Research on Engineering Structures & Materials
www.jresm.org
Research Group

Research Article

An experimental study on strength of concrete having calcium carbonate as a partial replacement material to cement and natural river sand

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Article Info

Article history:

Received 16 Apr 2024
Accepted 27 Aug 2024

Keywords:

Calcium carbonate powder;
Calcium carbonate sand;
Compressive strength;
Flexural strength;
Split tensile strength

Abstract

Limestone is a sedimentary rock mainly composed of calcium carbonate mineral. Limestone is quarried abundantly in and around Piduguralla region, Andhra Pradesh, India. Good quality limestone is used to manufacture cement. Calcium oxide is used as white wash which is obtained by heating calcium carbonate. Limestone, as fine powder or as coarse grains is also used as base for paint. In this research, the calcium carbonate mineral in the form of limestone procured from Piduguralla region is used in concrete in two different forms i.e as powder form and as sand form. The cement was partially replaced with the calcium carbonate powder when the calcium carbonate is used as fine powder. The natural river sand was partially/fully replaced with calcium carbonate sand when the calcium carbonate is used as sand (coarser) form. Experiments on cube, cylinder and beam specimens are conducted using Universal Testing Machine to establish compression strength, split tensile strength and flexural strength of concrete having calcium carbonate. The test results support the usage of calcium carbonate in concrete to enhance the strength of concrete. Up to thirty percent cement can be replaced with calcium carbonate powder without adversely affecting the strength of concrete. Natural river sand can be partially/fully replaced with calcium carbonate sand which in turn increases the strength of concrete, but the optimum percentage of replacement is fifty percent of natural sand.

1. Introduction

India is the most populous country in the world and hence the infrastructural development works are increasing year by year which in turn increases the demand for concrete. Cement is the essential component in concrete. To protect the environment from greenhouse gases released during the cement production, an alternative to cement is necessary. An estimation of about 52.3% of worldwide CO_2 will be released from the cement industries of India by 2070 [11]. These consequences made the engineers to focus on changing the present way of preparing the concrete or mortar mix by replacing the cement with suitable other materials for getting economical and long-lasting concrete. If the cement is partially replaced with other suitable material without affecting the strength of concrete, then the consumption of cement can be reduced, which in turn prevent the environmental damage. The waste materials which are released from different industries as by-products are the probable alternatives for cement. These untreated waste materials such as fly ash, rice husk ash, silica fume, granite waste, blast furnace slag, marble powder etc., are released from industries and dumped into environment may cause hazardous

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DOI: http://dx.doi.org/10.17515/resm2024.242ma0416rs

environment. Hence, they can be used for producing concrete. Also, a large amount of river sand is used as fine aggregate for preparing concrete and mortar leading to exploitation of river sand in an uncontrolled manner causing shortage of it. Due to this heavy demand in construction industries, natural river sand also requires immediate substitution. Hence researchers are showing interest on waste materials. Apart from the by-products of various industries, mined calcium carbonate can also be used as alternative material for cement and natural sand. The mined calcium carbonate boulders are crushed into granular or powder form which is used as a raw material for cement manufacturing and as base in paints. From many years the CCP is used as a building material, as a constituent of cement and as an aggregate for roads in construction industries. It is also used as a filler material in paints and plastics. The calcined calcium carbonate is used as whitewashing the walls. Calcium carbonate can cut down the acidic nature by maintaining the alkalinity and hence used to defuse the acidic content in soil and water. It has the capability of removing Sulfur dioxide and Nitrogen dioxide emissions from fossil fuels.

Jingliang Xia *et al* concluded that at lower dosage of Calcium carbonate powder can decrease the drying shrinkage of white High Strength Concrete (HSC) and at higher dosage can increase the workability, whiteness and mechanical properties and decrease the impermeability and carbonation resistance of white HSC [1]. Dhanendra Kumar *et al* determined that in Strain Hardening Cementitious Composites depending upon the increase in weight ratio of slag (substitute to fly ash in normal SHCC) to cement the compressive strength decreased and depending upon the increase in volume ratio of calcium carbonate powder (substitute to silica sand in normal SHCC) to solids the compressive strength improved by minimizing the cement content [2]. Ali Heidari *et al* have replaced silica sand with calcium carbonate in Reactive Powder Concrete decreased cement usage and enhanced flexural, compressive and tensile strengths at certain ratios of sand to cement and trimmed down the water absorption of concrete [3]. Joaquin Abellan-Garcia *et al* found that calcium carbonate increased rheological properties of Ultra High-Performance Concrete and Ultra High-Performance Fibre Reinforced Concrete (FRC) by lessening the requirement of chemical admixtures like superplasticizer which led to the fall of drying shrinkage [4].

Xuejiao Zhu *et al* proved that Calcium Carbonate Precipitating Biomass Powder has the capability of suppressing the corrosion and closing the cracks automatically in structures which are in contact with water [5]. Y.S. Zhang *et al* disclosed that the Microbially induced $CaCO_3$ precipitation can work as a medicine for concrete cracks, and it is environmental friendly with less maintenance [6]. Joaquin Abellan Garcia *et al* declares that by partial replacement of cement and microsilica with micro $CaCO_3$ and waste glass respectively increased the compressive strength, rheological properties of concrete and declined the superplasticizer usage which optimized the cost of Ultra High-Performance Concrete (HPC) [7]. Y. El Hafiane *et al* finalized those mechanical properties of the hardened material increased by calcium carbonate which is used partially as an alternative for calcium aluminate cement on addition of a dispersant [8]. Mingli Cao *et al* investigated that Calcium Carbonate Whiskers in mortar has capability of increasing the compressive strength, prohibiting the cracks in further enlargement and increasing the mortar compactness leading to resistance against abrasion [9].

P.Rashidi Rad *et al* said that the concrete can be long lasting with high mechanical strength, workable and sustainable when mixed with admixtures called calcium carbonate powder and micro silica gel which in turn increased the properties of fresh and hardened concrete [10]. Bhaskar Prakash *et al* conclude that waste marble powder as a sustainable replacement to cement hiked the workability and compressive strength by increasing hydration process [11]. Wenhao Song *et al* studied and stated that by replacing the fine aggregate with modified Waste Marble Powder (WMP) mixed with stearic acid the fresh mortar fluidity increased along with resistance against corrosion and also condensed water absorption of mortar mix [12]. Ahmed Essam *et al* proved that by partial replacement of cement with waste Marble Powder (MP) gives a denser mixture resulting to decrease in workability, emission of carbon dioxide and calcium hydroxide content leading to higher mechanical strength to get Eco- High-performance concrete [13]. Bing Liu *et al* explored that alkali activated binders prepared with waste marble powder augmented the early compressive and flexural strength but reduction in overall strength [14]. Elyas Asadi Shamsabadi *et al* researched-on waste marble powder usage in concrete mix and identified that by using Machine Learning approach the compressive strength of mix can be measured accurately, and hydration of cement takes place at early age [15].

