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Bond efficiency factor at different textile geometries reinforced concrete beams

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***Abstract*-- Textile reinforced non-structural concrete member has been commonplace in last decade in such application such as façade. The mutli-advantages of textile reinforcement have attracted the researchers to investigate applying this material in the role of a main reinforcement. Because of this, the cover thickness could be theoretically reduced due to the textile resistance to the corrosion. However, there are some impediments need to be studied. The interaction between the matrix and textile reinforcement which is represented by the bond efficiency factor of textile is one of the areas that needs to be fully understood. The impact of bond on the behaviour of textile reinforced concrete beams is notable. Therefore, this study investigated experimentally the effect of using different textile reinforcement geometries on the bond efficiency factor. Ten beams reinforced by different textile geometries were investigated. Four bending test was carried out. The results show that the average bond efficiency factor is 0.52 of uni-axial carbon textile reinforced concrete beam.**

***Keywords*— Textile reinforcement, TRC, Beam, Bond efficiency factor, Textile geometry**

I. Introduction

Textile reinforced concrete (TRC) has been gaining more tension in last decade. It has been applied in construction as non-structural concrete members such as façade. The engineers recently begin to use it to be the main reinforcement in the structural members. However, there are many issues need to be investigated before being applying textile material to reinforce concrete. One of these impediments is the design methodology which needs a fully understanding of TRC behaviour. The design methodology is currently under development. Therefore, the efficiency factors which are fibre length, fibre orientation, and bond have to be taken into consideration in the design method.

Bond efficiency is a crucial factor which represents the bond interaction between the textile and matrix and between the filaments themselves. Some researchers [1] concluded that the bond behaviour is significantly affected by fibre properties such as diameter and tensile strength, the binding, and the cross section of the yarns which affects the roving geometry and thus the matrix penetration. Others [2, 3] have emphasized that the geometry of yarn may have a considerable positive or negative effect on the bond behaviour e.g. that short weft knit could increase the bonding and the composite performance. The bond efficiency of the fibre reinforced concrete is further significantly influenced by the type of yarn (single/bundle) and the fabric pattern (woven, knitted, etc.) [2-4]. Understanding the relationship between the efficiency factor and these various textile parameters would allow us to account for them in design of fibre-reinforced load bearing elements i.e. beams. Therefore, this study is designed to investigate the bond partial efficiency factor for various carbon fibre and textile types so that it can be used in design, as the literature has not experimentally investigated this issue in the context of flexural performance.

In this study, we have investigated the bond efficiency factor of a number of carbon fibre textile geometries, in TRC beams tested in bending. The work is intended as preliminary to development of a model and design method for predicting the ultimate (and/or serviceability) behaviour of load-bearing TRC components.

II. Experimental work

A number of concrete prisms were reinforced with different geometries of textile reinforcement. Four point bending tests were used to study the behaviour of theses prisms. The details of the experimental work are in the following sections.

A. *Tensile Strength of Rovings*

It is found that the textile reinforcement has tensile strength lower than multi-filaments roving and multi-filaments roving is weaker than single filament [5]. The manufacturer's data for textile material normally pertains to the tensile strength of one filament. Therefore, the importance of obtaining the actual tensile strength of the textile filaments is highly recommended. Thus, ten roving samples were tested. Nominal textile reinforcement properties are shown in Table I according to the data sheet from the manufacturing company.

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TABLE I. NOMINAL CARBON TEXTILE REINFORCEMENT PROPERTIES AS SUPPLIED

Properties	Uni-directional, 50k
Filament diameter, µm	7.0
Number of filaments, k	50
Fabric weight, g/m^2	130
Mesh spacing	-
Tensile strength, f_f (MPa)	4000
Modulus, E_f (MPa)	235000

The total length of the tested roving was 33.5 cm and the last 8 cm of each edge was encased in resin to form a grip that could be held in the jaws of the testing machine.
The rovings were tested on a tensile testing machine, (Instron –TVL) with 300kN capacity, as it is shown in Figure 1 The clear distance between the two holders was 17.5 cm. The stroke rate was 1 mm/min.

Figure 1. The setup of tensile test

B. *Concrete proportions*

Fine grained concrete was used to enhance the probability of penetrating the textile reinforcement. Furthermore, the maximum aggregate size was 2 mm to be sure there is some penetration to some extent, with a water/binder ratio of 0.42. Fly ash (27%) was used as a partial replacement for cement to improve the workability and stability of the mixture as recommended by previous workers [6]. For determining the optimum mixture with regard to consistency and workability a preliminary experiments were carried. Table II shows the concrete proportions that are used in this experimental work. The flow table test was applied with reference to BS EN 12350-5 and found to be 250mm.

