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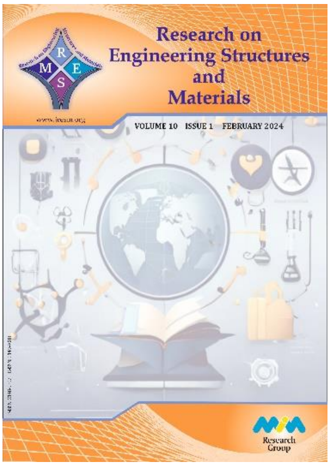

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Research Article

Evaluation of strength of self-compacting concrete having dolomite powder as partial replacement for cement

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Abstract

Now a day, the utilization of self-compacting concrete (SCC) has become popular in creating RC structures. Apart from self-compaction, SCC has got many advantages such as excellent flow ability, filling ability, smooth finish of surface, ease of work etc. The use of waste material in concrete is the area of having scope for researchers for many years. Use of waste material reduces the consumption of cement by construction sector. In this present experimental work, dolomite powder is used as fractional replacement material for cement. The cement in the SCC is replaced by dolomite at fractions of 10%, 20%, 30%, 40%, 50%, 60%, and 70%. Fly ash is also added to the mix at constant fraction of 18% of the cement. The strength of SCC is assessed by performing compression test, splitting tension test and bending test. The test results showed that the use of dolomite powder in SCC is advantageous up to 20% replacement fraction. It is also observed that the strength of DC40 mix (i.e the mix having Dolomite at 40% of cement) is almost equal to the strength of normal SCC. Even at 70% replacement level, the strength of SCC having dolomite achieved is 25 MPa. SEM images are analyzed to identify the spread of hydrated products.

1. Introduction

Cement concrete is widely used in the construction industry as a building material. Cement is the most important component in concrete. It plays a major role on the compressive strength and binder properties of concrete. During the production of cement process, a large amount of CO_2 is released into the global environment due to the burning of argillaceous and calcareous materials at high temperature [1].

Self-compacting concrete (SCC) is one of the innovative concretes which is widely used in present construction sector [2]. The fresh SCC has a capability of flowing, passing and filling into the congested parts of structural elements under its self-weight without any segregation, bleeding and blocking. The SCC consists of high finer materials and lesser volume of coarse aggregate compared to normal concrete to get consistent viscous flow. Some of the industrial wastes are utilized as the secondary ingredients of concrete by many researchers [3]. Fine particles are needed in SCC at higher volume, which is fulfilled by addition industrial wastes like flyash, metakolin, GGBS, dolomite etc as mineral admixtures. Among the industrial wastes, flyash is widely used secondary cementitious material upto certain limit of replacement. Cement is replaced by dolomite powder and obtained optimum compressive strength at 30% is 63.1MPa in the mix also having flyash and slag material [4].

Lime stone is one of the natural minerals and it is used as a raw material in manufacturing of Portland cement up to 20% and dolomite powder is used upto30% as the cementitious

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product at low water binder ratio [5, 6]. The previous researchers found that lime stone is affected by dilution, heterogenous nucleation, filling. Now a days it is observed that a particle of lime stone powder below 20 microns is not completely inert and it reacts with cement and participate in C_3S hydration [6]. Due to the use of limestone powder as partial replacement material for cement, carbon footprint can be reduced [5]. Dolomite is one of the minerals obtained from the dolomitic limestone deposits. Dolomite is formed under two processes one is direct precipitation of dolomite from the formation solution and second one is dolomitization process that means dissolution of calcite and reacting with Ca and Mg ions [7]. The presence of magnesium carbonate in the raw material, causes damage of concrete when it is added as raw material in the production of clinker as it forms MgO and later it converts into brucite ($Mg(OH)_2$) during cement hydration process, which creates unsoundness as it is expansive reaction in concrete. It is accepted that the dolomite can be added to the concrete, in the form of powder at the time of making concrete, as it does not produce above stated unsoundness problems in the concrete.

The powder form of dolomite can be obtained from a quarry as a tertiary product [8]. In addition to its low cost, dolomite also offers several enhancements to concrete, such as improved workability, increased compressive strength, and durability [7]. The combination of fly ash and dolomite can replace the cement in concrete at a higher dosage [9]. Incorporating the dolomitic lime stone powder at higher dosage more than 25%, reduces the compressive strength of concrete [10]. The dolomite concrete has a resistance of 1N NAOH solution up to 6 months under immersion. A good rate of compressive strength development can be observed in dolomite concrete having 2% nano silica [11].

