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A PROPOSED USE OF CONCRETE CLOTH IN THE REPAIR WORKS OF CONCRETE BEAMS

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Abstract: Concrete Cloth (CC) is an innovative material composed of a flexible aluminate cement powder-impregnated fabric that rapidly hardens upon hydration to form a thin, durable, waterproof and fire-resistant concrete layer. The material is delivered in the form of rolls at various thicknesses which allows their placement without a need for a plant or mixing equipment. Their ease and rapid installation facilitates their use in a wide range of applications such as slope stability, ditch lining and fast deploying shelters to name a few. This study aims at achieving a better understanding of the properties and performance of the concrete cloth material particularly when used in repair works. Tests including composition, microscopic analysis, chemical analysis, density and response to moisture were performed on the concrete cloth.

Sets of pre-cracked beams were prepared with crack length-to-beam depth ratio of ¼, ½, and ¾. The cloth material was installed to fortify the beam using three different adhesion techniques; Hilti anchors, epoxy resins and cementitious grout. The beams were tested under a three-point flexural test while deflection was recorded. Results indicate that the concrete cloth can enhance the flexural strength of the beams, although special adjustment needs to be introduced when used in repair works to enhance its benefits compared to other repair techniques.

1 INTRODUCTION

Concrete Cloth was first invented and patented in 2005 by Peter Brewin and Will Crawford. The invention of Concrete Cloth has provided the construction industry with a spectrum of highly valued applications and solutions, due to its durable qualities and components (Zhang, 2016). These properties include water resistance, fire proof, high abrasion, chemical resistance and an extremely fast setting time (Hegger and Voss, 2008). They have proven beneficial in a wide variety of functions such as ditch lining, slope stability and the establishment of Concrete Canvas shelters which are quick and easy to develop and are invaluable in situations such as natural disaster scenarios (Keytech, 2014). Concrete Cloth is a Geo-Synthetic Cementitious Composite Material (GCCM), which is composed of three main parts (see Figure 1). The first of which is a solid fabric layer which is made using a Rachel machine (Karl Mayer GmbH, 2014). This layer ensures that cement powder does not escape, while still allowing water to pass through and hydrate the cement powder. The next layer is the 3D spacer and cement powder. The 3D spacer is an important component of CC because it provides the product with the necessary rigidity and stiffness needed for construction applications without creating a reaction with the cement powder (Fangyu Han, 2014). The mesh fabric is made in the same way as the solid fabric but with denser material and threads; this is done in order to allow cement powder to pass through in the manufacturing process. The mesh fabric is covered using a PVC membrane that is impermeable to both water and cement powder resulting in a well packaged product that hydrates the cement without allowing leakage (Hui Li, 2016).

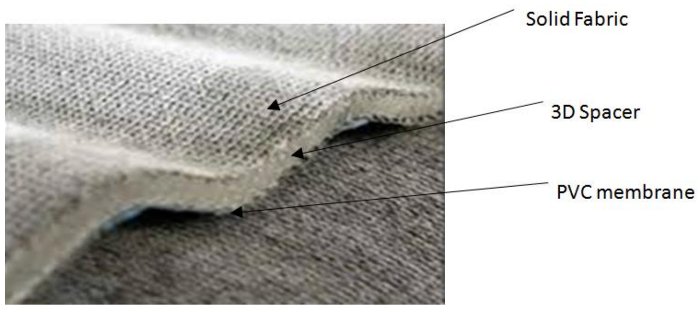

Figure 1: Composition of the concrete cloth

2 EXPERIMENTAL PROGRAM

2.1 Material Properties

Concrete Cloth: Thicknesses of 5mm (CC5), 8mm (CC8), and 13mm (CC13)

Fine Aggregates: Well graded sand was used as fine aggregates, with specific gravity of 2.51

Coarse Aggregates: Dolomite was used as coarse aggregate, with specific gravity of 2.55

Water: Normal tap water was used in the curing and in the concrete mix.

Cement: Ordinary Portland cement, Type I, was used with specific gravity of 3.15

2.2 Concrete Mix Design

The following table represents concrete mix designed used in the beam repair application.

Table 1: Mix design for $1m^3$

	Weight (kg)	Specific Gravity	Volume (m^3)
Cement:	375	3.15	0.12
Water:	170	1.00	0.17
Coarse Aggregates:	1120	2.01	0.56
Fine Aggregates:	341	2.55	0.13
Admixture type A:	2 liters		

2.3 Tests

Dissection and Observation: Dissection was done by cutting through two identical 100X100 mm samples of the 55mm cloth. Each sample was weighed before dissecting it. Then, three layers of the sample were separated and each layer was weighed to classify the composition of the cloth by weight. Another identical sample was hydrated and its weight was observed before and after hydration to calculate the water gain.

