaining higher flowing properties and strength of SCC, a rounded, uncrushed coarse aggregate of the gravel sediment is preferable. However, in the present research work, after survey locally available natural, dry, and clean siliceous sand and crushed granite aggregate of 16mm nominal size are used. The specific gravity and fineness modulus of coarse and fine aggregate 2.78, 2.61, and 2.80, 2.64, respectively conform to IS-383[12] employed. The specific gravity of coarse aggregate found out by wire basket method of size less than 6.3mm mesh, as shown in fig.

C. Water

Water is an essential parameter to maintained water to powder ratio for obtaining fresh and hardened property SCCat different edges. In the present experimental work, potable water was used at 28±1^{0}C for all binary and ternary blended SCC mixes.

D. Lime Powder and Marble powder

Limestone powder is one of the traditional materials used as a Type I inert or nearly inert from ancient times as cement alone is not sufficient to control the strength and for higher strength. To reduce the heat of hydration and risk of cracking, filler play a vital role in SCC mixes as an addition. The waste marble pieces were collected from the processing plant. The marble powder prepared from chips and small pieces ground in powder form used as an addition in binary and ternary mixes of SCC with a different combination. Fillers LP and MPused passing from 125µm sieve.

E. Superplasticizer (SP)

The new generation superplasticizer naphthalene formaldehyde-based (1.5% weight of powder content) was employed to reduce water demand in SCC. Also, to obtain improved and consistent performance SCC mix. The elasticity of their chemical structure is a typical advantage that can be modified and tailored to conquer the issue of compatibility with cement, such as fresh state preservation of workability.

F. Viscosity modifying admixture (VMA)

The combination of SP and VMA reduced the sensitivity to variation in SCC constitutes, principally aggregate moisture content. The combined effect improved stability and robustness. For all mixes, 0.20% VMA was used to reduce bleeding and segregation in SCC.

III. MIX DESIGN FOR SCC

A. Self-compacting Mortar (SCM)

The procedure used was based on ASTM C-311[13] and BS-3892 [14]. Control mortar blocks prepared by mixing 1350g sand, 450g Portland cement, and 225ml water in a planetary orbital mixer for 5 minutes.

Cast iron molds conforming to IS standards were used for casting mortar cubes. Three molds of size 70.6 mm x 70.6 mm x 70.6 mm were filled with mortar mix for each curing age (curing age - 7 and 28days). Mortar cubes after casting were placed in a humid atmosphere with 27+2C^0 temperature and about 65% humidity for 24 hrs. The mortar cubes were removed after 24 hrs.from the molds and were placed in freshwater for curing. After 7 and 28 days of curing, cubes were taken out of the water and tested in a fully saturated surface dry condition. Compressive strength was found by crushing mortar cubes under a compression testing machine (CTM). Casting, curing, and testing procedures discussed above were repeated for each replacement level specified in Table 3.

Cement was replaced by LP and MP in 1 part of the cement. Three cubes were cast for each replacement level and for every curing period.

B. Self-Compacting Concrete (SCC)

The mix design is proportioningwas conducted for SCC with target compressive strength 30 MPa following EFNARC guideline [15],a new mix design of Nan-Su [16], and a new mix design developed by Vilas V. [17] used. For laboratory trials, the initial mix prepared by keeping the water to binder ratio 0.43, powder content between 360-500 kg/m^3, water content 150-210 Kg/m^{3,} and fine aggregate to total aggregate ratio was 0.54. The 400kg/m^3 cement and with a different replacement of cement by 0%, 10%, 15%, and 20% with LP and MP of SCC.The fine aggregate and coarse aggregate content kept constant for all mixes as 996.85 kg/m^3 and 792.56 kg/m^{3,} respectively.

The experimental program aimed at studying the fresh and hardened property of SCC, comparing with Normal SCC without filler. The three different percentage of LP(10,15, & 20%) and MP(10,15&20%) as substitute for cement with different combination 25%L-75%M, 50%L-50%M, 75L%-25%M, 100%L-0%M and 0%L-100%M was prepared in laboratory. SCC0 stands for SCC without filler, 0L-100M in 10% replacement stands for 0% lime and 100% marble, and the same for 15% and 20% replacement mixes.