The objective of this study is to assess the impact of replacing cement with dolomite powder on properties of SCC such as compressive strength, splitting tensile strength and bending strength.

2. Materials

Cement, fly ash, dolomite powder, fine aggregate, coarse aggregate, super plasticizer and water are used to prepare SCC. The cement used is, of choice for general concreting purposes, Ordinary Portland Cement (OPC 53 grade) that conforms to IS: 12269 standards. The Specific gravity of cement is 3.15 and fineness of cement is 4.48% which is less than 10% as per IS 4031 part-1. Dolomite is a mineral composed of calcium magnesium bicarbonate, formulated as $CaMg(CO_3)_2$. The Dolomite Powder used in this study is collected at a place called Piduguralla which is famous as lime city of Andhra Pradesh. Specific Gravity of dolomite powder is 2.86 which should be appeared as very white smooth nature.

Fly ash is a waste product produced by burning coal in thermal power projects. Fly ash is procured from the Vijayawada Thermal Power Station located nearby Vijayawada city of Andhra Pradesh. The specific gravity of fly ash is 2.30. The sand used in this study conforms to grading zone-II as per IS: 383-1970 and has a specific gravity of 2.60. The fineness modulus of the sand is 2.68. Polycarboxylate ether-based superplasticizer (PCE) confirming to IS 9102 is a new generation of high-performance concrete admixture and specific gravity of superplasticizer is 1.08 is used in this study.

3. Experimental Program

M40 grade SCC mix is used in this study having weight ratio of 1:0.219:1.899:2.083:0.01:0.43 (Cement, fly ash, Fine aggregate, coarse aggregate, super plasticizer and water respectively). All materials for making SCC were mixed properly to obtain a fresh SCC mix. The fresh SCC mix flow properties were assessed and are within the limits specified by EFNARC [12]. For easy de-moulding, oil was applied to the inner faces of mould. The SCC was poured into the moulds to prepare test specimens. The casted specimens were de-moulded after 24 hours and cured in water for 7days and for 28 days. Then the specimens were tested till failure using the universal testing machine (Figure 1, 2 & 3).

Fig. 1. Failure of cube specimen under compressive load

Fig. 2. Split tensile test on SCC specimen

Fig. 3. Flexural test on SCC specimen

4. Test Results and Discussion

4.1 Fresh Properties of Concrete

After obtaining satisfactory SCC mix from various trial mixes, cement was replaced by dolomite powder at different percentages. Mixes are designated as DC0, DC10, DC20, DC30, DC40, DC50, DC60 and DC70 respectively. Mix without dolomite powder is designated as DC0 which is control mix.

Table 1 Values of slump flow test

Mix designation	Average Diameter D in mm	T500 in sec
DC0	731	3.37
DC10	705	3.51
DC20	706	3.40
DC30	713	3.20
DC40	723	2.79
DC50	729	2.48
DC60	690	2.12
DC70	689	2.05

Fig. 4. Slump flow of DC0 mix proportion

4.2 Hardened Properties of Concrete

After completion of curing of specimens, the following specimens are tested under compressive testing machine and universal testing machine. The compressive strength test results are presented in Figure 5. The values obtained as ratio between compressive strength of concrete having dolomite (f_{cd}) and compressive strength of normal concrete i.e without dolomite (f_{co}) are shown in Table 2. The variations in f_{cd}/f_{co} are shown in Figure 11(a,b). The splitting tension strength test results are presented in Figure 8. The values obtained as ratio between splitting tension strength of concrete having dolomite (f_{td}) and splitting tension strength of normal concrete i.e without dolomite (f_{to}) are shown in Table 2. The variations in f_{td}/f_{to} are shown in Figure 12(a,b). The flexural strength test results are presented in Figure 9. The values obtained as ratio between Flexural strength of concrete having dolomite (f_{rd}) and Flexural strength of normal concrete i.e without dolomite (f_{ro}) are shown in Table 2. The variation in f_{rd}/f_{ro} are shown in Figure 13.

