Influence of Polymer Fiber on Strength of Concrete

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Abstract

This paper outlines an experimental study that measures the effects of polymer fiber on proprieties of concrete. However, polymer fiber may serve as a superplasticizer admixture which may result to concrete's lower rate of water absorption, high-range water reducer, greater strength and excellent in elasticity. Hence, an experimental investigation was conducted to determine the optimum dosage for the admixtures and to study the effect of over dosage of the mentioned admixtures. This elastic property of the polymer fiber reinforced in cement-concrete mix may produce better earthquake resistance of the building or structure as it deflects for a while as the load is applied and then returns to its original position as the load is removed. The experiments made were concrete with polymer fiber (polyvinyl alcohol, polyvinyl acetate) as the experimental group and a standard concrete mix being the control group. Polymer fiber used has been dissolved in water with five different proportions ranging from 2% to 10% with respect to cement's percent by weight in kg. This specimen is molded in a cylinder with constant volume of cement, sand and gravel at 1:2:4 mix proportion of class "A". The specimens formed were cured and tested to compressive strength on the 7th, 14th and 28th days after curing. Results prove that concrete mix having polymer fiber gave greater strength results than the standard mix.

Keywords: *ASTM, construction materials, plasticizer, polymers*

1. Introduction

An admixture, according to the ASTM C-125-97a standards, is a material other than water, aggregates or hydraulic cement that is used as an ingredient of concrete or mortar, and is added to the batch immediately before or during mixing. A material such as a grinding aid added to cement during its manufacture is termed an additive [1]. Superplasticizer is a type of water reducers; however, the difference between superplasticizer and water reducer is that superplasticizer will significantly reduce the water required for concrete mixing [2].

Superplasticizer is a type of water reducers; however, the difference between superplasticizer and water reducer is that superplasticizer will significantly reduce the water required for concrete mixing [3]. Generally, there are four main categories of superplasticizer: sulfonated melamine- formaldehyde condensates, sulfonated naphthalene- formaldehyde condenses, modified lignosulfonates and others such as sulfonic- acid esters and carbohydrate esters. Effects of superplasticizer are obvious, *i.e.*, to produce concrete with a very high workability or concrete with a very high strength. Mechanism of superplasticizer is through giving the cement particles highly negative charge so that they repel each other due to the same electrostatic charge. By deflocculating the cement particles, more water is provided for concrete mixing [3]. For general usage, dosage of superplasticizer is between 1- 3 l/m^3. However, the dosage can be increased to as high as 5- 20 l/m^3

In engineering, materials are employed to design and build structures, develop and produce new products. Recent developments are focused on producing composite and polymeric materials. Composite materials are made up of two or more separate materials combined in macroscopic structural units (or through physical change). Many materials that have two or more constituents, such as metallic alloys and polymer blends, are not composites, as the structural unit is formed at the microscopic (or through chemical change) rather than macroscopic level. Examples of composite materials are straw brick, paper, reinforced concrete, wood, and polymers reinforced with graphite (carbon) or glass fibers. Whereas, polymeric materials are those, which belong to a group of carbon-containing (organic) materials, natural or manmade, that have macromolecular structure: very large molecules made up of repeating molecular units. Examples of these are timber, rubber, polyethylene, polyester, polyvinyl chloride, wool, cotton, silk, starch and cellulose. Most polymers are plastic, which means that they can be easily bent into different shapes.

However, these materials can still be improved by adding other materials to further modify its property, which are called admixtures. An admixture of concrete is a material other than water, aggregates, cement, and fiber, added to plastic concrete or mortar to change one or more of its properties at the fresh or hardened stages [4]. Admixtures are introduced before, during, or (in some cases) after the mixing of the major ingredients. Admixtures are generally divided into two groups: chemical admixtures and mineral admixtures [5]. Chemical admixtures used in concrete generally serve as water reducers, accelerators, set retarders, or a combination. ASTM C494, "Standard Specification for Chemical Admixtures for Concrete," contains classifications shown in Appendix A [5]. High-range admixtures reduce the amount of water needed to produce a concrete of a specific consistency by 12% or more. One potential admixture being used today is superplasticizer. Superplasticizers are high-range water-reducing admixtures that meet the requirements of ASTM C494 Type F or G [5] (refer to Appendix A). They are often used to achieve high-strength concrete from mixes with a low water-cement ratio with good workability and low segregation.

This research covers the experimentation of adding polymer fiber into the concrete mix before mixing. Mix proportion used was with respect to the cement's percent by weight in kg being an admixture only. The experiment consists of eighteen specimens: five experimental groups with varying proportions of polymer fiber to cement and a standard mix having no polymer fiber, each being poured and molded in three cylinders for different curing ages. Testing the specimens is classified according to the curing age of the concrete as on the seventh, fourteenth and twenty-eighth days.

