MATERIAL AND STRUCTURAL CHARACTERISTICS OF FIBRE-REINFORCED CONCRETE

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Introduction

Timuran Engineering Sdn Bhd had engaged a group of faculty members from the Faculty of Civil Engineering of Universiti Teknologi MARA in Shah Alam for the establishment of both the material and structural characteristics of fibrous concrete of different grades containing fibers of different types and dosages. Five (5) different tests were conducted on both fresh and hardened fibrous and control concrete samples/specimens to quantify the performance of the fiber reinforced concrete. The tests are:

a) Wash test or fiber content test

In this test, fibers are extracted from a fresh fibrous concrete sample and the fiber content determined from their mass and the volume of the concrete as described in Appendix B.

b) Compression test

In this test, compressive strengths of water-cured hardened fibrous and control concrete cubes are ascertained at 28 days of age as described in Appendix C.

c) Flexural test

This test is conducted on water-cured hardened fibrous and control concrete prisms at 28 days of age to evaluate their flexural strengths (or moduli of rupture) and flexural toughness parameters via a third-point loading system as described in Appendix D.

d) Impact test

In this test, qualitative and comparative assesments of the impact resistance of hardened fibrous and control concrete are carried out in accordance with the procedures described in Appendix E on cylindrical specimens by measuring/observing:

i. the energy consumed to fracture,
ii. the number of blows in a "repeated impact" procedure to achieve a prescribed level of distress, and
iii. the extent of damage.

e) Plastic Shrinkage test

The test, as described in Appendix F, evaluates the plastic shrinkage crack areas of green fibrous and control concrete panels after 24 hours of casting for a qualitative assessment of fibre-bridging and fibre-intercepting ability of the different types of fibers used either in isolation or combinations.

Materials

Five concrete grades of 25, 30, 40, 50 and 60 were specified and the contents of their constituents are detailed in Table 1.

Table 1: Mix proportions of plain concrete

Ingredients	Unit	G25	G30	G40	G50	G60
Cement	(kg/m^3)	290	320	380	440	500
Water	(kg/m^3)	185	185	160	160	160
Fine aggregates	(kg/m^3)	900	869	821	763	706
Coarse aggregates	(kg/m^3)	982	988	1053	1061	1067
Water-to-cement ratio	(%)	0.64	0.58	0.42	0.36	0.32

Fibers of different types and specifications were introduced into the different grades of concrete to assess the effects that they have on the properties of the concrete in its fresh and hardened states. Tables 2a and 2b give the specifications for the three types of fibers used in the present test program, and they are hooked end steel, fibrillated polypropylene and multifilament polypropylene fibers.

Table 2a : Steel fiber types and specifications

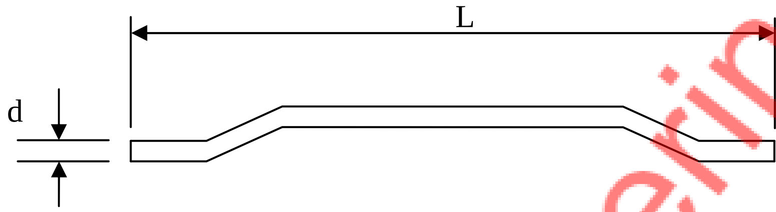
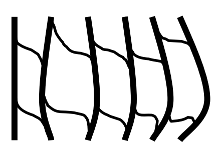
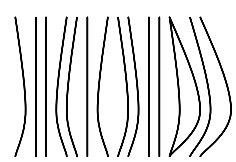
Stahlcon steel fibre	
	
Designation	HE 0.75/60
Type	Hook End Steel Fiber
Fibre diameter, d	0.75 mm (±0.02mm)
Fibre Length, L	60 mm (± 2mm)
Tensile strength of wire	Min 1200 Mpa
Aspect Ratio (L/d)	80 (± 5)
Quantity (pc/kg)	4600

Table 2b : Polypropylene fiber types and specifications

Mega Mesh polypropylene fibre		
Type	Mega Mesh I	Mega Mesh II
		
Fibre type	Fibrillated	Multi Filament
Material	100% virgin Polypropylene	100% virgin Polypropylene
Length	19mm	12mm
Specific Gravity	0.9 kg/dm3	0.9 kg/dm3
E-modulus	3900 N/mm2	3500 N/mm2
Tensile Strength	400 N/mm2	400 N/mm2
Quantity / cm3	7,100,000	26,000,000
Standard Dosage	900 g/m3	600 g/m3

The different grades of concrete were reinforced with randomly distributed short steel and/or polypropylene fibers at different dosages according to Table 3 and subjected to the range of tests in Table A1.

