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Application of Fiber Reinforcement Concrete Technique in Civil Constructions (pp. 157-172)

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Abstract

Deterioration of concrete structures due to steel corrosion is a matter of considerable concern since the repairing of these structures proved to be a costly process. Repair and rehabilitation of the civil structures needs an enduring repair material. The ideal durable repair material should have low shrinkage, good thermal expansion, substantial modulus of elasticity, high tensile strength, improved fatigue and impact resistance. Reinforcing the concrete structures with fibers such as polyester is one of the possible ways to provide all the criteria of the durable repair material. This type of reinforcement is called Fiber Reinforcement of Concrete Structures. There is an increasing worldwide interest in utilizing fiber. reinforced concrete structures for civil infrastructure applications To study the commercial viability of FRC Techniques in civil construction, three slabs were constructed by using polyester fiber along with cement matrix in Amara Development Association Training center ,Bahir Dar ,Ethiopia.The perfomace of the constructed slab was evaluated by various testing *methods. The results of the experiment have strong implication to apply this technology in civil construction works.*

Key words: Fiber, Polymers, Exposure Concrete, FRC-Fiber Reinforcement concrete

Introduction

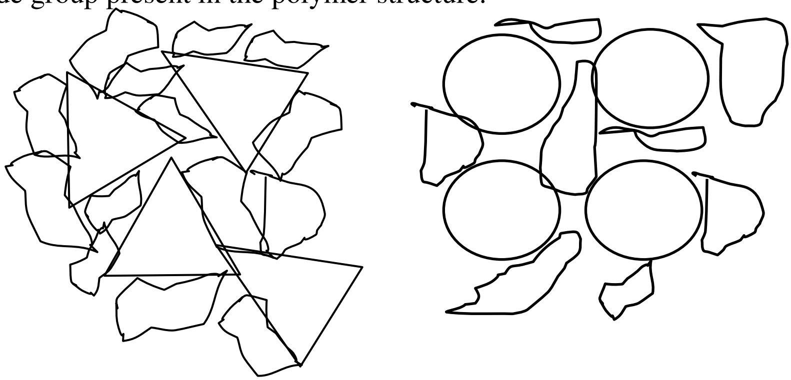
Civil structures made of steel reinforced concrete normally suffer from corrosion of the steel by the salt, which results in the failure of those structures (Bartos, 1991). Constant maintenance and repairing is needed to enhance the life cycle of those civil structures. There are many ways to minimize the failure of the concrete structures made of steel reinforce concrete. The customary approach is to adhesively bond fiber polymer composites onto the structure. This also helps to increase the toughness and tensile strength and improve the cracking and deformation characteristics of the resultant composite (Ramakrishna et al, 1989). But this method adds another layer, which is prone to degradation. These fiber polymer composites have been shown to suffer from degradation when exposed to marine environment due to surface blistering. As a result, the adhesive bond strength is reduced, which results in the de-lamination of the composite. Another approach is to replace the bars in the steel with fibers to produce a fiber reinforced concrete and this is termed as FRC. Basically this method of reinforcing the concrete substantially alters the properties of the non-reinforced cement-based matrix which is brittle in nature, possesses little tensile strength compared to the inherent compressive strength (William and Jeffery, 1999). The principal reason for incorporating fibers into a cement matrix is to increase the toughness and tensile strength, and improve the cracking deformation characteristics of the resultant composite. In order for fiber reinforced concrete (FRC) to be a viable construction material, it must be able to compete economically with existing reinforcing systems (Hannant, 1978). Only a few of the possible hundreds of fiber types have been found suitable for commercial applications. This paper deals specifically with the concrete reinforced with the 'polyester fibers'. The objective of this research is to explore the properties of polyester fibers in specific environments to which the commercial FRCs are exposed.

Background of Fiber Reinforced Concrete

Portland cement concrete is considered to be a relatively brittle material. When subjected to tensile stresses, non-reinforced concrete will crack and fail. Since mid 1800's steel reinforcing has been used to overcome this problem. As a composite system, the reinforcing steel is assumed to carry all tensile loads.