Ismail Sedat Buyuksagis *et al* determined that there is a raise in bending and compressive strength, water absorption, porosity of mortar mix with higher density when the mortar is mixed with marble powder and this additive can also be used in adhesive mortar [16]. K.I. Syed Ahmed Kabeer *et al* found that for saving water and river sand in cement mortar a waste product released from cutting the marble stones was used which increased the mechanical properties, bond and adhesive strength of mortar in construction projects [17]. Manpreet Singh *et al* disclosed that by substituting the cement with Waste Marble Powder (WMP) the durability and strength of the concrete increased and made the mixture denser which in turn fight against permeability and sorptivity [18]. Kirti Vardhan *et al* declared that on 10% substitution of cement with marble powder increased the workability but on more replacement of material caused a delay in hydration of cement and made the microstructure porous [19]. Valeria Corinaldesi *et al* derived that by replacing the sand with Marble Powder (MP) the compressive strength increased at same workability and due to its filler ability, the strength achieved even at early ages [20]. Kursat Esat Alyamac *et al* investigated that the marble industry waste can be used as a filler material in Self Compacting Concrete and monograms were prepared by conducting tests on fresh and hard mixes for getting economic mix design [21].

Muhammad Junaid Munir *et al* studied that Alkali Silica Reaction (ASR) is controlled by using waste Marble Powder (MP) as a substitute for cement in preparation of mortar mix led to the development of compressive strength and suppression of ASR expansion [22]. Kirti Vardhan *et al* finalized that the resistance against chloride ion penetration, sorptivity, water absorption, workability of concrete mix is declined and enhanced the compressive and split tensile strength of concrete mix by partial substitution of waste marble to fine aggregate making the mix denser [23]. L.G.Li *et al* said that the marble dust can be used as a substitute to cement paste which increased the durability, dimensional stability, mortar impermeability, carbonation resistance, water resistance and reduced shrinkage strain and shrinkage rate [24]. Omar M. Omar *et al* presented that there is an improvement in compressive strength, tensile strength and flexural strength of concrete when fine aggregate is partially substituted with Lime stone Waste and Marble Powder [25]. Abhishek Kumar *et al* have examined that Stone dust can be used as a partial substitution to fine aggregate and concrete is prepared by adding fixed percentage of steel fibres which enhanced the compressive strength and durability up to certain percentage of stone dust substitution [26]. Tao Fu *et al* proved that the use of stone powder in manufactured sand concrete first enhanced the slump, compressive and split tensile strength of concrete and the strengths reduced later [27]. Ashu Singh *et al* determined that the stone powder and ceramic waste materials which are used as sand improved the strength of concrete and reduced the cost of concrete by reducing the usage of aggregates [28]. Mohanad Yaseen Abdulwahid *et al* in his study replaced the coarse aggregate of pervious concrete with stone powder which enhanced the strength, and the rate of strength gain improved along with mechanical properties of concrete with the use of Sand Stone and Marlstone [29]. Er. Farooq Ahmad Parray *et al* explored that the workability of concrete reduced due to substitution of river sand with fine sized clastic sediment Stone Powder (SP) but there is an improvement in compressive strength, split tensile strength and flexural strength of concrete [30]. Lalit Kumar Gupta *et al* proved that the waste Granite Powder can be used as an alternative to sand in mortar which improved the compressive strength, bond strength, adhesive strength and mortar shrinkage; hence this mortar can be used for plastering and masonry work [31]. Kishan Lal Jain *et al* researched on an area of usage of glass powder as replacement of cement and granite waste as fine aggregate which suppressed the water absorption, permeability and increased durability, resistance against acid attack and sulphate attack [32]. T. Balasubramaniam *et al* concluded that on partial substitution of fine aggregate with both bottom ash and granite powder, the negative effect of using only bottom ash on strength characteristics, porosity, interlocking of particles and fighting against entry of acid or saline water into concrete mix can be reduced [33]. Abhishek Jain *et al* determined that the compressive strength, chloride resistance, carbonation resistance, corrosion resistance was increased, and shrinkage deformation was decreased due to 50% replacement of sand with granite powder waste to form environmentally friendly blended self-compacted concrete compared to fly ash [34]. The calcium carbonate is used in various construction sectors. The available literature is also diversified. The literature available on study of the strength of concrete having calcium carbonate is meagre. Many researchers used silica sand, glass fibres, micro silica gel etc., in addition to calcium carbonate in the concrete. Effect of incorporating only calcium carbonate in normal concrete is not studied previously. In addition, present research by the authors considered the calcium carbonate in powder form as well as in sand form. The objective of the research is to study the strength aspects of concrete having calcium carbonate. The following aspects are considered to achieve the objective of the study.

- Determination of compressive strength, split tensile strength and flexural strength of various concrete mixes having calcium carbonate powder at various percentages ranging from 0 to 50% (0, 10, 20, 30, 40 and 50 percentage of cement).
- Determination of compressive strength, split tensile strength and flexural strength of various concrete mixes having calcium carbonate in coarser (sand) form at various percentages ranging from 0 to 100% (0, 25, 50, 75 and 100 percentage of natural sand).
- Prediction of strength of concrete having calcium carbonate by developing mathematical models.

2. Materials

Ordinary Portland Cement of 53 grade confirming to IS 12269:2013. Natural river sand of Zone III as per IS 383:2016 and having specific gravity of 2.7. Stone aggregate of size 20mm and 10mm confirming to IS 383:2016. Calcium Carbonate Powder (Fig.1a) (limestone in powder form mainly consists of calcite) having specific gravity of 2.7 and Calcium Carbonate Sand (Fig.1b) (lime stone in coarser form mainly consists of calcite) of Zone III as per IS 383:2016 having specific gravity of 2.7.