4.2.1 Cube Compressive Strength

The cube compressive strength of SCC having dolomite increases as percentage of dolomite increases in the mix upto 20% dolomite replacement. replaced of higher percentages of dolomite i.e more than 20% decreases the compressive strength of SCC having dolomite. By replacement of cement by dolomite to the normal SCC, the maximum percentage of increase in compressive strength is 45% which is observed at 20% cement replaced with dolomite. At 40% replacement level, the compressive strength of dolomite concrete is more or less equal to the compressive strength of normal concrete. It can be understood that 40% of cement can be replaced with dolomite powder without adversely affecting the compressive strength of the mix. The cost of dolomite powder is 2.6 times cheaper than that of cement. Hence it is economical to use the dolomite powder in the mix as a partial replacement material to cement. Also, by saving the consumption of cement, release of CO_2 into the environment during the manufacturing of cement can be minimized. Even at 70% cement replacement level with dolomite, 25MPa compressive strength is achieved. At 70% replacement level, the compressive strength of dolomite concrete is dropped to 54% compared to the compressive strength of normal concrete.

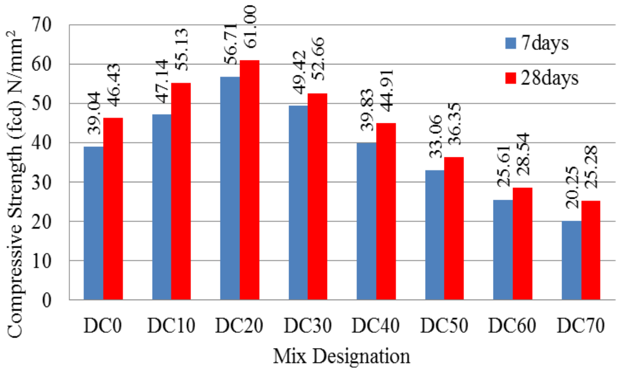


Fig. 5. Cube compressive strength of SCC at 7 days and 28 days

4.2.2 Cylinder Compressive Strength

The variation in cylinder compressive strength of SCC having dolomite powder follows the trend of cube compressive strength.

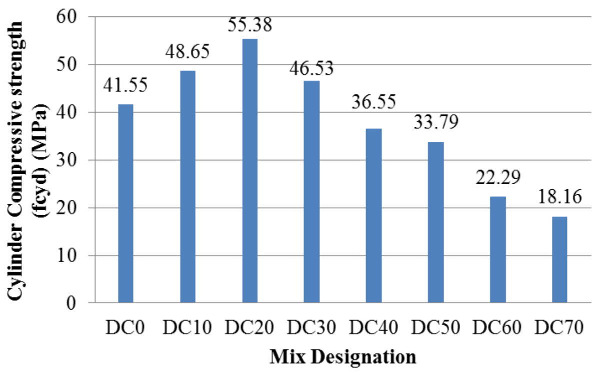


Fig. 6. Cylinder compressive strength of SCC at 28 days

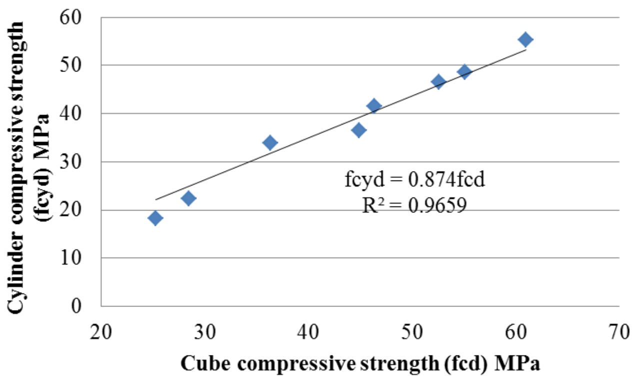


Fig. 7. Relation between f_{cyd} and f_{cd} at 28days

The cylinder compressive strength of SCC having dolomite increases as percentage of dolomite increases in the mix up to 20% dolomite replacement. replacement of higher percentages of dolomite i.e more than 20%, decreases the cylinder compressive strength of SCC having dolomite.