The problem with employing steel in concrete is that over time steel corrodes due to the ingress of chloride ions (Alias and Brown, 1992). In the northeast, where sodium chloride de-icing salts are commonly used and a large amount of coastal area exists, chlorides are readily available for penetration into concrete to promote corrosion, which favors the formation of rust. Rust has a volume between four to ten times the iron, which dissolves to form it. The volume expansion produces large tensile stresses in the concrete, which initiates cracks and results in concrete spalling from the surface (Balaguru and Slattum, 1995). Although some measures are available to reduce corrosion of steel in concrete such as corrosion inhibitive admixtures and coatings, a better and permanent solution may be replace the steel with a reinforcement that is less environmentally sensitive.

More recently micro fibers, such as those used in traditional composite materials have been introduced into the concrete mixture to increase its toughness, or ability to resist crack growth (Ahmed, 1982). FRC is Portland cement concrete reinforced with more or less randomly distributed fibers. In FRC, thousands of small fibers are dispersed and distributed randomly in the concrete during mixing, and thus improve concrete properties in all directions (Ziad and Gregory, 1989). Fibers help to improve the post peak ductility performance, pre-crack tensile strength, fatigue strength, impact strength and eliminate temperature and shrinkage cracks (Morton and Hearle, 1975). Several different types of fibers, both manmade and natural, have been incorporated into concrete. Use of natural fibers in concrete precedes the advent of conventional reinforced concrete in historical context. However, the technical aspects of FRC systems remained essentially undeveloped. Since the advent of fiber reinforcing of concrete in the 1940's, a great deal of testing has been conducted on the various fibrous materials to determine the actual characteristics and advantages for each product. Several different types of fibers have been used to reinforce the cement-based matrices. The choice of fibers varies from synthetic organic materials such as polypropylene or carbon, synthetic inorganic such as steel or glass, natural organic such as cellulose or sisal to natural inorganic asbestos. Currently the commercial products are reinforced with steel, glass, polyester and polypropylene fibers. The selection of the type of fibers is guided by the properties of the fibers such as diameter, specific gravity, Young's modulus, tensile strength etc and the extent these fibers affect the properties of the cement matrix (Ramakrishnan, et al, 1989). The advantages of using triangular cross sectional fiber in FRC technique is indicated in Fig.1. It is shown in Fig.2 that the bonding characteristics of polyester is better than nylon due to their functional side group present in the polymer structure.



More surface area for binding, better locking

Less surface area for binding,

Fig.1 Cross Sectional Shape of FRC Polyester on Locking Characteristics

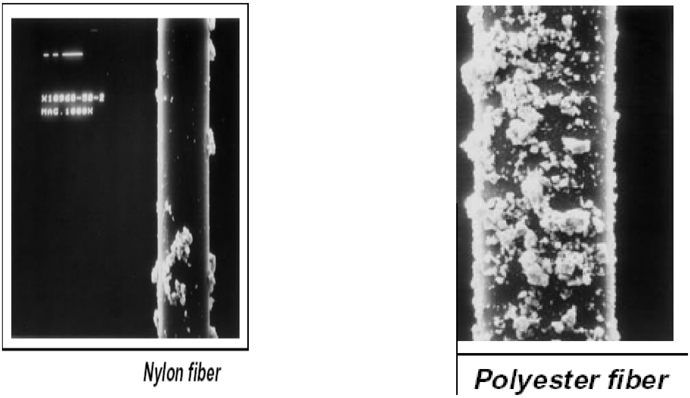


Fig.2 Comparative Bonding Properties of Nylon and Polyester Fibers

Fabrication of Polyester Fiber Reinforced Concrete

Polyester fibers are added to the concrete in several different forms and by using various techniques. The fibers can be incorporated into concrete as short discrete chopped fibers, as a continuous network of fibrillated film, or as a woven mesh. The form of the available fiber decides the method of fabrication. Each and every method has its own limitations. The choice of the method is guided by the volume percentage of the fibers that can be obtained during fabrication using a particular technique (Frank, 1960).

