Utilization of Waste Cotton Fibers in Concrete: Investigating the Optimal Fiber Length and Amount Based on Split Tensile and Compressive Behavior

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Abstract: This research aims to study the effect of waste cotton fibers on the properties of concrete. Varying lengths and amounts of fibers were investigated, specifically, 10 mm, 30 mm, and 50 mm lengths and 0.2%, 0.6%, and 1.0% amounts by weight of cement. The study was done in two phases. The first phase is to evaluate the effect of workability in terms of slump. The second phase to is evaluate the strength. These were done to find the optimum fiber amount and fiber length to improve the properties of concrete with cotton fibers. The experiments collected data were the slump test, compression test, and split tensile test. The analysis of results found that 0.6% of cotton fiber amount by weight of cement with a 0.6 water-cement ratio would produce acceptable workability, with a slump ranging from 155 mm to 174 mm. The compressive tests show that the addition of fibers has a negligible effect on the compressive strength of concrete, as the highest and lowest compressive strength in the range of results showed only a difference of 0.63 MPa. The split tensile strength tests showed that the 30 mm and 50 mm concrete had significantly higher split tensile strength than the control, with the 50 mm samples with the highest. In addition, a cost analysis was done comparing the utilization of waste cotton fiber in concrete to conventional concrete. Based on the results, the best way of improving the strength properties of concrete especially the tensile strength is to use the 30 mm cotton fibers.

Key Words: cotton fibers; concrete; fiber length; fiber amount; textile waste utilization.

1. INTRODUCTION

One of the most urgent concerns of the world today is waste control. The amount of solid waste that is being produced is rapidly increasing. According to Mawis (2019), the Philippines' solid waste generation steadily increased from 37,427.46 tons per day in 2012 to 40,087.45 tons per day in 2016. An estimated 165% increase by 2025, resulting in 77,776 tons of solid waste generation per day. The textile industry contributes significantly to solid waste generation in the Philippines. According to the Department of Environment and Natural Resources, the textile waste generated amounted to 1.61% of all accumulated waste from 2008 - 2013. In landfills, these materials will contribute to the production of greenhouse gases and will take 20 - 200 years to decompose. One of the materials contributing to the textile waste is the cotton waste. There are many types of cotton waste generated because of unused material from manufacturing and salvaged cotton from clothes that have been thrown away. Some cotton waste comes in fibers, fabric, yarn, thread, and more.

All these products are readily available in the Philippines because of the country's large cotton and textile industry.

In conjunction to this, the construction industry is a significant contributor to pollution. According to a report made by the United Nations, the construction industry is significantly responsible for the world's carbon dioxide emissions. In response to this, innovative and environmentally conscious materials are being developed and coming to the forefront of the industry.

In recent years, multiple studies from Qin et al. (2019), Kong et al. (2017), and Thamizharasan et al. (2016) investigated waste fiber materials such as recycled plastic, steel, and fabric for use in fiber reinforced concrete. One potential waste material candidate is waste cotton fibers. However, existing research on this topic is still inadequate. Therefore, the focus of this study is to investigate the utilization of cotton waste fiber in concrete for the potential use in different structural members.

2. METHODOLOGY

2.1 Research Design

Tests were done based on ASTM procedures; ASTM C143 to test the workability of concrete, ASTM C39 for its compressive strength, and ASTM C496 for its split tensile strength. The variables considered important in these experiments are the water to cement ratio (w/c), the length of the cotton fiber, and the amount of cotton fiber added to the concrete mix.

The w/c ratios that were chosen were 0.5 and 0.6. These relatively high values were selected because they will increase the workability of the fresh concrete mix. This will compensate for the likelihood that the addition of fibers will lessen the workability of the fresh concrete mix. Additionally, these values were based on a study by Zakaria et al. (2017), which used similar w/c ratios ranging from 0.55 to 0.60.

