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Effect of Using Marble Powder on the Properties of Recycled Aggregate Self-Curing Concrete

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ABSTRACT

Marble is an industrial waste product obtained during marble stone cutting. It can be used as a replacement for cement in several concrete types. It offers a low-cost constituent with long-lasting effects. Marble powder can react with cement hydration products, forming extra cementitious components that add to the concrete's strength and durability. The improvement of the mechanical properties depends on the replacement ratio of marble powder. In this study, marble powder was used as a replacement for cement to examine recycled aggregate self-curing concrete mixes. Recycling aggregates is an efficient way to reduce negative environmental consequences. To obtain self-curing concrete, self-curing agents were used. Chemical compounds such as Polyethylene glycol are used to mitigate water loss and enhance the effectiveness of the curing processes in concrete. Additionally, some recycled aggregate types may retain an amount of water, which acts as a reservoir, allowing the hydration process to continue within a self-curing regime. The compressive and flexure strengths were studied for both traditional control mixes and self-curing mixes for different recycled aggregates. Also, the durability performance of self-curing RC beams with recycled aggregate were tested under chloride attack (8% concentration) that lasted for up to 60 days. Test results showed that the properties of self-curing concrete containing recycled aggregates were improved due to the replacement of 5 percent of cement using marble powder. Based on durability tests, it was found that the performance of natural dolomite in was superior to that of the recycled aggregate.

Keywords: *marble; powder; durability; self-curing; recycle.*

1. Introduction

Using the marble powder as a replacement for cement has been shown to have several beneficial effects on the resulting concrete [1]. In addition to improving the concrete strength and durability, the use of marble powder can also improve the workability of the concrete and reduce the amount of cement needed, making it easier to handle and place [2]. The use of marble powder is not limited to concrete; as it used in many industrial applications including glass and paper manufacturing which help to protect the environment and address issues of cement shortages [3]. The Use of marble powder in recycled-aggregate self-curing concrete (RA-SC) has been found to improve the properties of this type of concrete [4].

The vast growing construction sector and the availability of demolition wastes from the rehabilitation and natural catastrophes, sparked the interest in employing recycled construction materials in concrete manufacturing. Recycled aggregates are aggregates made from materials that were previously used in a product or construction [5]. The main difference in the properties of coarse recycled aggregate concrete observed in many research studies is an increased water absorption capacity when compared to coarse natural aggregates, which is due to the greater porosity of the mortar adhering to the aggregate in recycled aggregate concrete. Due to the high porosity of the attached mortar, smaller sizes of recycled aggregate concrete have higher adhering mortar and a higher water requirement for the concrete mixes [6]. Red brick aggregate is primarily used as a coarse aggregate. This brick type is porous and its bulk density lies between that of normal-weight and lightweight aggregates enabling lower concrete unit weight [7].

The qualities of concrete formed using crushed brick aggregate are determined by the parent brick: (1) concrete unit weight is reduced due to the increased porosity; (2) water requirement of the mixture increases as water absorption of the brick aggregate increases, and therefore concrete strength declines;

accordingly, and (3) concrete strength improves as brick strength increases [8]. One of the most critical procedures to achieve the required qualities of concrete is curing. Self-curing concrete is a novel development in concrete curing with an acceptable durability performance [9]. The primary idea behind this technique is to provide internal supply of water to concrete so that it may be cured on its own. This is performed by incorporating water into the concrete materials or by reducing water evaporation from the concrete and consequently, enhancing its water retention capacity [10] .

Durability is defined as the capacity of concrete to resist long-term deterioration due to both internal and external aggressive environment [11]. Internal curing can be achieved with a variety of materials, including wood powder, lightweight aggregate, and chemical additions (shrinkage-reducing admixtures of the propylene glycol and polyethylene glycol) [12]. The use of poly-glycol chemicals in concrete mixes has recently been recommended as a way to reduce the risk of cracking in concrete structures caused by drying shrinkage. This admixture works by changing the surface tension of the mixing water, rather than reducing water evaporation. This method can reduce drying shrinkage strain, but not to eliminate it. Furthermore, because of the reduced shrinkage caused by water evaporation, the compressive strength is increased [13]. Thus, self-curing concrete with such potentials finds its way as a good alternative for laying concrete in certain applications where external curing may not be available [14]. This study investigates the effect of using marble powder as replacement for cement in improving the behavior and durability of recycled-aggregate self-curing concrete.

