A NEW CONCRETE REINFORCEMENT MATERIAL DEVELOPED IN SOUTH AFRICA FOR THE LOCAL AND INTERNATIONAL TRANSPORTATION INDUSTRY

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ABSTRACT

Oxyfibre is a new type of surface chemically modified polypropylene fibre used to reinforce and improve the overall properties of concrete materials. The product is the first type of polypropylene fibre with a permanent modified wettable surface in the world and has the international patent in major regions in the world. Oxyfibre is an ideal reinforcement for concrete to improve the cracking resistance, impact resistance, toughness and durability of hardened concrete materials. When using in steel reinforced concrete structures, the fibres in concrete can help to reduce the corrosion rate of the steel reinforcement and thus prolong the service life of the concrete structures.

Oxyfibre can be used with all the conventional concrete mixing procedures and mixing ratio. Oxyfibre can be added into concrete via hand mixing, all type of mechanical mixers, ready mix concrete batching plant and ready mix concrete truck. The fibres have found wide applications in construction industry, such as float foundation, concrete floor and pre-cast concrete components, etc. In transportation industries, Oxyfibre has already been successfully used in ordinary concrete road, farm road, parking lot, road side drainage, underground road way in mine and in sprayed concrete for tunnel and shaft lining to prevent rock blasting. In these applications, Oxyfibre is mainly used to replace the steel mesh and thus results in a reduction in material and labour cost.

1. INTRODUCTION

Oxyfibre is a surface chemically modified polypropylene (PP) fibrillated tape used to reinforce and improve the overall properties of concrete materials. The product is the first type of fluoropolymer fibre, with a permanent modified wettable surface, in the world and has international patents in major regions of the world. Through polypropylene fibre surface oxyfluorination, a permanent polar and Lewis acidic surface is established on the polypropylene fibre which can form a Lewis acid – base interfacial interaction with basic cementitious materials to form an electron share bond.

Due to the fibrillation process applied during the fibre production, Oxyfibre also has good mechanical bonding and interlocking with concrete matrices and therefore makes it an ideal reinforcement for concrete to improve the cracking resistance, impact resistance, toughness and durability of hardened concrete materials. When using in steel reinforced concrete structures, Oxyfibre in concrete can help to reduce the corrosion rate of the steel reinforcement and thus prolong the service life of the concrete structures.

Oxyfibre can be used with all the conventional concrete mixing procedures and mixing ratios. Oxyfibre can be added into concrete via hand mixing, various types of mechanical mixers, ready mix concrete batching plant and ready-mixed concrete trucks.

Oxyfibre has found wide applications in the construction industry, such as raft foundations, concrete floors and pre-cast concrete components, etc.

In the transportation industry, Oxyfibre has already been successfully used in ordinary concrete roads, farm roads, parking areas, road side drainages, tollgate areas, underground road ways in mines and as sprayed concrete for tunnel and shaft lining to prevent rock blasting. In these applications, Oxyfibre is mainly used to replace the steel mesh and thus results in a reduction in material and labour cost.

2. STRONG INTERFACIAL BONDING WITH CEMENTITIOUS MATRIX

The manufacturing process for production of Oxyfibre has been continuously improved to obtain increased interfacial bonding strength with the cementitious matrix. The Oxyfibre produced by the latest in – line oxyfluorination process (in-line II) can be marked as the forth generation of Oxyfibre comparing to the previous three generations of Oxyfibre which were produced by batch, dynamic and old in-line (in-line I) oxyfluorination process respectively.

In order to examine the improved interfacial bonding of Oxyfibre with the cementitious matrix, the embedded fibre pull-out test were conducted on Oxyfibre manufactured using different processes and compared to the untreated fibrillated polypropylene tape. Forty mm long tapes were embedded in the cement mortar cast in a custom-made dumbbell shape mould, see the following sketch. A polyethylene sheet in the middle of the mould is to prevent the bonding between the two sections of a specimen.

The cement mortar matrix was prepared according to the following mixing ratio - Cement (Lafarge Build crete 32.5): Water : River sand = 1 : 0.52 : 2.

