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Improving Concrete Properties with Fibers Addition

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***Abstract*—**This study investigated the improvement in concrete properties with addition of cellulose, steel, carbon and PET fibers. Each fiber was added at four percentages to the fresh concrete, which was moist-cured for 28-days and then tested for compressive, flexural and tensile strengths. Changes in strength and increases in cost were analyzed. Results showed that addition of cellulose caused a decrease between 9.8% and 16.4% in compressive strength. This range may be acceptable as cellulose fibers can significantly increase the concrete resistance to fire, and freezing and thawing cycles. Addition of steel fibers to concrete increased the compressive strength by up to 20%. Increases 121.5% and 80.7% were reported in tensile and flexural strengths respectively. Carbon fibers increased flexural and tensile strengths by up to 11% and 45%, respectively. Concrete strength properties decreased after the addition of PET fibers. Results showed that improvement in strength after addition of steel and carbon fibers may justify the extra cost of fibers.

***Keywords*—**Concrete, compressive strength, fibers, flexural strength, tensile strength.

I. Introduction

CONCRETE is the second most consumed substance on earth; on average, each person uses nearly three tonnes a year. Through time, different materials have been added to concrete in order to improve or alter its properties. The addition of fibers, such as steel, glass, polymeric materials, carbon, cellulose, and nylon to fresh concrete in order to improve specific characteristic(s) such as compressive strength, toughness, flexural strength, flexural toughness, and/or abrasion, has received more attention from researchers and the concrete industry lately [1].

As concluded in [2], adding cellulose fiber to concrete resulted in low shrinkage cracking, excellent freeze and thaw performance, high toughness, fire resistance, and reduced rate of water absorption. Moreover, it causes reduction in crack generation/propagation, helps to protect embedded rebars, and may result in small increase on flexural and compressive strength. The aforementioned study found that addition of cellulose fiber does not decrease the workability of the fresh concrete as other fibers usually do [1], cellulose fibers can improve frost and impact resistance and reduce permeability of concrete.

Addition of steel fibers can increase compressive, tensile, and flexural strengths of concretes along with the post-cracking ductility. Furthermore, the steel fibers raise the resistance of concrete to cracking. The use of steel fiber increases impact resistance and provides ductile failure under compression, flexure and torsion, besides increase in fatigue resistance [3].

Carbon fibers have low density, high thermal conductivity, good chemical stability and excellent abrasion resistance, and can be used to reduce or eliminate cracking and shrinkage [4]. These fibers increase some structural properties such as tensile and flexural strengths, flexural toughness and impact resistance [5]. Carbon fibers also increase freeze-thaw durability and dry shrinkage. However, the addition of carbon fibers decreases the electrical resistance [6].

Although PET fibers resistance in the alkali environment provided by Portland cement is poor [7], [8], PET fiber addition increased ductility and reduced shrinkage cracking [9]. PET fibers addition improved the bending strength and toughness [7].

II. Materials

A. Aggregates

The coarse aggregate used in this research was crushed stone with relative density of 2.68, and nominal maximum size of 16mm. The grain size of the fine aggregates ranges between 0.075 and 4.75mm and has relative density of 2.64.

B. Cellulose Fibers

The pulp grade used on this research was the Northern Bleached Softwood Kraft (NBSK), which is commonly used as reinforcement in produced papers. The material applied in the experiment had a high moister content (more than 500%) and was oven dried prior to being added to the fresh concrete. The fibers have a density of 1.1g/cm³ and can be dispersed in water.

C. Steel Fibers

The steel fibers used in this research were 33mm long and 0.55mm diameter with a hooked end and a tensile strength of 1200MPa and a density of 7.85g/cm³.

D. Carbon Fibers

Chopped carbon fibers were added to the fresh concrete. The fibers were 6.1mm in length and with 4.6GPa tensile strength, 243GPa tensile modulus, and specific gravity of 1.8.

E. PET Fibers

The PET fibers for the research were hand cut from PET bottles with an average of 50mm length and around 1.5mm width. The density of the material was found to be 1.45g/cm³. Fig. 1 shows a photo of the four fibers used in the study.

