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Strengthening reinforced concrete columns by jacketing using self-compacting concrete with different types of aggregates

Hamdy K. Shehab El-Din[1], Salah Abd El- Magied [2], Mahmoud A. Khater[3], Samar A. Arafa[4]
[1]Professor of Reinforced Concrete, Department of Structure Engineering, Zagazig, Egypt.
[2] Assistance Professor of Concrete, Department of Structure Engineering, Zagazig, Egypt.
[3] Lecture of Concrete, Department of Structure Engineering, Zagazig, Egypt.
[4] Demonstrator, Department of Structure Engineering, Zagazig, Egypt.

*Abstract— **This research studied the behaviour of reinforced concrete columns strengthened by jacketing with self-compacting concrete using different types of aggregates. The study, based on experimental results of twenty columns (150X150mm and 700mm height) strengthened with 50mm thick jacket. The samples are distributed as follows: Two samples are used as a reference without strengthening to determine the failure load of columns. Nine samples of gravel columns, classified into three groups: Each Three columns strengthened using jacketing techniques of: gravel, dolomite and basalt respectively (each group consists of one column with no treatment, one column with epoxy and one column consisting of epoxy and dowels). Nine samples of dolomite columns with the same classification of gravel samples as mentioned above. The results reveal observed behaviour, ultimate load-vertical displacement curves, the failure modes and the effect of variables on measured values, comparisons of the experimental results and the crack formation was influenced by both the jacketing type and the concrete agent.***

Keywords-**Self-Compacting Concrete, Column Strengthening, Aggregate, Concrete Agent, Cracks, Jacketing.**

I. INTRODUCTION

The improvement of deteriorated structural performance of damaged buildings is the process of increasing the performance of structures more than the initial performance level that the structure was designed to meet. , structural members within those buildings need to be reinforced to increase their capacity in order to ensure structural soundness and maintain the design safety factor , this process will be required wherever the loading on a structure may be larger than the design load. [1].

It is recommended to strengthen the four sides of square RC columns using the Fibrous UHPSCC as a jacketing material, as it is a high compressive strength material and reinforced by FFP fibers, which resulted in enhancing the ductility and reducing the jacketing thickness.

The self-compaction behavior of the Fibrous UHPSCC is very effective in terms of casting the RC column jackets easily without manual compaction. The importance of using self-compacting concrete is the fact that the real jacketing thickness is usually thin and steel-congested which often causes segregation and honeycombing problems [2].

Various methods of reinforcement increase the rigidity of the reinforced element. The concrete cladding is very effective, the resistance of the element increases as the liner thickness increases. Beyond 10cm thickness, the added weight of the liner increases the weight, which in specific cases requires resizing the foundation. In the case of reinforcement by TFC (carbon fiber fabric type), the stress of concrete with increasing number of layers of TFC fabric increases in rigidity. The use of corners considerably improves the resistance of the elements [3].

Self-compacting concrete (SCC) mix design tool is developed based on the key proportions of the constituents. This tool is very simple and user-friendly for the self-compacting concrete mix design. It can be used for the SCC mix with or without blended cement and coarse aggregate with or without coarse aggregate blending. This tool can also be enhanced for multi-blended cements with more additives and it is useful for Self-compacting mortar design. It displays all necessary data for SCC mix design and constituent materials for SCC or SCM for the required volume as well [4].

When self-compacting concrete is used so widely where it is seen as a “standard concrete” rather than a “special concrete,” we will have to succeed in creating durable and reliable concrete structures that require minimum maintenance works [5].

The static, short-term loading behavior of the reinforced concrete columns strengthened by recasting with or without the addition of tensile steel bars has been proved to be very satisfactory in the present experimental program. However, the problem of joint cracking was a point of concern and considered important for the research to further explore the capability of the repair method of carrying out more tests [6].

Self-compacting concrete jacketing examined seems to be an effective rehabilitation technique to reinforced concrete beams damaged by shear. The load bearing capacity and the overall structural performance of the jacketed beams were ameliorated with respect to the initially tested specimens. A good agreement between the predicted results and the test data of this study can be observed [7].

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Using steel jacketing techniques for strengthening RC columns has been proven to be effective since it increases the column capacity to a minimum of 20%. The failure mode of the control reinforced concrete column was brittle while strengthening with steel jacket has changed failure mode to be more ductile. Specimen strengthened with angles or channel sections with batten plates showed a higher failure load than those strengthened with plates [8].