2. Research significance

This study aimed at investigating the effect of using marble powder on the properties of recycled-aggregate self-curing (RA-SC) concrete in terms of consistency and compressive strength. RC beams were cast using conventional and recycled aggregate mixes to evaluate their structural behavior after extended exposure under the attack of concentrated sodium chloride solution. The primary variables in this study were the marble-cement replacement ratio (5, 10, and 15% of cement by weight) and the coarse aggregate types (crushed concrete and crushed red brick as recycled aggregate versus crushed dolomite). The research significance arises knowing that Egypt is one of the largest marble producers and dealing with its powder as a byproduct represents a challenge. The research results are assumed to suggest a means of enhancing the performance of a special type of concrete that can be used in areas lacking water for concrete curing purposes.

3. Materials and test specimens

All of the tests in this study were conducted in the quality control and construction materials laboratory at the Faculty of Engineering, Menoufia University.

3.1 Materials

The cement used was ordinary Portland cement (CEM I 42.5N) produced by the Suez cement factory. The cement satisfied the Egyptian Standard Specification (ESS 4756-1/2022) requirements [15]. The fine aggregate used was natural siliceous sand compatible with the Egyptian specification (ESS 1109/2021) [16] and ASTM C-33 [17] with a fineness modulus of 2.61, a specific gravity of 2.60 and a water absorption ratio of 0.65 percent. Table (1) shows the grading of the used sand. Natural and recycled coarse aggregates were used. Dolomite was utilized as a natural coarse aggregate, while crushed concrete and crushed red brick were recycled materials. The dolomite particles were mostly angular. The grading and properties of coarse aggregates are given in Tables (2 and 3).

A modified polycarboxylate based high range water reducer (HRWR) with a commercial trade name Sikament-163M was used. The HRWR has a turbid appearance and a density of 1.08 kg/liter and complies with ASTM C-494 Types G and F [18]. Another chemical additive was polyethylene glycol (PEG400) was utilized. PEG 400 acts as a shrinkage-reducing admixture to obtain self-curing concrete by generating an interior barrier that prevents fresh concrete from excessive water evaporation [19]. The additive is produced by Morgan Chemicals Pvt. Ltd., Egypt. The properties of PEG400 as specified by the manufacturer are given in Table (4).

Marble powder is a metamorphic stone made from pure limestone that had been changed into marble. The purity of the limestone determines the color and appearance of the marble so that in case pf limestone is 100% calcite lime stone, marble is to be white. Marbles are crystalline rocks made up mostly of calcite, dolomite, and serpentine minerals. The increased mineral content varies with the source [20]. The chemical analysis of the used marble powder indicted that the powder is mainly composed of CaO (43.2%), SiO_2 (13.8%), MgO (2.7%) and Al_2O_3 (2.5 %) percent and Table (5) shows the physical properties of the marble powder as provided by the producer.

The concrete beams were reinforced utilizing 8mm and 10 mm rebars for the stirrups and bottom reinforcement. The grade of the rebars were B240D-P and B500DWR.

Table 1- Grading of Fine Aggregate

Sieve Size, mm	% passing	ASTM C33	
		min.	max.
4.75	100	95	100
2.36	95	80	100
1.18	75	50	85
0.61	45	25	60
0.30	15	5	30
0.15	0	0	10

Table 2- Grading of Coarse Aggregates (% Passing)

Sieve Size, mm	Aggregate type			ASTM C33	
	D	CC	CRB	min.	max.
19	95	95	90	90	100
9.5	53	27	24	20	55
4.75	5	5	1	0	10
2.36	0.5	0	0	0	5

D: dolomite, CC: crushed concrete, and CRB: crushed red brick

Table 3- Coarse Aggregate Properties

Property	Aggregate Type		
	D	CC	CRB
Specific gravity	2.65	2.4	1.7
Absorption, %	0.77	5	10
Crushing Modulus	18.1	12.5	8.2

D: dolomite, CC: crushed concrete, and CRB: crushed red brick

Table 4- Prosperities of PEG400

Propriety	Value
molecular weight, gm/mol	380 to 420
Hydroxyl Number, mg KOH/g	264 to 300
Density, g/cc	1.13
Freezing temperature, °C	4 - 8
Solubility in water, %	100
Viscosity at 25°C, mm^2/sec.	90

Table 5- Physical Properties of Marble Powder

Property	Value
Loss of ignition, %	43.6
Specific gravity	2.63
Fineness, m^2/kg	350
Color	Light gray
Water absorption, %	0.97

3.2 Preparing and Testing Concrete Samples

The experimental program was divided into two stages. In stage one, the effect of using the marble powder at 5, 10, and 15 percent replacement of cement weight on the properties of recycled aggregate self-curing (RA-SC) concrete cast with different coarse aggregates was studied. As a percentage of the total weight fine materials (cement and marble powder), the HRWR dosages was 0.75 percent in the mixes containing dolomite and crushed concrete. This ratio was 0.5 percent in the mixes incorporating crushed red brick. The corresponding ratios of PEG 400 were 0.25 and 0.5 percent, respectively.