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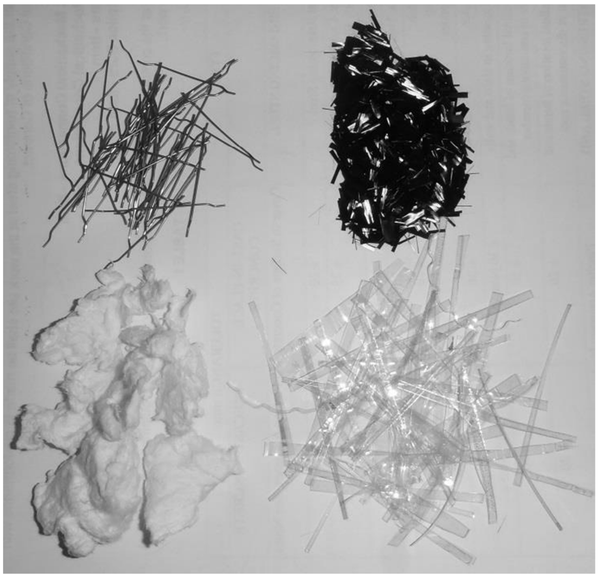

Fig. 1 Fibers used in this study

III. Procedure

A. Preparing the Mix

Each of the four fibers in the study was tested at four different percentages (volume of fibers/ volume of concrete) along with tests on plain concrete as a control. For each percentage, compressive, flexural, and tensile strengths were tested on concrete specimens that were moist-cured for 28 days.

The concrete mix used in this study was a rich mix with small size aggregates [10]. The plain concrete was made with proportions shown in Table I.

TABLE I
PLAIN CONCRETE MIX

Material	Mass (kg/m³)
Water	189
Cement	377
Coarse aggregate	897
Fine aggregate	864

The concrete-fibers mixtures were prepared by gradually adding the fibers to the fresh concrete while mixing adding enough fibers on plain concrete admixture until the desirable percentage of fibers by volume was reached. The best way found to mix the fibers with the concrete was thoroughly mix the regular ingredients of the concrete (cement, water, coarse and fine aggregates) and then slowly add the fibers to the concrete while the mechanical mixer was rotating. The homogeneity of the mix was visually evaluated.

The workability of the concrete was one of the properties compared in this study, and effort was made to keep the workability, in all mixtures, between 75mm and 100mm. After the fibers were totally mixed with the fresh concrete, a slump test was performed as in [11]. For samples with slump outside the desirable range, plasticizer was added and another slump test was performed. This was repeated until the slump of the mixture reached the specified range or until the maximum allowed volume of plasticizer was used.

The concrete cylinders used to tensile (150mm dia. and 300mm long) and compressive strength (100mm dia. and 200mm long) tests were consolidated by rodding, whereas the beams (150mmX150mmX500mm) used for flexural strength tests were consolidated by vibration. The cylinders and beams were casted as in [12].

After casting the specimens were left to set, and were demolded on the following day. The specimens were then immersed in water to cure for 28-days [12].

Capping of all samples for compressive strength tests was made with sulfur-based capping compound.

All tests were carried according to CSA Standard, for compressive [13], tensile [14], and flexural [15] strengths.

The addition method for cellulose fibers was a little different from the others. It had to be dispersed in water with the aid of a small mechanical mixer and then added to the concrete. During the whole process, all the water used to disperse the fibers was deduced from the water added to the mix, keeping the same water cement ratio in all mixes.

IV. Results

A. Cellulose Fibers

In comparison with the four fibers investigated in this study, adding cellulose fibers resulted in the least reduction of workability, even though it was necessary to use plasticizer at all percentages.

Mixture prepared with the first two percentages of cellulose fibers (0.2% and 0.3%) achieved the desired slump range and the mixtures were workable and could easily be rodded and vibrated. However, with 0.4% and 0.5% fibers the mixtures had slump lower than specified values, although they were able to be rodded and vibrated with the 0.5% mixture being slightly harder to work with.

The results showed that the decrease in the compressive strength is proportional to the percentage of the cellulose fibers. At 0.5% of cellulose, concrete had its compressive strength reduced by 17%. Performance of concrete on compressive strength with addition of cellulose fibers is shown in Fig. 2.

Addition of cellulose fibers also worsened concrete flexural and tensile strength as shown in Table III.

Although the addition of cellulose fibers slightly increases the cost of the concrete mixture (see Table II) and decreases the compressive, tensile strength of the concrete, considering concrete price, the addition of cellulose fibers to concrete is not an advantage for the mechanical properties evaluated; however, for other parameters, such as the ones cited in [2], it may be advantageous. A summary of results for the performance of cellulose fibers added to the concrete matrix can be seen at Table III and the economical comparative can be found at Table II.

B. Steel Fibers

The workability of the steel fibers was remarkably impaired by the ability of the steel to build on itself. Often, the mix did not have the desired slump but remained workable, and was found to segregate with more than 1200ml/m^3 plasticizer was added.

