

Bond Strength between Concrete and AR-Glass Roving with Variables of Development Length

Jongho Park, Taekyun Kim, Jinwoong Choi, Sungnam Hong, Sun-Kyu Park

Abstract—Recently, the climate change is the one of the main problems. This abnormal phenomenon is consisted of the scorching heat, heavy rain and snowfall, and cold wave that will be enlarged abnormal climate change repeatedly. Accordingly, the width of temperature change is increased more and more by abnormal climate, and it is the main factor of cracking in the reinforced concrete. The crack of the reinforced concrete will affect corrosion of steel re-bar which can decrease durability of the structure easily. Hence, the elimination of the durability weakening factor (steel re-bar) is needed. Textile which weaves the carbon, AR-glass and aramid fiber has been studied actively for exchanging the steel re-bar in the Europe for about 15 years because of its good durability. To apply textile as the concrete reinforcement, the bond strength between concrete and textile will be investigated closely. Therefore, in this paper, pull-out test was performed with change of development length of textile. Significant load and stress was increasing at D80. But, bond stress decreased by increasing development length.

Keywords—Bond strength, climate change, pull-out test, replacement of reinforcement material, textile.

I. INTRODUCTION

REINFORCED concrete has been used as the main construction composite material that can be complementary to compression and tension. However, its durability is decreased continuously and is threatened because of aging, increasing weight with being bigger and taller of structure, cracks due to external forces, and exposure to a variety of environmental conditions caused by abnormal climate. In particular, the climate is the one of the main problems nowadays. Main problems included scorching heat, heavy rain, snowfall and cold wave that cause temperature change, and it is the main factor of durability weakening because the crack width is increasing easily by temperature. Then water, oxygen or any material that can be caused corrosion penetrate through crack and will be meet a steel re-bar. After that, its corrosion mechanism is starting and durability was decreased. Alongside this, maintenance costs are also increasing.

To solve and adjust to the problem of durability decreasing,

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various researchers have been studying retrofitting methods [1]. Fiber Reinforced Plastic (FRP) has been conducted to rehabilitate and restore the capacity of the structure with its high strength and corrosion resistant and applied. FRP sheet, plate, and a grid shape was developed, and recently, form of a FRP bar reinforcing in concrete was performed. Also, a research of a concrete which is healed itself and suppressed of crack to increase the durability have been conducted. Blended cements such as ternary cements were performed and recently the self-healing concrete that is repaired crack itself, and furthermore a smart concrete which is diagnosed and repair have been studied actively [2]. On the other side, according to the aging of the structure, the necessary for maintenance, repair and reconstruction, the modular structure was applied to practice construction [1]. It is expected improvement safety, quality durability, economy and environmental issues efficiently. These research has resulted in strengthening of the structure, increased durability, reduced maintenance cost etc. However, as the majority of this previous research have been conducted on reinforced concrete, the results fail to compensate for certain concerns, such as the corrosion of steel, difficulty of maintenance and limit of weight reduction from the thickness of cover concrete. As such, there remains need to leave the frame of steel reinforced concrete. Therefore, a textile reinforced concrete (TRC) has been actively conducted to replace steel re-bar with textile for about 15 years in Germany, Israel, Spain, USA, and China due to its advantage such as durability, light weight and free formability [2]. In particular, Germany has generated a report defining TRC and standardizing testing methods with RILEM [3]-[5]. Current studies of TRC include bond and tensile test, characteristics of cracking and application. As a composite material, the strength of TRC depends not only on that of its components, but also on the bond between reinforcement and matrix. Analysis of this bond is thus one of the main topics in TRC studies. The bond can be affected by many factors, such as curing conditions and pressure applied after laminate casting [6], fabrication technique, fibre type and treatment of fibre surface. To study this phenomenon, pull-out and tensile tests have been performed and numerous models developed [7]-[9]. These many researches were performed for thin-plate TRC which is best shape in maximization its advantages. Therefore, each bond and tensile test has performed in limit variable such as number of laminate of textile, type of fibre, meso-mechanical of textile fabrics. However, precious TRC researches did not consider the effect of the development of length and the different variables of the textile reinforcement on pull-out tests. A composite member, like reinforce concrete, presupposes a

complete adhesion between the two materials so that it can resist an external force through complete integral action. As such, it is essential to investigate the bond behavior of TRC. In this paper, the pull-out test was conducted to induce change of slip, pull-out load, and stress with development of length.

