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Development and Evaluation of Eco-Friendly SCC Incorporating Marble Sludge Powder as Cement Replacement

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Abstract - Self-Compacting Concrete (SCC) has had a remarkable impact on the concrete construction industry, especially the precast concrete industry. The marble powder (MP), obtained from waste sludge marble processing, has a high specific surface area; this could mean that it can be used as filler added to self-compacting concrete (SCC). Marble Sludge Powder (MSP) and Crushed Rock Dust (CRD) can be used as filler and helps to reduce the total voids content in concrete. For all pastes, the morphological forms and the chemical composition of the main mineral components were analyzed by the scanning electron microscope (SEM) and X-ray diffraction (XRD). The hydration, micro structure, and mineralogical changes has been studied. Experimental results show that the cement-MP paste volume has significant effects on the self-compacting and the self- leveling properties in the fresh state of SCC. The study on physical, chemical and mechanical properties such as compressive strength and split tensile strength and the durability tests include water absorption test, water permeability, rapid chloride permeability; electrical resistivity and half-cell potential are carried out in this study. From the results it is confirmed that compressive strength increases with increase in percentage replacement of MSP up to 15% of CRD in place of FA. It is found that split tensile strength is directly proportional to the compressive strength.

Key Words: Self-Compacting Concrete (SCC), Marble Powder (MP), Marble Sludge Powder (MSP), Crushed Rock Dust (CRD), Compressive Strength, Split Tensile Strength, Durability Tests, X-ray Diffraction (XRD), Scanning Electron Microscope (SEM), Water Permeability, Electrical Resistivity.

1. INTRODUCTION

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.

Concrete that requires little vibration or compaction has been used in Europe since the early 1970s but self-compacting concrete was not developed until the late 1980's in Japan. In Europe it was probably first used in civil works for transportation networks in Sweden in the mid l990's. The European Countries funded a multi-national, industry lead project SCC 1997- 2000 and since then SCC has found increasing use in all European countries.

Fig -1: Self-compacting machine

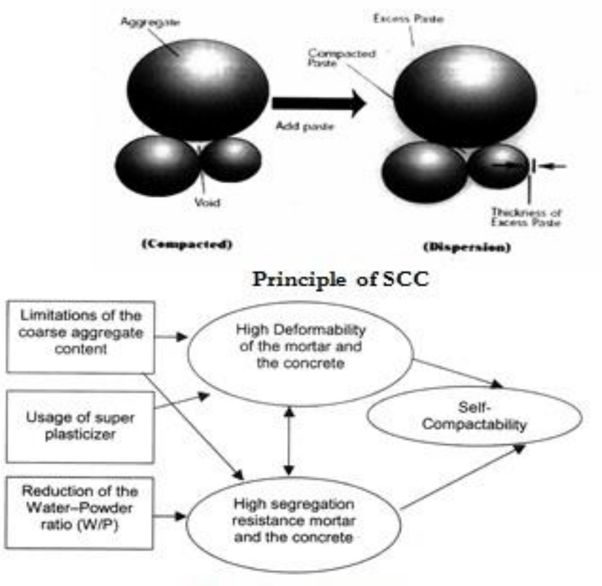

Fig: 2 Flow chart for SCC

2. LITERATURE REVIEW

2.1 Marble Powder as Cement Replacement

M. Shahul Hameed et al. (2012) and **Omar et al. (2012)** highlighted that marble powder, a byproduct from the marble industry (30–40% waste), can be used as a filler in SCC. Their work demonstrated that replacing cement with marble powder and fly ash improves both fresh (slump flow, V-funnel, L-box, U-box) and hardened (compressive, tensile, flexural strength, Young's modulus) properties. Additionally, they emphasized the ecological benefits such as reduction in CO_2 emissions and landfill usage.

Hassan A. Mohamadien (2012) investigated the replacement of cement with marble powder and dust at varying percentages (0–50%) and found that **15% replacement** showed maximum strength gain—**31.4% (7 days)** and **48.3% (28 days)** improvement in compressive strength.