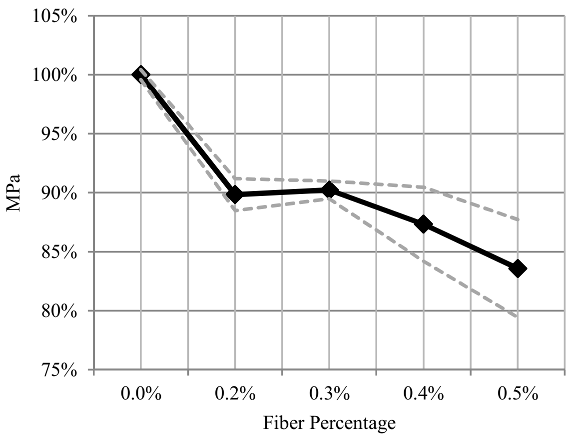

Fig. 2 Compressive strength for concrete with cellulose fibers and its standard deviation

At the 0.5% percentage of fiber, the concrete did not need plasticizer and the slump was within the desired range.

For the 1.5% and 2.3%, approximately the same amount of plasticizer was added, although it did not help because the fibers made a strong bond that did not allow slump improvement. The mix was workable and was able to be vibrated but harder to be consolidated when using a rod. Even though specified slump was not achieved, it is important to notice that the maximum amount of plasticizer was not used for steel fibers in order to avoid segregation. At 2.3% some voids were found when specimens where demolded.

At the highest percentage the mix workability was worse than others and concrete started to segregate. The concrete was found to be really difficult to cast, and rodding was not efficient, because it did not penetrate the entire layer, which made specimens poorly vibrated. A lot of effort had to be made when tapping the cylinders, on the side, to make mortar come to the surface, lots of bubbles came out during the process. As a result of the bad consolidation, the specimens had lots of voids. The excess of fiber harmed the finishing ability of the concrete.

Even though adding steel fibers at 0.5% and 1.5% percentages reduced the concrete compressive strength, fibers at higher concentrations improved the concrete strength by up to 20%.

Except at 0.5%, steel fibers are helpful with tensile strength. When 3% of fibers were added, there was an increase of 121% of concrete's original tensile strength. Tensile strength of concrete with addition of steel fibers is shown in Fig. 3.

The addition of steel fibers always improved concrete flexural strength at the studied percentages. The fact that at 3.0% there was lower improvement than at 2.3% can be explained by difficulty in rodding the concrete with the former percentage and the steel fibers were not as dispersed.

When it comes to concrete cost, even though it was the fiber with better results for mechanical properties, it is the most expensive, raising the price up to 211%.

Table IV shows all the results obtained for steel fibers and the economical comparative can be found at Table II.

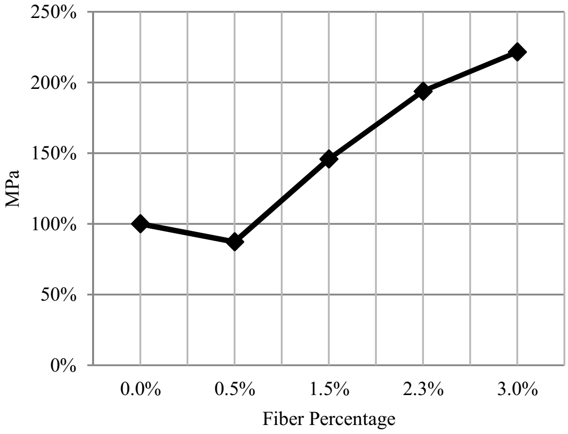

Fig. 3 Tensile strength for concrete with steel fibers

C. Carbon Fibers

At the first and second percentages tested, 0.2 and 0.3%, carbon fibers did not change workability and the concrete mixture behaved similar to regular concrete after adding plasticizer. During the process of carbon fiber addition, it could be observed that it was drying the mix and turning it into a rigid and not workable mix.

At 0.4% of carbon fibers, the specified slump could not be reached and the mix was very dry and unworkable. At 0.5% of fibers addition, the mix was even drier and seemed to have almost no workability. Moreover, it could not be vibrated, and had to be consolidated using a rod. Attempt to vibrate is shown on Fig. 4.

Fig. 4 Attempt to vibrate carbon fibers

As for concrete compressive strength, except at the percentage of 0.5% of carbon fibers, influence on the concrete compressive strength was very minimal. At the greatest percentage, the fibers were able to increase the compressive strength by up to 9.6%.

It was also noticed that at higher percentages of carbon fibers the standard deviation of the compressive strength tends to increase.