Tensile Strength: The test was conducted to determine the axial tensile strength of the cloth in different alignments (X and Y) in accordance to ASTM D-5035. The test was conducted on 6 specimens of dimensions 25X50 mm, 3 of them were cut parallel to the fibers and the others were cut perpendicular to the fibers Figure 2a shows the tensile strength test setup.

Flexural Strength: This test was conducted to determine the moment the cloth can withstand before failure when flexure loading is applied. It was done in accordance to ASTM C-1185**.** Three identical samples with dimensions of 152X305 mm were tested. The concrete cloth was placed in the testing machine with the PVC layer facing upward and the solid fabric facing the rollers. Figure 2b shows the flexural strength test setup.

Compressive Strength: This test was conducted to evaluate the compressive strength of Calcium Aluminate Cement using 50 mm cubes in accordance to ASTM C-109. Figure 2c shows the tensile strength test setup.

Energy Dispersive X-ray (EDX) Analysis: This test was done to determine the elemental composition of the Calcium Aluminate by extracting a cement sample from the cloth and sending it to a chemical lab for classification. Figure 2d shows the EDX analyzer.

a) Tensile Strength test b) Flexural Strength Test c) Comp. Strength Test d) EDX Analysis

Figure 2: Experimental Tests

2.4 Beam Repair Application

This experiment was conducted to test if the cloth is an effective material to be used in beam repair. 12 pre-cracked beams of dimensions 150X150X750 mm were cast with crack depths to beam depth ratio of ¼, ½ and ¾ (three beams for each ratio). In addition, one solid beam of the same dimension was cast and used as control specimen.

While casting the pre-cracked beams, a 2 X (d) X 150 mm well lubricated metal sheet was inserted at mid span of the beam to create an artificial crack of the designated ratio of ¼, ½, and ¾. The beams were left to harden for 2 hours and then the metal sheets were removed. All test beams were removed from the mold after 24 hours and were left to cure for 28 days.

CC13 strips of dimensions 200X450 mm forming a u-shape were applied at the center of each beam over the pre-cracked area. Three different materials were used to attach the CC13 strip to the beam namely; Hilti bolts, Epoxy and Grout as shown in Figure 3.

Hilti bolts of 8 mm diameter and 6 mm length were used to attach the CC13 strip. The concrete cloth was applied on the beam and then a Hilti drill was used to drill in both the cloth and the beam to a depth of 50 mm. The cloth was then removed and the hole was cleaned using a blower. The cloth was then put in place again and the Hilti bolts were hammered and then screwed in place before adding water to hydrate the cloth. Four bolts were applied on the three faces of the beam as shown in Figure 3. Water was then added and the cloth was left to harden for 10 days.

As for the epoxy adhesive, the epoxy was mixed using a mixer adding both resin and hardener to form the epoxy compound. The epoxy was applied on the beam covering the CC13 area. The cloth was then applied and kept in place using metal clamps for two hours as shown in Figure 3. Water was used to hydrate the concrete cloth after 2 hours and then again after 1 hour.

As the grout is a liquid compound and does not bond easily to surfaces, a method was devised to apply the grout with minimum seepage. The beam was placed vertically and the cloth was held in place using metal clamps. Grout was poured in the gap between the cloths and then the beam was placed on the other side and grout was added and left for 2 hours. Water was then used to hydrate the cloth until saturation and hydrated again after 1 hour.

A flexural test was conducted on the beams under three-points loading according to ASTM C78M. A comparison was done for flexural strength of the cracked beams.

a) Botts b) Epoxy c) Grout

Figure 3: Repaired Beam Flexural Tests

3 TEST RESULTS AND DISCUSSION

3.1 Dissection and Observation

For the first specimen, close observation revealed that the material is made of four different components, each one with different role inside the cloth. The first component is the solid fabric, which is the layer where water is added to hydrate the cloth. On the other side of the cloth is the PVC membrane which is the layer that locks everything inside the cloth and it is responsible for preventing over hydration. Once the sample is hydrated, the PVC locks the water inside so it prevents any excessive water from entering the cloth. After removing the PVC layer that locks the cement, all the cement inside the cloth fell immediately. Between the PVC membrane and solid fabric, the 3D spacer is located, which is the layer that contains the Calcium Aluminate Cement that is responsible for hardening the cloth. Above the 3D spacer is the mesh fabric that consists of holes that help in placing the cement inside the 3D spacer. Calcium Aluminate Cement was found representing a great percentage of the total weight, followed by the PVC layer and the solid fabric and finally the least percentage went to the mesh fabric. Table 2 shows the weight distribution of the different components of the sample. Weight of the 3d spacer was negligible.