The cotton fiber lengths that were chosen in this study were 10mm, 30mm, and 50mm, which was based on existing studies, namely Thamizharasan et al. (2016), Jaiswal et al. (2014), and Zakaria et al. (2017). These related works of literature garnered varying results, partly attributed to their use of differing lengths. The amounts of fibers chosen were 0.2%, 0.6%, and 1% by weight of cement which was also based on the studies above. All parameters are summarized in Table 1.

Table 1. Summary of chosen parameters.

Water to Cement Ratio	0.5, 0.6
Fiber Length (mm)	10, 30, 50
Fiber Amount (% by weight of cement)	0.2, 0.6, 1

2.2 Experimental Setup

The samples needed in the experiment are cylindrical samples with dimensions of 300mm height by 150mm diameter. These samples were initially planned to be cured for only 28 days, but due to the restrictions brought by the Covid-19 pandemic, inducing a lockdown period, the split-tensile samples were instead cured for 158 days for the control samples and samples with 10mm fibers and 165 days for samples with 30mm and 50mm fibers.

2.3 Preparation of Materials

There are several treatments that can be applied to cotton fibers. In this study, the treatment process used was mercerizing of cotton. Mercerization is an alkali treatment of cellulosic material such as cotton. The treatment process is listed as follows: (1) Prepare the 30% solution of Sodium Hydroxide (NaOH), (2) Immerse the cotton fibers in the solution at a relatively cool temperature of 20° C for four to five (4-5) minutes, (3) Cotton is squeezed and washed in a bath at 85-degree Celsius two (2) times and rinsing it again with cold water (18 °C) to neutralize the Sodium Hydroxide, (4) Dry the fibers in a hot air-drying room.

This treatment of the cotton fibers increases properties such as fiber strength, shrinkage resistance, luster, and surface area. In cutting the cotton fibers to their desired lengths, the roll-and-cut technique sought to be the most efficient way of bundling the strands for accuracy in cutting the fibers to their desired lengths, namely 10mm, 30mm, and 50mm as seen in Figure 1.

Fig. 1. Cut cotton fibers (10mm, 30mm, and 50mm from left to right, respectively).

2.4 Mix Design

The experiment utilized the absolute volume mix design method for the concrete. For the first stage of this study, w/c ratios of 0.5 and 0.6 were used, denoted as Mix Design 1 and Mix Design 2, respectively. Additionally, three (3) different fiber lengths (10mm, 30mm, 50mm) and three different fiber amounts (0.2%, 0.6%, 1.0% by weight of cement) were used in conjunction with each other as well as a control sample with no cotton fibers. This produced ten (10) unique mixes for each mix design.

To simplify the design mixes, Table 2 summarize the amount of ingredient of the two different mix designs. Meanwhile, Table 3, show the amounts of cotton used per specimen.

Table 2. Tabulated design mix proportion by weight per sample.

Mix Design	Cement (kg)	Sand (kg)	Gravel (kg)	Water (kg)
1	2.500	6.140	4.360	1.466
2	2.083	6.485	4.360	1.477

Table 3. Amount of cotton per sample (in g).

Mix Design	% of fibers by weight of cement (g)		
	0.2%	0.6%	1.0%
1	5	15	25
2	4	13	21

3. RESULTS AND DISCUSSION

3.1 Workability Test

Table 4 shows the results of the slump test conducted using a w/c ratio of 0.5 while varying the amount of cotton and varying the length of cotton fibers that were added to the concrete mixes. Moreover, a control sample was tested to determine the effect of adding cotton fibers to the concrete mix on the overall workability of concrete. The control sample showcased the highest values of workability while the concrete mix that used the 50-mm cotton fibers with an amount of 1% of the weight of cement showcased the lowest values of workability. Aside from that, it can be observed that the use of a longer length of cotton and the use of more cotton fibers further decreases the value of workability.