2. Literature Review

Concrete consists of a mixture of cement, water, and non-cementing or inert materials such as sand in combination with gravel, crushed stone or air-cooled iron blast furnace slag. As stated on the National Structural Code of the Philippines Sec. 403.7.1, Admixture to be use in concrete shall be subjected to prior approval by the engineer [6]; Sec. 403.7.5, Water reducing admixtures, retarding admixtures, accelerating admixtures, water-reducing and accelerating admixtures shall conform to "Specification for Chemical Admixtures for Concrete" or "Specification for Chemical Admixtures for Use in Producing Flowing Concrete" [6]; and Sec. 403.7.8, Admixtures used in concrete containing ASTM C845 expansive cement shall be compatible with the cement and produce no deleterious effects [7].

Somayaji's Civil Engineering Materials textbook also states that, "cement admixture is a material other than water, aggregates, cement, and fiber, added to plastic concrete or mortar to change one or more of its properties at the fresh or hardened stages." Admixtures may be classified as chemical admixture or mineral admixture [1, 14]."

According to McGraw Hill's Civil Engineering Handbook "when Portland cement is replaced by a polymer, the resulting concrete has a lower rate of water absorption, higher resistance to cycles of freezing and thawing, better resistance to chemicals, greater strength, and excellent adhesion qualities compared to most other cementitious materials [8, 12]." The most commonly used resins (polyesters and acrylics) are mixed with aggregates as a monomer, with a cross-linking agent (hardener) and a catalyst, to reach full polymerization [9, 13]. Polymer concretes are usually reinforced with metal fibers, glass fibers, or mats of glass fiber. Polymer-Impregnated Concrete (PIC) is cured Portland cement concrete that is impregnated with a monomer using pressure or a vacuum process. The monomer (most often an acrylic) is polymerized by a catalyst, heat, or ultraviolet radiation. A continuous surface layer is formed that waterproofs and strengthens and fills the voids."

The American Concrete Institute (ACI) Committee has reported a present state development of the mechanics for fiber reinforcing of Portland cement concrete by metallic, glass, plastic and natural fibers along with techniques for mixing and mix proportioning, placing, finishing and actual and potential applications [10, 15].

2.1. Admixtures for Concrete

Admixtures are anything other than Portland cement, water, and aggregates that are added to a concrete mix to modify its properties. Included in this definition are chemical admixtures (ASTM C494 and C260), mineral admixtures (such as fly ash C618) and silica fume, corrosion inhibitors, colors, fibers, and miscellaneous (pumping aids, damp proofing, gas-forming, permeability-reducing agents) [12, 16]. Many concrete admixtures are available to modify, improve, or give special properties to concrete mixtures. Admixtures should be used only when they offer a needed improvement not economically attainable by adjusting the basic mixture. Since improvement of one characteristic often results in an adverse effect on other characteristics, admixtures must be used with care [13, 17].

2.2. Chemical Admixtures

They are used in concrete generally serve as water reducers, accelerators, set retarders, or a combination. ASTM C494, "Standard Specification for Chemical Admixtures for Concrete," contains the following classifications shown in Appendix A. High-range admixtures reduce the amount of water needed to produce a concrete of a specific consistency by 12% or more [14, 18].

2.2.1. Water-reducing admixtures: Decrease water requirements for a concrete mix by chemically reacting with early hydration products to form a monomolecular layer at the cement-water interface that lubricates the mix and exposes more cement particles for hydration.

2.2.2. Superplasticizers: They are high-range water-reducing admixtures that meet the requirements of ASTM C494 Type F or G. They are often used to achieve high-strength concrete from mixes with a low water-cement ratio with good workability and low segregation.

2.2.3. Air-entraining agents: Increase the resistance of concrete to frost action by introducing numerous tiny air bubbles into the hardened cement paste.

2.2.4. Set-accelerating admixtures: They are used to decrease the time from the start of addition of water to cement to initial set and to increase the rate of strength gain of concrete. The most commonly used set-accelerating admixture is calcium chloride.

2.2.5. Retarding admixtures: They are used to retard the initial set of concrete. A Type B or D admixture will allow transport of concrete for a longer time before initial set occurs. Final set also is delayed. Hence, precautions should be taken if retarded concrete is to be used in walls

2.3. Mineral Admixtures

These include fly ashes, pozzolans, and micro silicates. Natural cement is sometimes used as an admixture [19, 20].