Daniel, Roller and Anderson (1998), produced concrete panels reinforced with chopped mono-filament polyester fiber by a '*spraysuction de- watering*' technique. Fiber volume content up to 6% can be achieved by using the spray suction de-watering techniques. Composites incorporating chopped monofilament and chopped fibrillated polyester film are produced using a mixing, dewatering and pressing technique. Fiber volumes up to 11% have been obtained by mixing chopped fiber directly into the matrix at high water-cement ratios and then removing the excess water through suction and pressing.A hand lay-up technique was used to produce composites with continuous networks of polyester fibrillated films. Woven polypropylene mesh can be incorporated into a cement matrix using a hand lay-up technique. High volume percentage of fibers (up to 12%) in the cement matrix can be obtained by using continuous polyester film networks or woven mesh with the hand lay-up technique (Ahmed, 1982).

When chopped polyester fibers are incorporated into conventional ready mixconcrete, volume percentages of fibers must be kept relatively low. This indicates that special mixing conditions are needed for high fiber volumes. The practical implication of this is that low fiber volumes should be specified for placement. Several researchers have acknowledged that the addition of fiber to concrete has a marked effect on the concrete slump, which is a measure of how concrete flows. A low slump rate is undesirable as molds will not fill efficiently leaving voids. Fiber reinforced concrete slump is dependent on fiber length and fiber concentration. Because polyester fibers are hydrophobic and non-polar, they can be mixed ahead of time to ensure uniform dispersion in the concrete mix. In the case of fibrillated film or tape fibers, mixing should be kept to a minimum to avoid unnecessary shredding of the fibers (Ronald, 1984).

Polyester fibers are usually added to ready mixed concrete after all the normal ingredients are completely mixed. When placing concrete the workability of the concrete is affected as the addition of polypropylene fibers has a definite negative impact on the slump, workability and finishability of the concrete (Balaguru and Slattum, 1995). An optimum quantity of super plasticizer while mixing helps avoid the problem of reduction in workability. Ready mixed concrete containing polypropylene fibers can be placed using conventional methods. To ensure maximum performance all entrapped air must be expelled from the concrete to achieve optimum density. Also during the process of incorporating of fibers more compaction must be done than for the plain concrete. Generally, polyester fibers, when mixed with concrete, respond well to conventional compaction techniques and fibers do not easily segregate from the mix (William, James and Jeffery, 1999).

Properties of FRC Polyester & Technical Data

Basic Use

Fiber Type II is a virgin Polyester fiber designed specifically to provide concrete with protection against early age crack formation. When added to concrete during mixing, the fibers disperse uniformly and produce a three dimensional network of micro-reinforcement.

Every fiber helps to prevent the tiny fissures that can occur when concrete's tensile strength is weakest. By reducing early age crack formation, the number of weakened planes and the potential for future crack formation may also be reduced.

Fiber Type II is routinely used to enhance the performance of industrial and commercial floors, pavements, overlays, elevated slabs, residential concrete, precast concrete, barrier walls, tunnel and culvert linings, water reservoir linings, bridge deck overlays and various concrete repair systems. Almost any concrete product can benefit from Fiber Type II. The technical superiority of polyester fiber is stated in Table1.

Table 1: Technical Superiority of Polyester (Recron) Usage in FRC Techniques

Sr. N	Property	PP	RECRON 3s	Comment
1.	Fibre Cross section	Circular	Triangular	All fibres worldwide are circular. Recron 3s scores in better anchoring and thus gives improved strength properties.
	Fibre type	Fibrillated	Fine filaments	Recron 3s gives a very high number of fibres critical for performance. Fibrillated fibres do not open and stand protruded/bunch out.
3.	Specific Gravity	0.9	1.36	PP floats whereas Recron 3s due to its higher density than water mixes well.
4.	Melting Point °C	160	250 +	Better thermal stability
	UV stability	Poor	V. Good	UV resistance is essential for better sun exposure weather ability.
6.	Dry dispersion Wet	V. Good Medium	V. Good V. Good	Recron 3s disperses excellently due to special finish developed by RTC via extensive research. Years of effort put in.
7.	Fibre production/Cutting	Guillotine cutters, which lack cutting accuracy. Mixed lengths seen.	Accurate cutting at RILs state of art fibre production units	High quality of Recron 3s vs. any international concrete fibre brand.
8.	Alkali Resistance	Good	Good in mild (cement)	It is true that PP has better alkali resistance. But for application Recron 3s has very good alkaline resistance. Cement has 12/13 pH (0.7% NaOH). It goes down when sand, chips are mixed. Recron 3s is good at this pH &