Noha M. Soliman (2013) evaluated the effect of marble powder in reinforced concrete (RC) slabs, finding that partial cement replacement enhanced compressive and tensile strengths and improved structural stiffness and ultimate load-bearing capacity.

V.M. Sounthararajan & A. Sivakumar (2013) examined the addition of lime to marble powder and observed that 10% MP substitution improved compressive strength significantly, reaching 46.80 MPa at 7 days.

Animesh Mishra & Abhishek Pandey (2013) demonstrated that marble sludge dust could be a complete substitute for fine aggregate, leading to enhanced mechanical properties and sustainable use of resources.

Bahar Demirel (2010) studied fine aggregate replacement by marble powder (0–100%) and found that compressive strength improved with increasing MP content, along with better UPV and dynamic modulus.

Baboo Rai et al. (2011) concluded that using marble powder and granules as partial cement replacement enhances workability and compressive strength, supporting their sustainable application in concrete.

Veena G. Pathan & Md. Gulfam Pathan (2007) suggested that 10% MP replacement in cement improves both compressive and split tensile strength, and contributes to environmental sustainability.

Gulden Cagin Ulubeyli & Recep Artir (2015) found that SCC made with 10% marble powder and 25% fly ash showed enhanced fresh and hardened properties, with 25% MP offering optimum compressive strength.

2.2 Fly Ash and Other Mineral Additives in SCC

Bouziani Tayeb et al. (2011) analyzed the role of fly ash in Self-Compacting Lightweight Concrete (SCLWC) and concluded that varying fly ash content affects both workability and mechanical strength. Three mixes were tested, and results indicated that fly ash improves the workability and strength characteristics.

Ergun, A. (2011) emphasized that fly ash reduces the need for superplasticizers in SCC, contributing to better flowability and strength. He reported enhanced microstructure and volume stability when using a combination of fly ash and other fillers like limestone.

K. Sideris & Nikolaos S. (2009) used lightweight aggregates with fly ash in SCC and achieved a slump flow of ~700 mm and compressive strength up to 60 MPa, though they noted a lack of data on flexural and splitting tensile strength.

Zoran Grdić et al. (2008) used metakaolin in self-compacting high-strength concrete and emphasized the cost efficiency of using polycarboxylate superplasticizers. With Ground Granulated Blast Furnace Slag (GGBFS) as a cement substitute (20–80%), compressive strengths between 30–100 MPa were achieved.

2.3 Environmental and Structural Impacts

H.J.H. Brouwers & H.J. Radix (2005) addressed environmental concerns associated with marble waste, proposing the replacement of fine aggregates with waste marble powder. They noted that this substitution not only mitigates ecological damage but also contributes positively to SCC performance.

The reviewed literature consistently supports the use of marble powder and fly ash in SCC and SCLWC as sustainable and performance-enhancing additives. Marble powder up to 15% and fly ash up to 25% as partial cement replacement have shown significant improvements in mechanical and durability properties. These findings encourage further exploration of industrial byproducts to develop eco-friendly and structurally sound concrete.

3. METHODOLOGY

Dolomite, or serpentine materials are the major components of marble as crystalline rocks Marble waste can be recycled as a useful material. The most suitable inactivating method nowadays is recycling waste by producing new products or by addition as admixtures so that the environment is protected from waste deposits

The results of several scientific works, studied the incorporation of marble waste into cement-based products such as normal concrete and high strength concrete indicate an improvement in the compressive strength of concretes.

The use of cement in building materials is related especially to its hydration following the chemical reactions which form the hardened mass. This phenomenon allows predicting cement properties the chemical composition of hardened cement paste has a direct impact on the paste microstructure. That is why studying the mineral phase changes as well as the microstructure of maturing cement paste becomes a necessity to determine the strength of the crystalline lattice.