(a)


(b)

Fig. 1. (a) Calcium carbonate powder and (b) calcium carbonate sand

3. Experimental Program

The concrete mixes with calcium carbonate powder are designated as CP and with calcium carbonate sand as CS. Mix without CP and CS i.e control mix are designated as CP0 and CS0 respectively. The concrete mixes having 10%, 20%, 30%, 40% and 50% replacement of cement with calcium carbonate powder are given designation as CP10, CP20, CP30, CP40 and CP50 respectively. Similarly for the mixes where natural river sand replaced at 25%, 50%, 75% and 100% with calcium carbonate sand given signs as CS25, CS50, CS75 and CS100 respectively. The designation of different concrete mixes casted and corresponding mix proportions is shown in Table 1 and 2. The mix proportion is designed as per IS 10262:2019 and corrected according to the requirements by studying trail mixes.

Table 1. Mix proportion of calcium carbonate powder (CP) concrete mixes

Designation	Cement	CP	Fine Aggregate	Coarse Aggregate (20mm)	Coarse Aggregate (10mm)	Water
CP0	1	0	1.53	1.83	1.22	0.42
CP10	0.9	0.089	1.53	1.83	1.22	0.42
CP20	0.8	0.177	1.53	1.83	1.22	0.42
CP30	0.7	0.266	1.53	1.83	1.22	0.42
CP40	0.6	0.354	1.53	1.83	1.22	0.42
CP50	0.5	0.443	1.53	1.83	1.22	0.42

Table 2. Mix proportion of calcium carbonate sand (CS) concrete mixes

Designation	Cement	Fine Aggregate	CS	Coarse Aggregate (20mm)	Coarse Aggregate (10mm)	Water
CS0	1	1.53	0	1.83	1.22	0.42
CS25	1	1.148	0.383	1.83	1.22	0.42
CS50	1	0.765	0.765	1.83	1.22	0.42
CS75	1	0.383	1.148	1.83	1.22	0.42
CS100	1	0	1.53	1.83	1.22	0.42

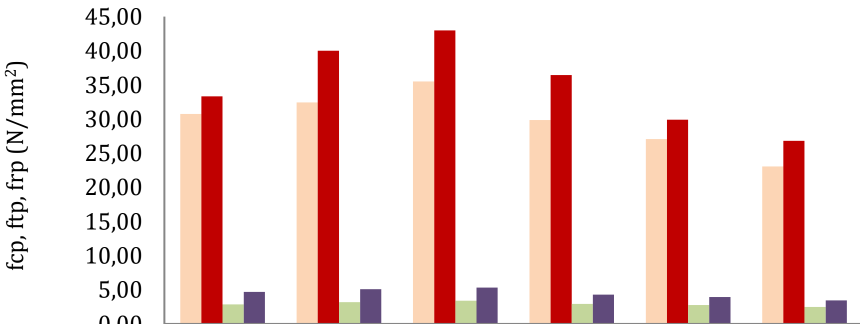
Concrete mixes were prepared as per the proportion and casted 100mm cube specimens, 100mm x 200mm cylinder specimens and 100mm x 100mm x 500mm beam specimens. The specimens were water immersed and cured till the test day. Strength tests were performed by using a universal testing machine. Compressive test was performed at 7 days and 28 days of curing age. Split tension test and flexure test were performed at 28 days of curing age.

4. Results and Discussion

In this research, the calcium carbonate in powder form was used as partial replacement material to cement. Also, the calcium carbonate in sand form was used as partial replacement material to natural river sand.

4.1 Calcium Carbonate in Powder Form

The compressive strength, split tensile strength and flexural strength values of CP designated concrete are shown in Fig.2. Here fcp is the compressive strength of concrete having calcium carbonate in powder form. fco is the value of compressive strength of concrete in which no calcium carbonate is present i.e compressive strength of control mix. ftp is the split tensile strength of concrete having calcium carbonate in powder form. fto is the value of split tensile strength of concrete in which no calcium carbonate is present i.e split tensile strength of control mix. frp is the flexural strength of concrete having calcium carbonate in powder form. fro is the value of flexural strength of concrete in which no calcium carbonate is present i.e flexural strength of control mix. The ratios of (fcp, ftp, frp) strength of concrete having calcium carbonate powder and corresponding strength of concrete not having calcium carbonate powder (fco, fto, fro) are shown in Table 3.



	CP0	CP10	CP20	CP30	CP40	CP50
fcp(7 Days)	30,75	32,43	35,50	29,86	27,06	23,05
fcp(28 Days)	33,33	40,01	42,98	36,45	29,90	26,80
ftp(28 Days)	2,87	3,20	3,40	2,93	2,76	2,49
frp(28 Days)	4,70	5,10	5,33	4,30	3,95	3,44

Fig. 2. Compressive, tensile and flexure strengths of concrete having calcium carbonate powder

Table 3. Ratios of strengths of concrete having CP and corresponding control mix

CP (%)	fcp/fco		ftp/fto	frp/fro
	7 Days	28 Days	28 Days	28 Days
0	1.00	1.00	1.00	1.00
10	1.05	1.20	1.11	1.09
20	1.15	1.29	1.18	1.13
30	0.97	1.09	1.02	0.91
40	0.88	0.90	0.96	0.84
50	0.75	0.80	0.87	0.73

4.1.1 Compressive Strength

After analyzing the test results, as percentage of calcium carbonate powder increases up to 20% the compressive strength of concrete increases. Beyond 20% and up to 50% replacement of cement with calcium carbonate, the compressive strength decreases. The maximum percentage increase in compressive strength at 28 days is 29% which is for CP20 Mix. At 30% replacement level, the compressive strength at 28 days of CP30 mix is almost equal to the CP0 Mix i.e., the mix without calcium carbonate. Therefore, a thirty percent of cement can be replaced with calcium carbonate powder without affecting strength adversely. The same trend is observed for 7 days compressive strength. At 50% replacement level, the decrease in compressive strength at 28 days is 20% than that of control mix (CP0).