After 24 hours, the specimens were released from the moulds and then water cured in a water tank at the temperature of 25 C. The specimens were taken out from the water tank after 7 days and the fibre pull-out test was performed on the specimens.

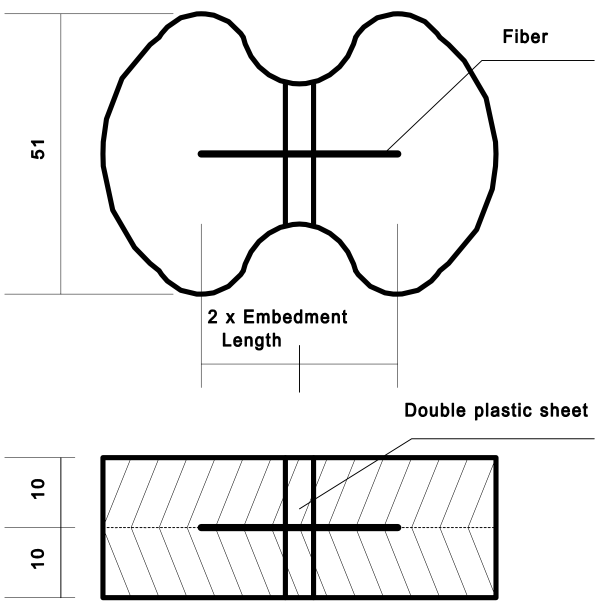

Figure 1.

The average shear bond strength was calculated using the equation as the following. All the interfacial shear bond strengths obtained are the average values obtained from testing of five specimens.

$$\tau_{bond} = P/(CL)$$

where τ_{bond} = the average interfacial shear bond strength;
P = maximum pull-out force;
C = perimeter of the cross-section of the fibre;
L = bonding length.

The results of the fibre pull-out tests on Oxyfibre manufactured using the various processes and untreated fibrillated polypropylene tapes are presented in the following Table 1.

It can be seen from the results in Table 1 that as the process is continuously improved, the bond strength of Oxyfibre with the cementitious matrix also shows continuous improvement. The interfacial shear bond strength of the Oxyfibre manufactured using the latest in-line II process is 3 – 4 times higher than that of the untreated fibre.

Table 1. Interfacial bond strengths between the cementitious matrix and the Oxyfibre manufactured using different surface oxyfluorination processes and their comparison to the untreated fibre.

Oxyfibre manufactured by various processes	Batch	Dynamic	In-line I	In-line II	Untreated
Interfacial shear bond strength (MPa)	0.17 – 0.21	0.17 – 0.19	0.25 – 0.29	0.36 – 0.47	< 0.10

3. ENHANCED CRACKING RESISTANCE AND MECHANICAL PERFORMANCE OF THE CONCRETE WHEN USING OXYFIBRE

3.1 Increased restrained plastic shrinkage cracking resistance

In order to examine the effect of incorporating Oxyfibre in concrete on the plastic shrinkage cracking, a restrained plastic shrinkage cracking test on concrete panels were performed. A 700 x 500 x 45 mm wooden mould was used to prepare the specimens and three 470 mm long 25 x 25 mm angle irons were fixed to the mould base to introduce restraints in the panel. In order to promote cracking, an electric fan providing an airflow velocity of 6 - 12 m/s was used to accelerate the water evaporation. During the tests, the ambient temperature, relative humidity and the rate of water evaporation from the fibrous concretes were measured as 20 ± 3°C, 50 ± 5% R.H. and 0.8-1.2 $kg/m^2/hr$, respectively.

After 4 hours of exposure, the crack length and width were measured using a ruler and a microscope with an accuracy of 0.001 mm. These results were used to calculate the crack area by multiplying the average crack width by the total crack length. For the concrete slab restrained plastic shrinkage cracking test, 15% fly ash Portland cement were used to prepare the concrete panels according to a mixing ratio of Cementitious materials : Water : Sand : Crushed stone (13 mm) = 1 : 0.50 : 2 : 2. A multi-flow pan mixer were used to mix the concrete for preparing the concrete panel specimens.

The results of the restrained plastic shrinkage tests on the 25 mm long Oxyfibre fibre reinforced concrete panels with different fibre dosage are exhibited in Table 2.