S.No	Composition	Proportion	
		Marble Powder (%)	Cement (%)
1	Silicon dioxide (SiO_2)	1.12	21.92
2	Alumina (Al_2O_3)	0.73	3.30
3	Calcium oxide (CaO)	83.22	63.0
4	Magnesium oxide (MgO)	0.52	3.07
5	Sodium oxide (Na_2O)	1.12	0.96
6	Potassium oxide (K_2O)	0.09	0.27
7	Ferric oxide (Fe_2O_3)	0.05	1.20

Table -1: Chemical composition of Marble powder and Cement

S.No	Materials	Fineness (%)	Specific Gravity
1	Marble powder	3	2.67
2	Cement	2	3.15

Table -2: Physical properties of Marble powder and Cement

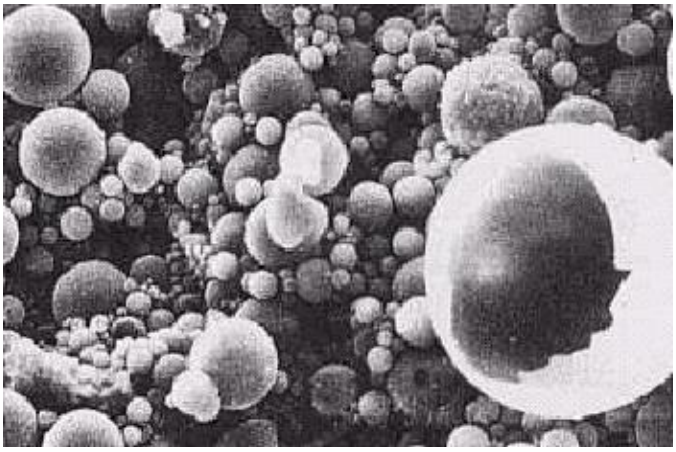

Fig: 3 Fly Ash

Fig: 4 Super plasticizers

Fig: 5 Slump Flow Test

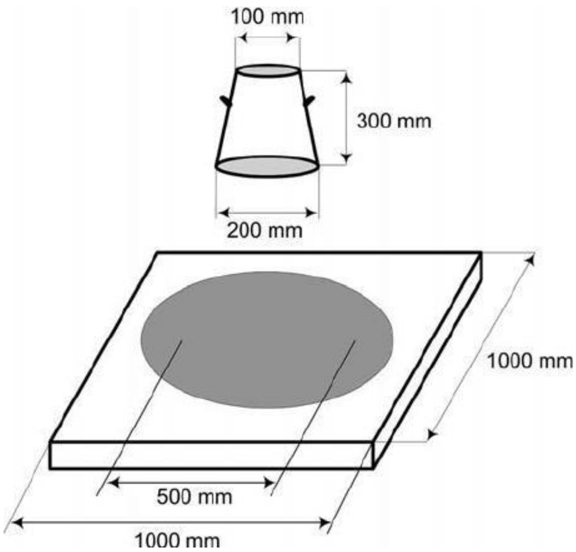

Fig: 6 Slump Flow Test Equipment

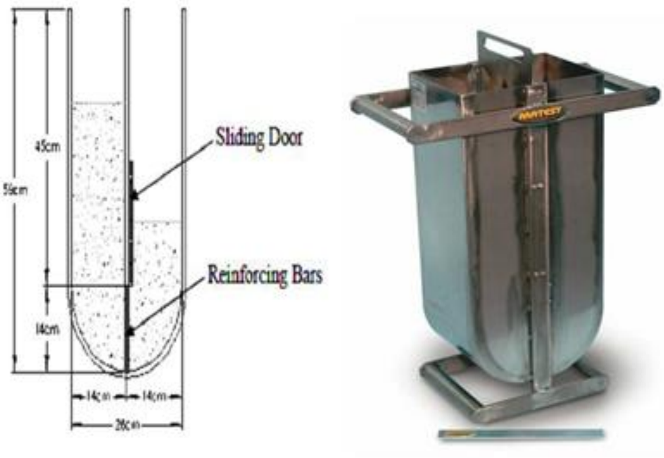

Fig:7 U-Box Test Equipment

4. RESULTS AND DISCUSSIONS

SCC has been considered as a great development in construction since its first developed in japan. The high fluidity is main property of SCC so that it can be placed under its self-Weight without vibration. In order to obtain SCC of high flow ability without segregation or bleeding during the transportation or placing, the use of high powder content, super plasticizers and viscosity modifying admixtures seems a good solution. However, the cost of such concrete is significantly higher. The use of mineral additives such as silica fumes (SFs), Fly ash (FA) and ground granulated blast-furnace slag could reduce material cost and enhance the self-compatibility. Several studies have shown that natural pozzolana have been widely used as a substitute for Portland cement in many applications because of its advantageous properties which include cost-reduction, reduction in heat evolution, decreased permeability and increased chemical resistance. Marble powder (MP) which is an inert material obtained as an industrial by-product during sawing, shaping, and polishing of marble has also successfully been used as an addition in SCC . Marble powder used as mineral addition of cement is reported to improve some properties of fresh and hardened self-compacting concrete (SCC). The fresh state properties studied in this research are the workability, air content and the mix density. Slump flow test, J-Ring test, L box test and funnel tests are conducted to find the workability of concrete.