2.3.1. Corrosion Inhibitors: They are sometimes added to a concrete mix to protect reinforcing steel. The steel usually is protected against corrosion by the high alkalinity of the concrete, which creates a passivation layer at the steel surface

2.3.2. Damp proofing admixtures: They may be a waterproofing or a damp proofing compound or an agent that creates an organic film around the reinforcing steel, supplementing the passivation layer. The latter type of admixture may be added at a fixed rate regardless of expected chloride exposure.

2.3.3. Gas-forming admixtures: They are used to form lightweight concrete. They are also used in masonry grout where it is desirable for the grout to expand and bond to the concrete masonry unit. They are typically an aluminum powder.

2.3.4. Coloring admixtures: They may be mineral oxides or manufactured pigments. Coloring requires careful control of materials, batching, and water addition in order to maintain a consistent color at the jobsite. Note that raw carbon black, commonly used for black color, greatly reduces the amount of entrained air in a mix.

2.4. Miscellaneous Admixtures

2.4.1. Bonding admixtures: They are organic polymer emulsions (sometimes called latexes). They usually increase the air content of mortars or concretes [15, 18]. The principal organic polymer emulsions used in these admixtures are polyvinyl acetate, acrylic or styrene-butadiene. The polyvinyl acetate types may or may not be re-emulsifiable. The re-emulsifiable polyvinyl acetate types should be restricted to interior or other areas not subjected to immersion. Bonding admixtures tend to render plastic concretes sticky and more difficult to place and finish. Part of this characteristic is due to their air-entrainment and part to the nature of the latex itself.

2.5. Polymer Csoncrete

When Portland cement is replaced by a polymer, the resulting concrete has a lower rate of water absorption, higher resistance to cycles of freezing and thawing, better resistance to chemicals, greater strength, and excellent adhesion qualities compared to most other cementitious materials [16, 21].

The most commonly used resins (polyesters and acrylics) are mixed with aggregates as a monomer, with a cross-linking agent (hardener) and a catalyst, to reach full polymerization [17, 22]. Polymer concretes are usually reinforced with metal fibers, glass fibers, or mats of glass fiber. Polymer-impregnated concrete (PIC) is cured Portland cement concrete that is impregnated with a monomer using pressure or a vacuum process. The monomer (most often an acrylic) is polymerized by a catalyst, heat, or ultraviolet radiation. A continuous surface layer is formed that waterproofs and strengthens and fills the voids.

3. Conceptual Framework

As illustrated in Figure 1, polymer fiber (polyvinyl alcohol) in powder form is being dissolved in water (at specified water requirements for the mix design) to become a solution. The solution will be soaked within twenty-four hours. This viscous liquid solution is being added to the cement, sand, and gravel at 1:2:4 proportional mix design of class “A”. Polymer fibers used is based on the cement’s percent by weight in kg. The concrete mix is being poured into the mold, measuring 6 inches diameter by 12 inches high cylinder and tamped layer by layer with the use of a rod. The specimen formed is being cured with water through sprinkling. Curing ages are 7 days, 14 days, and 28 days, respectively. After curing for certain days, it will then be subjected for testing on the hydraulic press to get its compressive strength.

