THE EVALUATION OF CHANGE IN CONCRETE STRENGTH DUE TO FABRIC FORMWORK

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ABSTRACT

Fabric, as a flexible formwork for concrete, gives builders, engineers, and architects the ability to form virtually any shape. This technique produces a superb concrete surface quality that requires no further touch up or finishing. Woven polyolefin fabrics are recommended for this application. The texture of this fabric allows water from concrete mix to bleed, and therefore reduces the water-cement ratio of the mix. Due to the reduction in the water-cement ratio, a higher compressive strength in fabric-formed concrete is achieved, which is also suggested by earlier studies. The current research study was conducted to investigate and document the changes in concrete strength and overall quality due to these woven polyolefin fabrics. Use of fabric formwork will result in a decrease in construction cost, construction waste, and greenhouse gas emissions. Two sets of tests were conducted in this research study: a comparison of the compressive strength of fabric-formed versus PVC-formed concrete cylinders, and a comparison of the behaviour of the fabric-formed columns versus cardboard-formed reinforced concrete columns. Variables in this research were limited to two types of fabric that included one with coarse and one with a more refined texture, and two types of concrete that included ordinary and flyash concrete.

The laboratory results revealed that the effects of fabric formwork on concrete quality in a large member are limited mostly to the surface zone and the core of the concrete remains the same as a conventionally formed concrete. Even though fabric-formed cylinder tests showed an average of a 15% increase in compressive strength of the concrete samples, the compressive strength of the reinforced columns did not dramatically change when compared to the companion cardboard formed control columns. This research confirmed that fabric formwork is a structurally safe alternative for forming reinforced concrete columns.

KEYWORDS

concrete, fabric formwork, flexible formwork, reinforced concrete column test

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INTRODUCTION

Concrete has been shaped in rigid inflexible molds since its invention. Stiff wood or steel formwork panels have been used since the mid-1800's, leading to the belief that structural form relies primarily on rectangular prismatic solids (West 2001). Eventually, if civil engineers could free their minds from thinking only of rigid, inflexible formwork for concrete, a wide range of previously impossible tasks would become feasible (Koerner and Welsh 1980).

Using fabric to form concrete produces variable geometries that are complicated or very expensive to create when using conventional formworks. Fabric formworks are 100 to 300 times lighter than conventional formworks, and they are also 1/10th the cost of formwork plywood per unit area (West 2001). Thus, not only fabric formwork increases the variety and form possibilities for structural members, but it is also inexpensive and easy to assemble and reassemble. More importantly, fabric formwork increases the surface quality and the compressive strength of the concrete. Permeable molds have also proved to be able to improve concrete resistance to chloride ion penetration (Marosszeky, et al. 1993). Another advantage of fabric formwork is increasing the resistance of the concrete against freezing and thawing cycles and chemical attacks (Malone 1999).

Tasks such as supporting hard to access areas for example foundations and underwater bridge piers (using inflatable concrete bags), pile jacking for reinforcing deteriorated wood, steel or concrete columns, and constructing columns for mines and cavern stability (Koerner and Welsh 1980), are some of the applications of the fabric formwork. This study is intended to establish fabric formwork as a flexible, safe, applicable, and economical formwork for concrete foundations, walls, beams, slabs, and columns.

Generally, in a conventional formwork, the concrete near the surface has more water than the concrete in the centre of the material mass. This high water-cement ratio at the surface, results in weaker and more permeable concrete (Reddi 1992). Bleeding characteristics of the available woven fabrics made of nylon, polyolefin, polyester, polypropylene, polyamide, and polyethylene, allow the extra water and air bubbles to bleed out from the formwork, thus reducing the water-cement ratio at the surface of the concrete member. This bleeding phenomenon creates a suction action which in turn increases the concentration of fine aggregates close to the surface of the concrete, giving it a very fine and impermeable surface.

Geotextile made by Propex was used in this study based on the recommendation of the Centre for Architectural Structures and Technology (C.A.S.T.) at the University of Manitoba, a centre experienced with fabric formwork for concrete. The fabric selected was Geotex 315ST as it had been shown to have suitable mechanical properties and had created a very good surface texture while exposed to cement mortar and fresh concrete. It was one of the least expensive fabrics available among Propex products.

Although mechanical properties and the workability of Geotex 315ST were known, the change in the concrete's overall quality was unknown to the authors. The knowledge of change in concrete properties due to fabric formwork was limited to a few research studies available; some claiming up to a fifty percent increase in concrete's compressive strength when cast in fabrics (Bindhoff and King 1982). Furthermore, these studies used methods that were not standardized.

Koerner and Welsh (1980) reported a reduction in the water-cement ratio of fabric-formed concrete mats from the 0.63 - 0.61 range down to 0.39 with no test on change in concrete compressive strength. Later, Bindhoff et al. (1982) reported a 50 percent increase in compressive strength of cement grout using the results from tests on cores from fabric-formed pile jackets and companion specimens cast in conventional watertight molds. Flyash was used in this research in order to increase the waterproofing properties of underwater concrete. The work of Pildysh and Wilson (1983) claimed a 50 to 100 percent increase in the compressive strength of concrete due to fabric formwork. Fabric socks with diameters of 152 by 610 mm (6 by 24 in.) were first vertically filled with grout under pressure, and then a 152 by 305 mm (6 by 12 in.) test cylinder was cut out and compared to control conventionally formed samples. In this study, 20 to 40 percent of flyash was used in the concrete mix design with only sand.

Lamberton (1989) reported a 50 percent increase in compressive strength in fabric-formed concrete specimens. Fabric socks with diameters of 140 by 760 mm (5.5 by 30 in.) were cast vertically under a 69 kPa injection pressure and then 152 by 305 mm (6 by 12 inch) cylinders were cut from the middle section of the hardened specimen. A 5 to 10 percent stretch in the fabric was considered with an initial 140 mm (5.5 inch) sock diameter. In the absence of gravel or large aggregates, cement mortar was used to cast the fabric-formed cylinders using portland cement and sand.

Further research also shows higher compressive strength in concrete produced with permeable but rigid formworks (Marosszeky, et al. 1993). Such formworks have an absorptive or permeable layer inside the formwork (often a woven or nonwoven fabric), filtering air and water from the concrete immediately behind the formwork. This filtration characteristic is similar to that of the fabric formwork studied in this research. Eventually, the surface of the concrete formed in such formworks is denser and stronger and has less imperfection than the same concrete formed in a conventional formwork (Malone 1999).

In a recent research study (Ghaib and Gorski 2001), textile mattresses were tailored with four kinds of fabrics and filled with concrete mixes with different slump values. Samples of 100 mm cubes were cut out from the hardened concrete mattress by electric saw and then compared to a series of control samples of 150 mm cubes. A total of 232 samples were tested in this research. The analysis of the compressive strength tests showed up to a 70 percent increase in compressive strength at the age of 28 days. It was found that the compressive strength of the concrete cast in fabric was a function of the pore size of the fabric used. In general, the compressive strength decreased as the pore sizes increased more than 0.35×10^{-3} m.

The present research study was designed to re-evaluate the change in concrete properties due to fabric formwork. The fabric cylinders used in this study simulated the standard cylinder test widely used in industry and since this method follows the available standards (ASTM C39/C39M-04a 2004), it represents the authentic changes in compressive strength of concrete.