Table 2. The ratio of strength of SCC having dolomite and strength of SCC not having dolomite

Mix ID	Percentage of Dolomite powder (D)	f_{cd}/f_{co}		f_{td}/f_{to}		f_{rd}/f_{ro}
		7 days	28 days	7 days	28 days	28 days
DC0	0	1.00	1.00	1.00	1.00	1.00
DC10	10	1.21	1.19	1.19	1.11	1.16
DC20	20	1.45	1.31	1.25	1.19	1.27
DC30	30	1.27	1.13	1.03	1.01	1.09
DC40	40	1.02	0.97	0.94	0.87	0.94
DC50	50	0.85	0.78	0.77	0.77	0.77
DC60	60	0.66	0.61	0.64	0.64	0.64
DC70	70	0.52	0.54	0.34	0.52	0.43

By replacement of dolomite to the normal SCC, the maximum percentage of increase in cylinder compressive strength is 33.28% which is observed at 20% cement replaced with dolomite. A plot between cube compressive strength values and cylinder compressive strength values at 28 days curing age is drawn which is shown in figure. A linear regression line passing through the origin is observed. From which it can be seen that the cylinder compressive strength is 0.874 times the cube compressive strength. The regression line is precisely close to the experimental values.

4.2.3 Splitting Tension Strength

The splitting tension strength of concrete having dolomite increases as percentage of dolomite increases in the mix up to 20% dolomite replacement. At 30% level of replacement, the splitting tension strength of dolomite concrete is equal to splitting tension strength of normal concrete. At 70% replacement level, the splitting tension strength of dolomite concrete is dropped to 48.34% compared to the splitting tension strength of normal concrete.

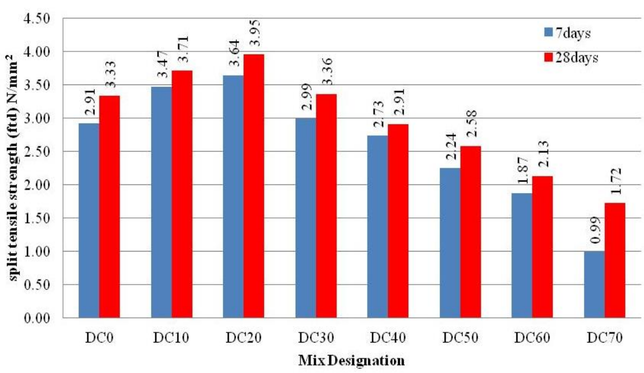


Fig. 8. Splitting tension strength of SCC at 7 and 28 days

4.2.4 Flexural Strength

As percentage of dolomite increases, the flexural strength also increases up to 20% replacement level. The flexural strength of dolomite concrete at 40% replacement level is equal to the flexural strength of normal concrete. At 70% replacement level, the flexural strength of dolomite concrete is dropped to 57% compared to the flexural strength of normal concrete.

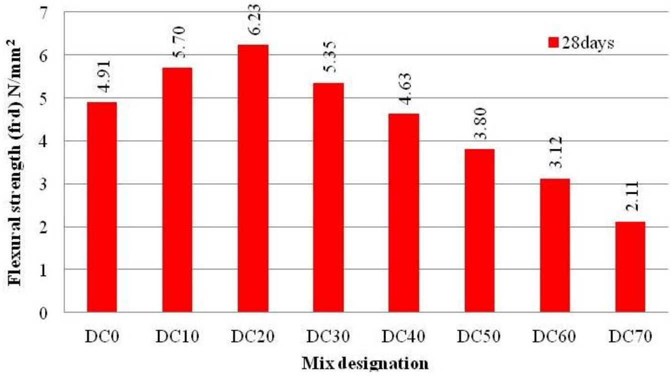


Fig. 9. Flexural strength of SCC at 28 days

Cube compressive strength values and flexural strength values at 28 days curing age are plotted as shown in figure 9. The trend line is passing through the origin. From which it can be perceived that the flexural strength is 0.102 times the cube compressive strength. The regression line fits well with in the experimental values.