4.1.2 Split Tensile Strength

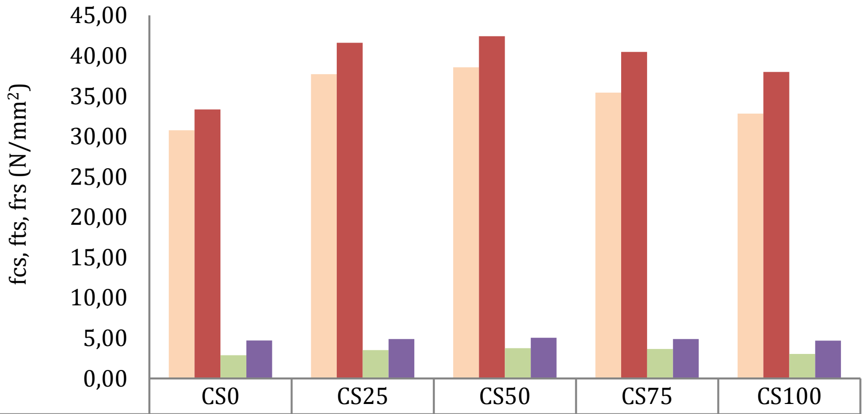
Up to 20% increase in calcium carbonate powder the split tensile strength of concrete increases. Beyond 20% and up to 50% replacement of cement with calcium carbonate, the split tensile strength decreases. The maximum percentage increase in split tensile strength at 28 days is 18% which is for CP20 Mix. At 30% replacement level, the split tensile strength at 28 days of CP30 mix is almost equal to the CP0 Mix i.e., the mix without calcium carbonate. Therefore, a thirty percent of cement can be replaced with calcium carbonate powder without affecting split tensile strength adversely. At 50% replacement level, the decrease in split tensile strength at 28 days is 13% than that of control mix (CP0).

4.1.3 Flexural Strength

As percentage of calcium carbonate powder increases up to 20% the flexural strength of concrete increases. Beyond 20% and up to 50% replacement of cement with calcium carbonate, the flexural strength decreases. The maximum percentage increase in flexural strength at 28 days is 13% which is for CP20 Mix. At 30% replacement level, the flexural strength at 28 days of CP30 mix is equal to or slightly less than the CP0 Mix i.e., the mix without calcium carbonate. Therefore, a thirty percent of cement can be replaced with calcium carbonate powder without affecting strength much adversely. At 50% replacement level, the decrease in compressive strength at 28 days is 27% than that of control mix (CP0).

4.2 Calcium Carbonate in Sand Form

The compressive strength, split tensile strength and flexural strength values of CS designated concrete are shown in Fig.3. Here fcs is the compressive strength of concrete having calcium carbonate in sand form. fco is the value of compressive strength of concrete in which no calcium carbonate is present i.e compressive strength of control mix. fts is the split tensile strength of concrete having calcium carbonate in sand form. fto is the value of split tensile strength of concrete in which no calcium carbonate is present i.e split tensile strength of control mix. frs is the flexural strength of concrete having calcium carbonate in sand form. fro is the value of flexural strength of concrete in which no calcium carbonate is present i.e flexural strength of control mix. The ratios of (fcs,fts,frs) strength of concrete having calcium carbonate sand and corresponding strength of concrete not having calcium carbonate sand (fco,fto,fro) are shown in Table 4.



	CS0	CS25	CS50	CS75	CS100
fcs(7 Days)	30,75	37,70	38,56	35,42	32,82
fcs(28 Days)	33,33	41,59	42,41	40,46	37,98
fts(28 Days)	2,87	3,52	3,75	3,65	3,04
frs(28 Days)	4,70	4,88	5,04	4,88	4,69

Fig. 3. Compressive, tensile and flexure strengths of concrete having calcium carbonate sand

Table 4. Ratios of strengths of concrete having cs and corresponding control mix

CS (%)	fcs/fco		fts/fto	frs/fro
	7 Days	28 Days	28 Days	28 Days
0	1.00	1.00	1.00	1.00
25	1.23	1.25	1.23	1.04
50	1.25	1.27	1.31	1.07
75	1.15	1.21	1.27	1.04
100	1.07	1.14	1.06	1.00

4.2.1 Compressive Strength

Addition of calcium carbonate in sand form enhances the compressive strength of all mixes compared to the control mix (CS0). The maximum percentage increase in compressive strength at 28 days is 27% which is for CS50 Mix. Even at 100% replacement level (i.e for CS100), the increase in compressive strength is 14%. Also at 7 days, the compressive strength of all mixes having calcium carbonate as sand is greater than that of control mix (CS0). With this analysis, natural sand can be partially or even fully can be replaced with calcium carbonate sand without any adverse effect on strength of concrete.

4.2.2 Split Tensile Strength

Addition of calcium carbonate in sand form enhances the split tensile strength of all mixes compared to the control mix (CS0). The maximum percentage increase in split tensile strength at 28 days is 31% which is for CS50 Mix. Therefore, the natural sand can be replaced at 50% level with the calcium carbonate sand with an advantageous gain in split tensile strength.

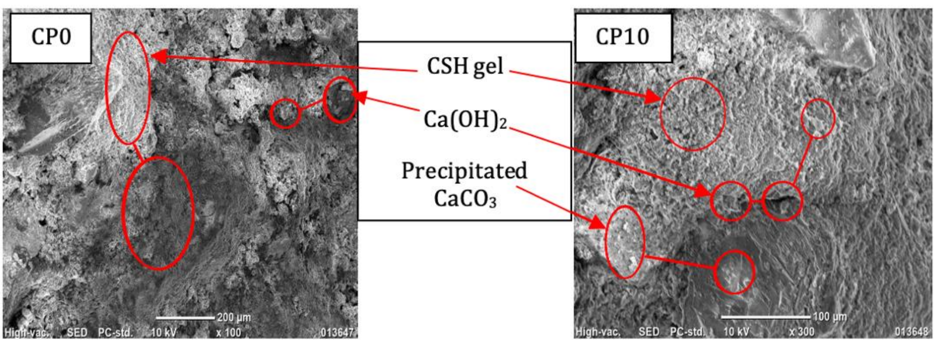
4.2.3 Flexural Strength

By addition of calcium carbonate in sand form, the flexural strength of all mixes is equal to or slightly greater than that of control mix (CS0). The maximum percentage increase in flexural strength at 28 days is 7% which is for CS50 Mix. From the above analysis it can be understood that the addition of calcium carbonate to the concrete as sand, does not affect the flexural strength of concrete adversely.

4.3 Microstructure Using SEM Images

SEM images of concrete having calcium carbonate as in powder form at various percentage levels are presented in Fig.4. For CP0, CP10, CP20 and CP30 distinct reaction products such as CSH gel, $Ca(OH)_2$ flakes, Ettringite can be seen. For CP40 and CP50 the spread of precipitated calcium carbonate can be visualized along with porous reaction products. For CP20 mix, i.e 20% cement is replaced by calcium carbonate powder, the spread of dense CSH gel can be observed. This can support the experimental test result of maximum strength obtained with CP20 mix.