MATERIALS

Fabric used in fabric formwork technique must be strong to carry the hydrostatic load and the hoop stresses developed in the fabric due to the pressure from the fluid concrete. In addition, it should be adequately porous to allow discharge of the excess water of the fresh concrete while preventing loss of solid elements, including cement and flyash particles (Lamberton 1989). Both fabrics used in this research study are polypropylene woven monofilament calendered (smoothed) and stabilized to resist degradation due to ultraviolet exposure (Propex 2006). Table 1 and Table 2 provide the mechanical properties of both fabrics in detail. Hydraulic pressure created by the liquid concrete creates hoop stress in the forming fabric. Knowing the

TABLE 1: Mechanical properties of Geotex 106F (www.propexinc.com).

Property	Test Method	Minimum Average Roll Value [English]	Minimum Average Roll Value [Metric]
Grab Tensile	ASTM-D-4632	370/250 lbs	1.64/1.11 kN
Grab Elongation	ASTM-D-4632	16%	16%
Mullen Burst	ASTM-D-3786	480 psi	3300 kPa
Puncture	ASTM-D-4833	120 lbs	0.533 kN
Trapezoidal Tear	ASTM-D-4533	100/60 lbs	0.445/0.265 kN
UV Resistance	ASTM-D-4355	90 % at 500 hr	90 % at 500 hr
AOS (max. average roll values)	ASTM-D-4751	70 sieve	0.212 mm
Permittivity	ASTM-D-4491	0.3 sec^{-1}	0.3 sec^{-1}
Flow Rate	ASTM-D-4491	22 $gal/min/ft^2$	895 $L/min/m^2$
% Open Area	CWO-22125	5%	5%

TABLE 2: Mechanical properties of Geotex 315ST (www.propexinc.com).

Property	Test Method	Minimum Average Roll Value [English]	Minimum Average Roll Value [Metric]
Grab Tensile	ASTM-D-4632	315 lbs	1.40 kN
Grab Elongation	ASTM-D-4632	15%	15%
Wide Width Tensile	ASTM-D-4595	175/175 lbs/in	30.7/30.7 kN/m
Wide Width Elongation	ASTM-D-4595	15/8 %	15/8 %
Mullen Burst	ASTM-D-3786	675 psi	4650 kPa
Puncture	ASTM-D-4833	150 lbs	0.667 kN
Trapezoidal Tear	ASTM-D-4533	120 lbs	0.533 kN
UV Resistance	ASTM-D-4355	70 % at 500 hr	70 % at 500 hr
AOS (max. average roll values)	ASTM-D-4751	40 sieve	0.425 mm
Permittivity	ASTM-D-4491	0.05 sec^{-1}	0.05 sec^{-1}
Flow Rate	ASTM-D-4491	4 $gal/min/ft^2$	160 $L/min/m^2$

magnitude of such stress can help select the forming membrane safely. Such stress was not measured in this study but was calculated for the column samples to be 3.45 MPa. Fabrics used were considered adequate for this research based on earlier experience of the authors.

In order to study specific effects on concrete strength and quality obtained by using commercially available woven polyolefin fabrics or geotextiles, it was necessary to form concrete cylinders using a variety of fabrics and concrete mix designs. Table 3 and Table 4 provide the proportions of the typical concrete mixes used in this research (Mindess et al. 2003).

TABLE 3: Typical concrete mix for normal concrete.

Material	Mix proportions, kg/m3
Water (kg)	147
Type 10 (I) Cement (kg)	400
Uncrushed Gravel (kg)	1023
Sand (kg)	693
Total (kg)	**2263**
w/c	**0.37**

TABLE 4: Typical concrete mix for flyash concrete.

Material	Mix proportions, kg/m3
Water (kg)	147
Type 10 (I) Cement (kg)	280
Type C Flyash (Kg)	120
Uncrushed Gravel (kg)	1023
Sand (kg)	693
Total (kg)	**2263**
w/cementitious materials	**0.37**

TABLE 5: Test results for concrete columns.

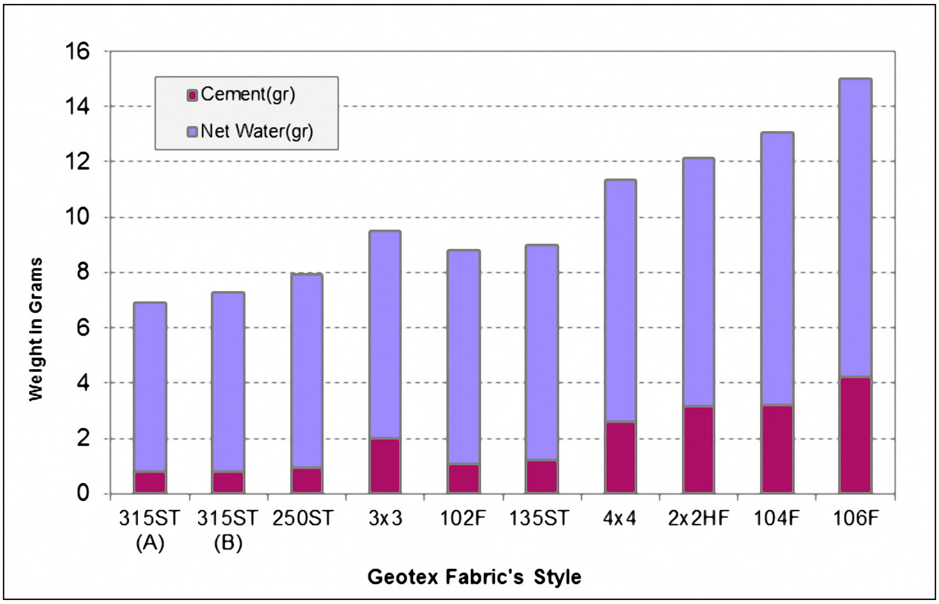
Column's Name	Formwork	Concrete type	f'c @ 56 days [MPa]	Experimental max. load (kN)
FF-NC-1	Fabric (Geotex 315ST)	Normal	31.27	1850.06
CT-NC-1	Cardboard Tube	Normal	31.27	2200.09
FF-NC-2	Fabric (Geotex 315ST)	Normal	26.99	1703.18
CT-NC-2	Cardboard Tube	Normal	26.99	1744.29
FF-FAC	Fabric (Geotex 315ST)	Flyash	39.21	2271.74
CT-FAC	Cardboard Tube	Flyash	39.21	2165.56

To reduce the number of samples to a reasonable number, a test was designed to determine the bleeding ratio of the available fabrics and hence their suitability for formwork. Fabrics with a tendency of allowing cement paste bleeding were not desirable. Nine types of available fabrics were installed at the bottom of a wood test box with fabric covered openings and plastic containers installed underneath to collect the water/cement paste residue that would bleed through the fabric. The box was then filled with fresh concrete (Figure 1) and some pressure was applied on top using a flat wood surface and steel weights. As soon as the bleeding stopped, the water-cement paste that bled through the fabric (Figure 2) was analyzed. Based on the results available in (Figure 3), two fabrics with the minimum and maximum water bleeding were selected.

FIGURE 1: Test setup for box test.

FIGURE 2: Collected cement and water bled through the fabrics.

FIGURE 3: Box test results for normal concrete.