Table 2: Weight Distribution

Item	Weight (g)	Percentage
Sample	61.8	100
Cement	48.7	78.8
PVC layer	6.7	10.8
Solid Fabric	3.1	5.06
Mesh Fabric	1.7	2.75
Cement Losses	1.6	2.59

For the second specimen, it was required to determine the weight gain of the specimen after hydration to estimate the amount of water needed for the specimen to harden. The sample was weighed and prepared before hydration and weighed again after adding water and leaving it to harden for 24 hours. The test results are given in Table 3.

Table 3: Weight gain after hydration

Sample weight before hydration	**56.6 g**
Sample weight after hydration	70.7 g
Different in weights	14.1 g
Weight gain	25 %

3.2 Tensile Test

This test was conducted with 6 similar specimens, 3 in each direction X and Y. Tensile test was performed on each specimen and a graph was plotted with Strain (mm/mm) on the X-axis and Stress (MPa) on the Y-axis.

The tensile test results are given in Table 4 and Figures 4 and 5.

Table 4: Tensile test results

	X axis (parallel to fibers)	Y axis (perpendicular to fibers)
Average Breaking Force: (kN)	12.5	6.13
Average Elongation Before Failure (mm)	15.75	32
Strain (mm/mm)	0.21	0.427

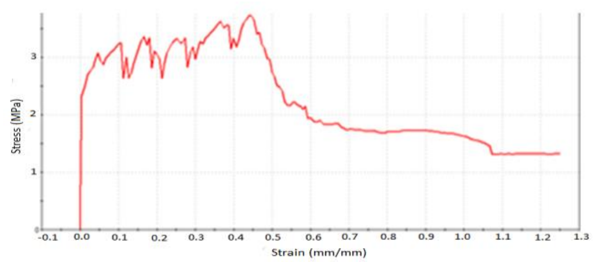

Figure 4: Stress-strain curve in the X-direction

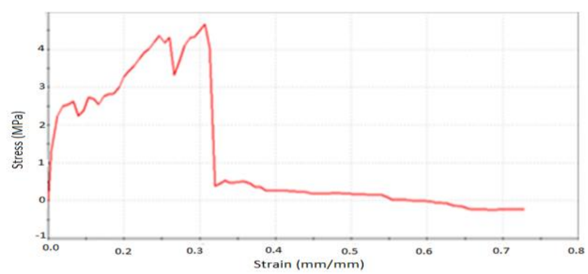

Figure 5: Stress-strain curve in the Y-direction

Figure 4 shows the stress-strain graph for the specimen placed parallel to the X-direction with a maximum stress at 3.67 MPa with strain 0.44. While in Figure 5 the specimen was placed parallel to the Y-direction with maximum stress at 4.6 with strain 0.305.

As shown in the X-direction graph, Figure 4, the graph started off exponentially and then the failure in concrete occurred at 0.04 mm/mm after which it gained strength from the fabric. Consecutively, the slope started to increase again until a point where the fabric started to fail. This fluctuation in the graph continued until a severe drop, where the fabric failed completely.

As for the Y-direction graph, the curve started off exponentially as the stress was resisted by both the concrete and the fabric and then a series of fluctuations started to occur due to failure of concrete inside the cloth. After the concrete failed, the tension was only resisted by the fabric inside the cloth. All specimens failed in the middle section, which shows that failure occurred in the fabric itself and not due to the jaws.

While preparing the specimens, it was observed that cutting parallel to the fibers was much easier compared to cutting perpendicular to the fibers, which shows that properties in the X direction are different than the properties in the Y direction.

For the X-axis the average breaking force is almost twice that of the Y-axis. In a similar manner, the average elongation before failure for the Y-axis is almost twice that of the X-axis with equivalent strains reflecting these values.

3.3 Flexural Strength Test

The load-deflection results of the flexural test are shown in Figure 6. It was observed that the material is much more flexible and resilient than anticipated for such a material as concrete, which in this case led to failure due to slippage instead of failure due to brittleness. This gives an indication that the material has great potential in the repair of concrete beams. The fluctuations in the graph are due to the slippage of the material on the roller supports.