The concrete density was found by filling a cylinder of known volume and weighing it, while air content was calculated using the actual density (A) and theoretical density (T) of the concrete considering air content of 0 % as per ASTM C138/C138M. The hardened properties included compressive strength, splitting tensile strength, modulus of elasticity and the flexural strength of the concrete. The ASTM procedures are followed for testing of all the properties under consideration. The tests used to determine the workability of concrete are slump flow test, J-Ring test, Funnel test and L box test. 3 cylinders with a diameter of 100 mm and 200 mm height each were casted to test the compressive strength, splitting tensile strength and modulus of elasticity. 3 small scale beams with dimensions 80 80 400 mm each were casted to test the flexural strength of each concrete type using third point loading test.

The hardened properties studied in this study are compressive strength (CS), splitting tensile strength (STS), modulus of elasticity (E) and flexural strength (FS). 12 cylinders with diameter 100 mm and height of 200 mm were casted for each concrete type. Curing of all samples and their testing was performed according to the ASTM standard 6 cylinders were used for testing the compressive strength, 3 cylinders were tested at concrete age of 7 days to obtain the early strength gain and the other, 3 at 28 days for comparison among the concrete types as per ASTM standards 3 cylinders were tested for splitting tensile strength and modulus of elasticity at 28 days as per ASTM standards.

The flexural strength was obtained by testing 3 small scale 80 mm × 80 mm × 400 mm beams for each type of concrete. These beams were tested at 28 days in third point loading.

Concrete type	CS (MPa)	STS (MPa)	E (MPa)	FS (MPa)	Density (kg/m3)
SCLWC100	59.4	3.14	17,235	3.35	1678
SCLWC125	67.4	3.95	17,232	3.68	1699
SCLWC150	67.4	3.93	17,302	3.05	1703

Table -3: Hardened concrete properties

Concrete type	Air content (%)	Fresh state density (kg/m^3)
SCLWC100	3.93	1709
SCLWC125	2.28	1741
SCLWC150	2.22	1744

Table -4: Change of air content with concrete density

Concrete type	Slump flow according to EFNARC (mm)	V-funnel time (sec)
SCLWC100	795	13
SCLWC125	785	14
SCLWC150	805	12

Table -5: Fresh state concrete properties

Type of Mix	Cement (kg/cum)	Fly ash (kg/cum)	Marble powder (kg/cum)	Coarse aggregate (kg/cum)	Fine aggregate (kg/cum)
M-30(0% MP + 25% FA)	375	125	0	741.69	955.12
M-30(5%MP + 25% FA)	350	125	25	741.69	955.12
M-30(10%MP + 25% FA)	325	125	50	741.69	955.12
M-30(15%MP + 25% FA)	300	125	75	741.69	955.12
M-30(20%MP + 25% FA)	275	125	100	741.69	955.12
M-30(25%MP + 25% FA)	250	125	125	741.69	955.12