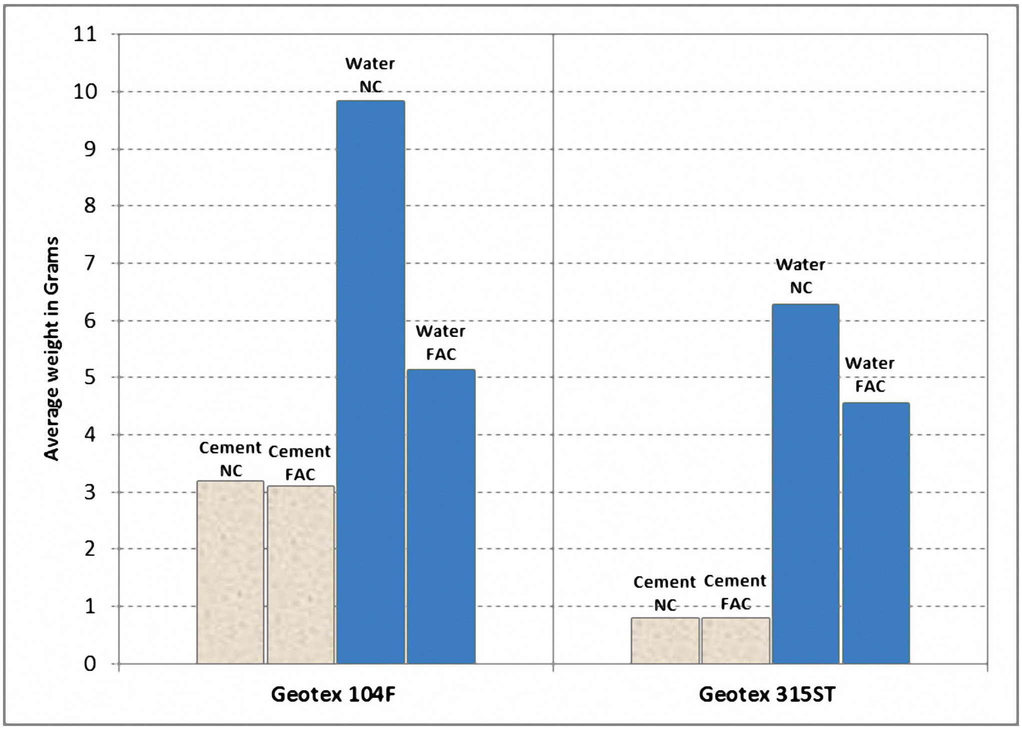
There are reports on fine additives such as silica fume having the tendency to clog filter fabrics associated with permeable formworks (Malone 1999). Mixes of ordinary concrete, however, have not shown any significant blockage in the formwork liner (Nolan, Basheer and Long 1995). Generally, particles of a typical silica fume are smaller than 1 micron (Malhotra and Carette 1982), while the average diameter of a typical cement particle is approximately 10 µm (Kosmatka, et al. 1995). In addition, the size of the spherical particles of flyash ranges between 10 and 100 micron (FHWA 2003).

Since flyash concrete was used in this study, a similar box experiment was conducted to observe if fine flyash particles are able to clog the fabric pores and therefore prevent bleeding. Only the two fabrics selected from the first box test were used. Type C flyash was used to substitute 30 percent of the cement in initial mix design (Table 2). Similar to the first box test, bled water-paste from the fabrics was collected in containers and weighed in wet and dry form to measure the amount of water and cementitious materials bled from the two fabrics. Since only 6 pieces of fabric were installed in this box, individual samples had a larger area exposed to the fresh concrete. Therefore, before deriving the results, corrections were applied to the areas to make them consistent with the first box test results.

As seen in (Figure 4), both fabrics bled almost the same amount of cementitious material when exposed to both normal concrete and flyash concrete. Therefore, Geotex 106F, which has larger pores, bled much less water when exposed to flyash concrete, meaning that some clogging happened when cementitious paste tried to pass through the fabric. This is caused by the use of flyash in concrete and an increase in amount of very fine particles in the concrete mix.

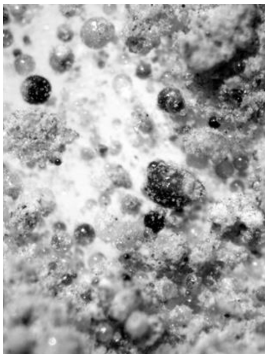
In order to investigate the characteristics of the collected dried cementitious material from this test, the material was examined under a stereoscopic zoom microscope (Nikon SMZ800) using a maximum magnification of 378x to observe if flyash bled through the fabrics. Dry passed cementitious material was set under the microscope and the visual results were compared to both pure flyash and pure cement. Based on observations, Geotex 315ST

FIGURE 4: Box test results for Geotex 315ST and Geotex 106F (normal and flyash concrete).

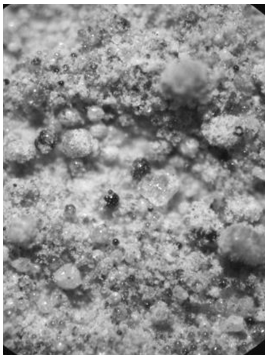


did not bleed any significant amount of flyash, while Geotex 106F, which has larger pores, passed a small amount of flyash (Figure 5). As seen in (Figure 4), Geotex 315ST bled much less cementitious material compared to Geotex 106F, which might be directly a result of the size of its pores and flyash beads that are responsible for clogging them.

FIGURE 5: Microscopic pictures comparing bled dried cementitious material from different fabrics.



a) Pure Flyash



b) Material bled from Geotex 106F

c) Material bled from Geotex 315ST

Previous work on permeable formwork liners has shown that the effect of bleeding is limited only to a few tens of millimetres of the surface of the concrete (Malone 1999). It is important to determine the depth of the bleeding effect on the change in cement or fine aggregate concentration close to the surface of the specimens as a function of diameter of the fabric-formed cylinder. Concrete cylinders were cast in 102, 152, 203, and 254 mm (4, 6, 8 and 10 inches). Wood and fabric molds were made then cylinders were cast using a 30 MPa (f'_c = 30 MPa) concrete. Hardened young samples were all vertically cut in half and sections were studied visually using a microscope. No visual concentration of cement/fine aggregates was seen in all sizes and all sections had the same texture throughout. No relationship between the size of sample and the bleeding depth was found in this test.

RELATIONSHIP BETWEEN HEIGHT OF A STRUCTURAL CONCRETE MEMBER AND THE BLEEDING/STRENGTH

It can be hypothesized that the amount of bleeding along the height of a fabric-formed column varies as a function of location along the column's height. In order to establish this relationship, pressure applied to the bottom and middle of the columns due to the self-weight of normal density concrete was simulated by using a mechanical press (Figure 6). The main purpose was to establish a relationship between the height of the column and the bleeding and also the effects of the reduction of water-cement ratio on the compressive strength of the specimens.

FIGURE 6: Application of lever systems.

a) Finished lever system used as the press machine.

b) Collection of bleeding water during the bleeding test.

The mechanical press was designed and fabricated in the laboratory and calculations were done to find the load necessary to simulate pressure at various heights along the column using an adjustable lever handle. A series of tests were conducted to establish an assumed linear relationship between the height of a column and the bleeding ratio. A set of 54 samples were cast (Figure 7) and the bleeding water (Figure 8) was measured to check if the bleeding ratio along the height of a column follows a straight line.

FIGURE 7: Fabric-form for concrete cylinders (152 by 305 mm - 6 by 12 inch).

FIGURE 8: Bled clear water from the walls of a fabric formed concrete cylinder after casting.

Using the results from the bleeding/strength tests, it was possible to plot the graphs provided in (Figure 9). The results show more bleedings from Geotex 106F, which was the more porous fabric. If there were more bleeding, it would cause reduction in the water cement ratio, and therefore a larger gain in the compressive strength of the concrete. As shown in (Figure 10), the flyash concrete gained more strength than the normal concrete. As shown in (Figure 10 and Figure 11), a linear relationship exists between the depth and the bleeding and therefore the compressive strength of a vertical concrete member. Eventually, taking advantage of the results concluded from this experiment, a series of cylinder tests, simulating only the top-end-unpressured point of the length of the column were designed. Ultimately, all the results could then be then translated to various locations along the column height; as in the linear relationship in (Figure 10).

FIGURE 9: Bled water results for cylinders formed by Geotex 315ST and Geotex 106F.