Table 3: Fiber dosages

Grade	**Fibre Reinforce Dosage (kg/m^3)**										
	Plain	Steel Fibre (SF)						Polypropylene Fibre (PF)		SF + PF	
G25	0	15	20	25	30	40	50	0.9 (FBP)	0.6 (MFP)	10 (SF)+ 0.9 (FBP)	10 (SF)+ 0.6 (MFP)
G30	0	15	20	25	30	40	50	0.9 (FBP)	0.6 (MFP)	10 (SF)+ 0.9 (FBP)	10 (SF)+ 0.6 (MFP)
G40	-	-	20	-	-	-	-	-	-	-	-
G50	-	-	20	-	-	-	-	-	-	-	-
G60	-	-	20	-	-	-	-	-	-	-	-

SF - Stahlcon steel fibre HE 0.75/60
PF - Mega Mesh Polypropylene fibre
FBP - Mega Mesh I – 19mm fibrillated polypropylene fibre
MFP - Mega Mesh II – 12mm multifilament polypropylene fibre

Methods

The methods of testing followed those of established and accepted laboratory specimen preparations and evaluation procedures and they are given in the Appendices B-F.

Results and Discussions

In Tables A2(a-c), conducting a wash test on all the fresh fibrous concrete reveals an acceptable amount of fibers present in each one of them, with fiber counts match closely the dosages prescribed.

Tables A3(a) and A3(b) highlight the insignificant effect of introducing distributed fibers on the compressive strengths of the two grades of concrete experimented. Even at a fairly high dosage of 50 kg/m^3, only a marginal increase of 1.2% is observed for the G25 concrete while for the G30 concrete, the increase is 3%. In Table A3(c), the average compressive strengths of three cubes of G40, G50 and G60 with 20 kg/m^{3}of steel fibers recorded are 52, 66 and 72 MPa, respectively, and they are included in this report only for completeness.

The flexural toughness indices computed to ASTM C 1018 are reported in Tables A4(a-c) as I_5, I_{10} and I_{20} for both grades of concrete. Since the numbers reported vary not only considerably but also inconsistently, another approach of quantifying the enhanced ductility of fiber-reinforced concrete is adopted, which is the Equivalent Flexural Ratio as defined in JSCE-SF4 and labeled as $R_{e,3}$.

Tables A5(a) and A5(b) show a clear indication of an increasing $R_{e,3}$ value with dosage of steel fibers for dosages ranging from 0 to 50 kg/m^3. Attempts were also made to seek a cheaper solution by resorting to a hybrid fibrous concrete where a lower dosage of the more expensive steel fiber is combined with a higher dosage of the cheaper polypropylene fiber. Introducing 10 kg/m^3 of steel fibers in combination with 0.6 kg/m^3 of multifilament polypropylene fibers result in a fibrous concrete of comparable ductility to a 15-kg/m^3 steel fiber-reinforced concrete for the G25 and G30 concrete. It is also worth reporting the 100% increase in the modulus of rupture of the fibrous concrete with a steel fiber dosage of 50 kg/m^3 over that of plain G25 and G30 concrete of equal mix proportions. In Table A5(c), scrutinizing the figures for $f_{e,3}$, $R_{e,3}$ and the flexural strength (MOR) for G40, G50 and G60 concrete at a steel-fiber-dosage of 20 kg/m^3 reveals the possibility of producing lower grade concrete of G25 and G30 of equal, if not better, toughness than those of the higher grade concrete through the introduction of steel fibers of not only the right dosage but also with the right combination steel fibers with cheaper polypropylene fibers.