Table -6: Mix Design Proportion M-30

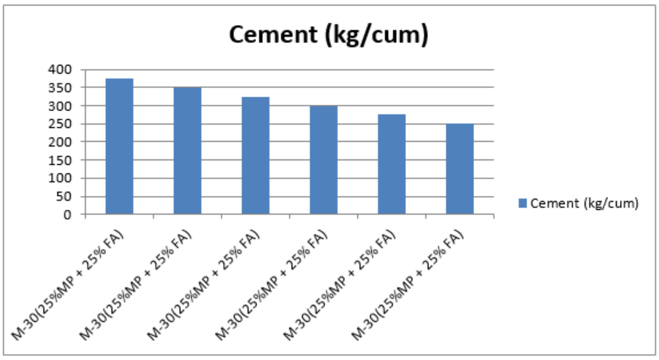

Fig:8 Type of mix vs Cement (kg/cum)

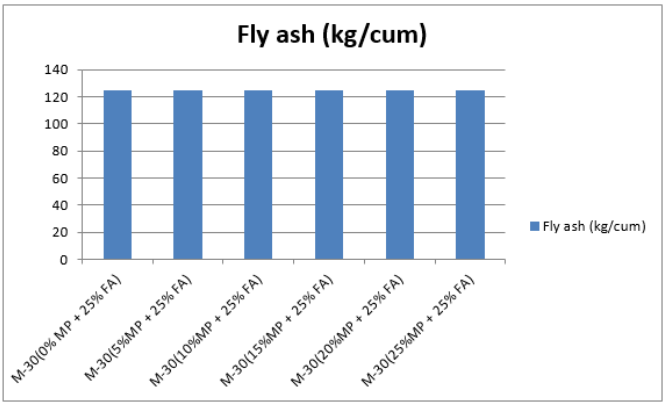

Fig:9 Type of mix vs Fly ash (kg/cum)

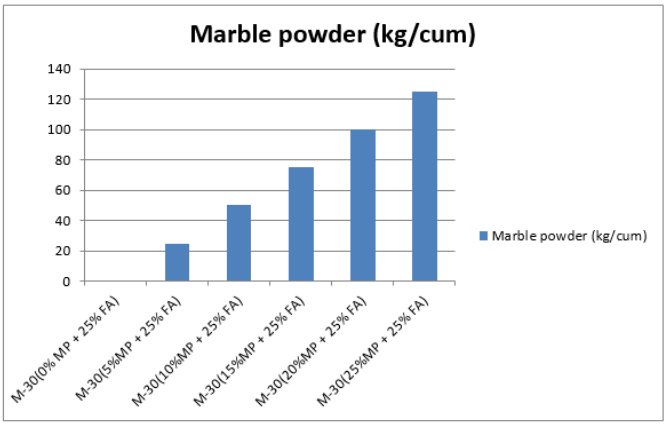

Fig:10 Type of mix vs Marble powder (kg/cum)

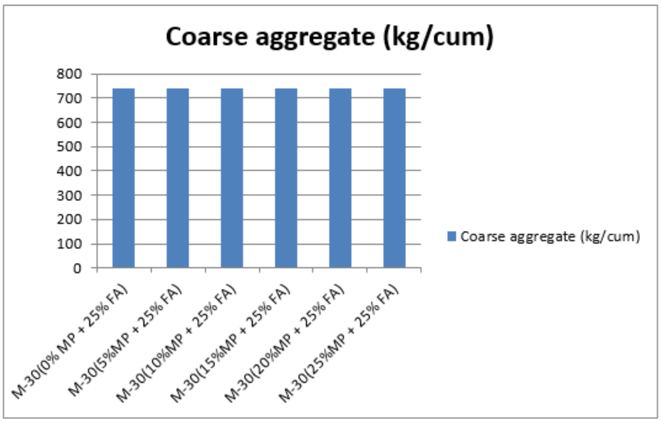

Fig:11 Type of mix vs Coarse aggregate (kg/cum)