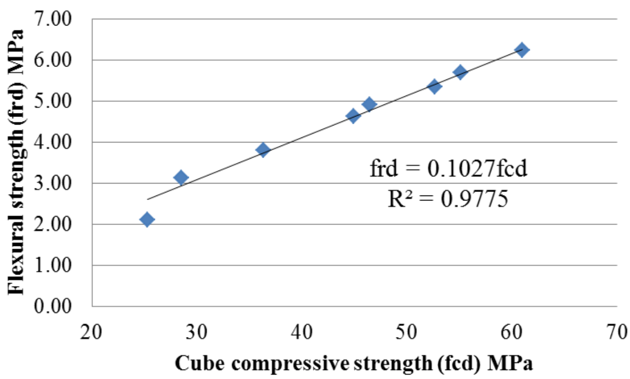
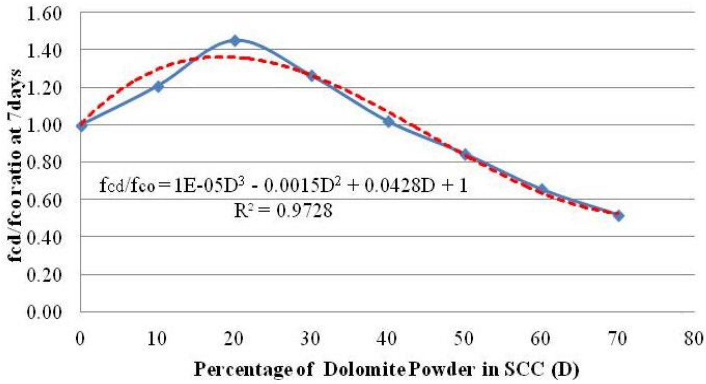


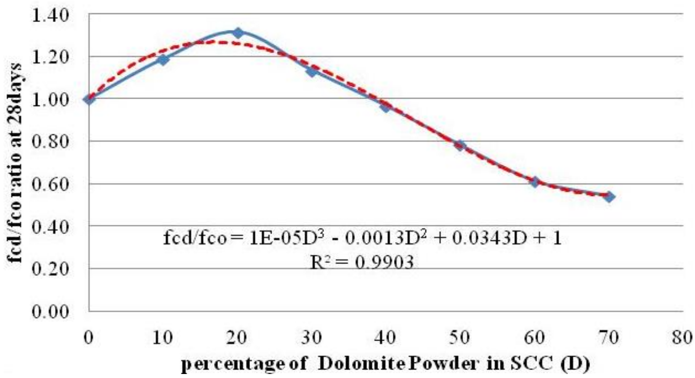
Fig. 10. Relation between f_{rd} and f_{cd} at 28days

4.2.5 Prediction of Strength

Curves are developed by taking ratio of strength of dolomite concrete to strength of normal concrete on Y-axis and percentage of dolomite in the mix on X-axis. Figure 11 shows the plot between f_{cd}/f_{co} and percentage of dolomite. A trend line is also drawn to develop the best fit equation between f_{cd}/f_{co} and percentage of dolomite in the mix. By knowing the percentage of dolomite in the mix, compressive strength of concrete can be predicted by the developed equation.