The different kinds of binary and ternary blended SCC prepared with mixing cement, sand, aggregate, filler, and chemical admixture with 0.43 water to powder ratio (as per laboratory test trials) and EFNARC guideline [15].To obtain the flowability, passing ability, and filling ability, the proportion of coarse and fine aggregate was adjusted.

IV. RESULTS AND DISCUSSION

A. Performance of cement paste with LP and MP

Table 2 represents the test results for the replacement of cement by LP and MP in a paste. The outcomes of the test for OPC comply following, IS 4031:1988.[18] Table 2. Test results of LP and MP with OPC for Standard Consistency, setting time, and soundness. The standard consistency of OPC was found out to be 28%. Accordingly, the IST and FST for OPC obtained to be more than 30 min and less than 600minute, respectively. The soundness resulted in 1mm for OPC. The requirement of water increased as an increase in the percentage replacement.

B. Marsh cone Test (ASTM C939 / C939M - 16a)

It has been noticed from several trials that all groups of superplasticizers with different types of a binder have not explained in the same degree of advancement in fluidity. Also, cement is very perplexing, involving many factors like the composition of cement, fineness, and type of cement.Therefore, to initiate the flow of the mix,the Marshcone testwas performed.

Marsh cone is a conical brass or iron vessel inside smooth, with a 5mm diameter aperture at the bottom. The Marsh cone test was carried out to decide the superplasticizer doses for the SCC concrete mix. The test required 2 kg cement and 900ml of water (w/c= 0.45) with different doses of plasticizer of 0.6, 0.8, 1.0, 1.2, 1.4, 1.5, and 1.6 % by weight of cement to prepared paste. After the proper dry mix, water is added. Before the test, the slurry should be sieved through 1.18 sieves to exclude lumps. First, close the bottom of an aperture with a finger and pours one-liter of cement slurry into the Marsh cone. After starting the stopwatch, the flow out time was recorded in seconds. This time is called the 'Marsh Cone' Time. The time elapses for a consistent free flow of paste through the cone was recorded for different mixes.

The doses of superplasticizer at the minimum time with the constant free flow have chosen and obtained a value of 1.4% by weight of cement. However, after individual trial mixes with fine and coarse aggregate content, 1.5% doses are appropriate and decided for practical work of SCC.

Table 1. Marsh Cone Test results for paste

SP % By weight of cement	0.6	0.8	1.0	1.2	1.4	1.6
Marsh cone time in sec (T)	191	170	115	84	64	60

C. Compressive strength of mortar test: (as per IS: 4031-Part 6: 1988)

The compressive strength of cement mortar is the essential parameter helpful to understand the behavior of lime and marble powder in cementitious medium. Cement and sand mix was prepared to form mortar with water. The mortar was prepared with 1:3 mix proportions having one part of cement and three parts of Indian Standard sand. Water content was kept as 0.85% of the standard consistency of cement and sand. Experimental results obtained for standard consistency, setting time, compatibility, and compressive strength testswereperformed and discussed.

Fig.2Marsh cone flow and SCC specimen

D. Strength Activity Index Test

It is vital to understand the filler effect and the pozzolanic activity of LP and MP of cement mortar in a cementitious medium. Based on the compressive strength results of mortar, the Strength Activity Index test (SAI) with OPC was determined as per guidelines by ASTM C311-77[13] and BS 3892[14]. This index helped to relate the results and find the performance of LP and MP as pozzolanic material. SAI is a number based on the compressive strength of sample cubes.

$$PAI = \frac{A_P}{B_N} X100 \qquad (1)$$

Where Ap = A mix average compressive strength of testcube containing pozzolana (MPa),

B_N = Average compressive strength of Normal Pozzolana free test cube mix (MPa).

Fig.3Mortar cube SAI Test specimen

The test for strength activity index is used to determine whether fly ash or natural pozzolan results in an acceptable level of strength development when used with hydraulic cement in concrete. Since the test is performed with mortar, the results may not directly correlate how the fly ash or natural pozzolan will contribute to strength in concrete ASTM C-311[13]. According to BS-3892[14], SAI results greater than 0.80 after 28 days indicate positive Pozzolanic activity for a cement replacement of 20%.