SEM images of concrete having calcium carbonate as in sand form at various replacement levels (i.e CS25, CS50, CS75 and CS100) are presented in Fig.5. Sand particles are identified on the SEM image and encircled with red colour. The interfacial transition zone is marked with white colour. The alphabets on SEM images i.e CS stands for calcium carbonate sand particle and NS stands for natural sand particle. Natural sand particle can be identified by its glossy finish whereas calcium carbonate sand particle can be identified by its dull finish. Reaction products such as CSH gel can be observed along the periphery of the sand particles. The joint between sand particle and reaction products is called as interfacial transition zone (ITZ).



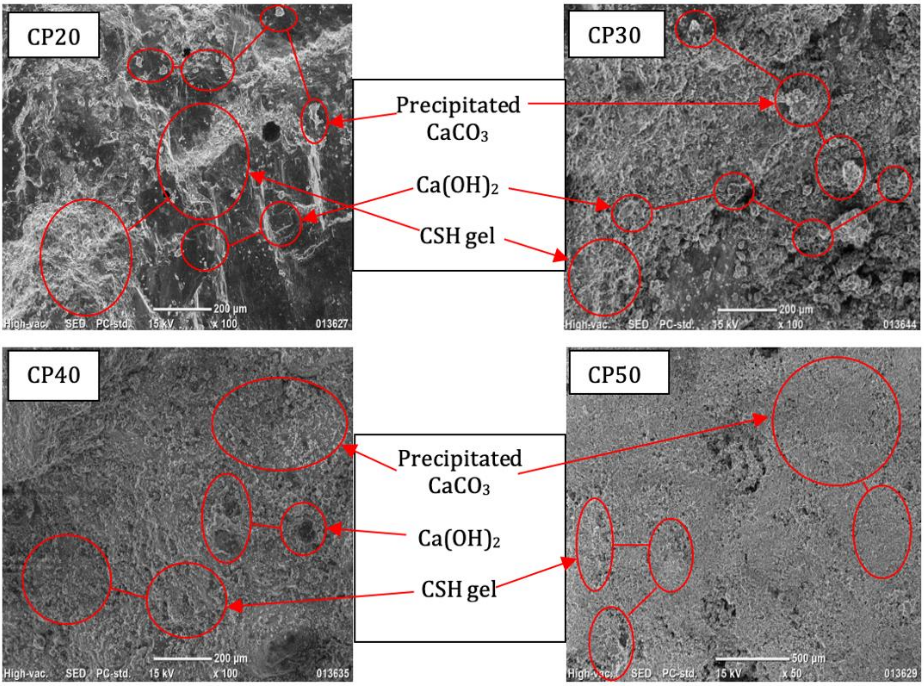


Fig. 4. SEM images of concrete having calcium carbonate as in powder form

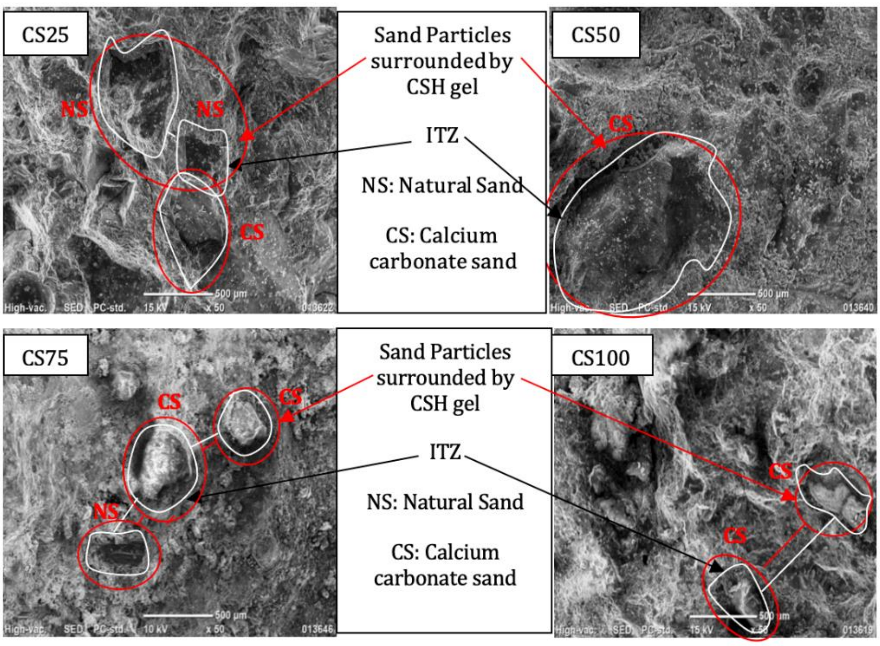


Fig. 5. SEM images of concrete having calcium carbonate as in Sand form

The ITZ region of CS particle can be seen as bright and in white colour which indicates the reaction products of CS particle. The CS particle is reactive and participates in the cement reaction with water producing CSH gel which strengthens the ITZ. This could be the reason for increase in strength of CS25, CS50, CS75 and CS100 mixtures compared with that of CS0 mixture.

4.4 Prediction of Strength

Plots are drawn (Fig.6 and Fig.7) with percentage of calcium carbonate on x-axis and strength ratios (fcp/fco, ftp/fto, frp/fro, fcs/fco, fts/fto, frs/fro) on y-axis. Second order polynomial equations are developed to predict the strength of concrete having calcium carbonate using the above-mentioned plots.