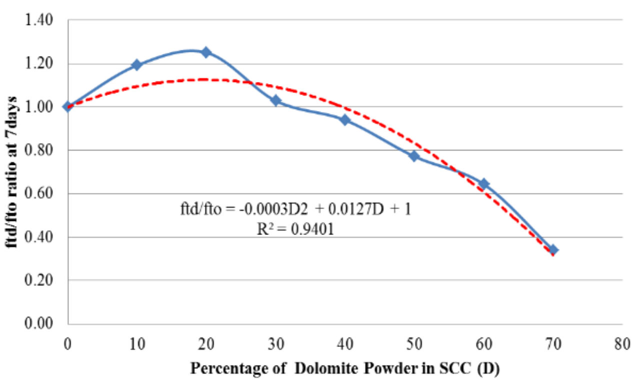
a) At 7days



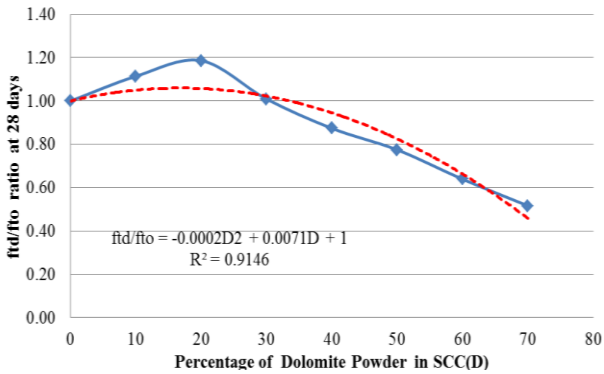
b) At 28days

Fig. 11. (a-b) Variation of f_{cd}/f_{co} with percentage of dolomite powder

Likewise, curves are developed to predict splitting tension strength and flexural strength. The developed equations, predicted values of the strength and percentage error in predicting strength are given table. Out of twenty-four predicted strength values, the percentage error of nineteen values is falling below/nearer to 10%, which shows that the predicted strength values are matching well with the experimental values.



a) At 7days



b) At 28days

Fig. 12. (a-b) Variation of f_{td}/f_{to} with percentage of dolomite powder

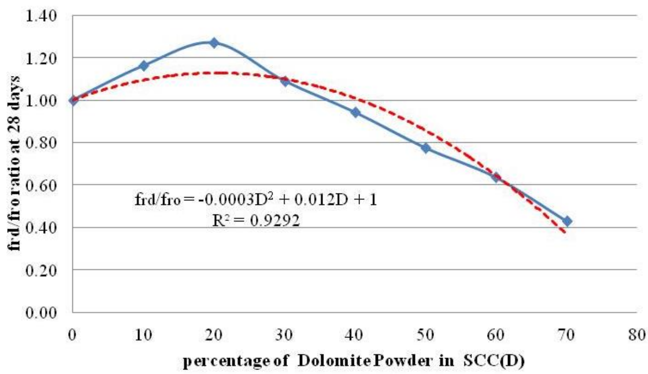


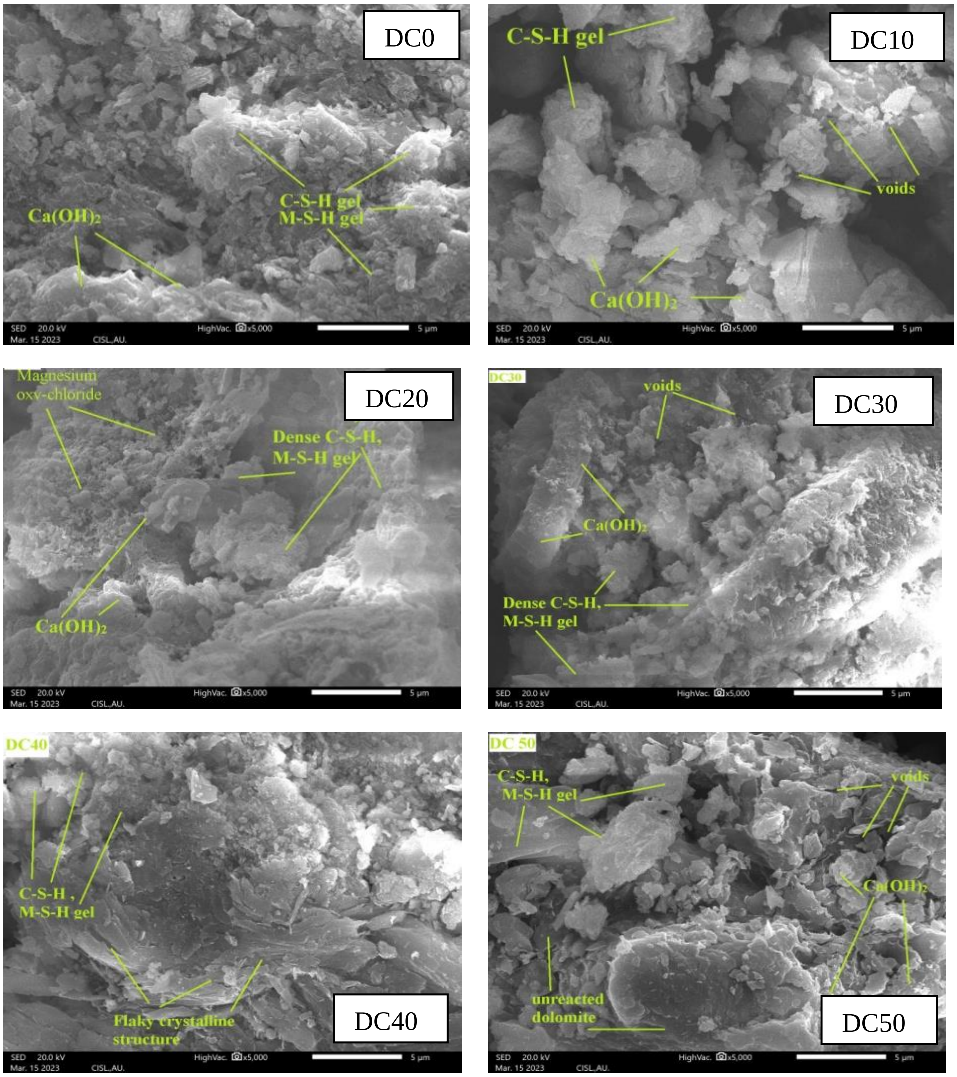
Fig. 13. Variation of f_{rd}/f_{ro} with percentage of dolomite powder