3.4 Compressive Strength

The results of the conducted compressive tests are shown in figure 7. It includes the results of the Calcium Aluminate Cement used in the production of the cloth and the results of the normal Portland cement using the same mix. The results represent the average of 12 cubes from each type.

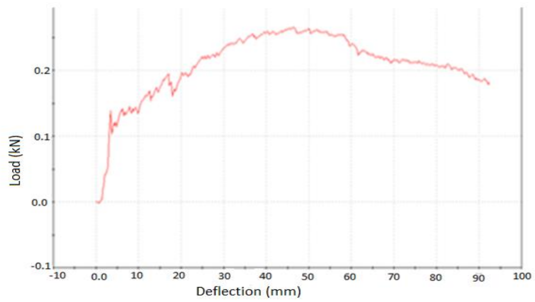

Figure 6: Load –deflection curve

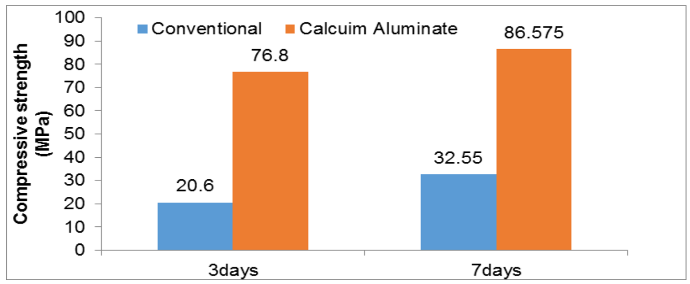

Figure 7: Compressive test results

The results in Figure 7 show that Calcium Aluminate has higher compressive strength at both early and late stages, compared to the conventional Portland cement. For instance, the Calcium Aluminate had an average compressive strength of 76.8 MPA compared with the conventional cement of 20.6 MPa. It can also be noted that the gain in strength between 3 and 7 days for the conventional cement is higher than the Calcium Aluminate. This is to prove that the Calcium Aluminate is a fast hardening type of cement that reaches its maximum strength at an early stage.

3.5 Energy Dispersive X-ray Analysis

The results for the EDX analysis conducted on the cement specimen that was found inside the concrete cloth are shown in Table 5 as well as figure 6 below.

Table 5: EDX results

Element	Atomic Weight%
Oxygen	63.21
Aluminium	17.07
Calcium	16.26
Iron	3.46

In addition to the results above there were traces of silicon found in the sample, but due to the calibration of the EDX which uses silicon as its detector element, it didn’t show on the spectrometry graph. Thus results shown above that were attained from the spectrum of the sample show us that the cement used in the concrete cloth has all the elements that exist in Calcium Aluminate Cement, which verifies the claim made by the manufacturing company that Calcium Aluminate Cement was used without any additives. The compounds that are found in CAC are usually Monocalcium Aluminate ($CaAl_2O_4$), Iron Oxide (Fe_2O_3), and Silicon Dioxide (SiO_2). But from the high percentage of Iron in the sample, as well as its grey color, it can be concluded that this specific type of CAC is made with red bauxite.

3.6 Concrete Cloth Beam Repair

3.6.1 Flexural Beam Test Quantitative Results

The ultimate load obtained from the flexural test on the repaired and control beams are given in Table 6 and Figure 8. The results show that the beams with grouts and bolts showed a slight improvement compared to the cracked beams without the cloth. However, they didn't show a great potential in this application compared to the flexure strength of the solid control beam without cracks. For instance, for the quarterly cracked beam, the flexure strength for the beams with grout increased from 3.7 kN to 11.6, which is almost 50 % of the strength of the solid beam. It can also be noted that the beams with Epoxy showed higher potential in the repair application as the beams with ratio equals ¼ achieved almost the same strength of the control beam, the ultimate load for the repaired beam was 20.1 kN compared to 21.76 kN for the control solid beam.