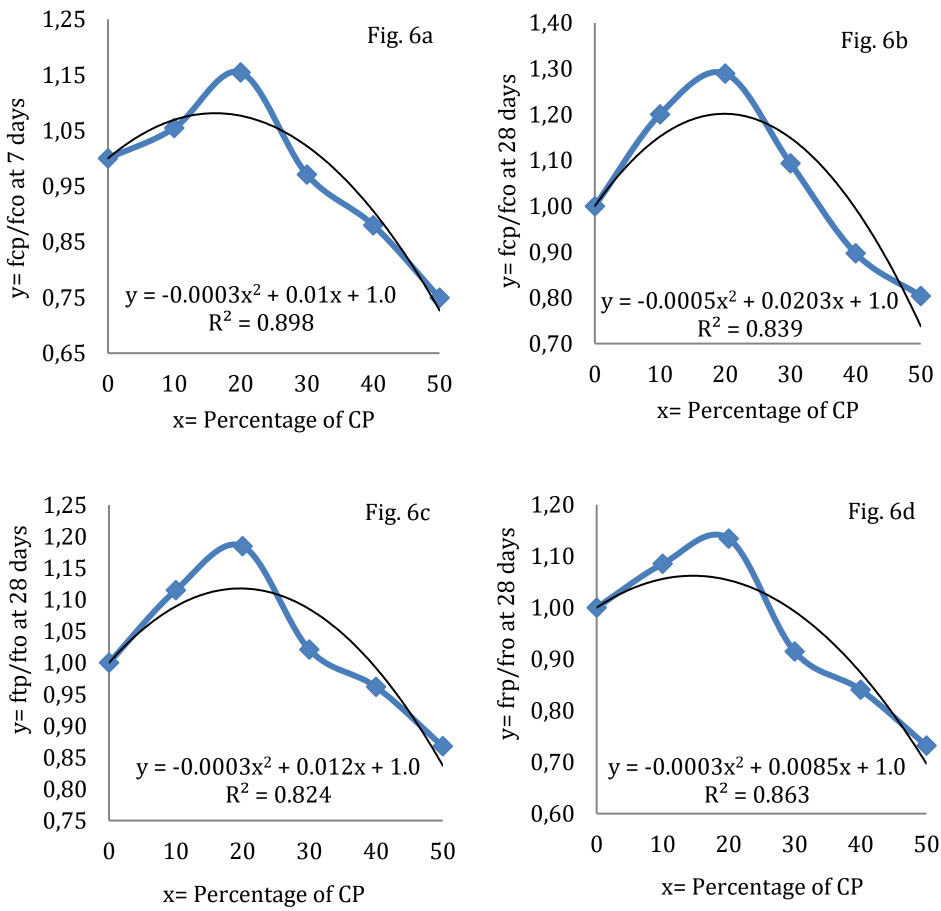


Fig. 6. Plots between percentage of calcium carbonate powder and corresponding strength ratios

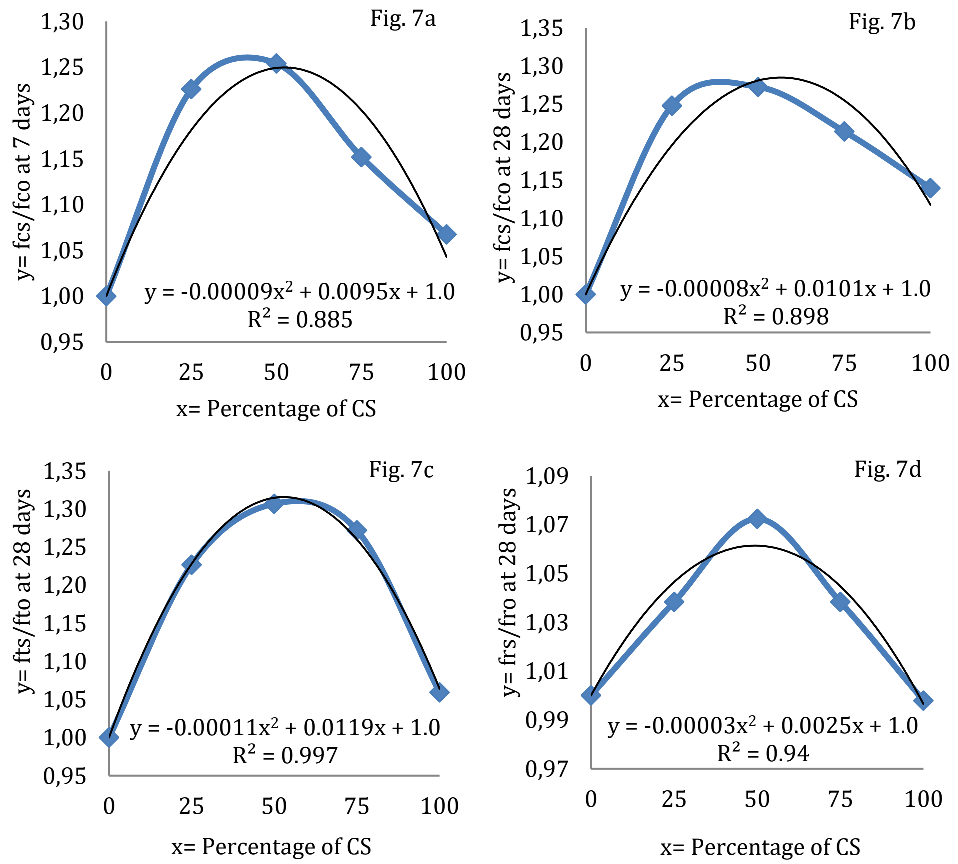


Fig. 7. Plots between percentage of calcium carbonate sand and corresponding strength ratios

Strength values of concrete having calcium carbonate are calculated using the developed expressions and shown in Table 5 and 6. The percentage error in calculating the strength is also shown in Table 5 and 6.

Table 5. Predicted strengths of concrete having calcium carbonate powder and percentage error

CP (%)	Predicted fcp (N/mm²)				Predicted ftp (N/mm²)		Predicted frp (N/mm²)	
	7 Days	Error %	28 Days	Error %	28 Days	Error %	28 Days	Error %
0	30.75	0.00	33.33	0.00	2.87	0.00	4.70	0.00
10	32.90	0.47	38.43	-1.58	3.13	-0.07	4.96	-0.14
20	33.21	-2.29	40.20	-2.78	3.21	-0.19	4.94	-0.40
30	31.67	1.81	38.63	2.18	3.13	0.20	4.63	0.33
40	28.29	1.23	33.73	3.83	2.87	0.11	4.04	0.09
50	23.06	0.01	25.50	-1.30	2.44	-0.05	3.17	-0.27

Table 6. Predicted strengths of concrete having calcium carbonate sand and percentage error

CS (%)	Predicted fcs (N/mm^2)				Predicted fts (N/mm^2)		Predicted frs (N/mm^2)	
	7 Days	Error %	28 Days	Error %	28 Days	Error %	28 Days	Error %
0	30.75	0.00	33.33	0.00	2.87	0.00	4.70	0.00
25	36.32	-1.38	40.08	-1.51	3.53	0.01	4.91	0.03
50	38.44	-0.12	43.50	1.09	3.79	0.04	4.94	-0.11
75	37.09	1.67	43.58	3.12	3.66	0.01	4.79	-0.09
100	32.29	-0.53	40.33	2.35	3.13	0.09	4.47	-0.23

It can be observed that the percentage error is within ±4%, hence the developed expressions can be used to predict the strength of concrete having calcium carbonate after knowing the replacement percentage and the corresponding strength of concrete without having calcium carbonate.