Conventional Curing in air was used in this stage. The description and ratios of the used concrete mixtures used are shown in Table (6). In all mixes, the water to cement and marble powder weight ratio was 0.40. Four mixes for each coarse aggregate type were test in compression at 7 and 28 days using 100mm cubes. For each of the twelve mixes, three prisms 100x100x500 mm were tested at 28 days to determine the flexure strength.

In stage two, three selected RA-SC mixes were used to cast RC beams that were stored in an aggressive environment of 8% concentrated sodium chloride solution. The chloride attack was accelerated utilizing an electrochemical circuit providing electrical current flow. The dimensions of the test beams were 100x150x1000 mm with bottom reinforcement of two 10mm rebars, top reinforcement of two 8mm rebars and 8mm stirrups spaced at 100 mm, Fig. (1). A total of six RC beams were cast. Three of them were cured in air and tested at the age 28days, while the other three typical beams were stored for 60 days in the attacking NaCl solution and attached in an electrochemical cell. The beams were tested under four-point loading (shear span= 300 mm). The mid span deflections and strains in the tension and compressions strains were measured during the loading course.

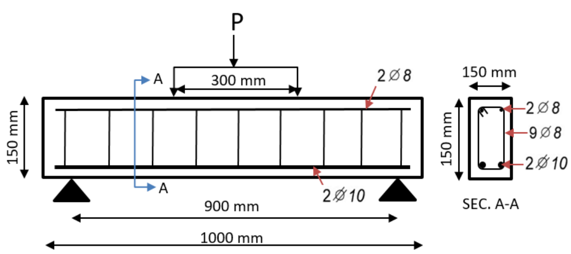

Figure 1- Dimensions and load configuration of test beams

3.3 Chloride Attack Simulation

The chloride attack simulation was carried out by soaking the RC beam specimens in an 8% NaCl solution for 60 days. Figure (2) depicts the use of an electrochemical cell to expedite the corrosion process and shows the connection of the steel rebars to the electrical cell. The rebars are attached to the anode, while a steel rebar was attached to the negative cathode and submerged into the NaCl solution. Ions are extracted at the surface of the reinforcing steel bars, while being replaced by ionized atoms continuously causing the corrosion of the rebars. The electrons emitted by the ionized iron atoms travel via the wire connected to the cathode bar. The accumulated released electrons at the cathode bar attract positive hydrogen ions. The hydrogen ions are adsorbed at the surface of the rebars and subsequently combine with electrons to generate hydrogen gas [21].

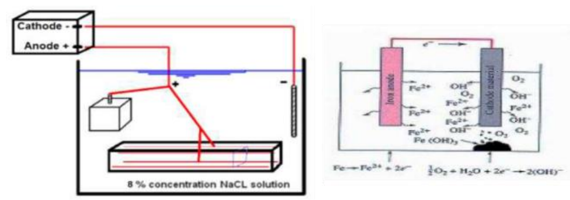

Figure 2- Electrochemical cell

The cathode bar doesn't corrode. It merely offers a surface for hydrogen ions to interact and react with electrons [22]. Electrons stay going around the wire until all of the rebars have corroded or all of the hydrogen ions in the solution have been depleted, leaving no additional positive ions to take over their function. Stray currents' corrosive effects are proven by passing direct current through a cell containing an 8% NaCl solution. Hydrogen bubbles occur on rebars at the negative terminal, whereas those at the positive terminal experience rapid corrosion.