Table 4. Slump test results of 0.5 w/c ratio mix.

w/c ratio	%Cotton	Length	Average
0.5	0	0	209.0
	0.2	10	167.5
	0.6		167.5
	1		138.5
	0.2	30	182.5
	0.6		164.5
	1		117.5
	0.2	50	128.0
	0.6		155.5
	1		33.0

Table 5. Slump test results of 0.6 w/c ratio mix.

w/c ratio	%Cotton	Length	Average
0.6	0	0	202
	0.2	10	212
	0.6		171
	1		151
	0.2	30	199
	0.6		173.5
	1		120
	0.2	50	199
	0.6		154.5
	1		35

Table 5 showcases the slump test results of 0.6 w/c ratio concrete mix. Like the 0.5 w/c ratio concrete mix, it can be observed that the control sample yielded the highest values for workability while the concrete mix that made use of 50mm cotton fibers with an amount of 1% per cement weight yielded the lowest values for workability. It can also be observed that the use of longer cotton fiber lengths and higher amounts of cotton yield lower values of workability.

On average, the higher the w/c ratio yields higher workability. This trend was expected because a higher water ratio in a concrete mix will result in higher workability. It is also seen in Figure 2 that workability decreases as more cotton is added. Additionally, there is a steeper decline in workability for longer cotton fibers as more cotton is added. This is due to the more significant amounts and lengths of fibrous cotton material that holds the fresh concrete together and the absorption of water by the fibers, thus reducing the water content of the mix.

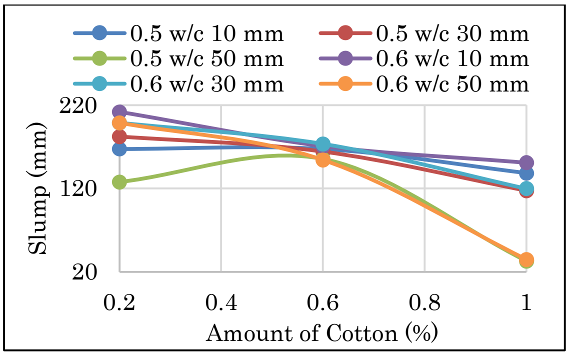

Fig. 2. Workability of 10mm, 30mm, and 50mm fibers for 0.5 and 0.6 w/c ratio.

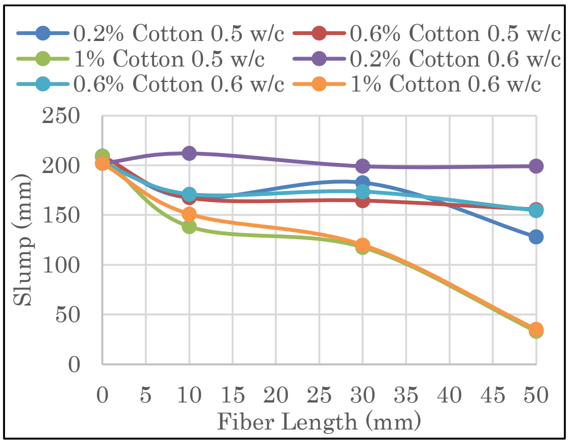

Fig. 3. Workability results by fiber length.

When analyzing the results of the workability tests, it is seen in Figure 3, the 0.6% amount of cotton yields the best results when it comes to achieving the target slump. It averages close to 150mm on all mixes with 0.6% cotton fibers and both w/c ratios. As for the w/c ratios, both the 0.5 and 0.6 show a similar trend in workability but 0.6 shows slightly higher workability in all types and configurations of cotton fibers in the mix. With these results as guide, the final mix design used in stage 2 of the experiment adopted the mix design following the 0.6 w/c ratio and the cotton amount of 0.6% by weight of cement.