Technical Data

Chemical: Fiber Type II is a polyester (PET) co-polymer fiber manufactures to meet precise engineering standards. Fiber Type II is chemically resistant and non-toxic. Fiber Type II should not react with chemical admixtures or calcium chloride. Fiber Type II will not rust, rot, or corrode.

Physical Properties:

Specific Gravity	1.34
Tensile Strength	36.213 to 39.03 kN/m^2
Young's Modulus	236.23 kN/m^2
Melting Point, deg F	490 to 500
Ductility Range, deg F	-100 to 440

Ignition Point, deg F	1100
Thermal Conductivity	Low
Electrical Conductivity	Low
Chemical Resistance	High
Standard Length	1.905cm
Standard Dosage	600 g/m^3
	600g/m^3 to 1097g/m^3

Installation

Addition/Mixing Procedures:

Fiber Type II is very easy to add: One pre-weighed bag per cubic meter of concrete. It may be added with the coarse and fine aggregate at the batch plant, with the other ingredients, no additional mixing time is required. If added at the job site, approximately 13 to 15 minutes of mixing is required with the drum rotating at mixing speed. Over mixing should not alter its performance.

Availability and Cost

Fiber Type II can be purchased internationally. Orders are shipped UPS, common carrier, contract carrier or air freight. General estimating should be based on $.05 per 0.093m^3 per 2.54cm of concrete thickness. Price may vary based on volume and location.

Role of Fibers in FRC Applications

The FRC in concrete plays the following roles:

- Checks crack
- Reduces permeability- seepage of water
- Holds small aggregates
- Improves endurance under breaking load – 3 times higher than plain concrete, thus, M-40 concrete broke in 40 sec in the laboratory while M 40 concrete with fiber took 1 min 20 sec to break, that too not in pieces.
- Increases abrasion resistance by 40% thereby making for improved life of walkways, roads, and industrial flooring.

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- Tests have shown that floor with fiber where there is heavy movement of vehicle with load has lasted longer, thus 6 months without fiber but 9 months without surface cracks, with fiber.
- In areas where there is high soil water, it saves pile from water seepage.
- The mix could be redefined to achieve economies.

Fiber composition in Cement Matrix

Fiber reinforced concrete has started to find its place in many areas of civil infrastructure applications where the need for repairing, increased durability arises. Also FRCs are used in civil structures where corrosion can be avoided at the maximum.Fiber reinforced concrete is better suited to minimize cavitation /erosion damage in structures such as sluice-ways, navigational locks and bridge piers where high velocity flows are encountered (Feldman and Barbalata, 1996). A substantial weight saving can be realized using relatively thin FRC sections having the equivalent strength of thicker plain concrete sections. When used in bridges it helps to avoid catastrophic failures. Also in the quake prone areas the use of fiber reinforced concrete would certainly minimize the human casualties. In addition, polypropylene fibers reduce or relieve internal forces by blocking microscopic cracks from forming within the concrete (Reinhardt and Naaman, 1991). The main disadvantage associated with the fiber reinforced concrete is fabrication. The process of incorporating fibers into the cement matrix is labor intensive and costlier than the production of the plain concrete. The real advantages gained by the use of FRC overrides this disadvantage

The Advantages of Using POLYESTER in FRC

Controls Cracking

The addition of Polyester in concrete products and stucco prevents cracking caused by volume change.