Table 6- Concrete Mix Constituents

Mix	Aggregate type	Concrete Constituents, kg/m^3					
		C	MP	S	CA	HRWR	PEG400
D0	Dolomite	350	0	653	1306	2.63	0.88
D5		333	17	652	1304		
D10		315	35	651	1302		
D15		298	52	650	1300		
C0	Crushed concrete	350	0	630	1259	2.63	0.88
C5		333	17	629	1258		
C10		315	35	628	1256		
C15		350	52	627	1255		
B0	Crushed red brick	400	0	456	912	1.75	1.75
B5		333	17	456	911		
B10		315	35	455	910		
B15		298	52	455	909		

C: cement, MP: marble powder, S: sand, CA: coarse aggregate

4. RA-SC Mixes Test Results

Marble powder is an inert and does not react with cement paste. Its inclusion in the concrete mix in small amounts as a replacement of cement improves workability of fresh concrete. It helps in the dispersion as well as compaction of the cement paste, which results in increased strength. Increased powder percentage, conversely, produces a separation of fine and coarse aggregate and reduces concrete strength. The results of slump tests using marble powder are shown in Fig. (3). It can be seen that the slump values dramatically decrease as the marble content increases.

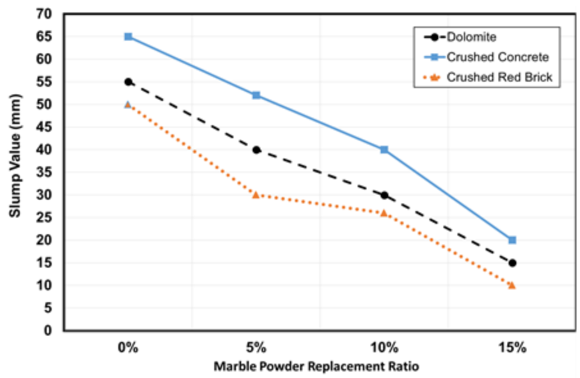

Figure 3- The Relation between slump and marble powder ratio

Figures (4-6) show a plot of the compression and flexure test results for the twelve mixes. The results of the compression tests at 28 days show that the D0 mix proportioned with traditional dolomite coarse aggregate achieved a compressive strength of 35 MPa. This value decreased by 17 and 20 percent due to the use of crushed concrete and crushed red brick due to the low intrinsic strength of these aggregates indicated by the fracture modulus. The relative values for the compressive strength reported in Table (7) indicate a peak value for a marble powder (MP) replacement ratio about five percent value. The compressive strength increased by 20, 17 and 14 percent in mixes D5, C5 and B5, respectively. Beyond this ratio, the compressive strength remarkably decreased as the MP ratio increased. These results influenced the negative effect of larger MP contents on the workability and compacting ability of fresh concrete.

The rate of strength gain, expressed by the ratio of the compressive strength at 28 to the corresponding value at 7 days for a given mix, is reported in Table (7). This ratio was 117, 121, and 127 percent in mixes D0, C0 and B0, respectively indicating acceptable strength gain rates. The corresponding ratios in the mixes incorporating 5 percent MP were 131, 117, and 123 in mixes D5, C5 and B5, respectively. It can be concluded that the use of PEG 400 to produce self-curing mixes was satisfactory .

On the other hand, the flexure strength relative values shown in Table (7) indicated typical trends as the compressive strength. The flexure strength increased by 15, 25 and 14 percent in mixes D5, C5 and B5, respectively. Beyond this ratio, the flexure strength remarkably decreased as the MP ratio increased.

Table 7- Relative compression and flexure strength

Mix	Relative Comp. Strength		Relative Flexure Strength
	fc_{28}	fc_{28} / fc_7	
D0	1.00	1.17	1.00
D5	1.20	1.31	1.15
D10	0.89	1.24	0.93
D15	0.71	1.32	0.79
C0	0.83	1.21	0.87
C5	0.97	1.17	1.08
C10	0.74	1.30	0.72
C15	0.66	1.28	0.64
B0	0.80	1.27	0.82
B5	0.91	1.23	0.93
B10	0.69	1.33	0.64
B15	0.54	1.27	0.49