TABLE II. CONCRETE MIX PROPORTIONS

Concrete Mixture	Type	Proportion (kg/m^3)
Cement	OPC	265
Fly ash	EN 450	100
Total binder	-	365
Plasticizer (SP)	*ViscoCrete 25 MP*	*2%*
Sand	-	1040
w/b ratio	-	*0.42*
Water	Tap water	153.3
Total		1558.3

The mix was poured into the prism mould (100 x 100 x 500 mm) up to a depth of 1 to 1.5 cm to act as a cover of the reinforcement, and then the textile reinforcements were collected and laid into the mould by hand. The horizontal strip spacing was held constant at ~25 mm. The compressive strength of the matrix was also measured by casting 100 mm. After casting, the prisms were left for 24 hrs then de-moulded and cured for 28 days at 20±2 ^{o}C and 100% relative humidity. The average compressive strength of the matrix was 53 MPa with standard deviation 2.7 MPa (tested using a ToniPACT 3000 testing machine with 3000 kN capacity)

C. *Textile Reinforcement*

Figure 2 shows the carbon fibre textile reinforcements (FORMAX, UK) used to reinforce the prisms. The one-dimensional, uni-directional carbon was used to create different geometries of reinforcement lay-outs such as twisted, braided, and bundling reinforcement to study the performance of each one. Table I demonstrates the textile properties provided by manufacturer.

D. *Four point bending tests*

To study the flexural behaviour of the prisms, four-point bending tests were performed after the prisms were cured for 28 days. An LVDT was installed at the middle of span to measure the deflection. A ToniPACT 3000 testing machine in 150 kN capacity mode was used to perform the test at a loading rate of 0.1 kN/sec. Figure 3 shows the setup of the test. A digital data acquisition system was connected to record the load versus deflection.

Figure 2. Carbon textile reinforcement uni-direction 50k.

The number of strips should be considered 4 in all beams the spacing between strips is 2.5 cm. There is no spacing between the rovings, textile rovings piled over each other, Figure 3 two identical specimens were taken into account for each test.

I. Results and discussion

A. *Tensile Strength*

The average value of ultimate tensile strength of 10 roving specimens was 1550 MPa with standard deviation of 60 MPa. The results show the significant difference between the tensile strength of the single filament that provided by manufacturer (4000 MPa) and the actual roving tensile strength. Therefore, the tensile strength of single filament should not be used as σ_f of roving or textile reinforcement. Thus the average roving strength value was used in determination of efficiency factors etc.

B. *Bond Efficiency Factor*

The bond efficiency factor could be determined by calculating the bending moment using Voss's equation [1]. The equation is as following:

$$M = k_{fl,p} F_{ctu}\, z \qquad (1)$$

Where $k_{fl,p}$ is the factor for bending loading, $k_{fl,p} = 1 + 40\frac{A_t}{A_c}$ in case of carbon TRC. F_{ctu} is the tension force and z *(arm)* is the distance between the tension force and the compression force (≈90% of the static effective height). The tension force is:

$$F_{ctu} = A_t f_t k_1 k_{0,\alpha} \qquad (2)$$

where, A_t is cross sectional area of textile reinforcement.
f_t is tensile strength of the filament.
k_1 is the efficiency factor: $k_1 = \frac{\sigma_{max}}{f_{filament}}$
$k_{0,\alpha}$ is the factor for orientation of the reinforcement: $k_{0,\alpha} = 1 - \frac{\alpha}{90^o}$
Here, the orientation efficiency factor is 1 for uni-directional reinforcement.
Because the textile reinforcement is used, the efficiency factor (η) needs to be added into the calculation.

$$M = \eta_\tau k_{fl,p} F_{ctu}\, z \qquad (3)$$

η_τ is the bond efficiency factor.

The bond efficiency factor can then be computed by dividing the actual experimental moment M_u as measured during the four-point testing into the calculated theoretical nominal moment M (i.e. assuming that the bond efficiency factor is unity); since moment is proportional to load, this is equal to P_u/P. The theoretical calculated load (P) is ~ *55 kN.*

C. *Textile geometry*

Figure 4 and Table III show how the different layouts of individual reinforcement elements - straight rovings (control), bundled rovings (b), braided rovings (br) and twisted rovings (t) (see Figure 5) - affect the bond efficiency factor, ultimate load P_u and load-deflection curve at the same volume fraction.

When the roving is used as it is without changing in the geometry as in UT_4 the average bond efficiency (η_τ) is 0.50 and the average ultimate load is 27.5 kN. Nevertheless, when the carbon fibre rovings are divided into bundles (UT_{4b}) the bond efficiency increased by 18%, therefore, the average ultimate load is raised to 32.7 kN and the ductility is also improved as shown in Figure 4. This can be accounted for the clear increase in the contact area between the matrix and filaments. For braided rovings, three pieces of fibre are woven together (UT_{4br}). The average bond efficiency factor decreased by 14% with a corresponding reduction in the average ultimate load. However, the ductility significantly increased to almost double that of UT_4. Due to the complicated contact, the partial failure in the filaments may explain the decrease in ultimate load and the increase in the deflection. When the carbon rovings were twisted rather than woven (UT_{4t}) the average efficiency factor dropped significantly to 0.25; a 50% reduction in the bond efficiency factor in comparison with UT_4. The failure here was brittle, indicating that the arrangement was such that the effective volume fraction of fibre dropped below the critical value (Figure 4). The failure suddenly occurred after the concrete started cracking. This can be attributed to the decrease in the contact area and the complexity of the cross section along the rovings.