Table 6: Cracked Beam results (kN)

Ratio	Without Concrete Cloth	Hilti Bolts	Epoxy Adhesive	Cementitious Grout	Solid Beam
0	-	-	-	-	21.76
1/4	3.70	6.70	20.10	11.60	-
1/2	2.90	5.30	18.04	8.00	-
3/4	1.30	4.40	15.87	5.20	-

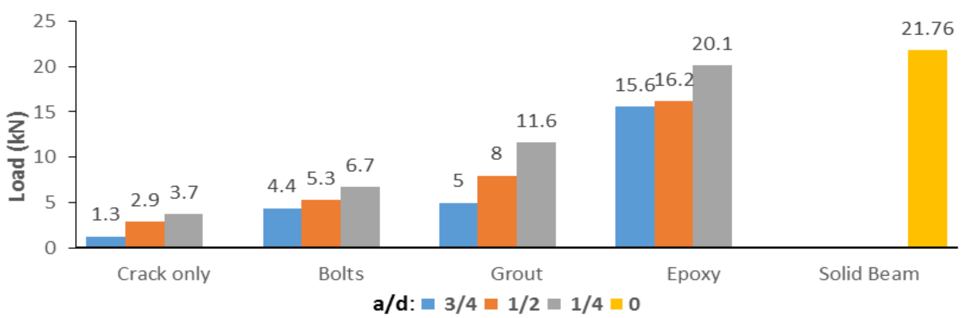

Figure 8: Flexural strength test results

To further elaborate on the results, they were classified according to the percentage increase is strength compared to the cracked beams without concrete cloth. This comparison is given in Table 7 and Figure 9.

Table 7: Percentage Increase in Strength from Unrepaired Beams

Ratio	Hilti Bolts	Epoxy Adhesive	Cementitious Grout
1/4	81%	443%	214%
1/2	83%	522%	176%
3/4	238%	1121%	300%

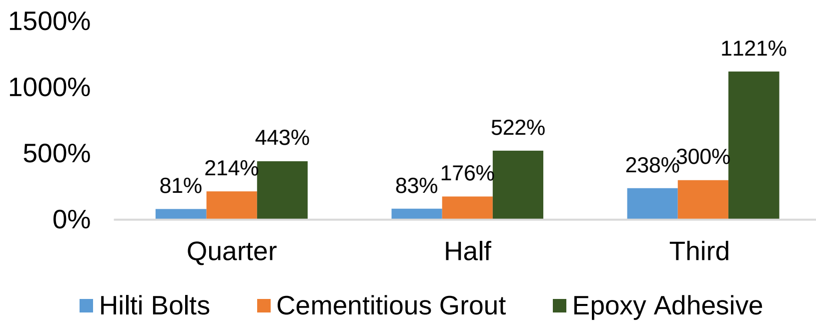

Figure 9: Percentage increase in ultimate load of the repaired beams

It can be noted that the percentage increase for the ¾-cracked beam bonded with epoxy reached 1121%. The failure load for the cracked beam without canvas was almost negligible because of the severe crack. After adding the cloth, it yielded a very high improvement of only 1.3 kN for the cracked only beam to 15.6 kN after adding the cloth. The smallest increase in percentage was attributed to the beams with bolts due to the rapid failure of the beam without transferring the load to the canvas, which occurred due to the lack of contact area between the two. This means that the only part of the cloth that was resisting the load was the part around the bolt which was attached but was not enough to resist the shear created.

The results were also classified according to the percentage of strength restored compared to the solid beam and the results are shown in Table 8 and Figure 10. The results show that the beams with Epoxy was the most efficient at restoring the beam to its original strength. It can also be noted that the percentage increased in strength grew as the crack depth decreased. For instance, the quarterly cracked beam restored almost 92% of its expected original strength. While the ½-cracked beam restored only 83%. This concludes that repairing beams with the cloth are most optimum for the early stage cracks.

Table 8: Percentage Strength Restored from Solid Beam

Ratio	Hilti Bolts	Epoxy Adhesive	Cementitious Grout
1/4	31%	92%	53%
1/2	24%	83%	37%
3/4	20%	73%	24%