Table 3. Predicted strength of SCC using the developed equations and percentage error

Designation	Compressive strength (N/mm²) f_{cd}/f_{co}=1E-05D^3 - 0.0013D^2 + 0.0343D + 1 R^2 = 0.9903		Splitting tension strength (N/mm²) f_{td}/f_{to}=-0.0002D^2 + 0.0071D + 1 R^2 = 0.9146		Flexural strength (N/mm²) f_{rd}/f_{ro}=-0.0003D^2 + 0.012D + 1 R^2 = 0.9292	
	Predicted	% Error	Predicted	% Error	Predicted	% Error
DC0	46.43	0.00	3.33	0.00	4.91	0.00
DC10	56.78	3.00	3.50	-5.66	5.30	-7.06
DC20	57.85	-5.16	3.54	-10.47	5.49	-11.89
DC30	52.42	-0.46	3.44	2.38	5.48	2.51
DC40	43.27	-3.65	3.21	10.31	5.28	14.18
DC50	33.20	-8.66	2.85	10.35	4.89	28.46
DC60	24.98	-12.47	2.35	10.37	4.29	37.54
DC70	21.40	-15.31	1.72	0.09	3.50	16.31

5. SEM Analysis

Using scanning electron microscope (SEM) images, hardened concrete quality can be analyzed by studying the microstructure of concrete [12]. The hydration phase and the mineral additives used can be identified in the SEM image [13]. The topography and pattern of a material can be identified in the SEM micrographs. In this experiment, photos were taken after mounting the crushed concrete fragments on the SEM stub [14]. The curing age of all SCC mixes is of 28 days. SEM pictures of DC0, DC10, DC20, DC30, DC40, DC50, DC60, and DC70 mixes are presented in Figure 14 (DC0-DC70). The presented images demonstrate the distinct spreading of CSH (Calcium Silicate Hydrate gel), MSH (Magnesium Silicate Hydrate gel), $Ca(OH)_2$, unreacted dolomite, voids etc.[15-21].



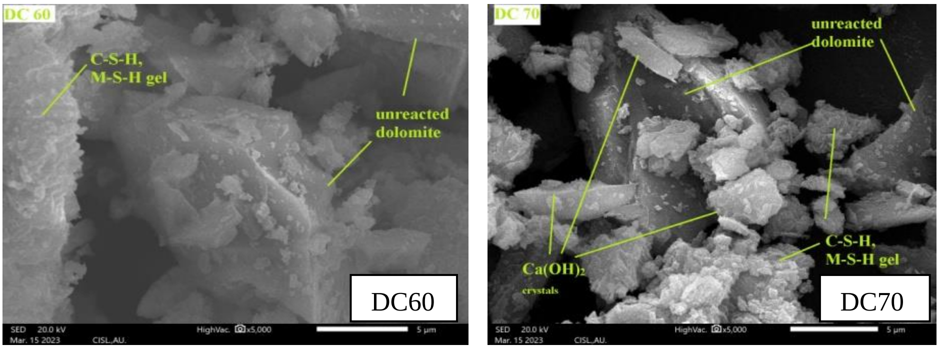


Fig. 14. (DC0-DC70) SEM Images of SCC mixes

CSH reflection is brighter than that of MSH. Like CSH, MSH also processes cementitious property. Mg ions are smaller than Ca ions in size. The flaky crystals are of 3-phase Magnesium oxy-chloride. Small needles are of 5-phase Magnesium oxy-chloride [22-24]. Both 3-phase and 5-phase oxy-chlorides are stable at normal temperature and at 8 to10 pH. When cement is replaced with dolomite powder, the pH of all mixes ranges from 9.8 to 10.9. Ca $(OH)_2$ appears as bright crystal in SEM images. The beneficial effect of Dolomite particles can be understood by observing the spread of dense, non-porous hydrated products like CSH, MSH and Magnesium oxy chlorides [25-28].