The crack control capacity (crack reduction percentage) in the above Table is calculated using the following formula:

$$\text{Crack control capacity} = \left(1 - \frac{\text{Crack area of fibrous concrete}}{\text{Crack area of plain concrete}}\right) \times 100\%$$

The results in Table 2 indicate that a small amount of PP fibres in concrete can effectively reduce the restrained plastic shrinkage cracking of the concrete panels. When 0.5% by volume of Oxyfibre is added into concrete, no visible shrinkage cracks can be observed. Compared to untreated PP fibres, Oxyfibre possesses a higher cracking control capacity which arises from their more effective crack bridging capacity due to the increased fibre/concrete interfacial bonding.

Table 2. Results of restrained panel plastic shrinkage tests on Oxyfibre (batch process) reinforced concrete panels with different fibre content comparing to the untreated fibre reinforced concrete.

Fibre type and volume content	Total crack length (mm)	Maximum crack width (mm)	Average crack width (mm)	Crack area (mm^2)	Crack control (%)
0% vol.	1275	1.1	0.26	331.5	–
UT 0.1% vol.	1170	0.63	0.23	263.3	20.6
F 0.1% vol.	470	0.62	0.33	155.1	53.2

* UT and F refers to untreated fibres and Oxyfibre, respectively

The results of the restrained concrete panel plastic shrinkage tests on various fibre reinforced ready-mixed concretes are presented in Table 3.

A mixer truck with a capacity of 6 m^3 was used to prepare the ready-mixed concrete according to the mixing ratio of Portland cement : Water: Decomposed granite sand : Dolerite stone (19mm) = 1 : 0.67 : 3.5 : 2.5. Different fibre dosages were used which mainly depends on the geometry of the fibres. The results indicate that Oxyfibre possesses the best plastic shrinkage cracking control capability among all the different fibrous concretes tested. It also indicates that steel mesh in concrete does not effectively control the plastic shrinkage cracking. It was observed that severe longitudinal and transverse shrinkage cracks occurred along the steel wire of the mesh. This means that the steel mesh in the concrete may become a type of internal restraint to the plastic shrinkage of concrete. The shrinkage cracking control capacity of steel mesh is therefore very limited.

3.2 Increased early strength development and impact resistance

The compressive strength of the 0.1% by volume Oxyfibre reinforced concrete under different curing period, compared to that of the plain and the untreated PP fibre reinforced concrete, are presented in Table 4. The compressive strength measurements were carried out according to the test method specified in the British Standard BS: 1881: 1970. An Avery-Denison 2000 kN compression testing machine was used to conduct the compression test, with a loading rate of 337 kN/min.

Table 3. Comparative results of restrained plastic shrinkage test on ready-mixed concrete panels reinforced with different types of fibres and steel mesh.

Type of fibre in concrete	Total crack length	Maximum crack width	Average crack width	Total crack area	Crack control
Plain concrete	1540 mm	1.16 mm	0.484 mm	745.36 mm^2	0
Steel fibre I (0.64% vol.)	1050 mm	0.752 mm	0.309 mm	324.45 mm^2	56.5%
Steel fibre II (0.64% vol.)	670 mm	0.550 mm	0.310 mm	207.70 mm^2	72.1%
Micro PP fibre I (0.067% vol.)	1170 mm	0.800 mm	0.323 mm	377.91 mm^2	49.3%
Type of fibre in concrete	Total crack length	Maximum crack width	Average crack width	Total crack area	Crack control
F PP (imported) tape fibre (0.2% vol.)	1270 mm	0.720 mm	0.264 mm	335.28 mm^2	55.0%
Micro PP fibre II (0.067% vol.)	1310 mm	0.650 mm	0.258 mm	337.98 mm^2	54.7%
UT PP tape (0.2% vol.)	1370 mm	0.644 mm	0.291 mm	398.67 mm^2	46.5%
Oxyfibre (batch) (0.2% vol.)	890 mm	0.540 mm	0.222 mm	197.58 mm^2	73.5%
Steel mesh	1710 mm	0.850 mm	0.347 mm	593.37 mm^2	20.4%

* F and UT refers to Oxyfibre and untreated PP fibres, respectively.