3.2 Compressive Strength Test

In stage 2, compressive strength evaluation of samples cast based on the final mix of 0.6 w/c and cotton amount of 0.6% was conducted. Table 6 shows the results of the compression tests. The results show that the control sample, the 10mm, 30mm, and 50mm tested for an average compressive strength of 20.707 MPa, 20.583 MPa, 21.043 MPa, and 20.412 MPa, respectively. Figure 4 shows the comparison of the compressive strengths of the different sample categories. The results show that 30mm cotton fibers yielded the highest compressive strength of 21.043 MPa, while 50mm cotton fibers yielded the lowest compressive strength of 20.412 MPa. Clumping of balling of fibers observed in the 50mm samples may have caused the decrease in strength. The use of these long fibers is more susceptible to clumping, which may cause consequential air pockets and inconsistencies in the concrete mix. On the other hand, the 10mm fibers were too short of providing any strength to the concrete. The 30mm fibers had enough length to provide some compressive strength to the concrete but were not too long to risk clumping.

Table 6. Adjusted compressive strength test results.

Category	Average Compressive Strength (MPa)	Percent Difference from Control
Control Sample	20.707	-
10 mm Cotton Fiber Lengths	20.583	-0.600%
30 mm Cotton Fiber Lengths	21.043	1.622%
50 mm Cotton Fiber Lengths	20.412	-1.423%

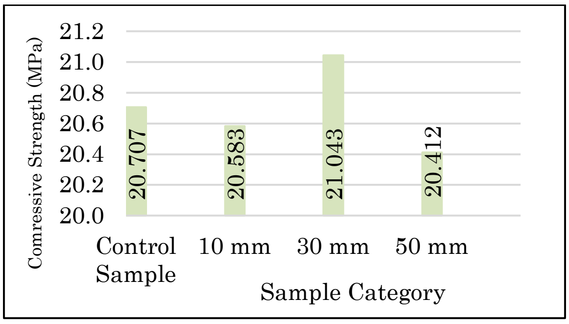

Fig. 4. Average compressive strength per category.

3.3 Split-Tensile Strength Test

Based on the results seen in Table 7, the concrete cylinders that used 50mm cotton fibers tested for the highest split tensile strength, which was

12.913 MPa. Meanwhile, the concrete cylinders that used 10mm concrete fibers tested for the lowest split tensile strength. Figure 5 compares the average of the split-tensile strengths, in MPa, of the different sample categories. The results show that using the 50mm cotton fibers resulted in the highest average split-tensile strength of 12.913 MPa while using the 10mm cotton fibers resulted in the lowest average split-tensile strength, 8.55 MPa. It can also be observed that the increase in strength between the 10mm and 30mm samples was 3.138 MPa. The increase in strength between the 30mm and 50mm samples was less, at only 1.225 MPa.

Table 7. Adjusted split-tensile strength results.

Category	Average Split Tensile Strength (Mpa)	Percent Difference from Control
Control Sample	9.290	-
10 mm Cotton Fiber Lengths	8.550	-7.97%
30 mm Cotton Fiber Lengths	11.688	25.81%
50 mm Cotton Fiber Lengths	12.913	39.00%

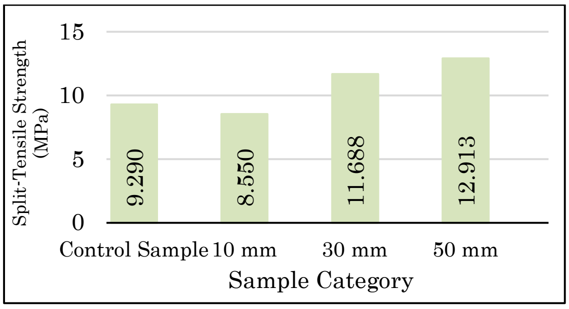

Fig. 5. Average split-tensile strength per category.

The split tensile properties show that the 50mm concrete samples produced the highest average strength having a value of 12.913 MPa. The trend of the split tensile strength shows that adding 10mm fiber lengths in concrete decreases the strength by 8.65% compared with the control samples. When analyzing the 30mm and 50mm fiber length concrete samples, increasing the length increases the split tensile strength. Compared to the control sample, the strength of the 50mm samples increased by 39.00%. Overall, the strength values are seen to have a more significant disparity than the compressive strength values, as the range of the lowest and highest strength values is 4.363 MPa. From observation, the increase in fiber length increases the split tensile strength of the concrete sample. However, the 10mm fiber length showed a decrease in strength that may have been caused by the fiber length not being long enough to act as tensile reinforcement to concrete.