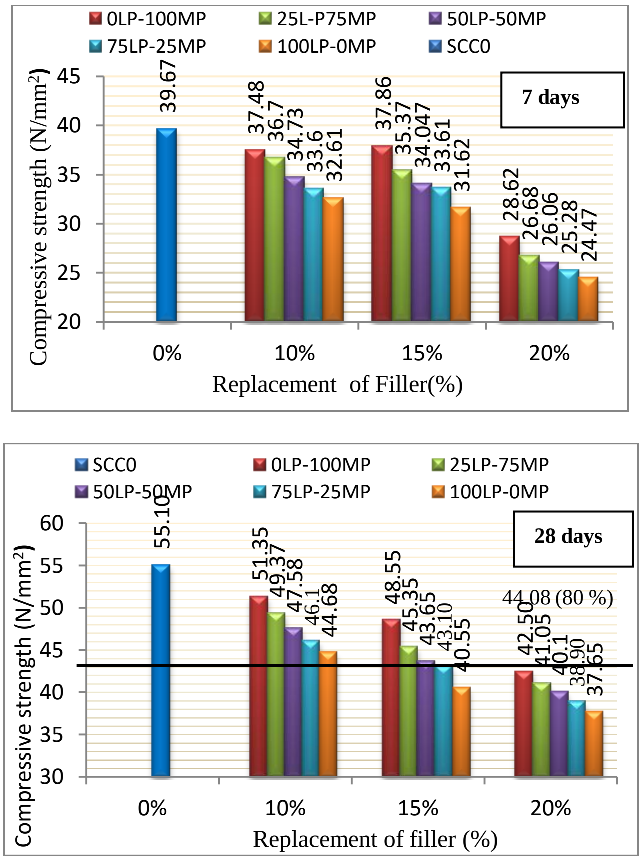

Fig.4.Compressive strength test for mortar cube specimen

The normal pozzolana free sample was prepared in the same manner. The pozzolana sample replaced by 10% and 20% of the Portland cement. Mix compositions have summarized in Table 3. Flow tests were carried out on pastes, according to EN 1015-3[19]. The water to binder ratio was altered so that the mixture had the same flow properties as the control mortar (+/-5mm).Mortar pastes were then remixed for 30 seconds and cast into six 70mm cubes with the aid of a vibrating table.

Figure 4. shows the strength of a mortar cube with the different replacement of filler MP and LP. The compression test reported the averages of three replicate results. The control mortar strength was 55.10 MPa at 28 days. Figure 4 shows that all test samples have a positive effect and strength at 28 days relative to the control mix samples. For 10%, 15%, and 20%, the test sample has up to 15% hasa higher value than 80% of the control mix. As per guidelines given in BS 3892[14], SAI derived. SAI decided concerning the individual curing period of OPC strength. SAI for MP and LP in OPC mortar have shown in Figure 4. SAI value was observed to be decreased with an increase in LP and MP content for 20% replacement, whereas with the increase in curing age SAIwas noted to be decreasing. For 10%, SAIdecreased from 93.19% to 81.08% (28 days) for all five combinations.

The strength of more than 20% of the normal sample with 10 and 15% replacement considered maybe comes from cement hydration. For 20%, it decreased from 77.13% to 68.33% (28 days). The black line indicates the limit of SAI value above which the value of mix is considered a pozzolanic reaction. Out of fifteen samples, eight samples have the SAI value of more than 80% of the normal non-pozzolanic sample. The SAI should be higher than 80% as per BS 3892[14]standards for a material to be pozzolanic. For the current study, SAI for LP and MP calculated and found to be below 80% of all five samples in 20% replacement. For 10% and 15% replacement, seven samples had a higher value than 80% of the normal sample.

The strength improvement results with MP and LP may be produced by the filler effect and the pozzolanic reaction between CH or $Ca(OH)_2$ from cement hydration, and $CaCO_3$ presents in lime. The dilution effect of lime may cause a decrease in compressive strength. The MP and LP act as filler only and fills the voids, make a dense structure.Due to the conversion of ettringite into mono sulfate, the induction perioddecreases during the first hour of the hydration.Bonavetti [20] have supported this hypothesis. However, strength is also related to other factors than only cement content. In particular, permeability, porosity, and hydration reaction kinetics all influence strength development.