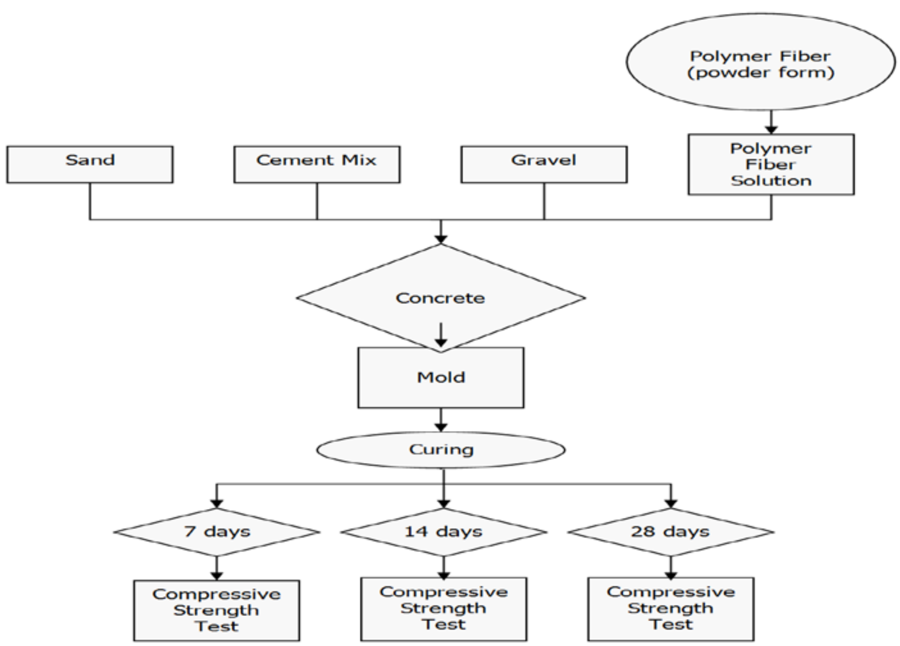


Figure 1. Conceptual Framework

4. Experimental Investigation

Experimental method of research was used for the formulation of the study being conducted. The researcher has used it to provide exact measures for more appropriate results as to compressive strength test is concerned. The experiments made were of five different groups, as to the polymer fibers being proportioned to the cement’s percent by weight in kg such as 2% to 98%, 4% to 96%, 6% to 94%, 8% to 92%, and 10% to 90%, respectively. This polymer fiber solution is being added to other aggregates to form concrete. Also, a control group with standard concrete mixes having no polymer fiber is made, to provide a reference for strength comparison.

The polymer fibers used in the experiment were of five different proportions: polymer fiber to cement's percent by weight in kg ranging from 2% to 98%, 4% to 96%, 6% to 94%, 8% to 92%, and 10% to 90%, respectively. This proportion is according to the specification of cement at 6 kg per three (3) pieces of cylinders, taken polymer fiber as ones and cement as tens percentage. The polymer fiber (polyvinyl alcohol, polyvinyl acetate) in powder form was dissolved into the water and soaked for 24 hours. Some important notes on polyvinyl alcohol have been listed on the Appendix B, C and D for further reference.

Mix specifications (per 3 pieces of cylinders) were: sand (fine aggregates) 8,340 cm^3; gravel (coarse aggregates) 16,680 cm^3; water 2.84 liters, with a design slump of 3 inches. Computation for materials to be used as well as its corresponding cost constraints has been showed in the Appendix E, F & G.

4.1. Experimental Procedure

The concrete mix was poured into eighteen molds, 6 inches diameter by 12 inches high cylinders. The specimens were grouped according to the proportions of polymer fiber to cement (by weight in kg) such as 2% to 98%, 4% to 96%, 6% to 94%, 8% to 92%, and 10% to 90%, respectively. These mixes were the experimental groups and a standard mix with no polymer fiber was the controlled group.

The polymer fiber solution (polyvinyl acetate being dissolved in water) was mixed manually with a shovel to sand and gravel at constant mix proportion of class "A" at 1:2:4. In the mixing process, it had been noticeable that the greater the polymer fiber the more viscous is the mix, which made it non-workable to place. After placing (pouring) into the cylinders, the specimens were tamped layer by layer with the use of a rod. The cylindrical molds used for handling specimen were removed two (2) days after pouring. Curing process used for the specimens was sprinkling method only due to the water-reduction characteristic of the polymer fiber as being added to the cement. The specimens were tested on the hydraulic press on the seventh, fourteenth and twenty-eighth days of curing as per ASTM designation to get the compressive strength. It was noted that the results taken from the standard mix was the same as the 6% to 94% proportions of polymer fiber to cement, respectively. Moreover, the 2% to 98% proportions of polymer fiber to cement gave the highest strength result.

5. Results and Discussion

Under compressive strength test with the use of the hydraulic press, the specimens were cracked as the concrete has reached its ultimate strength and recorded as listed above. As shown in Tables 1, 2 and 3, the results of the experimental group showed moderate advantage over the standard group as early as on the 7th day at the proportion of 4% to 96% and 2% to 98%, polymer fiber to cement, respectively. Likewise, it was observed, that the strengths obtained from the proportion of 6% to 94% seem equal to that of the standard mix. Moreover, at the 14th and 28th days, the specimen showed greater strength over the standard group at the proportion 6% to 94%, 4% to 96% and 2% to 98%. This time, the strength obtained from the proportion 4% to 96% and 6% to 94% gives higher strength to that of the standard mix. Most importantly, the proportion of 2% to 98% gives the highest strength obtained from 7, 14 and 28 days of curing.

Also, it was observed and inferred that the greater strength results are due to the bonded aggregates, which can be seen from the cracked specimens showing fine textures of aggregates. Graphical presentation of results has been showed in the Appendix H.