The image of DC0 shows porous structure of hydrated products. Ca $(OH)_2$ can be observed along with porous CSH gel. The images of DC10, DC20 and DC30 reflect the dense hydrated products. The hydrated products, CSH and MSH together can be observed as a dense non crystalline matrix. In the image of DC40, more flaky nature of hydrated product of dolomite can be observed [29-34]. The unreacted dolomite powder crystals can be seen in the images of DC50, DC60 and DC70.

6 Conclusions

The following conclusions are drawn from the study.

- For all the mixes, the fresh self-compacting concrete properties i.e slump flow, T500 results were achieved satisfactorily as per EFNARC guidelines.
- At higher dosages of dolomite powder i.e more than 40%, It is observed that time taken to spread 500mm is lesser than that of lower dosage mixes but within the limits as per guidelines.
- The flow diameter of all SCC mixes having dolomite powder is less than that of control SCC mix i.e DC0.
- The compressive strength of SCC can be increased due to the use of dolomite by replacing partially the cement in the mix i.e up to 30%. The maximum percentage of increase in the compressive strength is 31% at the replacement level of 20% at the age of 28 days.
- The maximum increase in compressive strength is 45% at the replacement level of 20% at the age of 7 days.
- The maximum increase in splitting tension strength is 19% at the replacement level of 20% at the age of 28 days.
- The maximum increase in splitting tension strength is 25% at the replacement level of 20% at the age of 7 days.
- The maximum increase in flexural strength is 27% at the replacement level of 20% at the age of 28 days.

- At 40% replacement of cement with dolomite, the compressive strength, splitting tension strength and flexural strength values of SCC having dolomite are almost equal to the corresponding strength values of normal SCC i.e DC0.
- Equations are developed to predict compressive strength, splitting tension strength and flexural strength of SCC having dolomite by knowing the corresponding strength of normal SCC (DC0) i.e. SCC which is not having dolomite.
- At lower dosages of Dolomite powder (i.e. up to 30%), the hydration products are seen as well spread dense amorphous matter in the SEM micrographs. At higher dosages, unreacted dolomite particles are observed in the SEM micrographs.

Nomenclature

SCC – Self Compacting Concrete
DC0 – Self Compacting Concrete without Dolomite Powder (Control Mix)
DC10 – Self Compacting Concrete with Dolomite Powder as 10% replacement.
DC20 – Self Compacting Concrete with Dolomite Powder as 20% replacement.
DC30 – Self Compacting Concrete with Dolomite Powder as 30% replacement.
DC40 – Self Compacting Concrete with Dolomite Powder as 40% replacement.
DC50 – Self Compacting Concrete with Dolomite Powder as 50% replacement.
DC60 – Self Compacting Concrete with Dolomite Powder as 60% replacement.
DC70 – Self Compacting Concrete with Dolomite Powder as 70% replacement.
$Ca(OH)_2$ – Calcium Hydroxide
f_{cd} – compressive stress of concrete cube with dolomite powder
f_{co} – compressive stress of concrete cube without dolomite powder
f_{rd} – Flexural stress of concrete cube with dolomite powder
f_{ro} – Flexural stress of concrete cube without dolomite powder
f_{td} – Indirect tension stress of concrete cube with dolomite powder
f_{to} – Indirect tension of concrete cube without dolomite powder
f_{cyd} – cylindrical compressive stress of concrete cube with dolomite powder
CSH – Calcium Silicate Hydrate gel
MSH – Magnesium Silicate Hydrate gel
EFNARC – The European Federation of Specialist Construction Chemicals and Concrete Systems.
$CaMg(CO_3)_2$ – Calcium Magnesium Bicarbonate

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