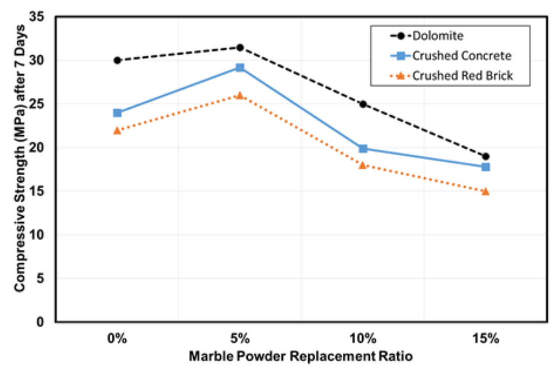

Figure 4- The effect of MP replacement on 7 -day compressive strength

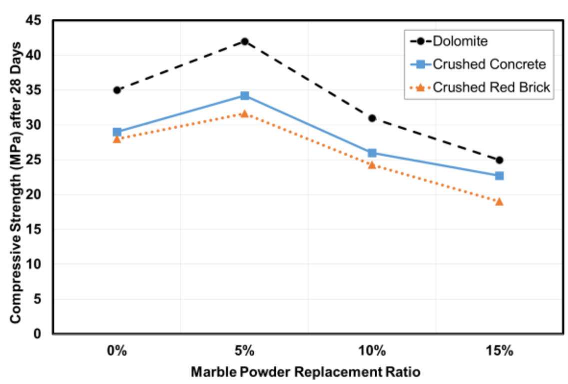

Figure 5- The effect of MP replacement on 28 -day compressive strength

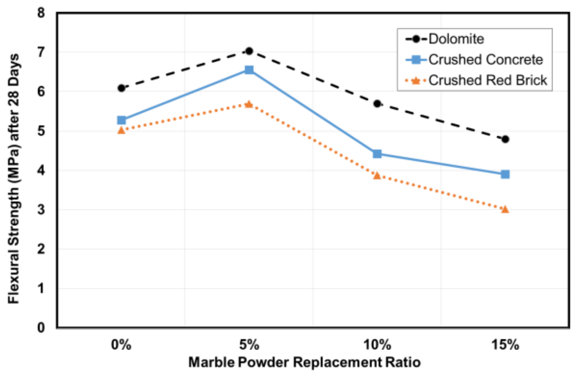

Figure 6- The effect of MP replacement on flexure strength

5. Behavior and Durability RA-SC RC Beams

Mixes D5, C5 and B5 with 5 percent marble powder replacement were selected to cast six beams (two beams for each mix). Three beams were cured in air and tested after 28 days to evaluate the structural behavior. The other three beams were tested after 60 days of being stored in an accelerated aggressive media. All beams were tested under four-point loading till failure. The deformations in terms of mid span deflection and strains were measured using mechanical devices and the cracking patterns were mapped during the whole loading course. The initial and ultimate loads were recorded and the failure modes and sequences were described.

Figures (7-9) show plots of the applied load versus the measured deformations for the tested beams. Fig. (10) shows the recorded cracking and ultimate loads. The load-deformation curves were similar indicating premature failure modes in all beams. The curves consisted of two parts indicating pre-cracking and post-cracking stages, while post-yielding response was not observed. In all beams failure occurred due to shear. This was attributed to insufficient shear reinforcement and lack of concrete strength as recycled aggregates was used. The failure modes and cracking patterns in Fig. (11) show that while beams BD28 and BD60, cast with dolomite, developed flexure cracks that continued to develop upwards till failure, beams BC28, BC60, BB28 and BB60 failed merely due to diagonal tension.

The cracking and ultimate load values in Fig. (11) show that the cracking loads in the control beams BD25, BC28 and BB28 were 20, 15 and 9 kN, respectively. The corresponding values for the ultimate loads were 67, 66 and 57 kN, respectively. These results are reflected by the low intrinsic tensile strength of the recycled aggregates leading to low cracking loads and premature failure due to shear. After 60 days of sever exposure in a concentrated Nacl solution, beams BD60, BC60 and BB60 developed lower ultimate loads by 19, 24 and 25 percent compared to the corresponding control beams. Again, these results suggested that the durability of RC beams are negatively influenced by the use of recycled aggregates types used in this research.