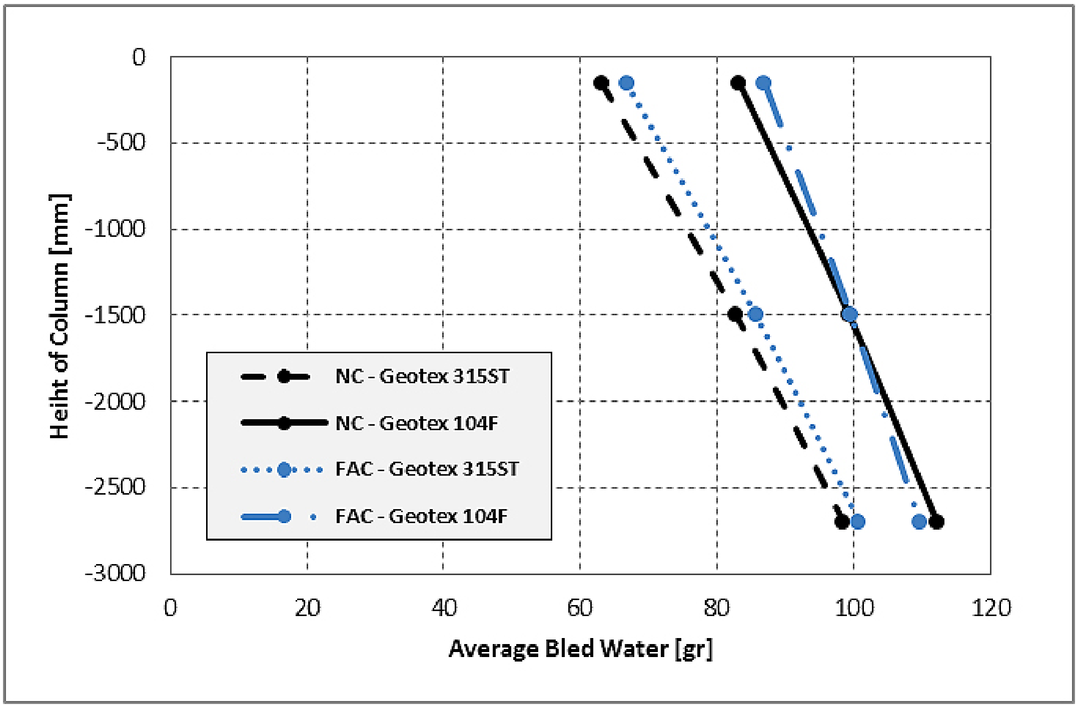


FIGURE 10: The effect of concrete height on concrete strength for fabric formed cylinders.

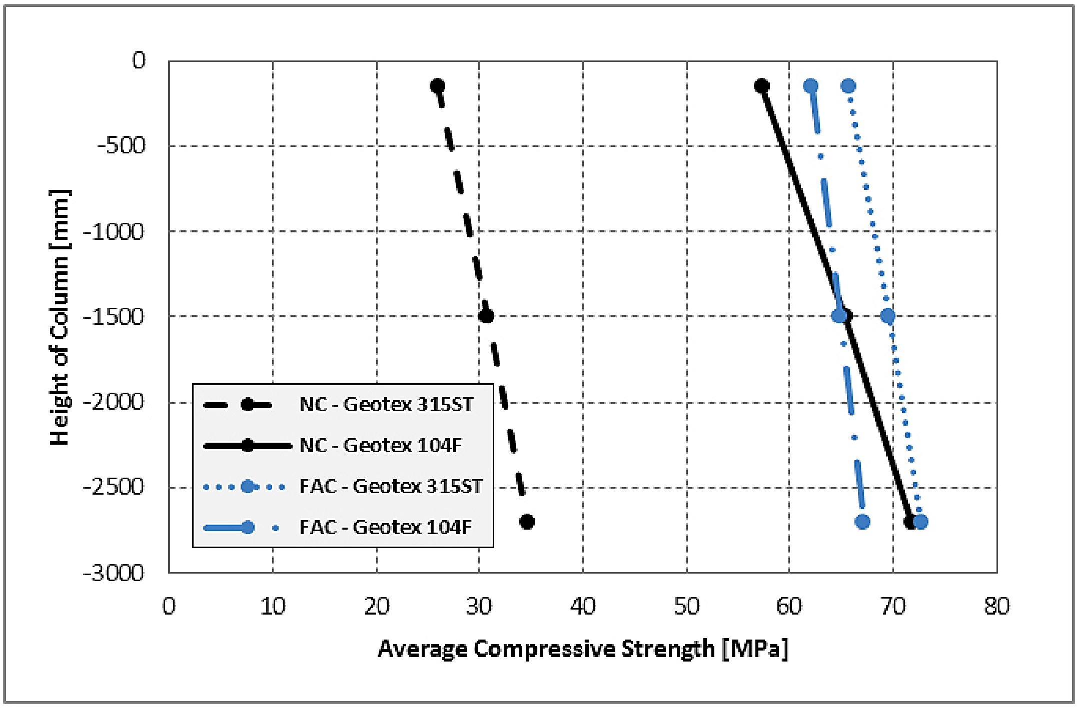
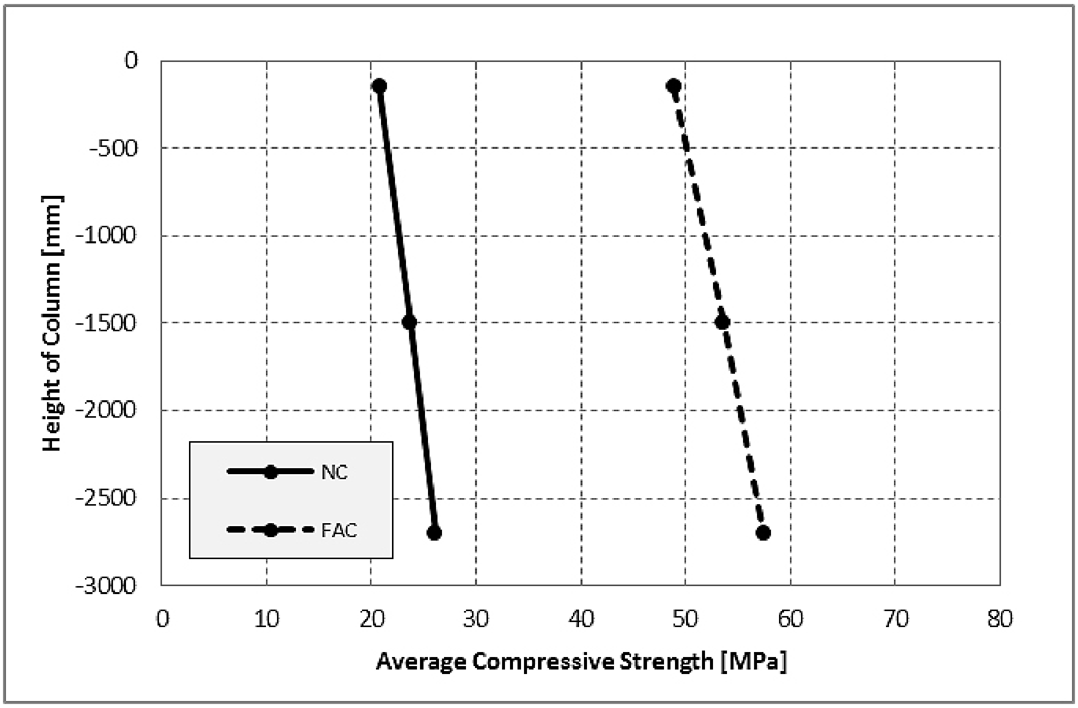


FIGURE 11: The effect of concrete height on concrete strength for PVC formed cylinders.