TABLE III. The bond efficiency factor at various fibre geometry

Textile Geometry	**A_t,mm^2**	**Ultimate Load, kN**	**Bond Efficiency Factor (min – max) ητ**
UT_{4t}, 50k	30	13.75	0.25* (0.25-0.26)
UT_{4br}, 50k	30	23.8	0.43 (0.43-0.43)
UT_4, 50k	30	27.5	0.50 (0.48-0.52)
UT_{4b}, 50k	30	32.7	0.59 (0.57-0.62)
		Average	0.51

* This value is not included in the average.

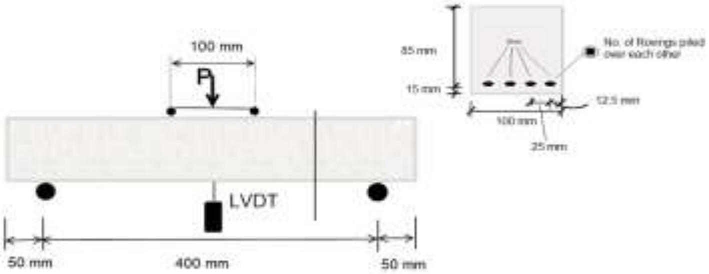

Figure 3. Four bending points test set-up, all dimensions in mm.

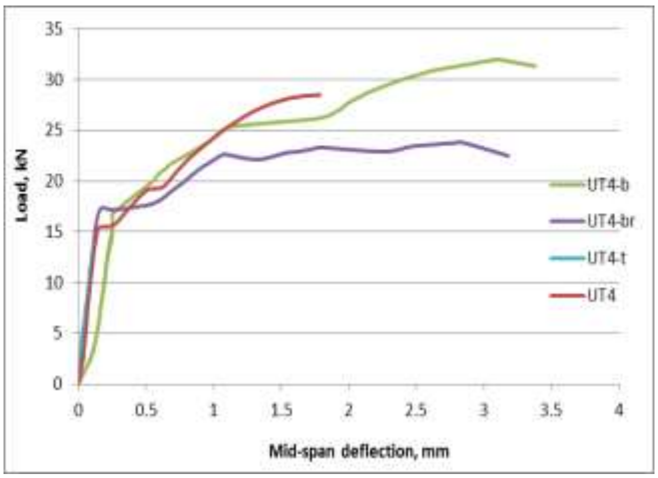

Figure 4. Load-deflection curves for different roving geometry at the same volume fraction

Very little was found in the literature on the bond efficiency factor. However, the findings of the current study are consistent with those of [7] who found that the tensile strength of single filament is lower than fabric and [1, 3] who found that the textile geometry significantly influenced the behaviour of textile reinforced concrete. However, in case of twisted rovings, the findings are in contrast with the results found by [3].

II. Conclusion

This paper has examined the role of using different textile geometries to reinforce beams and found the following:

- Voss's equation is highly overestimated the bending capacity of textile reinforced concrete beam.

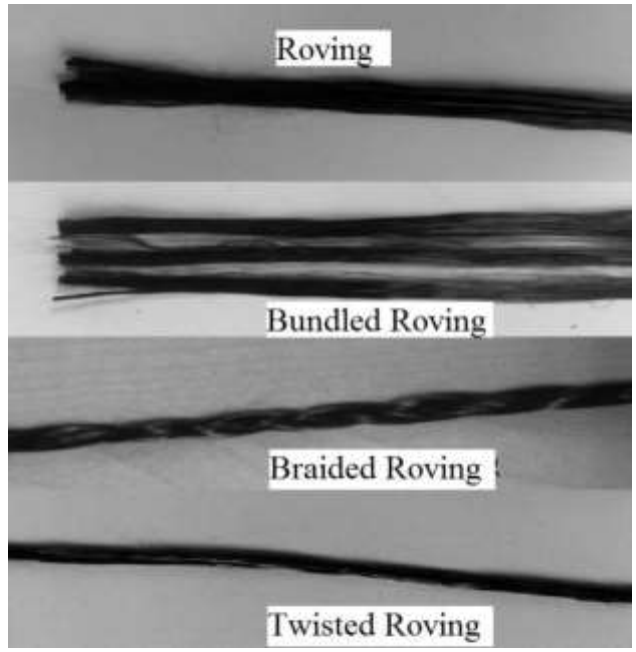

Figure 5. Roving geometry

- Twisted rovings obtained the lowest bond efficiency factor at 0.25 due to the decrease in the contact area and transverse load caused by twisted filaments.
- Bundled rovings obtained the highest bond efficiency factor as a result of the increase in the contact area.
- The average bond efficiency factor of different variation of textile rovings is 0.51.
- Tensile test confirmed that the tensile strength of roving is significantly lower than single filament.

Acknowledgment

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