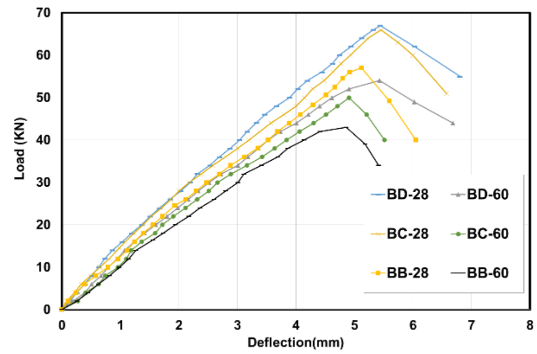

Figure 7- Load versus midspan deflection for test beams

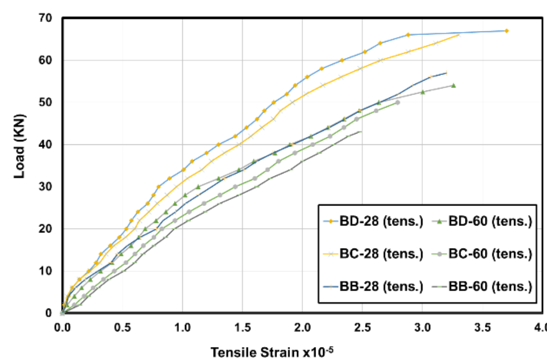

Figure 8- Load versus bottom tensile strain for test beams

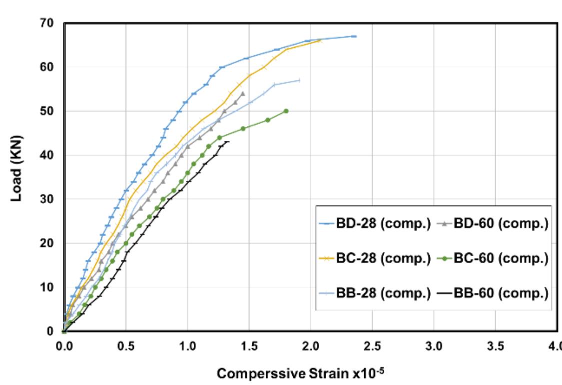

Figure 9- Load versus top compression strain for test beams

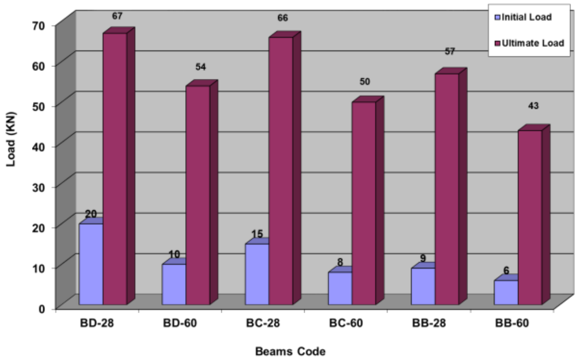

Figure 10- Load versus bottom tensile strain for test beams

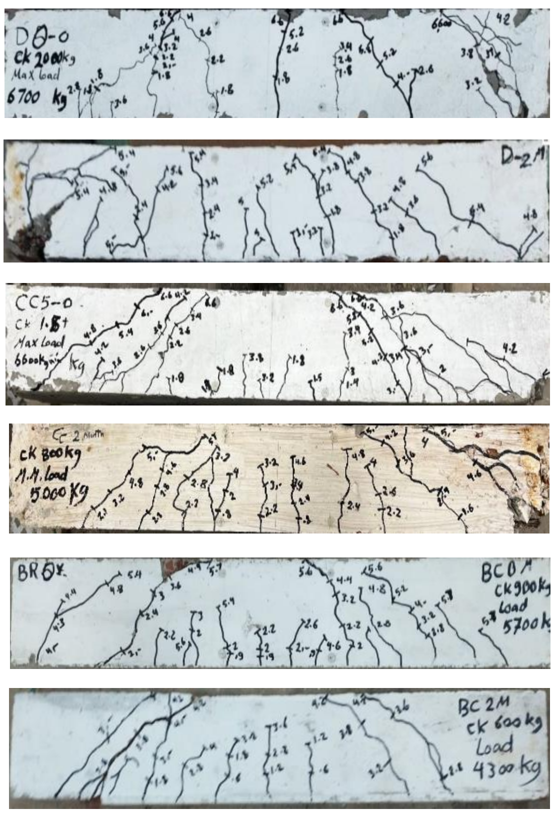

Figure 11- Failure modes and cracking patterns at failure

6. Conclusions

The following conclusions are derived based on the experiments conducted and the analysis of test results:

1- Workability in terms of compacting ability was improved by replacing 5 percent of cement with marble powder, which increased the compressive and flexure strength of the recycled aggregate self-curing concrete. As the powder content increased, the slump was remarkably reduced.

2- The optimum marble powder content as a replacement of cement was 5 percent by weight in all mixes. The compressive strength percentage increase in the self-curing concrete mixes incorporating dolomite, crushed concrete, and crushed brick was 20, 17 and 14 percent, respectively.

3- The use of PEG 400 to produce self-curing mixes was satisfactory regarding the rate of compressive strength gain while curing the test specimens in the air.

4- The low intrinsic tensile strength of the recycled aggregates produced lower cracking loads and premature failure due to shear.

5- After 60 days of sever exposure in a concentrated Nacl solution, the beams cast using dolomite, crushed concrete and crushed red bricks developed lower ultimate loads by 19, 24 and 25 percent compared to the corresponding control beams suggesting that the durability of RC beams are negatively influenced by the use of the used recycled aggregates types.

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