The results prove that polymer fiber satisfies strength requirements as it gives better results over the standard mix. As the standard mix only gives a range of values for 4,000 - 5,000 psi compressive strength, while the polymer fiber mix reached up to 6,000 psi. (Refer to Appendix I)

Table 1. 7th Days of Curing

Specimen Type	Cement Content %	Polymer Fiber Content %	Compressive Strength kg / cm²	Compressive Strength lb. / in²
Standard (Control)	100	0	225	3194
With Polymer Fiber	98	2	275	3903
With Polymer Fiber	96	4	250	3548
With Polymer Fiber	94	6	225	3194
With Polymer Fiber	92	8	175	2484
With Polymer Fiber	90	10	175	2484

Table 2. 14th Days of Curing

Specimen Type	Cement Content %	Polymer Fiber Content %	Compressive Strength kg / cm²	Compressive Strength lb. / in²
Standard (Control)	100	0	250	3548
With Polymer Fiber	98	2	300	4258
With Polymer Fiber	96	4	275	3903
With Polymer Fiber	94	6	275	3903
With Polymer Fiber	92	8	225	3194
With Polymer Fiber	90	10	200	2839

Table 3. 28th Days of Curing

Specimen Type	Cement Content %	Polymer Fiber Content %	Compressive Strength kg / cm²	Compressive Strength lb. / in²
Standard (Control)	100	0	300	4258
With Polymer Fiber	98	2	400	5677
With Polymer Fiber	96	4	350	4968
With Polymer Fiber	94	6	325	4613
With Polymer Fiber	92	8	275	3903
With Polymer Fiber	90	10	225	3194

6. Conclusion

This study has been made to determine the influence of polymer fiber on strength of concrete. Also, to further analyze polymer fiber and it's various structural applications that would greatly contribute to the construction industry.

The experiment made was formed by mixing dissolved polymer fiber (polyvinyl alcohol, polyvinyl acetate) into the cement, sand, and gravel at 1:2:4 mix proportion of class "A". The polymer fiber being added into the concrete mix has five different proportions ranging from 2% to 10% with respect to the cement's weight in kg. These concrete mixes were molded in a cylinder, and then cured for seven, fourteen and twenty-eight days. After curing at specified days, the specimens were subjected to compressive strength test with the use of the hydraulic press.

Based on the compressive strength test results, the specimens were noted that polymer fiber mix gives better strength than the standard mix up to 50% at the proportion 6% to 94%, polymer fiber to cement, respectively. It has also been found and observed that the greater the polymer fiber, the more viscous is the mix, which makes it non-workable to mix.

On the basis of the compressive strength test results and physical observations, the conclusion that, it is possible to add polymer fiber (polyvinyl chloride) as a cement admixture for concrete mixes showing greater strengths over the standard mix have been made. Besides, it gives the following consequences:

a).The proportion 2% of polymer fiber & 98% of cement by weights gave the highest compressive strength results. Proportion 6% of polymer fiber & 94% of cement gave equal strength to the standard mix.

b).Polymer fiber being added to the cement as an admixture gave efficient characteristic on the performance of the concrete with respect to its properties as to better strength, durability, elasticity and shrinkage.

c).Concrete may adopt the plastic's property in terms of elasticity itself. Giving higher strength results tend the concrete to deform but would certainly return to its original shape as unloaded.

7. Appendices

7.1. Appendix A: Chemical Admixtures

Type	Description	ASTM standards	Applications
A	Water-reducing admixtures	C494	To get dense concrete, to improve workability
B	Retarding admixtures	C494	To delay setting and hardening; hot-weather concreting; large structures
C	Accelerating admixtures	C494	To accelerate setting and early strength development; cold-weather concreting
D	Water-reducing and retarding admixtures	C494	Similar to those for types A and B
E	Water-reducing and accelerating admixtures	C494	Similar to those for types A and C
F	Water-reducing, high range admixtures	C494	In high-strength concrete; to improve watertightness and workability
G	Water-reducing, high range, and retarding admixtures	C494	Similar to those for types B and F
	Air-entraining admixtures	C260	To improve durability and workability
	Antifreeze admixtures		Cold-weather concreting; to minimize freezing of water in fresh concrete

7.2. Appendix B: Polyvinyl Alcohol

(PVA; PVOH) CAS: 9002-89-5 (-CH_2CHOH-)

A water-soluble synthetic polymer made by alcoholysis of polyvinyl acetate.

7.2.1. Properties: White to cream-colored powder. Properties depend on degree of polymerization and the percentage of alcoholysis, both of which are controllable in processing. Water solubility increases as molecular weight decreases; strength, elongation, tear resistance, and flexibility improve with increasing molecular weight. Tensile strength up to 22,000 psi; decomposes at 200°C. PVA has high impermeability to gases, is unaffected by oils, greases, and petroleum hydrocarbons. Attacked by acids and alkalies. It forms films by evaporation from water solution and combustible.

7.2.2. Grade: Super high viscosity (molecular weight 250,000-300,000), high viscosity (molecular weight 170,000-220,000), medium viscosity (molecular weight 120,000-150,000), and low viscosity (molecular weight 25,000-35,000).