Jacketing of reinforced concrete columns with steel longitudinal angles and transversal plates is a suitable method for retrofitting columns. Strength and ductility are substantially improved regardless of the method used to fix the jacket to the concrete. However, a recommendation is made to use epoxy resin to stick the angles to the concrete in order to avoid them from slipping. Slipping can also be avoided by heating the transversal plates before welding them to the angles at a minimum temperature of 70°C [9].

The RC jacketing strengthening method, unlike other techniques, leads to a uniform distributed increase in the strength and stiffness of columns. The durability of the original column is also improved, in contrast to the corrosion and fire protection that requires other techniques, where steel is exposed or epoxy resins are used. To conclude, this rehabilitation procedure does not require specialized workmanship. All this makes RC jacketing an extremely valuable choice in structural rehabilitation [10].

II. EXPERIMENTAL WORK

A. Description of tested specimens

For this study, twenty reinforced concrete column specimens were designed and manufactured. The columns were 700mm height, with cross section dimensions of 150mm by 150mm.. Two columns have been used as a reference. Eighteen columns were strengthened using self-compacting concrete with different types of aggregates in jacketing such as gravel, dolomite and basalt with different types of concrete agents, for instance using epoxy in some specimens, and using epoxy and dowels in other specimens, see Figure (2.1), and some specimens were strengthened without the use of a concrete agent between the old columns and jackets.

Group (1): Nine gravel samples: Three gravel jackets, three dolomite jackets, and three basalt jackets (with no concrete agent, with epoxy, with epoxy and dowels respectively).

Group (2): Nine dolomite samples: Three gravel jackets, three dolomite jackets, and three basalt jackets (without concrete agent, with epoxy, with epoxy and dowels respectively).

B. Materials used

1. Aggregates, water and steel

Natural rocked Gravel and Dolomite particles, which passed through a 10 mm sieve and rested on a 5 mm sieve, were used for columns. Gravel, Dolomite and Basalt particles also passed through a10 mm sieve and rested on a 5 mm sieve for jackets. Harsh desert sand is used; it was almost free from impurities, silt, loam and clay. Ordinary Portland cement used for the columns was provided by **SUEZ** Portland cement 42.5 N. **SINA** 52.5 N was used for jackets to achieve a higher strength. , Potable water free from impurities was used.

Two types of reinforcing bars were used in this experiment. The first was locally produced high strength steel with (FY/ f*ult*=36/52), where deformed bars were used as longitudinal reinforcement for columns. The second one was ordinary plain mild steel with (FY/f *ult*=24/35). Used as stirrups.

Tests were carried out for each bar size using 400 mm long specimens for bars with a diameter of 4 mm, 6 mm for stirrups of columns and jackets and 8 mm, 10 mm for longitudinal reinforcement of columns and jackets. All rebar was randomly chosen.

2. Super plasticizers

Sikament-NN was used as a high-range water-reducing admixture. It complies with ASTM C494 type F and BS 5075 Part 3. In this experiment, it was used for preparing Self-Compacting Concrete.

3. Silica fume

Silica fume was used for preparing Self-Compacting Concrete for the jacket and a byproduct has resulted from the reduction of high-purity quartz with coal or coke and wood chips in an electric arc furnace during the production of silicon metal or ferrosilicon alloys.

4. Concrete agents

- KEMAPOXY 104 was used to connect the old concrete of columns with the new concrete of jackets.

- KEMAPOXY 165 was used to fix dowels in the columns.

- DOWELS (sized 8 with L-shape) were used to strengthen some of the column samples in all faces of these columns as corrugated.

- ADDIBOND 65 was used for the settlement of top and bottom surfaces of the columns after jacketing.

C. Concrete mix design

The absolute volume method recommended by the ACI Committee was used to compute the quantities of material required for the test batch. Four mixes were designed in this experiment in order to get the required ultra-high compressive strength. Many experimental mixes were made to adjust the proportions of the materials used to give the required compressive strengths by batching the ratios for mixing as follows:

For columns

One concrete mix was designed to manufacture ordinary concrete columns with a compressive strength of (250 kg/cm^2). For its proportions, refer to Table (1).

Table (1) Concrete mix proportions for columns

Material	Proportions
Cement	350 kg/m3
Coarse aggregate (gravel or dolomite)	1229.7 kg/m3
Fine aggregate	662.13 kg/m3
Water	175 liters
W/C	0.5

For jackets

One concrete mix was designed to manufacture self-compacting concrete jackets with a compressive strength of (300 kg/cm^2). For its proportions, refer to Table (2).