3.4 Cost Analysis

The main cost difference will come from the treatment cost of the cotton fibers used in the concrete mix. The amount of material used such as cement, sand, gravel, and water stayed the same throughout the control mix and the mix with added cotton fibers. The concrete mixture considered is Mix Design 2 adopting the 0.6 water-to-cement ratio, and the cotton fiber amount of 0.6% by weight of cement. Since they have the same volume of concrete mix, the only deciding factor for a cost difference will stem from the cost of treatment used for the cotton fibers. The cost of raw cotton fiber is assumed to be zero since it is considered as waste. The summary of the cost analysis is shown in Table 8.

Table 8. Cost analysis summary.

Cost, Php	Control	10 mm	30 mm	50 mm
Concrete Cost	3512.59	3512.59	3512.59	3512.59
Treatment	0.00	47.13	47.13	47.13
Total Cost	3512.59	3559.72	3559.72	3559.72
% Increase	0.0 %	1.34 %	1.34 %	1.34 %
Strength, MPa	**Control**	**10 mm**	**30 mm**	**50 mm**
Compression	20.71	20.58	21.04	20.41
Split Tension	9.29	8.55	11.69	12.91
Strength/Cost, Php/MPa	**Control**	**10 mm**	**30 mm**	**50 mm**
Compression	169.61	172.97	169.19	174.41
Split Tension	378.10	416.34	304.51	275.73

The cost analysis includes only the materials used. The analysis was started by calculating the cost of one cubic meter of conventional concrete (without fiber) with the current prices of materials. The cost of material for treatment of fibers, which consist of sodium hydroxide and water used, was estimated at Php 47.13. This value was then added to determine the price of concrete with treated fibers per cubic meter. Comparison of the prices per cubic meter of the control concrete and concrete with fibers (10mm, 30mm, and 50mm) showed very minimal increase in cost. This price increase reached only 1.34% as seen in

Table 8. Although the treatment of the added cotton fibers resulted in a slight price increase, what is important to note is that it also resulted in an increase of both compressive strength and split tensile strength as seen for the 30mm and 50mm cotton fibers. To see the relation between strength and cost, the strength-cost ratio was calculated by dividing the strength value with the cost. The lower the ratio, the better is the mixture. The results show that best scenario of cotton fiber utilization is for the 30 mm fibers in terms of compression. Although in split tension, the strength-cost ratio is better at 50 mm fibers, the compressive strength and workability is lower.

4. CONCLUSIONS

Based on the results of the slump tests, the addition of longer cotton fibers and the increase of the amount of cotton fibers resulted in a decrease in the workability values. Aside from this, the results show that the workability values of the 0.6 w/c ratio concrete mix were higher than the workability values of the 0.5 w/c ratio concrete mix. This prompted to adoption of 0.6 w/c in the next phase of research.

In the next phase of research, the compressive tests show that the 30-mm concrete samples had the highest strength. The control specimens had higher strength than the 10mm and 50mm samples. However, the strength did not vary widely, seeing that the highest and lowest strengths have a difference of only 0.63 MPa. Therefore, it can be concluded that the addition of fibers and varying lengths of fibers do not significantly affect the compressive strength of concrete.

The split tensile tests show a more significant disparity between the specimens. The 50mm samples had the highest strength, followed by the 30mm samples. However, the 10mm samples had the lowest average strength. Therefore, the trend is that longer fibers will contribute greater split tensile strength, and concrete with too short fibers will be weaker than traditional concrete.

Based on the results, the 30mm cotton fibers were chosen to be the best in improving the strength properties of concrete included in the study. The use of the 30mm cotton fibers resulted in the improvement of compressive strength and split-tensile strength when compared to the control sample. Aside from those factors, the cost-effectiveness of the 30mm cotton fiber concrete samples showed the best results.

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