For tensile strength, carbon fibers caused different effects on the concrete. At 0.2%, it impaired concrete tensile strength. At 0.3% it barely improved its capacity. The two higher percentages presented good results, increasing 11% and 9.6% at 0.4% and 0.5%, respectively.

The addition of carbon fibers helped to improve concrete flexural strength at all percentages studied. The improvement varied from mild 6% at 0.3%, to significant 45% at 0.4% of fibers. The presumable reason why 0.5% did not have higher results than 0.4% is lack of vibration. Performance of concrete on flexural strength with addition of carbon fibers is shown in Fig. 5.

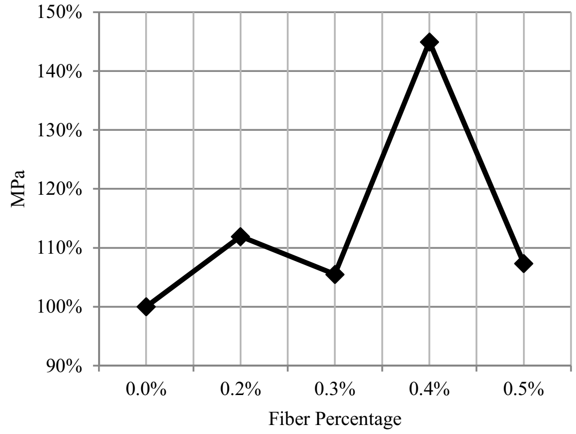

Fig. 5 Flexural strength for concrete with carbon fibers

While the addition of carbon fibers increased the concrete price by only 14%, it increased flexural strength by 45%, tensile strength by 11%, and lowered compressive strength by 2%.

Table V shows all results obtained for carbon fibers and the economical comparative can be found at Table II.

D.PET Fibers

The influence of PET fiber in the concrete workability was similar to the steel in some aspects. For instance at 0.5%, it was not necessary to use plasticizer to reach the desired slump and concrete had the same workability as plain concrete. Moreover, PET fibers also build on each other, having a smaller slump while the mixture was still workable.

At 1.0% and 1.5%, the slump was outside the range but the concrete had some mortar and reasonable workability. Rodding and vibration were not affected.

Workability was much impaired at a mixing percentage of 2.3% and the concrete was poorly vibrated. The excess of fiber harmed the finishing ability of the concrete.

The addition of PET fibers decreased the compressive strength by 30%. Performance of concrete on compressive strength with addition of PET fibers is shown in Fig. 6.

The addition of PET fibers also decreased concrete tensile and flexural strengths.

Although using PET fibers made concrete cheaper, in this research, it worsened concrete performance so much that its use is not advantageous.

Table IV shows all the results obtained for the PET fibers and the economical comparative can be found at Table II.

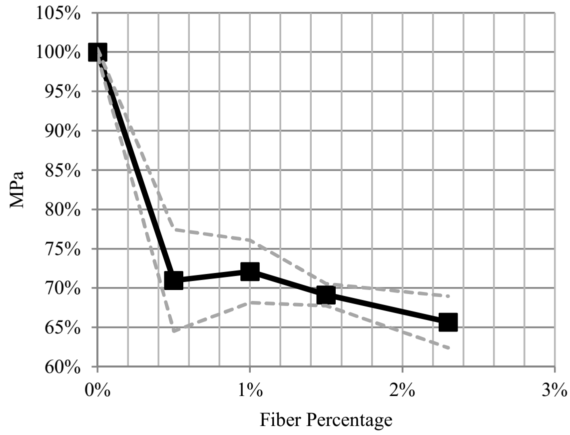

Fig. 6 Compressive strength for concrete with PET fibers and its standard deviation

TABLE II
CONCRETE PRICE

Concrete	Price (CAD)	Δ in Price
Plain	289.24	-
Cellulose 0.2%	301.34	4.2%
Cellulose 0.3%	312.67	8.1%
Cellulose 0.4%	317.63	9.8%
Cellulose 0.5%	318.35	10.1%
Steel 0.5%	389.41	34.6%
Steel 1.5%	599.72	107.3%
Steel 2.3%	759.90	162.7%
Steel 3.0%	900.06	211.2%
Carbon 0.2%	316.81	9.5%
Carbon 0.3%	318.63	10.2%
Carbon 0.4%	329.15	13.8%
Carbon 0.5%	332.79	15.1%
PET 0.5%	287.75	-0.5%
PET 1.0%	292.22	1.0%
PET 1.5%	290.70	0.5%
PET 2.3%	288.27	-0.3%

V. CONCLUSION

While reinforcement with carbon and steel fibers were able to improve concrete performance in general, increased percentages of cellulose and PET fibers degrade the concrete properties.

