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Effect of graded fibers on stress strain behaviour of Glass Fiber Reinforced Concrete in tension

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HIGHLIGHTS

- Mixing of fibers of different lengths (Graded fibers) improves workability and strain hardening.
- Graded fibers influenced stress-strain behaviour of GFRC.
- Fiber efficiency characteristics were quantified to investigate their effect on the tensile strength of GFRC.
- Strength, deformation and energy absorption capacity is higher for GGFRC than MGFRC.

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ABSTRACT

Effective blending of short length and long length fibers in concrete is termed as Graded fiber reinforced concrete. Earlier research shows that short length fibers primarily control the propagation of micro cracks, and improve the ultimate strength whereas, long length fibers arrest the macro cracks and improve the post crack deformation of concrete. Thus different combinations of short and long length fibers would help in arresting the micro and as well as macro cracks to improve both pre and post crack performances of concrete. An attempt has been made to study the effect of addition of Graded Glass Fibers with different fiber length and volume fraction in Glass Fiber Reinforced Concrete. The experimental work was carried out under uni-axial tension for M30 grade of concrete with the 0.1%, 0.2%, 0.3%, 0.4% & 0.50% fiber volume of Mono Glass Fibers (3 mm, 6 mm, 12 mm and 20 mm length fiber). In 0.3% fiber volume, different fiber volume combination of Glass fibers in Short Graded form (3 mm + 6 mm length fiber), combination of Glass fibers in Long Graded form (12 mm + 20 mm length fiber) and combination of Short Graded + Long Graded fibers to form Combined Graded fibers (3 mm + 6 mm + 12 mm + 20 mm length fiber) were studied. The results shows that the strength, deformation capacity and energy absorption capacity is higher for Graded Glass Fiber Reinforced concrete than Mono Glass Fiber Reinforced Concrete. Graded fibers improved the workability. Fiber efficiency characteristics (Fiber length, Fiber dispersion, fiber orientation) were quantified to investigate their effect on the tensile strength of Glass Fiber Reinforced Concrete (GFRC). For this purpose, optical microscopic study and an image analysis technique is used to examine the failed specimens of GFRC. The results of image analysis shows that the strength of fiber reinforced composite are dependent on the fiber efficiency characteristics.

1. Introduction

The most important advantage of addition of fibers in concrete is increase of tensile strength and enhancement of energy absorption capacity [1–3]. When the structure is loaded, the micro cracks open up and propagate which may lead to inelastic deformation in concrete [4,5]. Micro or short randomly dispersed fibers in concrete help to resist the opening of micro cracks and enhance the pre crack strength [6]. Moreover, the small fibers dispersed and distributed randomly in concrete help to bridge the internal micro cracks thus improve concrete properties in all directions [7,8]. Higher the volume of fibers, higher will be the strength and toughness of the composite. However addition of higher volume of fibers leads to practical problems such as bundling, balling and reduction in workability, hence, researchers have observed reduction in strength and toughness [9,10]. In a given volume, shorter the length of fiber, closer will be the spacing of fibers and will be as near as possible to the micro cracks. These fibers may initially contribute to delay in formation cracks but may be pulled out after micro cracks transformed into macro cracks. Then long length

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Nomenclature

GFRC	Glass Fiber Reinforced Concrete
MGFRC	Mono Glass Fiber Reinforced Concrete
GGFRC	Graded Glass Fiber Reinforced Concrete
SGF	Short Graded Fibers
LGF	Long Graded Fibers
CGF	Combined Graded Fibers
Vf	Volume Fraction,%
σ_t	Tensile strength of plain concrete, MPa
σ_t^P	stress at point P, MPa
ε_t^P	strain at point P
σ_t^Q	stress at point Q, MPa
ε_t^Q	strain at point Q
Ks	initial Stiffness, $\sigma_t^P / \varepsilon_t^P$
STF	strengthening Factor, σ_t^Q / σ_t
SHF	strain Hardening Factor, $\varepsilon_t^Q / \varepsilon_t^P$
EA	energy absorption
σ_b	bond strength of fiber
η_d	fiber dispersion coefficient
η_θ	fiber orientation coefficient
η_l	fiber length coefficient
Lc	fiber critical transfer length, mm
Le	fiber embedded length, mm
F_{max}	peak pull-out loads, Newton
σ_u^{Mt}	tensile Strength of MGFRC, MPa
σ_u^{CM-1}	calculated Tensile Strength of MGFRC from Eq. (1), MPa
σ_u^{CM-2}	calculated Tensile Strength of MGFRC from Eq. (2), MPa
σ_u^{Gt}	Tensile Strength of GGFRC, MPa
σ_u^{CG-1}	Calculated Tensile Strength of GGFRC from Eq. (1), MPa
σ_u^{CG-2}	Calculated Tensile Strength of GGFRC from Eq. (2), MPa

fibers bridge the crack and improves the post crack deformations of concrete, as the length of fiber increases resistance to post crack deformation increases. Hence, blending of short length fibers and long length fibers may enhance the composite strength and improves the overall deformations of the composite [11,12].