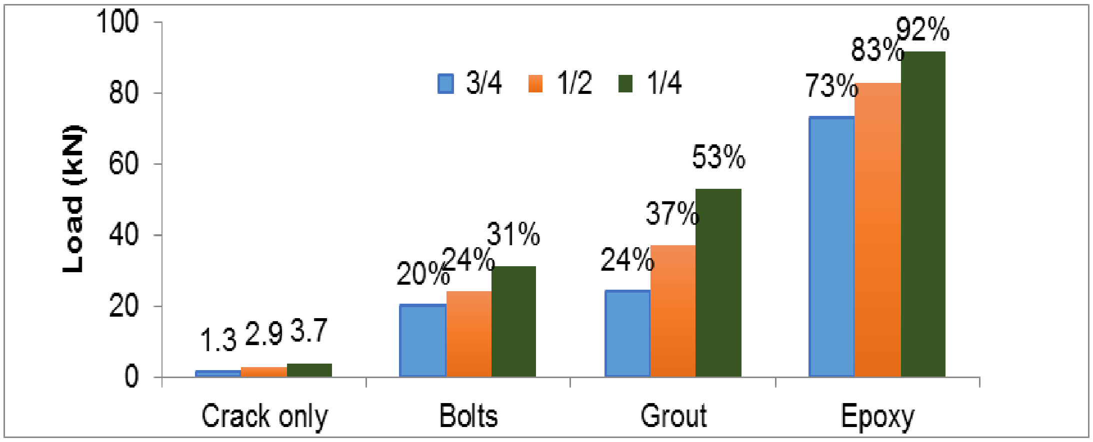

Figure 10: Percentage of the strength restored compared to the solid beam

3.6.2 Mode of Failure for the Repaired Beams

The observed modes of failure of the repaired test specimens are shown in Figure 11 and discussed in the following sections.

Hilti Bolts: Two modes of failure were observed. The first one is that the cloth started to tear away from the bolts due to shear stresses. The second main mode of failure is that the beam itself failed before fully transferring the load to the concrete cloth. This occurred as the bolts didn't provide enough contact area between the attached cloth and the beam. Therefore, the small gap between them didn't allow the load to be transferred

Epoxy Adhesive: The mode of failure that occurred was in the concrete cloth itself. The hardened cloth did not rupture but the adhesive between the mesh fabric and the PVC layer in the cloth itself failed. The beam and the canvas failed nearly at the same time, which is a good indication that they worked as one entity. It gives us an indication that if the adhesion between the PVC layer and mesh fabric was stronger, the failure load would have increased.

Cementitious Grout: The grout adhering the cloth to the beam failed due to excessive shear stresses. However, the concrete cloth itself remained full intact. Therefore, it didn't contribute enough to the strength of the beam, as they didn’t work as one entity.

a) Bolts **b) Epoxy** **c) Grout**

Figure 11: Mode of failure of the repaired beams

4. SUMMARY AND CONCLUSIONS

The application of concrete cloth in the repair of cracked beams was investigated. Many tests were conducted to further understand this unique material and enhance the research available on it. Five tests were conducted and their results analyzed. Twelve cracked beams were tested cases with different crack depths using three different repair techniques. Taking the materials and techniques implementation into consideration, the following can be concluded:

1. Concrete Cloth is a promising innovative material that has potential which is yet to be explored in the construction industry.
2. Microscopic examination reveals complex composite section for the concrete cloth that includes fibers and Calcium Aluminate Cement.
3. The Calcium Aluminate Cement (CAC) proved to be of high compressive strength compared to the Ordinary Portland Cement (OPC) when tested after 3 and 7 days of curing. CAC had a compressive strength of almost 4 times higher strength than the OPC after 3 days of curing and 3 times higher compressive strength after 7 days of curing.
4. The fabric’s properties are different in the parallel and perpendicular directions; the results have shown differences in tensile strength when conducting the test with and against the fabric direction. The results show that the average breaking force with the fabric is almost double the tensile strength compared to the against fabric direction. However, those against fiber direction show almost double the elongation length compared to the with fabric direction.
5. The flexural strength test shows that the material has high ductility behavior and as such the material did not reach fully rupture at failure.
6. The EDX analysis verified that the cement used in manufacturing the concrete cloth is in fact Calcium Aluminate Cement without other admixtures/additives.
7. Use of cloth material for repairing cracked beams yielded improvement in flexure strength of beams.
8. Clearly and as expected, the flexural strength of beams is highly correlated with crack length. The increase in crack length introduced a decrease in the flexural strength. Methods of bolting as well as grouting do not seem to be adequate when used in repair work involving concrete cloth.

9. Concrete cloth when applied with epoxy proves to be the most effective way of restoring the strength of cracked beams. It restores flexure strength in up to 92% for the quarterly cracked beam.
10. While this work was limited to plain; non-reinforced concrete, its results suggest that concrete cloth can be used in temporary and rapid repair works for damaged beams until full-scale thorough repair is performed.

5 RECOMMENDATIONS

1. Expansion of this experimental work to include larger sets of materials and other parameters.
2. Conduct wider sets of tests that covers long-term properties and durability testing.
3. It is of paramount importance to conduct repair work investigation for Concrete Cloth in reinforced concrete elements in order to simulate cases of exiting reinforced structures.
4. Perform a small scale pilot expertness of various repair methods including Concrete Cloth on full scale elements.

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