Increases Flexibility
The use of Polyester has demonstrated an increase in flexural strength in concrete products and stucco.

Reduces Water Permeability
The use of Polyester reduces water migration. They prevent water or moisture from entering and migrating throughout the concrete.

Reduces Rebound in Shotcrete
Polyester aids in reducing the "splattering" of shotcrete.

Safe and Easy To Use
Polyester is environmentally friendly and non-hazardous. They easily disperse and separate in the mix.

Methodology
Site: Amahra Region Development Association Training center (ADA), Bahir Dar, Ethiopia

Materials
Polyester fiber -12 mm stable length

Application Methods:
In order to assess the performance of FRC concrete, two small slabs were constructed (100cmX 50 cm X 20 cm) in the work site of ADA. One slab was constructed without Fiber and other slab was constructed incorporating fibers in the cement matrix.
Fiber Application rate: 120 grams /m^2
Mortar mix: 1:4 volume
Water: cement ratio: 0.8

The procedure consists in first dipping half the quantity of fibers in water and mixing thoroughly. Next, the half quantity of fiber was thoroughly mixed with mortar. The remaining half quantity of fiber was then added and thoroughly mixed together. The resulting mix was then applied over the selected construction areas.

Test Results

Table 2: Compressive Strength of FRC Composite

PROPERTIES	Without Recron 3s (N/mm^2	With Recron 3s (N/mm2)	% Increase
Compressive strength test	17.1	**20.9**	**22.2**
Flexural strength test	**5.2**	**6.9**	**32.7**
Tensile strength test	**1.97**	**2.1**	**6.6**

Recron: Commercial trade name of polyester

Table 3: Advantages of FRC Technique in Civil Construction

Mortar Mix	1:4(By Volume)	1:4(By Volume)	% Saved
Water /Cement Ratio	0.8	0.8	
Flow Percentage	20Min = 30 %	20Min = 27.25%	
	40Min = 40%	40Min = 23.20%	
	60Min = 43%	60Min = 30.20%	
Rebound Loss			
Ceiling	21.70 %	12.38 %	40%
Wall	22.00%	13.21%	39%
Quality of Mix	Good	Good	

Results & Discussion

The objective of the experiment is to generate the baseline tensile data for the polyester fibers for the working performance in civil engineering application. The evaluation of performance of the first phase of the proposed research, which is to evaluate the compressive strength, tensile strength, Flextural strength and rebound loss test of the with fiber and without fiber.

The experimental results given in Tables 2 and 3 have shown that the construction with fiber has very high compressive strength. This is due to the anisotropic characteristics of polyester fiber, a property which enables the structure to bear the tension applied on them in all direction. This results obtained from the flexural strength experiment indicated that the flexural strength of construction with FRC has 32.7% higher than that of construction without FRC. The reason for this great improvement is due to the formation of 3D structure between fiber, cement and other ingredients involved in the construction. The main reason for crack formation in the constructed area is due to sudden evaporation water from the inner part of the constructed area .This kind of sudden evaporation will disintegrate the isotropic structure of the constructed areas. In FRC technique, the presence of fiber will slow down the evaporation since polyester is a hydrophobic fiber will tend allow the water to drive away from the constructed areas at a slower rate. The tensile strength of construction with FRC was increased by 6.6 % (Shoa, Srinivasan and Shah, 2000).The polyester fiber do not have weld fails at higher loads. This is mainly because of fibers involved in FRC techniques have high tenacity. During the fiber manufacturing process of FRC fibers, their tenacity greatly improved by brought its hydrogen bond very close to the axis of its backbone chain. This arrangement would improve the load bearing capacity of the polyester fiber.

It is inferred from all the test results that the tensile behavior of the FRC concrete is greatly improved. Hence it can be concluded that

FRC technique serves to prevent the cracks and increase the service life of the construction

Conclusions

- Polyester fiber has been found to be effective in controlling crack formation
- Presence of FRC composites was found to significantly help to increase the serviceability of the constructed areas
- It reduces maintenance cost
- Its design methodology is easy
- It could lead to overall economy.

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