Table (2) Concrete mix proportions for jackets

Material	Proportions
Cement	400 kg/m3
Silica Fume	60 kg/m3
Coarse aggregate (gravel, dolomite or basalt)	1032.6 kg/m3
Fine aggregate	688.4 kg/m3
Water	180 liters
Superplasticizers	18 kg/m3
W/C	0.5
W/(C+F)	0.39

D. Mixing and casting

Since it is important to have a homogeneous concrete mix and to ensure the uniformity of the mix, the materials in their dry state (gravel, dolomite, basalt, sand, and cement) were first weighted and blended in the mixer for about one minute and the required water was then added to the mix. The contents were mixed mechanically for a period of about 5 minutes to ensure the homogeneity of the concrete mixes. All mixing procedures were carried out at room temperature (about 20 - 25°C). Timber forms were used to have the required dimensions; they were coated with oil before casting so as to ease the removal of the specimens from the forms after hardening. The reinforcing steel was directly set into the timber form. The reinforcement cages, see Figure (2.2), were placed in their proper position in the forms where they were supported on concrete chairs with a thickness equal to the required concrete cover. The concrete, after mixing, was then placed in the forms and in the control specimens (cubes). Standard cubes with dimensions of (15×15×15 cm) were used to measure the compressive strength.

E. Concrete Curing

After concreting was finished, the concrete was struck off level with the top edge of the forms and control cubes with minimum disturbance. Specimens were placed into the forms for 24 hours and the sides of the forms were then stripped away. The same was applied to the control cubes. The specimens were then covered with wet canvas and cured for 28 days. In the same conditions, the cubes were cured by submerging them in clean tap water for 28 days, and then tested on the same day of testing the specimens.

F. Test procedure

The strengthening system used in this research study was provided by Self-Compacting concrete.

I. Preparing Concrete surface by cleaning and sealing the crack, and smoothing it using a manual grinder. Columns were painted with a white plastic coat to facilitate the observation of the cracks during the test.

II. Adding the concrete agent for each group: the first group with no concrete agent, the second group with epoxy and the third group with epoxy plus dowels.

III. Jacketing with self-compacting concrete, as gravel and dolomite columns were strengthened by jacketing with self-compacting concrete, is divided into 3 groups: the first group was jacketed with Gravel, the second group was jacketed with Dolomite and the third group was jacketed with Basalt.

Finally, the strengthened columns were loaded till failure. After completion of the test, the column was photographed to show the failure mode. The control concrete cubes were tested in the same day of column testing in order to obtain the values of the crushing compressive strength.

Fig (1): Kimapoxy104 and dowels

Fig (2): The jacket

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. Reference columns

Gravel and dolomite column failed at 286 KN and 300KN.

B. Crack patterns and modes of failure

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Modes of failure of the tested columns in Table (3) showed that although the entire strengthened column failed at loads that exceeded the capacity of the control columns, most of the strengthened columns failed with de-bonding of jacket followed by concrete cover failure or no failure. Also, the results confirm that providing dowels and epoxy enhances the failure mode and the ultimate load as well.

Modes of failure were observed during the tests as shown in Figures 3-13. The four modes of failure can be described as follows:

The failure mode in case of **De-bonding of the jacket** was caused by de-bonding the steel jacket from the original columns. This failure mode occurred in columns C-C-3, C-F-2, and C-F-3 as shown in Figures (3), (4), and (5).

The failure mode in case of **Concrete cover failure** was caused by spalling off the concrete cover of jacket.This failure mode occurred in columns C-E-1 and C-E-3 as shown in Figures (6), and (7).

The failure mode in case of **De-bonding of the jacket and concrete cover failure** was caused by de-bonding the steel jacket from the original columns and the concrete cover of jacket spalled off. This failure mode occurred in columns C-A-1, C-A-2, C-A-3, C-B-1, C-B-2, C-B-3, C-C-1, C-D-1, C-E-2 and C-F-1 as shown in Figures (8), (9), and (10).

The failure mode in case of **Crushing failure** was caused by crushing the concrete in original column and jacket. This failure mode occurred in columns C-C-2, C-D-2, and C-D-3 as shown in Figures (11), (12), and (13).

