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A Study of Utilization Aspect of Polypropylene Fibre for Making Value Added Concrete

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ABSTRACT

Polypropylene is a synthetic hydrocarbon polymer, the fiber of which is made using extrusion processes by hot drawing the material through a die. Its use enables reliable and effective utilization of intrinsic tensile and flexural strength of the material along with significant reduction of plastic shrinkage cracking and minimizing of thermal cracking. The fibres are chemically inert, have hydrophobic surfaces, are very stable in the alkaline environment of concrete and resist plastic shrinkage cracking. Nevertheless, they also have some disadvantages including poor fire resistance, sensitivity to sunlight and oxygen, a low modulus of elasticity, and poor bonding with the concrete matrix. This study presents the information about the polypropylene fibre for sustainable and economical concrete. Polypropylene fibres can be used in concrete to improve its strength, abrasion resistance and other durability factors.

INTRODUCTION

Polypropylene fibre is a long chain of synthetic polymer composed of stereoregular isotactic polymer. Polypropylene fibre/ filament possesses all the outstanding properties associated with the Polypropylene Polymer. Being lightest amongst fibres, polypropylene yields higher length of fabric, than any other commercial fibre. It has high tensile strength, wrinkle resistance and abrasion resistance.

Most commercial polypropylene is isotactic and has an intermediate level of crystallinity between that of low-density polyethylene (LDPE) and high-density polyethylene (HDPE). Polypropylene is normally tough and flexible, especially when copolymerized with ethylene. This allows polypropylene to be used as an engineering plastic. Polypropylene is reasonably economical, and can be made translucent when uncolored but is not as readily made transparent as polystyrene, acrylic, or certain other plastics. It is often opaque or colored using pigments. Polypropylene has good resistance to fatigue. Polypropylene fibre is good, because it is not expensive, inert in high pH cementitious environment and easy to disperse.

Various fibres such as those made from polypropylene (PP) have been applied. PP fibres can be produced as monofilaments or as collated fibrillated fibre bundles; their properties are related to the degree of crystallinity. PP is a linear hydrocarbon, although in some cases methyl side groups are attached to alternate carbons to improve oxidation resistance. Commercial success of polypropylene fibres as a filler material in Portland cement concrete (PCC) is due to their advantageous properties.

The use of relatively low-modulus PP fibres does not yield substantial improvement of the tensile strength but does significantly improve the flexural strength, toughness and ductility. Initial bonding between the fibres and the concrete can be attributed to physical adhesion – and also to static friction caused by the surface finish of the fibres.

In general, friction plays an important role in confining stress – increasing with the fibre size. In addition, most fibre deformation processes lead to local mechanical interactions between fibre and matrix - involving a typical distribution of the load by the matrix. Some controversy seems to exist because fibres can reduce crack propagation but poor adherence of the fibres to the cement paste can furnish a passage for the penetration of external agents. Fibres act as cracks arresters through the initial loading stages, and increase the energy required for crack propagation what provides an increase in the strength. During the later stages of straining, the fibres distribute the microcracking, thus increasing toughness and apparent strength. The eventual failure of the fibres as well as of concrete is brittle; concrete disintegrates into pieces in a rather sudden way, while the fibres largely still preserve their original size.

Polypropylene fibres are tough but have low tensile strength and modulus of elasticity; they have a plastic stress-strain characteristic. Monofilament polypropylene fibres have inherent weak bond with the cement matrix because of their relatively small specific surface area. Fibrillated polypropylene fibres are slit and expanded into an open network thus offering a larger specific surface area with improved bond characteristics.

Polypropylene fibres are gaining in significance due to the low price of the raw polymer material and their high alkaline resistance). They are available indifferent forms like monofilament or fibrillated manufactured in a continuous process by extrusion of a polypropylene homopolymer resin. Micro synthetic fibres, based on 100% Polypropylene are used extensively in ground-supported slabs for the purpose of reducing, plastic shrinkage cracking and plastic settlement cracking.

Figure 1: polypropylene fibre
Source: http://www.google.co.in/images

SCENARIO OF POLYPROPYLENE FIBRE IN INDIA AND WORLD

Production of polypropylene fibre

Day by day the production capacity of polypropylene fibre is increases very speedy. In the year of 2004 and 2009, the production capacity is 41.3 and 49.6 million metric tons respectively as per the polypropylene market study by the Alberta Economic Development. The predicted market production in the year of 2012-13 is about 54.58 million metric tons. There are limited company in India who are produces only 9% polypropylene fibre from the total production of world. Reliance industries and IPCL is the major producer of the polypropylene fibre in India.