7.2.3. Use: Textile wrap and yarn size, laminating adhesives, molding powders, binder for cosmetic preparations, ceramics, leather, cloth, nonwoven fabrics and paper, paper coatings, grease proofing paper, emulsifying agent, thickener and stabilizer, photosynthetic films, cement and mortars, intermediate for other polyvinyl, imitation sponges and printing inks (glass).

7.3. Appendix C: Polyvinyl acetate

(PVAC) CAS: 9003-20-7 [CH_2CH ($OOCCH_3$)]

7.3.1. Properties: Colorless, odorless, transparent solid, insoluble in water, gasoline, oils, and fats; soluble in low molecular weight alcohols, esters, benzene, and chlorinated hydrocarbons, resistant to weathering and combustible.

7.3.2. Derivation: Polymerization of vinyl acetate with peroxide catalysts.

7.3.3. Use: Latex water paints; adhesives for paper, wood, glass metals, and porcelain; intermediate for conversion to polyvinyl alcohol and acetyls; sealant; shatterproof photographic bulbs; paper coating and paperboard; bookbinding; textile finishing; nonwoven fabric binder; component of lacquers, inks, and plastic wood; strengthening agent for cement.

7.4. Appendix D: Cement Chemistry

Portland cement typically consists of about 65 percent CaO, 21 percent SiO_2, 4.5 percent $A_{l2}O_3$, and 3 percent Fe_2O_3. In addition, small quantities—less than 2.5 percent—of SO_3, MgO, Na_2O, and K_2O are found. About 75 percent of Portland cement is composed of calcium silicates; compounds of aluminum, iron, and gypsum make up the balance. The four major compounds of Portland cement are:

Tricalcium silicate ($3CaO \bullet SiO_2$)
Dicalcium silicate ($2CaO \bullet SiO_2$)
Tricalcium aluminate ($3CaO \bullet Al_2O_3$)
Tetracalcium aluminoferrite ($4CaO \bullet Al_2O_3 \bullet Fe_2O_3$)

7.5. Appendix E: Materials and Concrete Mix

7.5.1. Materials

Radius of the Cylinder = 0.0762 m

Height of the Cylinder = 0.3048 m

Volume of one Cylinder = Area x Height
= $\pi r^2 h$
= $\pi (0.0762 \text{ m})^2 (0.3048 \text{ m})$
= $5.560 \times 10^{-3} \text{ m}^3$

Volume of 3 Cylinders = $3 \times 5.560 \times 10^{-3} \text{ m}^3$
= $16.68 \times 10^{-3} \text{ m}^3$

7.5.2. Concrete Mix

Class "A" mix (1 : 2 : 4) per three (3) pieces of cylinder

Cement : $16.68 \times 10^{-3} \text{ m}^3 \times 9$ = 0.15 bag
0.15 bag = 1 bag
x 40 kg
x = 6 kg

Sand : $16.68 \times 10^{-3} \text{ m}^3 \times 0.5$ = $8.34 \times 10^{-3} \text{ m}^3$

Gravel : $16.68 \times 10^{-3} \text{ m}^3 \times 1.0$ = $16.68 \times 10^{-3} \text{ m}^3$

Water : 5 gal = 1 bag of cement (40 kg)

$$\frac{5 \text{ gal}}{1 \text{ bag}} = \frac{x}{0.15 \text{ bag}}$$

$$x = \frac{0.75 \text{ gal}}{1 \text{ gal}} \frac{(231 \text{ in}^3)}{} \frac{(1.639 \times 10^{-5} \text{ m}^3)}{1 \text{ in}^3} \frac{(1000 \text{ li})}{1 \text{ m}^3}$$

$$x = 2.84 \text{ li} \approx 3 \text{ liters}$$

7.6. Appendix F: Concrete Mixture

Per three (3) pieces of cylinder

Specimen Type	Cement Content %	Polymer Fiber Content %	Cement Content Kg	Polymer Fiber Content kg	Sand cm^3	Gravel cm^3
Standard (Control)	100	0	6.00	0.00	8340	16680
With Polymer Fiber	98	2	5.88	0.12	8340	16680
With Polymer Fiber	96	4	5.76	0.24	8340	16680
With Polymer Fiber	94	6	5.62	0.36	8340	16680
With Polymer Fiber	92	8	5.52	0.48	8340	16680
With Polymer Fiber	90	10	5.40	0.60	8340	16680