II. TRC

A. Textile

Textile is grid shaped weaving fabric which is formed as fishnet with warp (longitudinal fiber) and weft (horizontal fiber). Textile was made by carbon, glass and aramid fiber. Each fiber has different properties and glass fiber, especially AR-glass fiber, is typically used due to good adhesion with concrete and good cost-effectiveness [10].

B. Concrete

According to using textile substitute for reinforcement, ordinary mixing method which consists of aggregate about 25mm cannot be used due to small gap of textile grid about 6~10mm. Therefore, fine aggregate that diameter is under 6mm is used for TRC concrete (fine concrete). It is concrete, but close to mortar. According to using fine concrete, sufficient amount of water is needed. Silica fume, fly-ash and superplasticizer is added for strength, durability and workability.

C. TRC

TRC is a concrete composite reinforcing textile made of carbon, glass and aramid fiber with no steel reinforcing and is expected to be used as a new composite due to its many advantages, such as lightweight, excellent durability, and free formability. Current TRC applications are concrete façade, sandwich panels, noise barriers and water protection walls.

III. EXPERIMENT PLAN

A. Test Set-up

In order to pull-out test with development of length of textile, three specimens were made each development length. The external textile is placed an epoxy resin with diameter 0.8 cm to avoid failure cause by clamping and slip between textile and clamping so that epoxy resin is used for load introduction and enforces the same introduced displacement. A 2000 kN UTM (Universal Test Machine) was used at a rate of 0.5mm/min (Displacement controlled) to failure or pull out. Two LVDT was set center at concrete fixing frame and ground. The specification and production process was showed in Figs. 1 and 2. Table I showed the variables in this experiment.

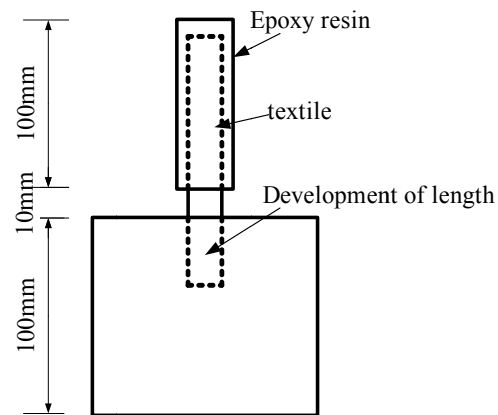


Fig. 1 Specification of specimen

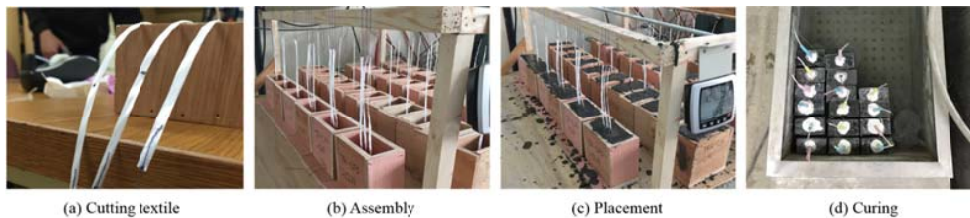


Fig. 2 Production process

TABLE I
NAME OF SPECIMENS

Specimen name	Development of length(mm)
D20	20
D40	40
D80	80
D100	100

B. Textile

Textile used in this test is AR-glass fiber with Zircon over 16% to resist alkali of concrete. 2,400 tex textile produced by Taishan Fiberglass Inc. was used and specification was shown in Table II.

TABLE II
SPECIFICATION OF TEXTILE OF AR-GLASS FIBER

Diameter (μm)	Tensile strength (MPa)	Modulus of elasticity (MPa)	Specific Gravity (g/cm ³)	Softening Point (°C)
27	1700	70	2.68	860

C. Concrete

A fine grained concrete was used with quartz sand 0.1~0.35 mm and 0.35~0.7 mm. To enhance durability and strength, fly-ash and silica fume were added. Table III showed mixing ratio of fine concrete which is 40MPa high strength.

TABLE III
CONCRETE MIXING RATIO

W/B ratio	Unit weight (kg)						
	Water	Cement	Fly-ash	Silica fume	No.6 sand	No.7 sand	SP
0.40	2.24	3.92	1.40	0.28	4.00	5.71	0.056

IV. EXPERIMENT RESULT

A. Load-Displacement

Fig. 3 shows the load-displacement of representative pull-out test. Similar behavior was shown except specimen of D80. D80 showed a rather gradual slope compared to others, it showed the greatest change in the displacement. The maximum load for D20 is 370N, D40 is 490N, D80 is 990N and D100 is 870N. As the development of length increases, pull-out load is increasing except D100. Compared to pull-out load of D20, loads of D40, D80 and D100 were greater than 32.4%, 254%, and 135, respectively. The increase in adhesion was evident with D80.