Demand of polypropylene fibre

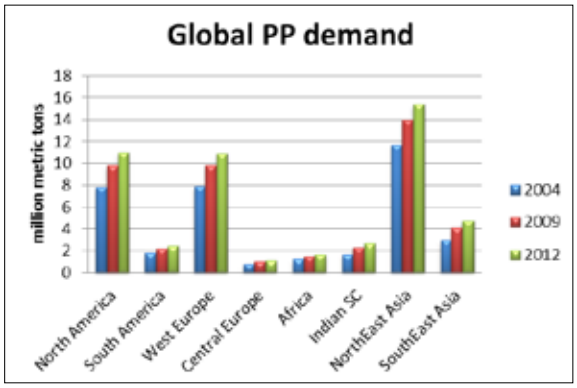
TABLE 1

WORLDWIDE POLYPROPYLENE FIBRE DEMAND FORECAST

Region	2004	2009	Predicted 2012
North America	7.80	9.80	11.00
South America	1.80	2.20	2.44
West Europe	7.90	9.80	10.94
Central Europe	0.80	1.00	1.12
Africa	1.25	1.50	1.65
Indian SC	1.70	2.30	2.66
North East Asia	11.70	14.00	15.38
South East Asia	3.00	4.10	4.76

Indian SC: Indian sub continents

Source: Polypropylene Market Study, Alberta Economic Development



Indian SC: Indian sub continents

Figure 2: Global polypropylene fibre demand
Source: Polypropylene Market Study, Alberta Economic Development

ROLE OF FIBRES IN CONCRETE

Cracks play an important role as they change concrete structures into permeable elements and consequently with a high risk of corrosion. Cracks not only reduce the quality of concrete and make structure out of service If these cracks do not exceed a certain width, they are neither harmful to a structure nor to its serviceability. Therefore, it is important to reduce the crack width and this can be achieved by adding polypropylene fibres to concrete. Thus addition of fibres in cement concrete matrix bridges these cracks and restrains them from further opening. In order to achieve more deflection in the beam, additional forces and energies are required to pull out or fracture the fibres. This process, apart from preserving the integrity of concrete, improves the load-carrying capacity of structural member beyond cracking.

PROPERTIES OF POLYPROPYLENE FIBRE

Mechanical properties

The mechanical properties of polypropylene are strongly dependent on time, temperature and stress. Furthermore, it is a semi-crystalline material, so the degree of crystallinity and orientation also affects the mechanical properties. Also the material can exist as homopolymer, block copolymer and random copolymer and can be extensively modified by fillers, reinforcements and modifiers. These factors also affect the mechanical properties.

A summary of the mechanical properties are given below,

- Tensile Strength: 25-33 Mpa
- Flexural Modulus: 1.2-1.5 Gpa
- Elongation at break: 150-300%
- Strain at yield: 10-12%

TABLE 2

PROPERTIES OF VARIOUS TYPES OF POLYPROPYLENE FIBRES

Fibre type	Mono filament	Micro filament	Fibrillated
Length (mm)	30-50	12-20	19-40
Diameter (mm)	0.30-0.35	0.05-0.20	0.20-0.30
Tensile strength (MPa)	547-658	330-414	500-750
Modulus of elasticity (GPa)	3.50-7.50	3.70-5.50	5.00-10.00
Specific surface (m2/kg)	91	225	58
Density (kg/cm3)	0.9	0.91	0.95

Source: S. K. Singh, "Polypropylene Fibre Reinforced Concrete", Roorkee, India, CE&CR, January 2011

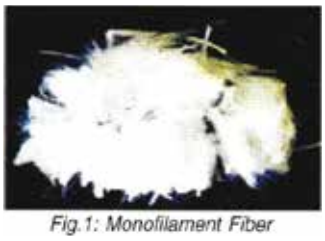


Figure 3: Monofilament fibre

Fibre 4: Fibrillated fibre
Source: S. K. Singh, "Polypropylene Fibre Reinforced Concrete", Roorkee, India, CE&CR, January 2011

Thermal properties

Polypropylene is a thermoplastic and hence softens when heated and hardens when cooled. It is hard at ambient temperatures and this inherent property allows permits economical processing techniques such as injection molding or extrusion. The softening point or resistance to deformation under heat limits its service temperature range. Melting point and the glass transition temperature control the operating range. When polypropylene is exposed to high temperatures within its maximum operating temperatures a gradual deterioration takes place. This effect is known as thermal ageing. It is an oxidation process and hence it is related to weathering. Polypropylene is more susceptible to oxidation by oxidizing agents and by air at elevated temperatures.

Chemical resistance

Polypropylene has a high resistance to chemical attack due to its non-polar nature. The term non-polar refers to the bond between atoms. The atoms of each element have specific electronegativity values of the atoms in a bond. If the electro-negativity value is greater the polarity of the bond will be higher. When this difference is small the material is said to be non-polar. In other words, the solubility of a polymer is related to the forces holding the molecule together, and one measure of this is the solubility parameter. Vulnerability is said to occur when the solubility parameter of the polymer and solvent are similar. It is understood that lower the value of the solubility parameter, the more resistant will be the polymer. In general, polypropylene is resistant to alcohols, organic acids, esters and ketones. It is swollen by aliphatic and aromatic hydrocarbons, and by halogenated hydrocarbons but is highly resistant to most inor-

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ganic acids and alkalis. However, it is readily attacked by strong, oxidizing acids and halogens. Contact with copper and copper alloys accelerates oxidation, particularly in the presence of fillers and reinforcements. Also the water absorption is very low and this is again because of the non-polar nature of the material.