7.7. Appendix G: Costing in Philippine Pesos

1 m^3 of sand = P 450.00

1 m^3 of gravel = P 850.00

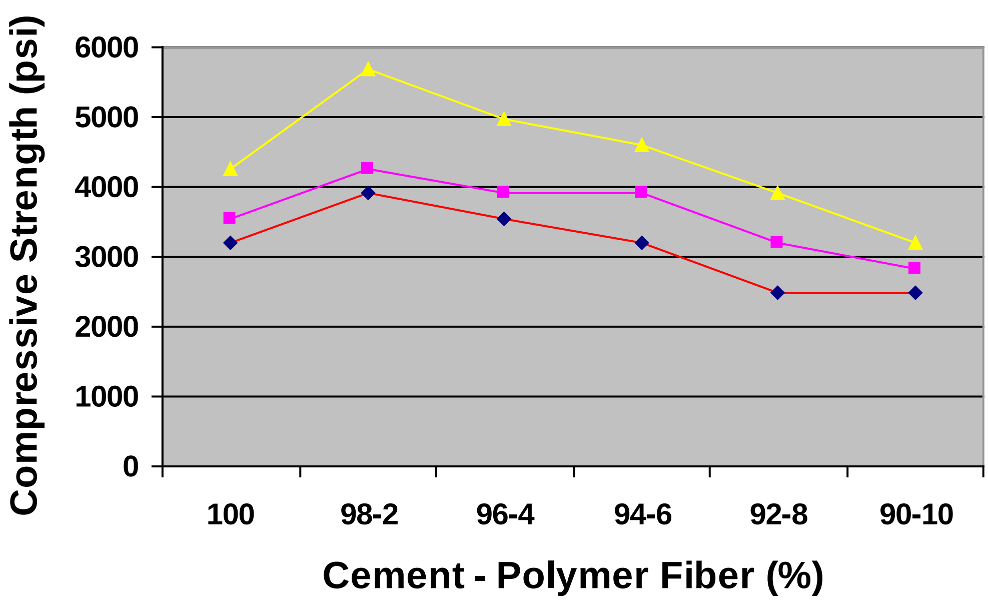
1 bag of cement (40 kg) = P 150.00

1 kg of PVA = P 100.00

Per three (3) pieces of cylinder

Specimen Type	Cement Content (Peso)	Polymer Fiber Content (Peso)	Sand cm^3 (Peso)	Gravel cm^3 (Peso)	TOTAL COST
Standard Mix (Control)	22.5		3.753	14.178	P 40.431
With 2% Polymer Fiber	22.05	12.00	3.753	14.178	P 51.981
With 4% Polymer Fiber	21.6	24.00	3.753	14.178	P 63.531
With 6% Polymer Fiber	21.15	36.00	3.753	14.178	P 75.081
With 8% Polymer Fiber	20.70	48.00	3.753	14.178	P 86.631
With 10% Polymer Fiber	20.25	60.00	3.753	14.178	P 98.181

7.8. Appendix H: Graphical Results



Legend:

After 7 Days of Curing

After 14 Days of Curing

After 28 Days of Curing

7.9. Appendix I: Typical Properties of Concrete-Polymer Materials

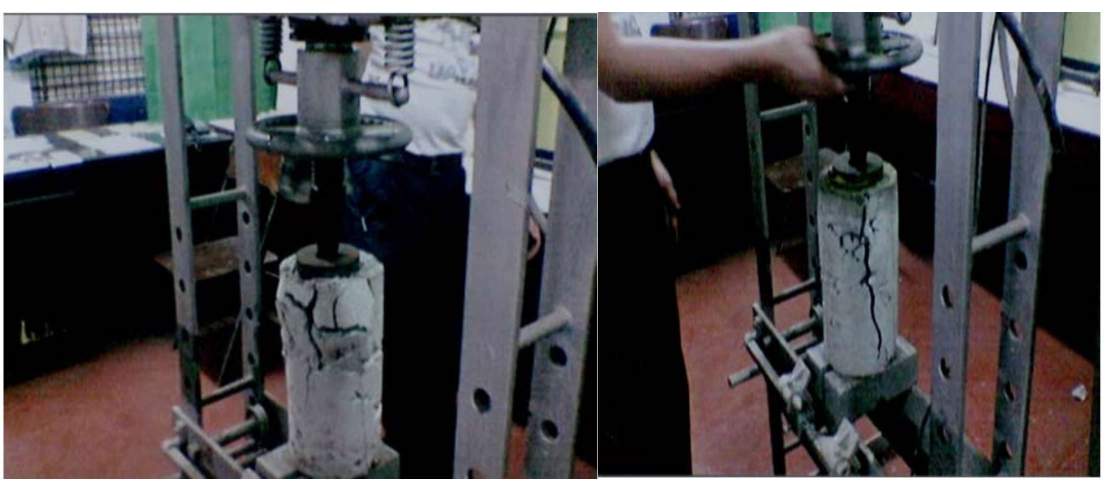
Property	Ordinary concrete	Polymer Concrete
Compressive strength, psi	4,000-5,000	6,000-20,000
Tensile strength, psi	300-350	1,000-2,000
Modulus of rupture, psi	400-600	1,200-4,000
Modulus of elasticity, psi	3-4 x 10^6	2-4 x 10^6
Abrasion resistance, factor of improvement	-	-
Water absorption	5-6	-
Freeze-thaw resistance, no. of cycles / % wt. loss	700/25	1,500/0-1