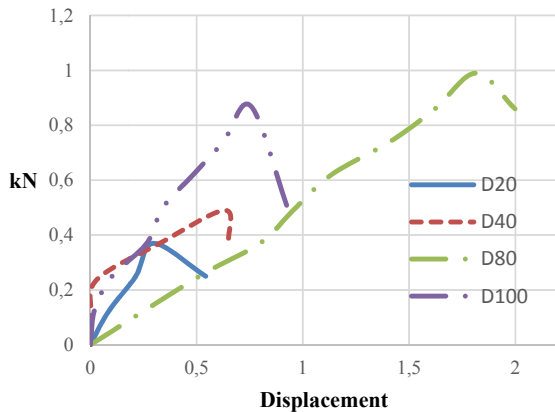


Fig. 3 Load and displacement of pull-out test

The maximum displacement at peak load point of D20 was 0.30 mm. For D40, D80 and D100 was 0.63, 1.82 and 0.76 mm, respectively. Except the D80, all specimens showed a displacement of less than 1 mm.

B. Stress and Slip

Tensile stress was shown in Table IV. Tensile strength used in this test is 1,700 MPa. Each specimen had 23.76%, 31.47%, 63.58% and 55.87% of tensile strength. It was quite good performance compared to previous research which showed up to 500N, 562MPa [11].

TABLE IV
TENSILE STRESS OF TEXTILE

Specimen	D20	D40	D80	D100
Area(mm ²)			0.916	
Tensile stress (MPa)	403.93	534.93	1080.79	949.78

Displacement of textile each specimen was calculated to derive slip between concrete and textile. Textile assumed the elastic behavior until maximum load. The slip is determined by

subtracting the displacement of elastic behavior to the displacement at maximum load. Table V shows the calculation slip of specimens.

TABLE V
CALCULATION SLIP OF SPECIMENS

Specimen	D20	D40	D80	D100
Displacement (mm)	0.30	0.63	1.82	0.76
Hooke's law (mm)	0.06	0.08	0.15	0.14
Slip (mm)	0.24	0.55	1.67	0.62
Ratio (Slip/Development length)	0.012	0.014	0.02	0.006

Slip is increased by increasing development of length, but D80 is only greater than 1 mm. Compared to ratio of slip and development of length, ratio is increasing from D20 to D80. At D100, ratio decreased dramatically. It is determined that specimen of D100 has a sufficient adhesive strength.

In order to calculate the bond stress, textile with width of 5 mm, each development of length and both side of the textile were considered for area of textile. Table VI showed the bond stress.

TABLE VI
BOND STRESS OF SPECIMENS

Specimen	D20	D40	D80	D100
Area of bond (mm ²)	200	400	800	1000
Bond stress (MPa)	1.85	1.23	1.24	0.87
Bond stress with slip (MPa)	1.87	1.24	1.26	0.88

The bond stress at maximum load is biggest D20 with 1.85 MPa and is smallest D100 with 0.87 MPa. D40 and D80 had similar value with 1.23 and 1.24. The bond stress considered slip was increased compare to ordinary stress, but growth rate could be negligible.

C. Failure

Figs. 4 and 5 show the failure of D20 and D100. In case of D20, external textile is damaged when it was pulled out first. In case of D100, it is clearly shown that textile is pulled out compare to D20. All specimens have a little slip, and most textiles failed at surface in the concrete.



Fig. 4 Failure of D20



Fig. 5 Failure of D100

V. CONCLUSION

In this study, pull-out test was performed between textile and concrete with change of development of length.

- 1) As the development of length increases, pull-out load is increased but decreased at D100. The maximum loads of D20, D40, D80 and D100 were 370 N, 490 N, 990 N and 870 N. Pull-out load dramatically increased on D80.
- 2) Tensile stress of each specimen was 23.76%, 31.47%, 63.58% and 55.87% of tensile strength on specification. It was quite good performance compared to previous research. Slip was calculated using Hooke's law and increased by increasing development of length. The bond stress was decreased by increasing development of length.
- 3) In this paper, bond strength between concrete and AR-glass roving by various development lengths was introduced simply. Result of pull-out test, in this paper, is not fully correct due to dependent variable which is not considered such as textile hardening with epoxy, and other variables such as huge load cell, eccentricity, curing of concrete. Further study will be needed through the controlling detail variables and derive the interface model between textile and concrete with development of length.

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