TABLE 3
COMPARISON OF VARIOUS TYPES OF FIBRES

Fibre type	Carbon	Steel	Glass	polypropylene
Tensile strength (MPa)	590 to 4800	1000	1700	200 to 700
Tensile modulus (GPa)	28 to 520	200	72	0.5 to 9.8
Relative adhesion	Poor to good	Excellent	Excellent	Poor
Relative alkali stability	Excellent	Excellent	Good	Excellent
Water absorption (% by mass)	Nil	-	-	Nil

Source: Nemkumar Banthia, Vivek Bindiganavile, John Jones, and Jeff Novak, "Fiber-reinforced concrete in precast concrete applications: Research leads to innovative products", PCI Journal, summer 2012.

ADVANTAGES

- Polypropylene is a light fibre; its density (0.91 gm/cm^3) is the lowest of all synthetic fibres.
- It does not absorb moisture; this means the wet and dry properties of the fibre are identical.
- It has excellent chemical resistance. Polypropylene fibres are very resistant to most acids and alkalis.
- The thermal conductivity of polypropylene fibre is lower than that of other fibres and may be used in applications as thermal wear.
- Improves homogeneity of the concrete by reducing segregation of aggregates.
- Reduces shrinkage crack/micro cracks.
- Increases abrasion resistance.
- Increases impact and shatter resistance.
- Increases ductility, compressive, flexural and tensile strength of concrete.
- FRC with polypropylene fibre dissipates more energy than plain concrete at junctions.
- Reduces water permeability.
- Increases freeze/thaw resistance
- Improves durability of the concrete
- Replaces or reduces "Non Structural Steel" in floors, roads and pavements and concrete overlays i.e. slab on grade
- Polypropylene fibre are environmental friendly and non-hazardous

DISADVANTAGES

- Low melting temperature which prevents it from being ironed like cotton, wool, nylon etc.,
- Hard to be dyed after manufacturing, except after substantial treatment and modification,
- High crystallinity and poor thermal conductivity leads to limited texturizability.
- Poor UV and thermal stability which requires addition of expensive UV stabilizers and antioxidants to overcome this problem,
- Poor adhesion to glues and latex.
- Flammable which melts and burns like wax.

CASE STUDY

In this study effects of addition of various proportions of polypropylene fiber on the properties of concrete. The concrete mix proportions were kept as 1: 2: 4.and polypropylene fibre is adding by 0.1% to 0.5% of cement weight. Tests were performed for compressive strength, tensile strength and flexural strength and sample tested after the curing period of 7 days and 28 days.

TABLE 4
PROPORTION OF CONCRETE FOR COMPRESSIVE STRENGTH TEST

Mix	Cement (Kg)	Sand (Kg)	CA (Kg)	Water (Kg)	Fibre (gm)
A	16	30	70	9.6	0
B	16	30	70	9.6	29.59
C	16	30	70	9.6	59.19
D	16	30	70	9.6	88.78

TABLE 5
PROPORTION OF CONCRETE FOR TENSILE STRENGTH TEST

Mix	Cement (Kg)	Sand (Kg)	CA (Kg)	Water (Kg)	Fibre (gm)
A	5	10	23	3	0
B	5	10	23	3	9.86
C	5	10	23	3	19.73
D	5	10	23	3	29.59

TABLE 6
PROPORTION OF CONCRETE FOR FLEXURAL TEST

Mix	Cement (Kg)	Sand (Kg)	CA (Kg)	Water (Kg)	Fibre (gm)
A	7	13	30	4.2	0
B	7	13	30	4.2	12.41
C	7	13	30	4.2	24.83
D	7	13	30	4.2	37.24

TABLE 7
TEST RESULT OF CONCRETE WITH POLYPROPYLENE FIBRE

Test	Days	A	B	C	D
Compressive strength	7	14.95	17.24	20.78	13.89
	28	19.45	20.05	20.47	18.87
Tensile strength	7	1.39	1.45	1.65	1.44
	28	2.05	2.08	2.11	2.03
Flexural strength	7	3.87	5.25	3.87	2.71
	28	6.00	6.58	5.42	4.65

Source: Saeed Ahmed,Imran A Bukhari, Javed Iqbal Siddiqui, Shahzad Ali Qureshi, "A Study On Properties Of Polypropylene Fiber", Singapore, August 2004

CONCLUSION

We can say that, by addition of polypropylene fibre up to 0.35% of cement in concrete it improve the compressive strength and tensile strength of concrete. For improve the flexural strength up to 0.20% of cement is permissible after which strength starts reducing with further increment in fiber ratios. Utilization of polypropylene fibre in concrete can save the metal costs and produce a 'greener' concrete for construction. An innovative material which can be used in concrete for improve its properties is formed through this study.

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