4.4.1 Comparison with Available Literature

The 28th day compressive strengths predicted using the proposed expression are compared with the published experimental results by various researchers (Table 7). The percentage error varies in between 2.55 and 23.50. The variation in percentage error is attributed to the factors such as difference in grade of concrete, mix proportions and interaction of additional materials in the concrete other than those used by the authors.

Table 7. Comparison of predicted 28th day compressive strength with the available literature

Referred Literature	Ali Heidari *et al* [3]			P.Rashidi Rad *et al* [10]		
Percentage of Calcium Carbonate Powder (x)	Experimental 28 Days Compressive Strength	Predicted Compressive Strength using $y = -0.0005x^2 + 0.0203x + 1.0$	% Error	Experimental 28 Days Compressive Strength	Predicted Compressive Strength using $y = -0.0005x^2 + 0.0203x + 1.0$	% Error
0.00	130.00	130.00	0.00	39	39.00	0.00
10.00	135.00	149.89	11.03	--	--	--
12.50	--	--	--	42	45.85	9.17
20.00	140.00	156.78	11.99	--	--	--
25.00	--	--	--	45	46.61	3.57
30.00	139.00	150.67	8.40	--	--	--
31.25	--	--	--	52	44.70	-14.04
37.50	--	--	--	43	41.27	-4.03
40.00	135.00	131.56	-2.55	--	--	--
43.75	--	--	--	40	36.31	-9.22
50.00	120.00	99.45	-17.13	39	29.84	-23.50

5. Conclusions

In this research, the calcium carbonate mineral in the form of lime stone is used as alternative material for cement and natural river sand. Following are the conclusions drawn from the study.

- A twenty per cent of the total cement content in the conventional concrete mix can be replaced with calcium carbonate powder advantageously. The maximum increase in compressive strength is 29% than that of concrete mixture without having calcium carbonate powder. Further, a thirty per cent of total cement can be replaced with calcium carbonate powder without affecting strength adversely.
- The maximum percentage increase in split tensile strength at 28 days is 18% which is at 20% replacement level. At 30% replacement level, the split tensile strength at 28 days of CP30 mix is almost equal to that of CP0 Mix i.e., the mix without calcium carbonate.
- The maximum percentage increase in flexural strength at 28 days is 13% which is at 20% replacement level. At 30% replacement level, the flexural strength at 28 days of CP30 mix is equal to or slightly less than that of the CP0 Mix i.e., the mix without calcium carbonate.
- Natural sand can be replaced partially or fully with calcium carbonate sand which enhances the compressive strength of concrete compared with that of the control mix concrete (CS0). The maximum percentage increase in compressive strength at 28 days is 27% which is at 50% replacement level.
- Addition of calcium carbonate in sand form enhances the split tensile strength of concrete compared to that of the control mix (CS0). The maximum percentage increase in split tensile strength at 28 days is 31% which is for CS50 Mix.
- By addition of calcium carbonate in sand form, the flexural strength of all mixes is equal to or slightly greater than that of control mix (CS0). The maximum percentage increase in flexural strength at 28 days is 7% which is for CS50 Mix.
- Expressions are developed to predict the strength of concrete having calcium carbonate.
- In summary, a thirty percent cement can be replaced with calcium carbonate powder without adverse effect on strength as calcium carbonate can be used in concrete as powder form. Similarly, the natural river sand can be partially/fully replaced with calcium carbonate sand (coarser). By using calcium carbonate in concrete, the quantities of cement and sand can be conserved.

Acknowledgement

The authors acknowledge the support and encouragement of the Management & Staff of R.V.R & J.C. College of Engineering, Chowdavaram, Guntur, AP.

References

[1] Xia J, Ke G, Leng F, Wang J, Ren L, Liang H. Effect of industrial-grade heavy calcium carbonate powder on properties of white high-strength concrete. Constr Build Mater. 2023;378:131211. https://doi.org/10.1016/j.conbuildmat.2023.131211

[2] Kumar D, Ravi RR. Development of strain-hardening cementitious composites utilizing slag and calcium carbonate powder. Constr Build Mater. 2021;273:122028. https://doi.org/10.1016/j.conbuildmat.2020.122028

[3] Heidari A, Shourabi FN. Mechanical properties of ultra-high performance concrete based on reactive powder concrete: Effect of sand-to-cement ratio, adding glass fiber and calcium carbonate. Constr Build Mater. 2023;368:130108. https://doi.org/10.1016/j.conbuildmat.2022.130108