The performance of the different series of fibrous G25 concrete under impact loads is summarized in Table A6 and depicted in Figure A1, with the impact resistance characterized by the amount of energy consumed to initiate first crack(s) in a cylindrical specimen and an additional energy to rupture the same specimen using the number of blows as an indirect measurement of the energy consumed to fracture. Those series with as low as 15 kg/m^3 of steel fibers have benefited considerably from the presence of the fibers, doubling the number of blows from those of the plain concrete, with the enhancement reaching four times when the dosage was doubled.

Suppression of plastic shrinkage cracks of fibre-reinforced G25 concrete is shown in Figure A2. The total crack area of G25 concrete added between 15 and 30 kg/m^3 of steel fibers dropped by between 70 and 55% from that of the plain concrete, and introducing polypropylene fibers, either fibrillated or multifilament, reduced further the total crack area. Generally, the total crack area reduces with increasing fiber content, with the greatest enhancement observed in the hybrid fibrous concrete, exhibiting surface cracks of a total crack area of only 7% of the plain concrete.

In Figures A3, A4 and A5, typical load-deformational characteristics of plain and fibre-reinforced G25, G30, G40, G50 and G60 concrete exhibit a ductile response of an otherwise brittle matrix due to the presence of randomly distributed steel and/or polyproplylene fibers. The fibers act as an efficient and effective three-dimensional reinforcement, intercepting and ridging structural cracks and redistributing internal stresses, and thus delaying rupture and avoiding suddenness of failure.

Conclusions

Standard tests were conducted on fresh and hardened fibrous and control concrete samples and there was substantial evidence of enhancement of cement concrete composites through the introduction of fibers of short lengths of steel and/or polypropylene. The greatest improvement is in the flexural strength and toughness as well as impact and plastic shrinkage crack resistance. Following is the summary of test result.

Table 4(a) : 28 days Compressive Strength and Equivalent Flexural Ratio, $R_{e,3}$ for FRC G25 & G30

Type of FRC		Concrete G25		Concrete G30	
Dosage (kg/m^3)		Compressive Strength (N/mm^2)	$R_{e,3}$ (%)	Compressive Strength (N/mm^2)	$R_{e,3}$ (%)
Plain concrete		32	14	35	15
SF	15	33	59	37	77
	20	33	62	36	78
	25	33	77	36	87
	30	32	83	36	91
	40	34	87	36	89
	50	32	89	36	90
PF	0.9 (FBP)	34	23	36	28
	0.6 (MFP)	33	18	36	13
SF + PF	10 (SF)+ 0.9 (FBP)	32	57	35	65
	10 (SF)+ 0.6 (MFP)	33	58	36	74

Table 4(b) : 28 days Compressive Strength and Equivalent Flexural Ratio, $R_{e,3}$ for FRC G40, G50 & G60

SFRC with dosage 20 kg/m^3		
Concrete	Compressive Strength (N/mm^2)	$R_{e,3}$ (%)
G40	52	78
G50	66	93
G60	72	53

Table 5 : Impact Resistant of FRC G25

Type of FRC		Numbers of blows	
Dosage (kg/m^3)		1st crack	Failure
Plain concrete		8	5
SF	15	12	10
	20	16	12
	25	20	17
	30	23	20
PF	0.9 (FBP)	15	11
	0.6 (MFP)	12	8
SF + PF	10 (SF)+ 0.9 (FBP)	18	16
	10 (SF)+ 0.6 (MFP)	16	14

Table 6 : Plastic Shrinkage Crack Reduction

Type of FRC		Crack area (mm2)	Reduction (%)
Dosage (kg/m^3)			
Plain concrete		544	0
SF	15	238	56%
	20	166	69%
	25	186	66%
	30	162	70%
PF	0.9 (FBP)	82	85%
	0.6 (MFP)	76	86%
SF + PF	10 (SF)+ 0.9 (FBP)	45	92%
	10 (SF)+ 0.6 (MFP)	39	93%

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