When analyzing the impact on concrete price, the use of carbon and steel fibers made concrete reasonably more expensive, but only for carbon fibers the price increase was compensated by the enhanced performance. The price increase using steel fibers was higher than the improvement obtained, although, adding steel fibers into concrete may reduce or eliminate the need for reinforcement bars, what may lower the total price of the structure [16].

TABLE III
CELLULOSE RESULTS

	Workability		Compressive		Flexural		Tensile	
	Plasticizer (mL)/m³	Slump (mm)	Strength (MPa)	Δ in Compressive Strength	Strength (MPa)	Δ in Flexural Strength	Strength (MPa)	Δ in Tensile Strength
Plain Concrete	0	85.0	42.9	-	6.46	-	3.75	-
Cellulose Fibers 0.2%	1217	75.0	38.5	-10.2%	6.35	-1.8%	2.69	-28.1%
Cellulose Fibers 0.3%	2431	75.0	38.7	-9.8%	5.46	-15.6%	3.07	-18.1%
Cellulose Fibers 0.4%	2915	55.0	37.5	-12.7%	5.63	-12.8%	3.41	-8.9%
Cellulose Fibers 0.5%	2912	25.0	35.8	-16.4%	5.93	-8.3%	2.73	-27.2%

TABLE IV
STEEL RESULTS

	Workability		Compressive		Flexural		Tensile	
	Plasticizer (mL)/m³	Slump (mm)	Strength (MPa)	Δ in Compressive Strength	Strength (MPa)	Δ in Flexural Strength	Strength (MPa)	Δ in Tensile Strength
Plain Concrete	0	85.0	42.9	-	6.46	-	3.75	-
Steel Fibers 0.5%	0	75.0	39.0	-9.0%	6.88	6.4%	3.27	-12.8%
Steel Fibers 1.5%	1145	20.0	41.0	-4.4%	9.43	45.9%	5.47	45.8%
Steel Fibers 2.3%	1135	0.0	45.2	5.3%	11.68	80.7%	7.27	93.3%
Steel Fibers 3%	1127	0.0	51.4	19.9%	10.85	67.9%	8.30	121.5%

TABLE V
CARBON RESULTS

	Workability		Compressive		Flexural		Tensile	
	Plasticizer (mL)/m³	Slump (mm)	Strength (MPa)	Δ in Compressive Strength	Strength (MPa)	Δ in Flexural Strength	Strength (MPa)	Δ in Tensile Strength
Plain Concrete	0	85.0	42.9	-	6.46	-	3.75	-
Carbon Fibers 0.2%	2321	95.0	43.1	0.5%	7.24	11.9%	2.98	-20.4%
Carbon Fibers 0.3%	2320	85.0	43.6	1.6%	6.82	5.5%	3.78	0.9%
Carbon Fibers 0.4%	2895	0.0	42.0	-2.1%	9.37	45.5%	4.17	11.3%
Carbon Fibers 0.5%	2892	0.0	47.0	9.6%	6.94	7.3%	4.11	9.7%

TABLE VI
PET RESULTS

	Workability		Compressive		Flexural		Tensile	
	Plasticizer (mL)/m³	Slump (mm)	Strength (MPa)	Δ in Compressive Strength	Strength (MPa)	Δ in Flexural Strength	Strength (MPa)	Δ in Tensile Strength
Plain Concrete	0	85.0	42.9	-	6.46	-	3.75	-
Pet Fibers 0.5%	0	85.0	30.4	-29.0%	5.58	-13.8%	2.61	-30.4%
Pet Fibers 1.0%	684	25.0	30.9	-27.9%	5.40	-16.5%	2.78	-25.7%
Pet Fibers 1.5%	681	0.0	29.7	-30.9%	5.19	-19.7%	2.71	-27.6%
Pet Fibers 2.3%	675	0.0	28.2	-34.3%	4.80	-25.7%	2.91	-22.3%

For compressive, tensile, and flexural strengths and workability, cellulose and PET fibers worsened concrete performance. The use of these fibers may be advantageous when the aim is reducing crack generation/propagation [2], [9], or other specific advantages provided by the fibers.

It is important to notice that the prices found in this research were for laboratory amounts, and may decrease when buying in bulk.

VI. FUTURE RESEARCH

Providing results from different concrete batches can provide smoother lines and reducing outlines. Designing the mix according to fibers properties, obtaining the best performance from the material instead of designing for plain concrete and then adding fibers. Furthermore, varying the fibers dimensions may change results found during this research.

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