7.10. Appendix J: Specimen at Curing Stage

Concrete specimens being cured by sprinkling method within 7, 14 and 28 days

7.11. Appendix L: Specimen under Compressive Strength Test

After 7, 14 and 28 days of curing



7.12. Appendix M: Specimen after Test

Crack specimens. Concrete with polymer fiber reached compressive strength test results up to 5677 psi, much greater than the standard mix.

References

[1] S. Somayaji, Civil Engineering Materials, National Bookstore, Manila, **(2001)**.
[2] J. G. Potyondy, Geotechnique, Popular Books, Manila, **(1961)**.
[3] P. Schossig and T. Haussmann, "Micro-encapsulated Phase-Change Materials Integrated into Construction Materials", Construction Materials, vol. 89, no. 2, **(2010)**.
[4] A. S. Herrmann and J. Nickel, "Construction Materials based upon Biologically Renewable Resources from Components to Finished Parts", Polymer Degradation and Stability, vol. 59, no. 1, **(1998)**, pp. 251-261.
[5] H. A. Van der Sloot and O. Hjelmar, "Similarities in the Leaching Behaviour of Trace Contaminants from Waste, Stabilized Waste, Construction Materials and Soils", Science of the Total Environment, vol. 178, no. 1, **(1996)**, pp. 111-126.
[6] The Association of Structural Engineers of the Philippines.National Structural Code of the Philippines, vol. 1, **(2001)**, pp. 5-9.
[7] S. H. Kosmatka, "Design and Control of Concrete Mixtures, Skokie 3", Portland Cement Association, **(2003)**.
[8] A. Horvath, "Construction Materials and the Environment", Annu. Rev. Environ. Resour, vol. 29, **(2003)**, pp. 181-204.
[9] J. Lindberg and R. Svenson, "Wool Fabrics as Garment Construction Materials", Journal of the Textile Institute Transactions, vol. 51, no. 12, **(1960)**, pp. 1475-1493.
[10] M. Tomikawa and H. Ohkawa, U.S. Patent No. 3,940,811. Washington, DC: U.S. Patent and Trademark Office, **(1976)**.
[11] J. D. Ferry, Viscoelastic Properties of Polymers, Wiley, New York, **(1976)**.
[12] B. J. Folmer, "Supramolecular Polymer Materials: Chain Extension of Telechelic Polymers Using a Reactive Hydrogen-Bonding Synthon", Advanced Materials, vol. 12, no. 12, **(2000)**, pp. 874-878.
[13] M. A. Stuart, "Emerging Applications of Stimuli-responsive Polymer Materials", Nature Materials, vol. 9, no. 2, **(2010)**, pp. 101-113.

[14] R. M. Aseeva, "Combustion of Polymer Materials", Carl Hanser Verlag, pp. 389, **(1986)**.
[15] C. Meredith, "Combinatorial Methods for Investigations in Polymer Materials Science", Mrs Bulletin, vol. 27, no. 04, **(1976)**, pp. 330-335.
[16] K. S. Raja and M. G. Finn, "Hybrid Virus-Polymer Materials", Synthesis and Properties of PEG-decorated Cowpea Mosaic Virus. Biomacromolecules, vol. 4, no. 3, **(2003)**, pp. 472-476.
[17] F. Ansari, Intelligent Civil Engineering Materials and Structures. ASCE, vol. 1, **(1976)**.
[18] J. F. Shackelford, Introduction to Materials Science for Engineers, Wiley, Los Angeles, **(2006)**.
[19] W. F. Chen and J. R. Liew, The Civil Engineering Handbook, CRC Press, New York, **(2001)**.
[20] J. F. Young, The Science and Technology of Civil Engineering Materials, New York, **(1986)**.
[21] P. Domone, Construction Materials: Their Nature and Behaviour, Spons Architecture Price Book, New York **(2010)**.
[22] T. U. Ganiron Jr, Recycled Window Glass for Non-Load Bearing Walls, International Journal of Innovation, Management and Technology, vol. 3, **(2012)**, pp. 725-730.

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