Table (3) Ultimate loads and failure modes of tested columns

Group		Column notation	Concrete agent	Failure load (KN)	Failure mode
GROUP(1) Gravel Columns	Group(A) Gravel jacket	**C-A-1**	Without concrete agent	900	DE bonding of jacket and concrete cover failure
GROUP(1) Gravel Columns	Group(A) Gravel jacket	**C-A-2**	With epoxy	1050	DE bonding of jacket and concrete cover failure
GROUP(1) Gravel Columns	Group(A) Gravel jacket	**C-A-3**	With epoxy plus dowels	710	DE bonding of jacket and concrete cover failure
GROUP(1) Gravel Columns	Group(B) Dolomite jacket	**C-B-1**	Without concrete agent	1220	DE bonding of jacket and concrete cover failure
GROUP(1) Gravel Columns	Group(B) Dolomite jacket	**C-B-2**	With epoxy	1410	DE bonding of jacket and concrete cover failure
GROUP(1) Gravel Columns	Group(B) Dolomite jacket	**C-B-3**	With epoxy plus dowels	1190	DE bonding of jacket and concrete cover failure
GROUP(2) Dolomite Columns	Group(C) Basalt jacket	**C-C-1**	Without concrete agent	1000	DE bonding of jacket and concrete cover failure
GROUP(2) Dolomite Columns	Group(C) Basalt jacket	**C-C-2**	With epoxy	1300	Crushing failure
GROUP(2) Dolomite Columns	Group(C) Basalt jacket	**C-C-3**	With epoxy plus dowels	1220	DE bonding of jacket
GROUP(2) Dolomite Columns	Group(D) Gravel jacket	**C-D-1**	Without concrete agent	890	DE bonding of jacket and concrete cover failure
GROUP(2) Dolomite Columns	Group(D) Gravel jacket	**C-D-2**	With epoxy	900	Crushing failure
GROUP(2) Dolomite Columns	Group(D) Gravel jacket	**C-D-3**	With epoxy plus dowels	1110	Crushing failure
GROUP(2) Dolomite Columns	Group(E) Dolomite jacket	**C-E-1**	Without concrete agent	1110	Concrete cover failure
GROUP(2) Dolomite Columns	Group(E) Dolomite jacket	**C-E-2**	With epoxy	1240	DE bonding of jacket and concrete cover failure
GROUP(2) Dolomite Columns	Group(E) Dolomite jacket	**C-E-3**	With epoxy plus dowels	1490	Concrete cover failure
GROUP(2) Dolomite Columns	Group(F) Basalt jacket	**C-F-1**	Without concrete agent	1050	DE bonding of jacket and concrete cover failure
GROUP(2) Dolomite Columns	Group(F) Basalt jacket	**C-F-2**	With epoxy	1080	DE bonding of jacket
GROUP(2) Dolomite Columns	Group(F) Basalt jacket	**C-F-3**	With epoxy plus dowels	1120	DE bonding of jacket

Fig (3) C-B-2

Fig (4) C-C-3

Fig (5) C-F-2

(De-bonding of jacket)

Fig (6) C-E-1

Fig (7) C-E-3

(Concrete cover failure)

Fig (8) C-B-1

Fig (9) C-A-1

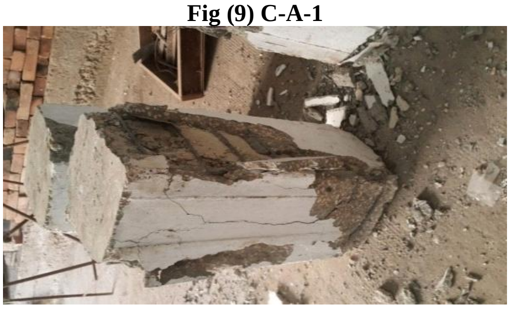

Fig (10) C-A-3

(De-bonding of jacket and concrete cover failure)

Fig (11) C-D-2

Fig (12) C-D-3

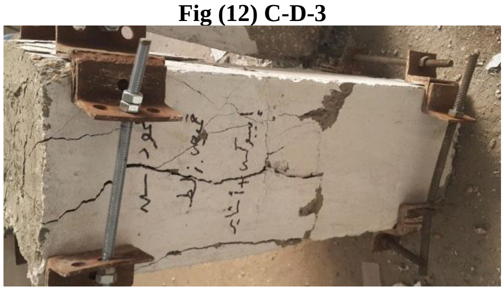

Fig (13) C-C-2

(Crushing failure)

C. *Behavior of the tested columns*

Based on the experimental results, the behavior of the tested columns is discussed in terms of the behavior observed, the ultimate load, the vertical displacement, the strengthening load level. Figure (3.1) shows the comparison of ultimate loads of the tested columns. The figure showed that the maximum load, in case of dolomite column with dolomite jacket and epoxy plus dowels, this specimen failed at 1490 KN, and for the next maximum load in case of gravel column with dolomite jacket with epoxy, this specimen failed at 1410 KN. Figures 3.2-3.7 show the relationship between the applied load and the measured vertical displacement for all the tested columns— a linear increase behavior followed by a nonlinear behavior until failure. The results showed that the strengthened column with epoxy plus dowels had better displacement behavior than with epoxy and with no concrete agent.