E. V-Funnel and Slump Test (JSCE, 1999)

The fresh SCC test was carried out by using V- funnel and Slump cone. V- Funnel test was carried out to decide the segregation resistance of fresh SCC produced by MP and LP.The V- shape container is filled with 7 liters of SCC, and flow measured in second. The slump spread is a circular flow measurement system for the concrete that deform by its own weight and overcome surface friction without any external energy. Preparing all mixes of LP and MP with different replacement and combination slump flow performed. The perpendicular two side flow dimensionswere measured and recorded. Figure 5 indicates the typical relationship between SCC V-funnel flow time to slump flow diameter for three replacement of LP & MP. The combination mixes have satisfied the flow criteria as per the EFNARC guideline [15].

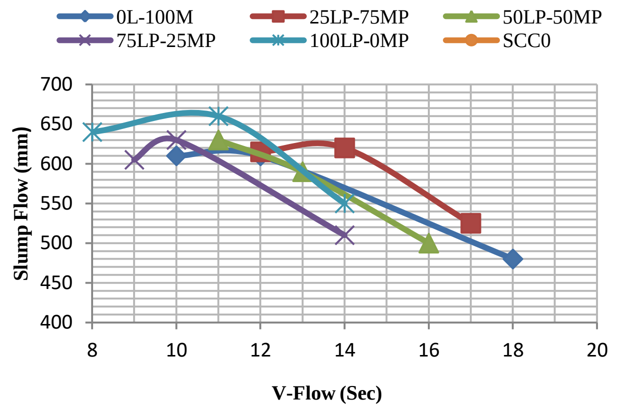

Fig.5.**A typical relationship between SCC V-funnel flow time to slump flow for different replacement of LP & MP.**

Figure 5 shows, the time elapses to flow through the neck of V- funnel increases as the diameter of the spread decrease. The visual observation indicated that the sticky paste matrix takes more time to spread and to pass through the funnel. The 10% and 15% replacement almost has resulted in average flow time and spread diameter 12 to 14 seconds and 550-600 mm diameter, respectively. While for at higher spread 600 to 650mm, the free flow observed without break and delay in time. The gap and interaction between the coarse aggregate fulfilled by homogeneous paste matrix resulted in higher segregation resistance.

V. CONCLUSION

- The concept of the present research hasto producing and promoting a sustainable cementitious system by saving cement and the environment.
- The finer particles of Marble powder and Lime powder showed significant improvement in the workability of binary and ternary SCC mixes. Also,all mix has satisfied the workability criteria of the FENARC guideline.
- The rounded and finer lime particles are easily soluble in water;thus, the contents of $Ca(OH)_2$ in the SCC mix increases during the plastic stage that covered the coarse aggregate content by paste and minimized friction between aggregate. Hence, provide better lubrication and improve the workability of the mix.

Table 2.Test results of LP and MP with OPC for Standard Consistency, setting time, and soundness.

% Replacement	0	10		15		20	
Property	OPC	LP	MP	LP	MP	LP	MP
Consistency (%)	29	32	31	34	31	39	32
IST (min)	103	165	145	192	164	258	206
FST (min)	308	392	381	469	445	514	492
Soundness (mm)	1	0.75	0.65	0.65	0.5	0.45	0.25

Table 3.Mix proportion of Mortar cube of SCC

Mix	Name of Mix	Cement (g)	Lime (LP)	Marble (MP)	% Replace	28 days comp. strength for mortar cube (Mpa)	SAI (%)
1	SCC0	450	0.0	0.0	0.0	55.10	-
2	0LP-100MP	405	0.0	45.00	10	51.35	93.19
3	25LP-75MP		15.0	30.00		49.37	89.56
4	50LP-50MP		22.50	22.50		47.58	86.35
5	75LP-25MP		45.0	15.00		46.1	83.67
6	100LP-0MP		45.00	0.00		44.68	81.08
7	0LP-100MP	382	0	68.0	15	48.55	88.11
8	25LP-75MP		17	51		45.35	82.30
9	50LP-50MP		34	34		43.65	79.21
10	75LP-25MP		51	17		43.10	78.22
11	100LP-0MP		68.0	0		40.55	73.59
12	0LP-100MP	360	0.0	90	20	42.50	77.13
13	25LP-75MP		30.0	60.0		41.05	74.68
14	50LP-50MP		45.0	45.0		40.10	72.77
15	75LP-25MP		60.0	30.0		38.90	70.59
16	100LP-0MP		90	0.0		37.65	68.33
Water cement ratio = 0.50 (normal),0.40 (filler), S.P= Superplasticizer 1.0%, Sand= 1350(g)							

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