Table 4. Early compressive strength development of the Oxyfibre (batch process) reinforced concrete compared to that of the plain concrete and untreated PP fibre reinforced concrete, with their standard deviation (S.D.) values.

Curing time	Fibre dosage - kg/m^3 (volume content; weight content)					
	Control	S.D.	0.9 (0.1%; 0.039%)			
			Untreated	S.D.	Oxyfibre	S.D.
8 hrs	0.97	0.150	0.89	0.225	1.6	0.027
16 hrs	6.5	0.314	5.1	0.139	6.6	0.162
1 day	6.5	0.085	6.2	0.250	7.8	0.255
3 days	14.3	0.453	14.8	0.381	17.5	0.283

The raw materials used in the test are Portland cement (Alpha CEM 1 42.5), crushed stone (19 mm), natural river sand, tap water and 25 mm long Oxyfibre. The mixing ratio used to prepare the compression specimens are as follows: Cement : Water : Stone : River sand = 1 : 0.7 : 3 : 3.

It can be seen from the above Table that when cured in air, Oxyfibre in concrete leads to a higher early strength development compared to that of the untreated PP fibres and plain concrete until the age of 3 days. Such early strength advantage will contribute to the reduction of time and labour cost of a concrete engineering project.

The impact resistances of the ready-mixed concrete reinforced with the various types of fibres are summarized in Table 8.3. The results indicate that the fibrous concrete reinforced with 0.20% by volume of Oxyfibre possesses the highest impact resistance among all the polypropylene fibre reinforced concrete. The impact resistance of the Oxyfibre reinforced concrete is about two times of that of the plain concrete. Only the fibrous concrete reinforced with the 0.64% steel fibres has an impact resistance higher than that of the Oxyfibre reinforced concretes. The higher cost and higher content needed for the steel fibres compared to that of Oxyfibre make the use of steel fibres a more expensive way to increase the impact resistance of the ready-mixed concrete.

Table 5. Impact resistance test results of the ready-mixed concrete reinforced with steel fibres and various PP fibres.

Type of fibre in concrete	Fibre volume content	First crack	Final failure
Plain concrete	0%	33	37
25 mm straight steel	0.64%	63	86
30 mm hooked-end steel fibre	0.64%	79	93
20 mm micro PP fibre I	0.067%	40	50
20 mm macro PP fibre	0.20%	44	51
13 mm micro PP fibre II	0.067%	18	27
25 mm untreated PP tape	0.20%	41	55
25 mm Oxyfibre (batch process)	0.20%	50	72
13 mm micro PP fibre III	0.067%	43	49
25 mm untreated fibrillated PP tape	0.20%	30	49

4. APPLICATIONS

4.1 Underground Roadways

Cube test results done on the current underground roadways mix design at PMC:

	Compressive Strength (MPa)
1 day	10.5
7 day	56.5
28 day	76.0
56 day	92.5
90 day	96.0

4.2 Roads

4.3 Side drains

4.4 Loading areas / Parking Garages at Shopping Malls

4.5 Walkways / Drive ways

 

5. CONCLUSION

- Oxyfluorination technology was found to produce a general improvement in the physical and mechanical properties of Oxyfibre reinforced concrete with no workability or distribution problems.
- The impact resistance, cracking control capacity and early strength development of Oxyfibre Reinforced Concrete showed a significant increase compared to those of plain concrete and unfluorinated PP fibre reinforced concrete.
- Oxyfibre in concrete could overcome the weakness of current commercial PP and steel fibres and enhance the reinforcing effect of PP fibres in concrete.
- Oxyfibre could be used as a cost effective alternative for steel mesh for plastic and drying shrinkage cracking control.
- In the local and international transportation industries, Oxyfibre could be widely used in concrete roads, farm roads, parking areas, road side drainages, tollgate areas, underground road ways, etc. as a cost effective, superior alternative to steel mesh and to enhance and improve the concrete properties.

Oxyfluorination, with technology of the future, creates a unique surface wettable fluoropolymer fibre, for the 21st century