D. Effect of original column aggregate on the tested columns

For gravel columns in case of gravel jacket, the best result was obtained when epoxy was used, then without the concrete agent, while the worst result was obtained when epoxy plus dowels was used, because the holes which made to fix the dowels affected the specimen and made it very weak.

In the case of dolomite jacket, the best result was obtained when epoxy was used and without Concrete agent, while the worst result was obtained when epoxy plus dowels was used because of the same reason above. In the case of basalt jacket, the best result was obtained when using epoxy, then using epoxy plus dowels, and then without the concrete agent.

For dolomite columns in case of gravel jacket the best result was obtained when epoxy plus dowels was used, then with epoxy, and then without the concrete agent. In the case of dolomite jacket, the best result was obtained when epoxy plus dowels was used, then with epoxy, and then without the concrete agent. In the case of basalt jacket, the best result was obtained when no concrete agent was used, then with epoxy plus dowels, and then with epoxy.

E. Strengthening and concrete agent effects on the ultimate load of tested columns

Table (4) shows that the increase in terms of the ultimate load provided by concrete jacket was significant for the dolomite column due to the coarse surface of dolomite concrete. Also, the results prove that providing dowels and epoxy enhances the failure mode and the ultimate load.

Strengthening with self-compacted concrete jackets for gravel columns resulted in a maximum increase in the ultimate loads by (393 %) for the dolomite jacket with epoxy, while for the dolomite column the maximum increase was (397%) for the dolomite jacket with epoxy and dowels.

Table (4) Effect of strengthening and concrete agent on ultimate load of tested columns

Column	Jacketing	Concrete agent	P ref. (KN)	P ult. (KN)	Percentage increase in ultimate load (%(
		without		900	214
	Gravel jacket	With epoxy		1050	267
		With epoxy and dowels		710	148
		without		1220	326
Gravel column	Dolomite jacket	With epoxy		1410	393
		With epoxy and dowels	286	1190	316
		without		1000	249
	Basalt jacket	With epoxy		1300	354
		With epoxy and dowels		1220	326
		without		890	196
	Gravel jacket	With epoxy		900	200
		With epoxy and dowels		1100	266
Dolomite column		without		1110	270
	Dolomite jacket	With epoxy		1240	313
		With epoxy and dowels	300	1490	397
		without		1050	250
	Basalt jacket	With epoxy		1080	260
		With epoxy and dowels		1120	273

IV. CONCLUSION

Findings from the experimental study of test results and variables showed a number of interesting points. Although most of these findings are written in their proper location through the text, they will be summarized here for reference:

1. The type of jacket aggregate is more effective in results than the concrete agent added.

2. Epoxy improved the behavior of the specimen, which strengthened with dolomite jackets (393%, 313%), more than the gravel (267%, 200%), and basalt jacket (354%, 260%).

3. Epoxy and dowels improved the behavior of the specimen, which strengthened with dolomite (316%, 397%) and basalt jacket (326%, 273%), more than the gravel jacket (148%, 273%).

4. It is recommended to strengthen with the dolomite jacket (393%, 397%), then with the basalt jacket (354%, 273%), and then with the gravel jacket (267%, 266%) in case of gravel or dolomite columns.

5. The best result was obtained when the dolomite column was strengthen with the dolomite jacket (with epoxy and dowels) (397%).

6. The worst result was obtained when the gravel column was strengthen with the gravel jacket (with epoxy and dowels) (148%), because dowels in gravel column made it weak due to the holes which we made to fix the dowels

7. It is recommended to strengthen the gravel columns with epoxy in case of gravel; dolomite or basalt jackets (267%, 393%, and 354%).

8. It is recommended to strengthen dolomite columns use epoxy and dowels in case of gravel, dolomite or basalt jackets (266%, 397%, and 273%).

9. The best result was obtained when the gravel column was strengthened with dolomite jacket using epoxy (393%), then when was strengthened with basalt jacket using epoxy (354%).

10. The best result was obtained when the dolomite column was strengthened with dolomite jacket using epoxy and dowels (397%), then when epoxy was used (313%).

V. FUTURE RECOMMENDATION

In the future works for strengthening concrete structure elements, it is preferred to use the dolomite aggregate especially when using self-compacting concrete.

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AUTHOR PROFILE

Hamdy K. Shehab El-Din[1]Professor of Reinforced Concrete, Faculty of Engineering-Zagazig University.

Salah Abd El- Magied [2] Assistance Professor of Concrete, Faculty of Engineering-Zagazig University.

Mahmoud A. Khater[3]Lecture of Concrete, Faculty of Engineering-Zagazig University.

Samar A. Arafa[4] Demonstrator, Faculty of Engineering-Zagazig University

Samar_design@yahoo.com 00201023899179