Type of Mix	Slump (mm)	T50cm Slump Flow (sec)	V-Funnel (sec)	L- Box {h2/h1}	U- Box {h2/h1} (mm)
M-30(0% MP + 25% FA)	600-750 mm	<6 sec.	8-12 sec.	0.8-1	0 to 30mm
M-30(5%MP + 25% FA)	655	4.5	10.8	0.82	28
M-30(10%MP + 25% FA)	660	4.1	9.6	0.85	26
M-30(15%MP + 25% FA)	675	3.7	8.7	0.88	23
M-30(20%MP + 25% FA)	695	3.2	8.2	0.90	22
M-30(25%MP + 25% FA)	702	3.1	7.9	0.92	19

Table -7: Mix Design Proportion M-30

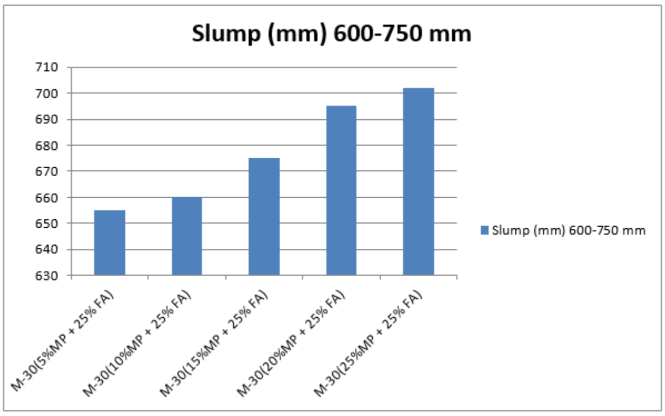

Fig:12 Type of mix vs Slump (mm)

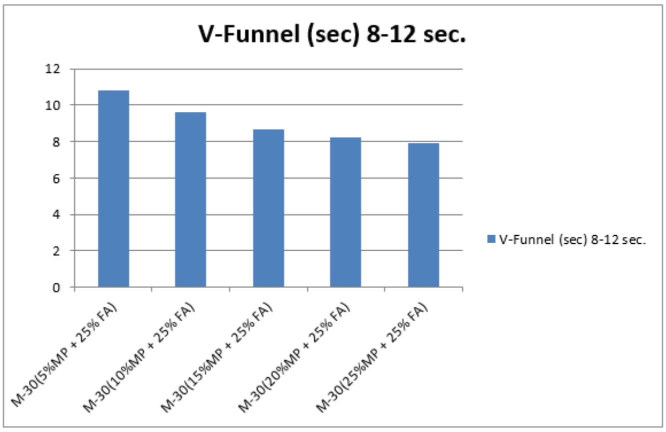

Fig:13 Type of mix vs V-Funnel (sec)

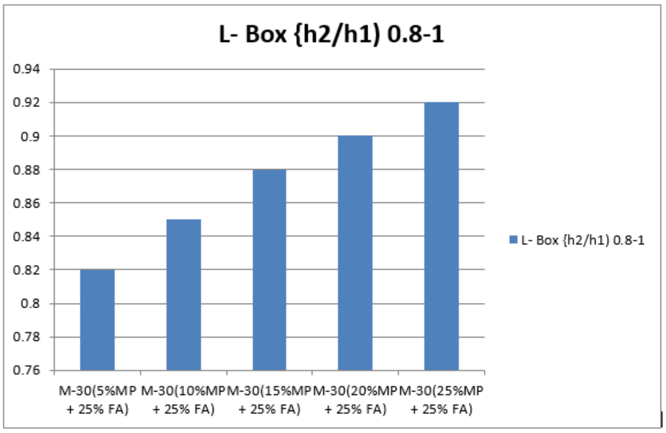

Fig:14 Type of mix vs L- Box {h2/h1)