The change in quality of the concrete surface due to vibration was also studied. Cylinders (152 by 305 mm; 6 by 12 in.) were cast using a relatively high slump commercial flyash concrete and vibrated for about eight seconds as suggested in earlier studies (Kosmatka, et al. 1995). The molds were removed after 24 hours. As a result, Geotex 315ST, which is a less porous fabric, produced a much better surface finish due to less fine aggregates and cement bleeding through the fabric pores. Geotex 106F, on the other hand, did not provide a homogenous texture and created some color variation on the surface due to loss of fine aggregate through the walls of the mold. As a result, bleeding water from the Geotex 106F was cloudier than the Geotex 315ST, confirming the escape of fine particles through the fabric pores.

COMPRESSIVE STRENGTH TESTS

There are no ASTM or Canadian standards for preparing fabric-formed laboratory test cylinders. The type of mold used in this research study intends to provide some basis for testing and comparing the quality of concrete cast in fabric molds. Compared to the "sock" and "mattress" techniques used in previous research testing (Lamberton 1989, Ghaib and Gorski 2001), the test procedure proposed in this study is attempting to be close to conventional cylinder casting as recommended in ASTM C39/C39M-04a (2004). The method provides more practical comparisons for structural applications. Compressive strength of all cylindrical concrete specimens was determined on the basis of the standard test method (ASTM C39/C39M-04a 2004).

Compressive strength of cylindrical concrete specimens was determined on the basis of the standard test method explained in ASTM C39/C39M-04a (2004). All cylinders were formed by fabric and were cast in vertical position and compacted using the standard procedure (ASTM C39/C39M-04a 2004). The bottom of the fabric-formed cylinders was protected by a plastic sheet in order to prevent water absorption from its wood base and thereby simulating the same condition as the PVC molds. All cylinders, PVC and fabric-formed samples, were cast using the same batch of fresh concrete and the same dimensions (152 by 203 mm; 4 by 8 in.). After casting, the specimens were covered with a plastic sheet for the first day and later on, after stripping the molds, they were transferred to a curing room. In this experiment, a total of 36 cylinders were cast using normal concrete: 12 cylinders using Geotex 315ST, 12 using Geotex 104F, and 12 using PVC molds. The same number of flyash concrete cylinders were made for a total of 72 specimens. All cylinders were cured in a humidity/temperature controlled curing room before testing for compressive strength. When visually inspected, the specimens formed with fabric had a finely textured surface imprint because of the inclusion of the fabric. Unlike PVC formed samples, no large aggregate or major imperfections were visible on the concrete surface.

Due to the flexibility of the fabric forms, the final hardened cylinders had minimal variation in diameter (1 to 4 mm). In order to consider the difference between the diameters of the fabric-formed specimens and companion control samples, the diameter of each fabric-formed cylinder was measured at three points, and then the average diameter value was used to find the actual area of cylinder cross-section. The average variation in diameter between fabric-formed cylinders and PVC formed cylinders was less than one percent. Cylinders were tested for compressive strength at the ages of 3, 7, 14 and 28 days. Comparison charts are provided in (Figure 12 and Figure 13). Compared to the PVC-formed control samples, the fabric-formed cylinders showed a change in density on average of 2% for normal concrete and 3.3% for flyash concrete, which can be considered insignificant.

FIGURE 12: Normal concrete compressive strength gain by time.

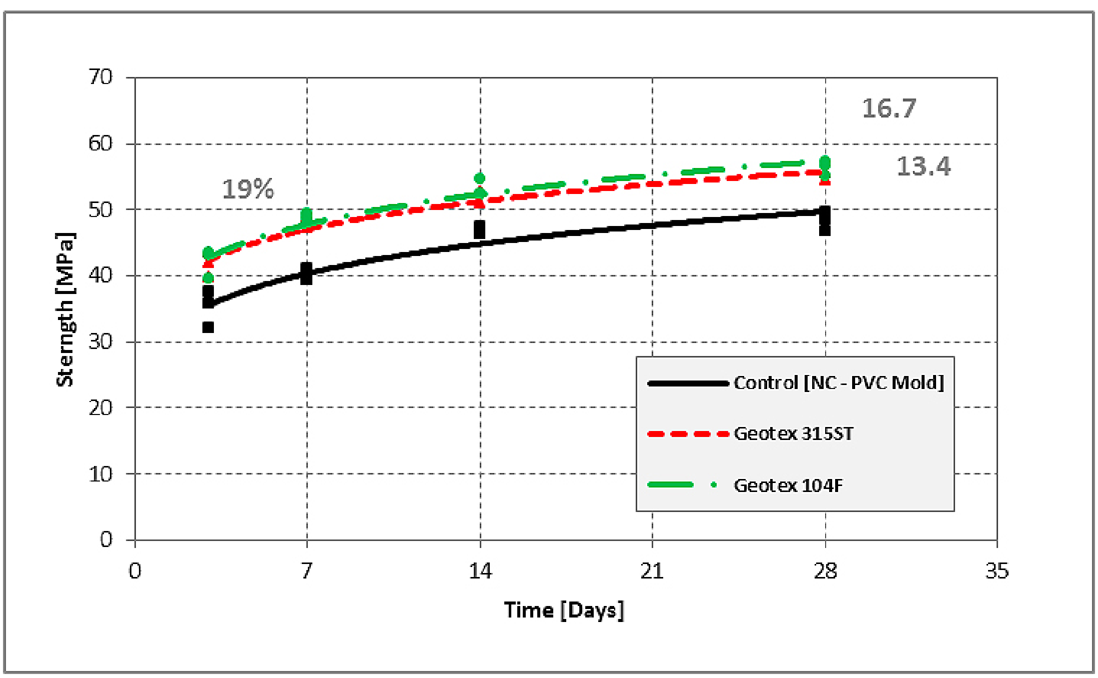
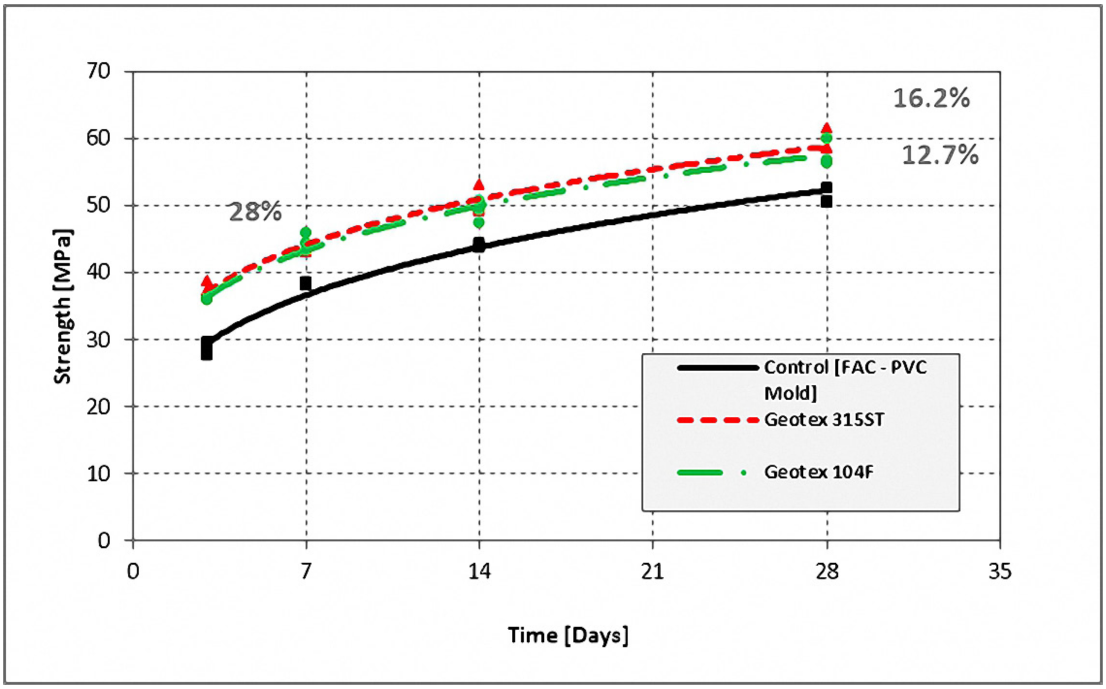


FIGURE 13: Flyash concrete compressive strength gain by time.