[4] Abellan-Garcia J, Khan MI, Abbas YMA, Martínez-Liron V, Carvajal-Munoz JS. The drying shrinkage response of recycled-waste-glass-powder-and calcium-carbonate-based ultrahigh-performance concrete. Constr Build Mater. 2023;379:131163. https://doi.org/10.1016/j.conbuildmat.2023.131163
[5] Zhu X, Sakarika M, Ganigue R, Van Tittelboom K, Ersan YC, Boon N, et al. Production of calcium carbonate-precipitating biomass powder as self-healing additive in concrete and performance evaluation in mortar. Cem Concr Compos. 2023;138:104952. https://doi.org/10.1016/j.cemconcomp.2023.104952
[6] Zhang YS, Liu Y, Sun XD, Zeng W, Xing HP, Lin JZ, et al. Application of microbially induced calcium carbonate precipitation (MICP) technique in concrete crack repair: A review. Constr Build Mater. 2024;411:134313. https://doi.org/10.1016/j.conbuildmat.2023.134313
[7] Abellan-Garcia J, Khan MI, Abbas YMA, Castro-Cabeza A, Carrillo J. Multi-criterion optimization of Low-Cost, Self-compacted and Eco-Friendly Micro-calcium-carbonate-and Waste-glass-flour-based Ultrahigh-Performance concrete. Constr Build Mater. 2023;371:130793. https://doi.org/10.1016/j.conbuildmat.2023.130793
[8] El Hafiane Y, Smith A, Abouliatim Y, Benhammou A, Abourriche A, Nibou L, et al. Substitution of aluminous cement by calcium carbonates in presence of carboxylic acid. Constr Build Mater. 2017;154:711-720. https://doi.org/10.1016/j.conbuildmat.2017.08.023
[9] Cao M, Liu Z, Xie C. Effectiveness of calcium carbonate whiskers in mortar for improving the abrasion resistance. Constr Build Mater. 2021;295:123583. https://doi.org/10.1016/j.conbuildmat.2021.123583
[10] Rashidi Rad P, Haj Sd TA, Darvishvand HR, Ebrahimi M. Technical and Economical Approaches in Application of Micro Silica Gel and Calcium Carbonate Powder in Self-compacting Concrete. Int J Eng Trans A: Basics. 2022;35(04):760-773. https://doi.org/10.5829/IJE.2022.35.04A.16
[11] Prakash B, Saravanan TJ, Kabeer KISA, Bisht K. Exploring the potential of waste marble powder as a sustainable substitute to cement in cement-based composites: A review. Constr Build Mater. 2023;401:132887. https://doi.org/10.1016/j.conbuildmat.2023.132887
[12] Song W, Wang Q, Qu L, Li X, Xu S. Study of water absorption and corrosion resistance of the mortar with waste marble powder. Constr Build Mater. 2022;345:128235. https://doi.org/10.1016/j.conbuildmat.2022.128235
[13] Essam A, Mostafa SA, Khan M, Tahwia AM. Modified particle packing approach for optimizing waste marble powder as a cement substitute in high-performance concrete. Constr Build Mater. 2023;409:133845. https://doi.org/10.1016/j.conbuildmat.2023.133845
[14] Liu B, Geng S, Ye J, Liu X, Lin W, Wu S, et al. A preliminary study on waste marble powder-based alkali-activated binders. Constr Build Mater. 2023;378:131094. https://doi.org/10.1016/j.conbuildmat.2023.131094
[15] Shamsabadi EA, Roshan N, Hadigheh SA, Nehdi ML, Khodabakhshian A, Ghalehnovi M. Machine learning-based compressive strength modelling of concrete incorporating waste marble powder. Constr Build Mater. 2022;324:126592. https://doi.org/10.1016/j.conbuildmat.2022.126592
[16] Buyuksagis IS, Uygunoglu T, Tatar E. Investigation on the usage of waste marble powder in cement-based adhesive mortar. Constr Build Mater. 2017;154:734-742. https://doi.org/10.1016/j.conbuildmat.2017.08.014
[17] Kabeer KISA, Kumar V. Utilization of marble powder as fine aggregate in mortar mixes. Constr Build Mater. 2018;165:321-332. https://doi.org/10.1016/j.conbuildmat.2018.01.061
[18] Singh M, Srivastava A, Bhunia D. Long term strength and durability parameters of hardened concrete on partially replacing cement by dried waste marble powder slurry.

Constr Build Mater. 2019;198:553-569. https://doi.org/10.1016/j.conbuildmat.2018.12.005
[19] Vardhan K, Goyal S, Siddique R, Singh M. Mechanical properties and microstructural analysis of cement mortar incorporating marble powder as partial replacement of cement. Constr Build Mater. 2015;96:615-621. https://doi.org/10.1016/j.conbuildmat.2015.08.071
[20] Corinaldesi V, Moriconi G, Naik TR. Characterization of marble powder for its use in mortar and concrete. Constr Build Mater. 2010;24:113-117. https://doi.org/10.1016/j.conbuildmat.2009.08.013
[21] Alyamac KE, Ince R. A preliminary concrete mix design for SCC with marble powders. Constr Build Mater. 2009;23:1201-1210. https://doi.org/10.1016/j.conbuildmat.2008.08.012
[22] Munir MJ, Kazmi SMS, Wu Y-F. Efficiency of waste marble powder in controlling alkali-silica reaction of concrete: A sustainable approach. Constr Build Mater. 2017;154:590-599. https://doi.org/10.1016/j.conbuildmat.2017.08.002
[23] Vardhan K, Siddique R, Goyal S. Strength, permeation and micro-structural characteristics of concrete incorporating waste marble. Constr Build Mater. 2019;203:45-55. https://doi.org/10.1016/j.conbuildmat.2019.01.079
[24] Li LG, Huang ZH, Tan YP, Kwan AKH, Liu F. Use of marble dust as paste replacement for recycling waste and improving durability and dimensional stability of mortar. Constr Build Mater. 2018;166:423-432. https://doi.org/10.1016/j.conbuildmat.2018.01.154
[25] Omar MO, Abd Elhameed GD, Sherif MA, Mohamadien HA. Influence of limestone waste as partial replacement material for sand and marble powder in concrete properties. HBRC J. 2012;8:193-203. https://doi.org/10.1016/j.hbrcj.2012.10.005
[26] Kumar A, Singh V. Study the effect of stone dust & Steel fibre on strength properties of concrete. Int J Civ Eng Technol (IJCIET). 2019;10(03):2211-2219.
[27] Fu T, Liang JL, Lan YF, Xiao YP, Wei JH. Effect of Stone Powder Content on Mechanical Properties of Manufactured Sand Concrete. Iran J Sci Technol Trans Civ Eng. 2022;46:4255-4264. https://doi.org/10.1007/s40996-022-00882-1
[28] Singh A, Sachan V. Experimental study on the strength of concrete by partial replacement of ceramic waste and stone powder as fine aggregate. IOSR J Mech Civ Eng (IOSR-JMCE). 2022;19(5):30-32.
[29] Abdulwahid MY. Influences of different stone powders on pervious concrete strength. Struct Concr. 2020;2020:1-7. https://doi.org/10.1002/suco.202000095
[30] Parray FA, Rani H, Kaur M. Exploration of Properties of Concrete by Partial Replacement of Fine Aggregate with Clastic Sediment Stone Powder. Int J Eng Res Technol (IJERT). 2020;9(02). https://doi.org/10.17577/IJERTV9IS020173
[31] Gupta LK, Vyas AK. Impact on mechanical properties of cement sand mortar containing waste granite powder. Constr Build Mater. 2018;191:155-164. https://doi.org/10.1016/j.conbuildmat.2018.09.203
[32] Lal KJ, Gaurav S, Gupta LK. Durability performance of waste granite and glass powder added concrete. Constr Build Mater. 2020;252:119075. https://doi.org/10.1016/j.conbuildmat.2020.119075
[33] Balasubramaniam T, Stephen SJ. Influence of industrial wastes on the mechanical and durability characteristics of high strength concrete. Constr Build Mater. 2022;317:126202. https://doi.org/10.1016/j.conbuildmat.2021.126202
[34] Abhishek J, Choudhary S, Gupta R, Chaudhary S, Gautam L. Effect of granite industry waste addition on durability properties of fly ash blended self-compacting concrete. Constr Build Mater. 2022;340:127727. https://doi.org/10.1016/j.conbuildmat.2022.127727