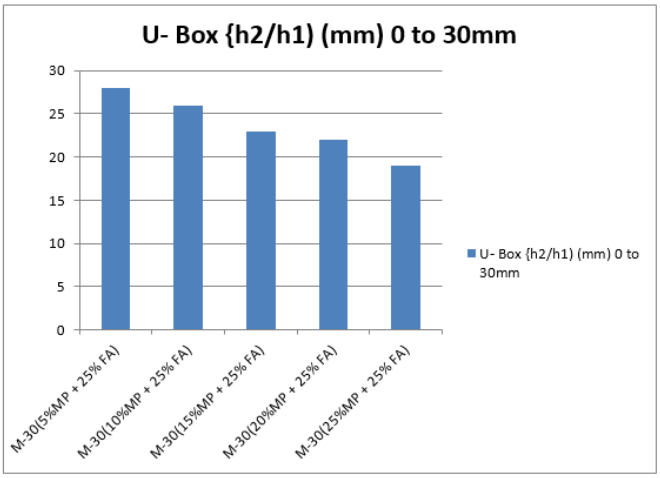

Fig:15 Type of mix vs U- Box {h2/h1) (mm)

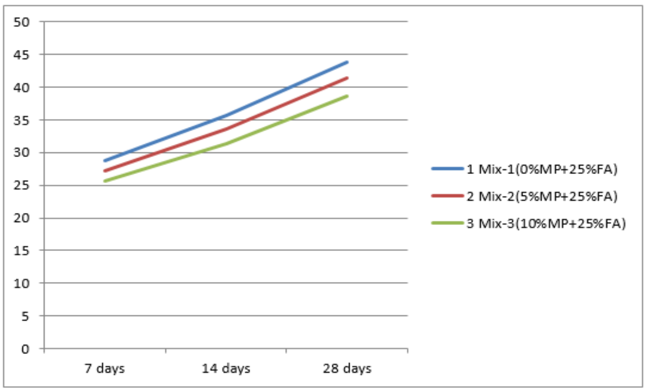

Fig:16 Harden property of compressive strength 7, 14, 28 days

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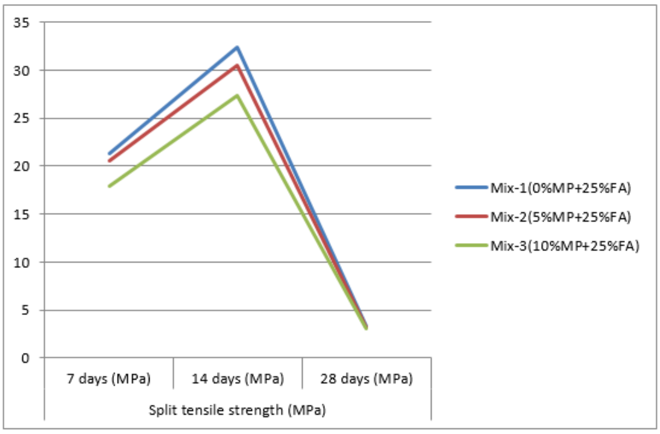

Fig:17 Harden property of Split tensile strength (MPa) 7, 14, 28 days

5. CONCLUSIONS

The study demonstrates that waste marble powder (MP), when used in the production of Self-Compacting Concrete (SCC), offers substantial benefits in both fresh and hardened concrete properties. Incorporating marble powder, particularly in combination with fly ash and micro-silica, yields promising results without negatively affecting the workability or mechanical performance of SCC.

The findings highlight that:

- Up to 10% substitution of cement with marble powder and 25% with fly ash enhances fresh properties such as filling ability, passing ability, slump flow, and reduces T50 flow time and V-funnel time, indicating improved mpressive strength, flexural strength, and split tensile strength are positively maintained when marble powder is used up to 10%.
- XRD analysis confirms that chemical variations in marble powder do not hinder the hydration process.
- SEM images reveal that excessive marble powder can lead to porous microstructures, potentially affecting compressive strength and rheological behavior.
- A strong correlation exists between the cement-MP paste volume and both fresh and hardened properties, underlining the importance of mix design optimization.

Marble powder, obtained as a by-product from marble cutting processes, thus serves as a sustainable filler material in SCC, contributing to resource conservation and environmental protection.

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