As seen in charts, compared to the control samples, cylinders cast in fabrics showed a 13.4 to 16.7% increase in compressive strength compared to normal concrete and there was a 12.7 to 16.2% increase in compressive strength for flyash concrete.

Specimens formed with Geotex 106F gained more strength when normal concrete was used compared to flyash concrete. On the other hand, Geotex 315ST cast samples resulted in more strength gain with flyash concrete compared to normal concrete. The difference between the average gained compressive strength at the age of 28 days for both fabrics in both normal and flyash concrete did not exceed more than 5.5%. It could be concluded that, regardless of the concrete type, both fabrics caused the same increase in compressive strength.

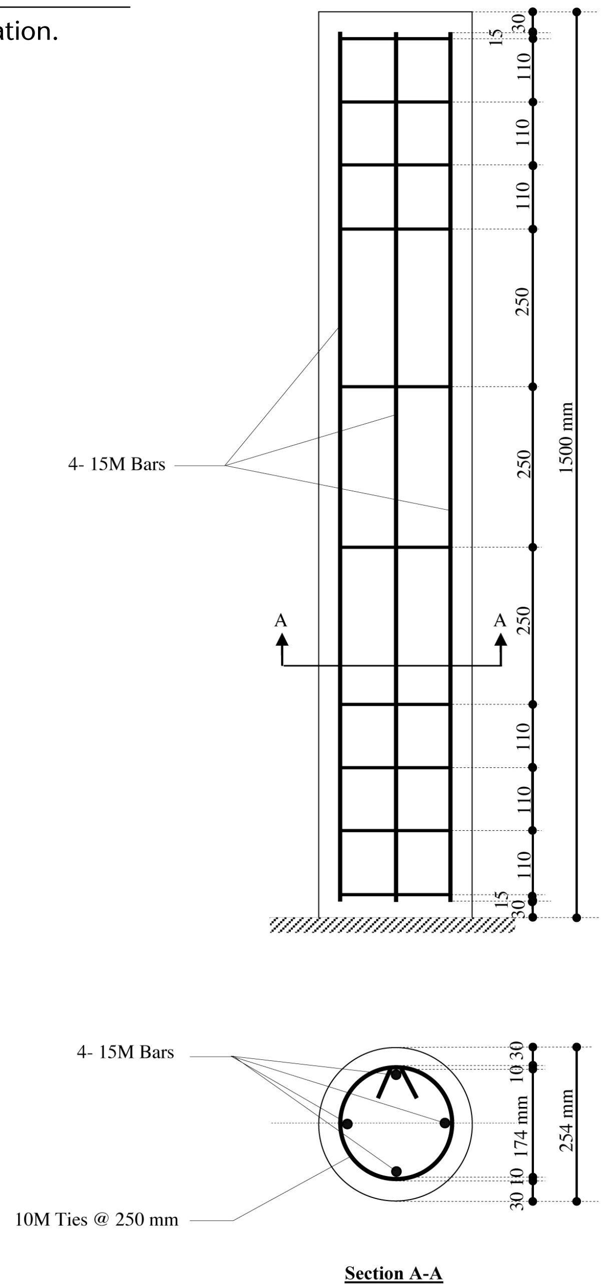
CONCRETE STRENGTH GAIN IN FULL SIZE SAMPLES

In order to compare the maximum load capacity of a vertical structural member formed with fabric, 254 mm diameter short reinforced concrete columns (slenderness ratio of 23.62) were designed and tested to failure under concentric axial load. The failure pattern and the maximum load capacity of the columns, formed with cardboard tubes and Geotex 315ST fabric, were investigated in this phase of the study. The columns were cast using normal and flyash concrete. Commercial 25 MPa concrete was ordered from a local ready mix concrete plant and delivered to the laboratory. An aggregate size of 5 to 20 mm, a slump of 90 mm, and an air content of 5 to 8% was specified.

A total of 15 companion cylinders were cast together with the columns. All columns and companion cylinders were cured in the same manner. The forms were stripped after one day, after which the columns, as well as the control samples, were cured for another 3 days using wet burlap and water. Dissimilar to the cardboard formed columns, no sign of color variation was observed in fabric-formed columns. The surface finish of Geotex 315ST formed columns were superior to the cardboard formed concrete. No imperfections or appearance of large aggregate were seen on the concrete surface.

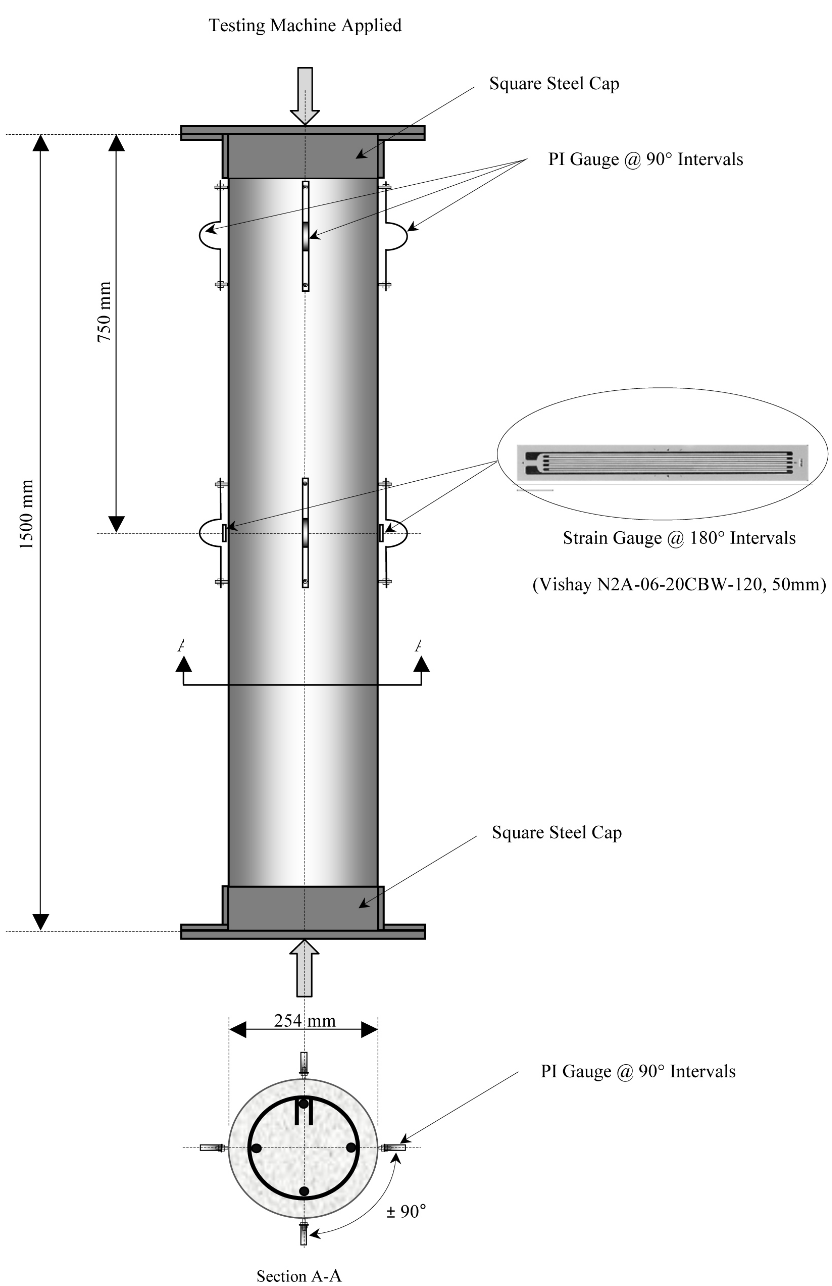
The sectional area of each column and the reinforcement ratio was adjusted to comply with the capacity of the available testing equipment in the structural laboratory at the University of Manitoba. The heights of the columns were selected to eliminate the slenderness effects. Columns were simply supported, and axial load was considered to be applied with zero eccentricity. As seen in (Figure 14), 15M longitudinal bars with a yield strength of 400 MPa were used as primary reinforcement and 10M bars were used as ties. Centre to centre spacing of ties was selected as 100 mm near the ends and 240 mm at the middle of the columns. The maximum axial load capacity of the columns was calculated according to CSA A23.3-04.