The improvement of such mechanical properties can be achieved through the addition of a moderate amount of properly distributed fibers. This improvement can be maximized by controlling the alignment and dispersion of continuous fibers in the matrix. Short fibers are dispersed randomly in all directions so as to exhibit isotropic behaviour [13,14]. However, the real fiber distribution is strongly influenced by various factors such as fiber material (metallic and non-metallic) and its characteristics (diameter, length, and volume fraction), the fluidity of the matrix, placing method, and shape of the form. [15].

Most research works devoted to the correlation at a macrostructural level between fiber distribution characteristics (i.e., coefficient to represent the average dispersion or orientation of fibers throughout the composites) and tensile properties (i.e., tensile strength or energy absorption capacity) [16,17]. Few studies have adopted a systematic approach from microscopic to macroscopic view, that is, from the bond behaviour of individual fiber distributed in the composites to the tensile behaviour of a fiber reinforced composite and its structural performance. While some researchers have focused on the systematic approach with special interest in the fiber orientation distribution. The approaches were limited to analytical studies with the assumption of an idealized fiber distribution and did not consider the actual fiber distribution, which is affected by diverse factors such as placing method, form shape, and fiber geometry [18–20].

2. Research significance

In this investigation combination of different lengths of mono fibers are considered and named as Graded fiber reinforced concrete to distinguish from Hybrid fiber reinforced concrete. Inspiration is obtained from concrete mix proportioning where in different sizes of aggregates are combined to obtain well graded aggregates. Similar synergy with well Graded fibers of different lengths may improve strength and deformation of concrete. In the present work four lengths of AR glass fibers 3 mm, 6 mm, 12 mm and 20 mm having aspect ratios (length/diameter) 214, 428, 856 and 1428 respectively are combined in different proportions to form Graded Glass Fibers.

The objective of this study is to systematically correlate the tensile strength of Glass Fiber Reinforced concrete by considering the effects of three different influencing parameters i.e., fiber length coefficient, orientation coefficient and fiber dispersion coefficient. This paper presents quantitative linkages between the material microstructure and composite macro behaviour of Mono Glass Fiber Reinforced Concrete and also Graded Glass Fiber Reinforced concrete. Image analysis technique was used to quantitatively evaluate the fiber efficiency characteristics with respect to loading direction.

3. Experimental study

3.1. Materials

Ordinary Portland Cement (OPC) of 53 grade confirming to IS12269 [21] and Specific Gravity of cement 3.11 was used. Aggregates confirming to IS 383 [22] were used. The Fine aggregate used was obtained from a nearby river source. The bulk density, specific gravity, and fineness modulus of the sand used were 1.41 g/cc, 2.68, and 2.43 respectively. Crushed granite was used as coarse aggregate. The coarse aggregate was obtained from a local crushing unit having 20 mm nominal size. The bulk density, specific gravity and fineness modulus of the coarse aggregate used were 1.46 g/cc, 2.78 and 7.1 respectively. Potable water was used in the experimental work for both mixing and curing. Conplast SP430 of FOSROC chemicals was used for all mixes as per IS 9103 [23]. Some of the typical properties of Glass fibers used in the present study were tensile strength-1700 MPa, Modulus of elasticity-73 GPa, Specific gravity 2.6, and Filament diameter-14 µm.

3.2. Mix design proportions

M30 mix was designed as per IS 10,262 [24] and the proportions are given in the Table 1 per cubic meter of concrete.

3.3. Volume proportion of fibers

Specimen containing only one length type of fiber is called Mono Fiber (MF). Variables in MF specimens are volume of fiber 0.1%, 0.2%, 0.3%, 0.4% and 0.5% and length of fibers 3 mm,6 mm,12 mm and 20 mm. Two or more length of fibers are mixed to form Graded Fibers. When the mixture consists of 3 mm and 6 mm is named as Short Graded Fiber (SGF), mixture consists of 12 mm and 20 mm is named as Long Graded Fiber (LGF) and mixture of all the four lengths 3 mm, 6 mm, 12 mm and 20 mm is named as Combined Graded Fiber (CGF). Alphabet A, B, C, D, E stands

Table 1
Mix proportions for M30 grade of concrete.

Mix	Coarse aggregate kg/m^3	Fine aggregate kg/m^3	Cement kg/m^3	Fly-ash kg/m^3	SP430 (ml/kg)	W/B
M30	1145	764	300	100	10*	0.43

* The amount of SP430 remains same for all the mixes (mono fibers, SGF, LGF and CGF).