FIGURE 14: Column reinforcement configuration.



Cured, ready to test columns were instrumented at mid-height and top end to measure the longitudinal and circumferential strains under the axial load. To measure circumferential strains, two strain gauges were installed at mid-height of each column, 750 mm from the top end with a 180 degree interval. A total of eight Pi-gauges were also installed on each column to measure longitudinal strain. Four Pi-gauges were placed at mid-height and four on the top end of each column to measure the displacement (Figure 15). A Data Acquisition System (DAQ) was used to record the test data gathered. Strain gauges and Pi gauges were all tested for proper resistance and were calibrated before every test session.

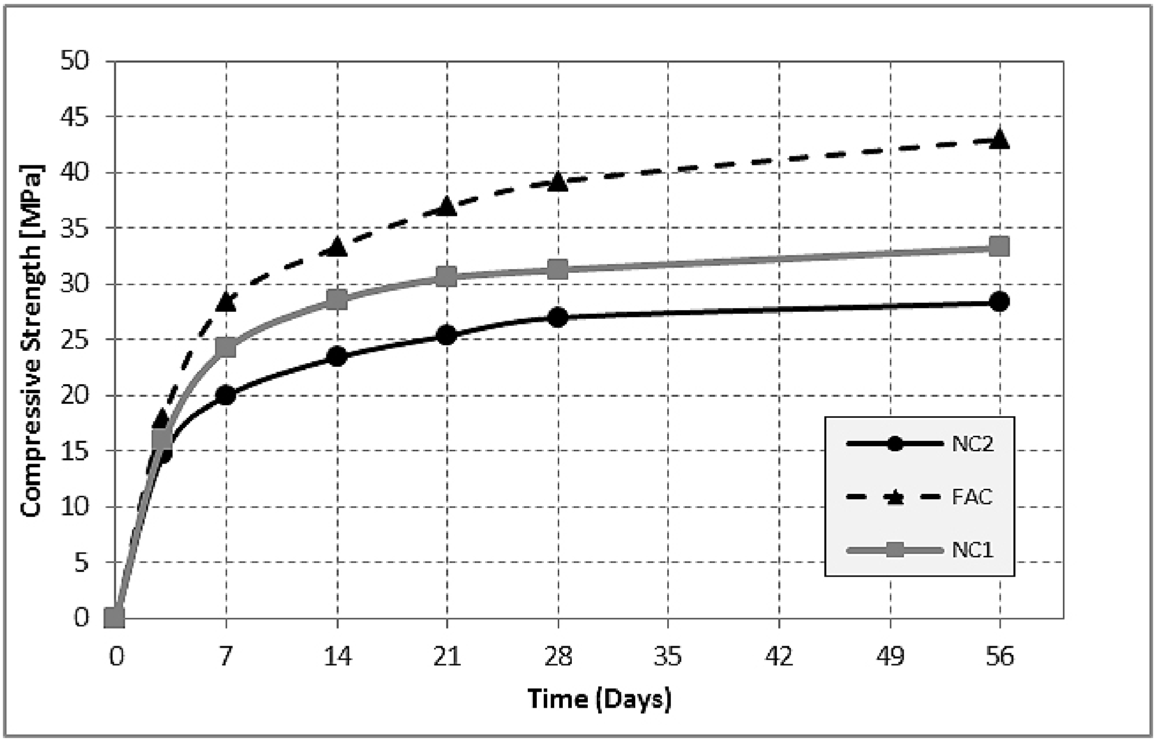
FIGURE 15: Concrete column instrumentation.



CYLINDER COMPRESSIVE TESTS RESULTS

Concrete cylinders were tested at the ages of 3, 7, 14, 28 and 56 days. The gain of compressive strength with time for both normal concrete (NC) and flyash concrete (FAC) is plotted in (Figure 16). As can be seen in the figure, the 28 day average compressive strength of the flyash sample was 39.2 MPa, while normal concrete specimens gained an average of 27 MPa. This compressive strength in both samples was used to estimate the maximum axial load capacity of the columns.

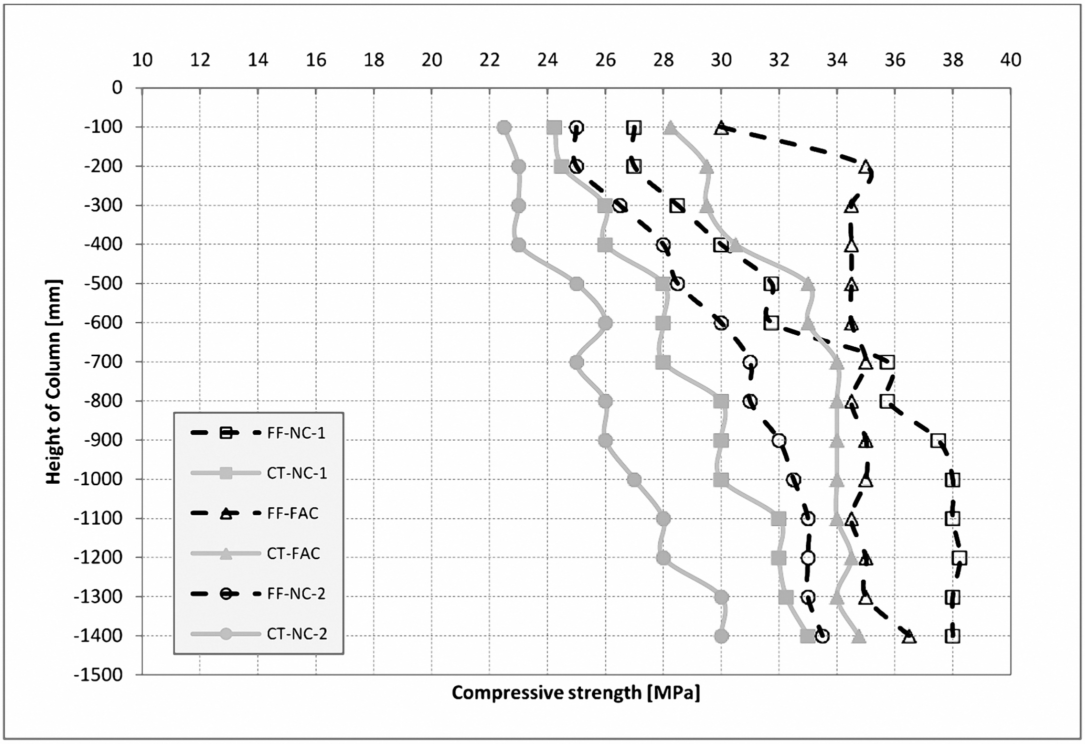
FIGURE 16: Concrete strength gain with time.



Concrete strength was also tested on the column surface using a Schmidt hammer. A Schmidt concrete test hammer (Proceq N/NR) was used to study the improvement in compressive strength of the columns along their height as a function of time. A grid of four vertical lines and 14 circumferential lines every 10 cm were drawn on the column surface. This grid was used to measure compressive strength at 14, 21, 28 and 56 days.

Instructions for preparation of the concrete surface were carefully followed before and during the use of the hammer. Each assigned point was tested for 8 impact readings. Following the manufacturer's manual, the impact points were spaced at least 20 mm apart. The mean value of the 8 rebound values (R) was then calculated. Conversion curves were used to find the corresponding compressive strength of the average R values. For comparison purposes, only 28 day readings are provided in (Figure 17). As seen in the chart, all columns formed with fabric showed more surface strength than those formed with cardboard. When normal concrete is used, the difference between the compressive strength of the specimens cast in cardboard versus fabric formwork at the bottom of the column is between 12 and 15%. The difference between the formworks when using flyash concrete was of minimal significance

FIGURE 17: Rebound tests results on columns at the age of 28 days.



(5% difference). This is an indication of flyash particles possibly clogging fabric pores and therefore reducing the amount of water bleeding and eventually resulting in less of increase in compressive strength.

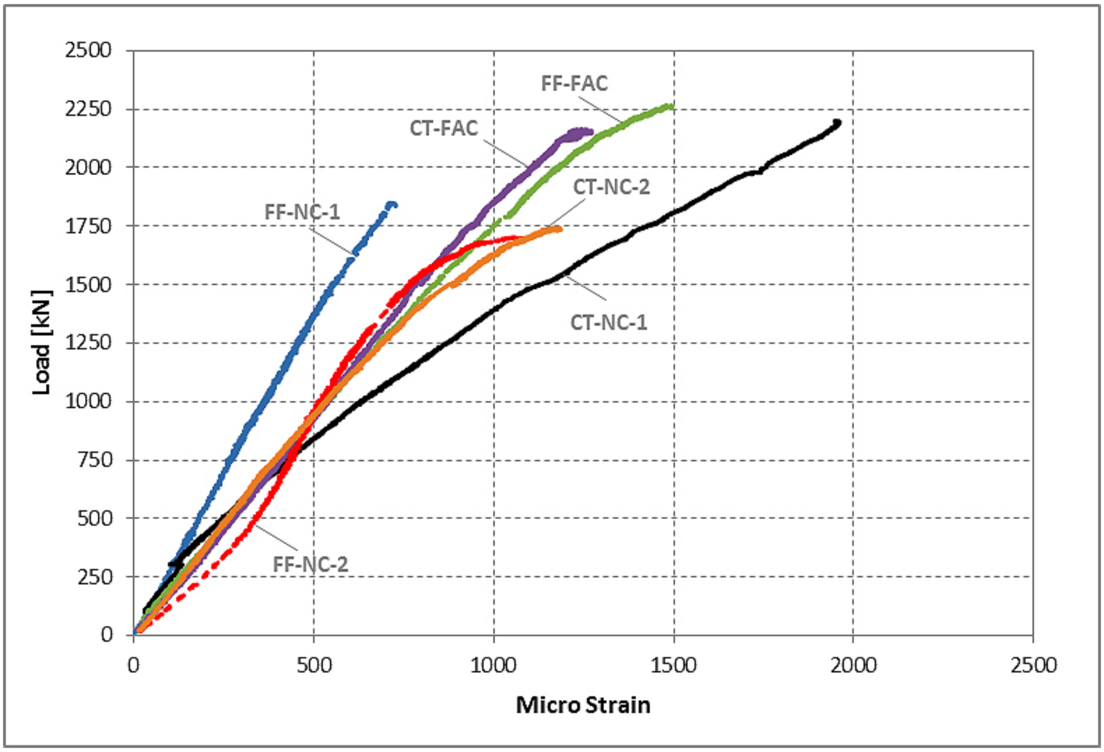
In addition, regardless of the formwork type, and referring to the results obtained from Schmidt hammer tests, the top end of the columns always proved to be weaker than other sections of the column. This is a phenomenon that appeared in both the cardboard and fabric-formed columns due to less compaction and less concrete density at top end of each column.

AXIAL LOAD TEST RESULTS OF FULL SIZE COLUMNS

All columns were aged for more than 56 days before testing. Specimens were oriented in the testing machine and concentric axial load was applied to the specimens with a constant load rate. Table 5 provides a summary of the specifications of the tested columns and results. The experimental load versus strain curves for all four columns tested in this study are shown in (Figure 18). As seen in the charts, both columns cast with flyash and normal concrete failed at almost the same load level regardless of the formwork type. Normal concrete columns formed with fabric and cardboard withstood 1703.18 kN and 1744.29 kN of axial load, respectively. The maximum axial load of the flyash specimen formed with fabric was 2271.74 kN, and it was 2165.56 kN for the cardboard formed column.

All four columns failed by the crushing of concrete at the top end. This type of failure has been experienced before in a research study conducted by Bazant and Kwon (1994) in which regardless of the cross sectional size of the column, fracture mechanism stayed the same. This may be due to the fact that top end of a vertical member has lower compressive strength than the other parts of the member, as supported by the data in (Figure 17).

FIGURE 18: Axial load response for columns cast in fabric formwork (FF) and cardboard formwork (CT).



Ultimate load capacity and the slope of the load versus strain curves of the fabric-formed columns are very close to those formed with cardboard; expressing the same strength and stiffness of the material. It is nearly impossible to form a perfectly straight column using fabric formwork, and there is likelihood of existence of very small values of eccentricity in loading condition. But results show that the effects of eccentricity could be neglected. Since both fabric-formed columns withstood the same axial load level as the cardboard formed control samples, the effects of fabric formwork on the concrete's quality in a large member seems to be limited mostly to the surface. The core concrete strength remains the same as a conventionally formed column.

CONCLUSIONS

1. As shown by Schmidt hammer test results, permeable fabric formwork for concrete can enhance the quality and the hardness of the surface zone of the concrete.

2. Based on results of this research study, geotextile fabrics such as Geotex 315ST are suitable for forming fresh concrete. Mechanical properties and the optimal bleeding ratio, availability, price, as well as the fabric texture/imprint produced make these products viable for use as concrete formwork.

3. Concrete texture produced by fabric formwork is without major surface imperfections sometimes seen in conventionally formed concrete. No color variation was observed on the surface of the fabric-formed columns. Very few imperfections or appearance of large

aggregate was seen when fabric formwork was used. Such concrete could be used as the surface for exposed structural members with no additional work.

4. Even though fabric-formed cylinder tests showed an average of 15% increase in compressive strength, the compressive strength of the fabric-formed reinforced columns did not change appreciably when compared to the companion cardboard formed control columns. Compression failure in columns occurs at the top where the bleeding effect and strength advantage are minimum due to minimal hydrostatic pressure. Ultimately, it can be concluded that fabric formwork is a structurally safe alternative for forming reinforced concrete columns.

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Notation

The following symbols are used in this paper:

f_y	=	Specified yield strength of steel reinforcement
f'_c	=	Specified compressive strength of concrete
R	=	Rebound Value

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