Proceedings of International Structural Engineering and Construction, 9(1), 2022
State-of-the-art Materials and Techniques in Structural Engineering and Construction
Edited by Holschemacher, K., Quapp, U., Singh, A., and Yazdani, S.

ISSN: 2644-108X
www.doi.org/10.14455/ISEC.2022.9(1).CAC-01

COLUMN CONFINEMENT WITH TEXTILE-REINFORCED CONCRETE (TRC)

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Textile reinforced concrete (TRC) is an innovative composite material consisting of a fine-grained concrete matrix and a textile reinforcement. Due to the corrosion-resistant reinforcement, the concrete cover, which is necessary for reinforced concrete constructions, can be reduced. Combining the tensile mechanical properties of carbon fibers with the compressive strength of fine-grained high-strength concrete, TRC can be seen as an efficient alternative to the previous reinforcement and strengthening measures for concrete columns. By confining the column with TRC, the lateral expansion of the concrete can be impeded. The resulting multiaxial compressive stress state allows to enhance the concretes compressive strength. The aim of this study is the investigation of various influences on the achievable strengthening effect. With the help of experiments on TRC, reinforced columns with circular cross-section mechanical property and constraint mechanism under uniaxial compression were documented and analyzed. Based on the test results, stress distribution and failure mechanisms of the reinforced specimens are studied. Furthermore, the load-displacement relationship of strengthened members is investigated. The effect of the ratio of textile reinforcement, section dimension and concrete strength on the ultimate strength of strengthened members is also evaluated.

Keywords: Concrete columns, Confinement, Strength, Reinforced concrete, Experimental tests, Strain-Stres.

1 INTRODUCTION

The construction industry takes the front position in terms of energy consumption and environmental pollution. It contributes about 13% of the gross national product (UNEP 2016). In relation to primary energy, nearly 40% of the total energy-related CO2 emissions can be assigned to the building sector (UNEP 2016). In order to reach the 2 degrees Celsius target of the Paris agreement, this needs to decrease by at least 80 % by 2050. In addition, the construction industry uses a considerable amount of material resources and non-renewable raw materials. About half of the annual steel production and 3 billion tons of raw materials are used for building projects (Krammer 2018).

As the initial cost of the construction projects is demanding in terms of cost, environment, and energy, the repair of existing structures has gained attention. Due to possible resource savings, conversion and repair measures for existing buildings are increasingly becoming the focus of economic efficiency. Reasons for such measures can have various origins. The restoration of the load-bearing capacity of a supporting structure after a fire or a shortening of the concrete structure during an extraordinary load situation can be conditions through which the load-bearing capacity can be efficiently restored with the established technologies.

As an essential element of the structural load-bearing structure, reinforced concrete (RC) columns have great potential in restoring the load-bearing capacity. However, their cross-sections rarely have larger bearing reserves, so that an increase in the column load-bearing capacity usually makes subsequent reinforcement unavoidable.

While classic reinforcement measures such as reinforced shotcrete shells have already been used in practice, efforts have been made to promote textile reinforced concrete (TRC) as a reinforcement measure in practice for years. Reinforcing columns with TRC has proven effective in numerous research efforts (Triantafillou *et al*. 2006, Caso *et al*. 2012, Ombres 2014). Cascardi *et al*. (2017) presents a summary of existing models and shows the discrepancies of these. Ortlepp *et al*. (2011) describes a design approach for determining the load-bearing capacity of textile-reinforced concrete columns, especially at the column head. In addition to improved serviceability properties (crack width, deflection), significant increases in load-bearing capacity have been demonstrated.

2 EXPERIMENTAL INVESTIGATIONS

2.1 Experimental Program

The following explanations refer only to a section of an extensive experimental program. The main objectives of the experimental program were (a) to analyze the possible increase in ultimate load and (b) to explore the bearing capacity proportions of the fine-grained concrete layer and the textile layers. A total of 9 steel-reinforced concrete cylindrical specimens with a diameter D of 200 mm and height H of 1000 mm have been tested under a longitudinal force load.

The experimental program is divided into three series, which are shown in Table 1. Series R represents the reference unconfined specimens consisting only of the reinforced core concrete. Series FB20 is the specimen equipped with a 20 mm thick layer of fine-grained concrete, while Series 2L20 is the confined one with two layers of carbon textile and a final thickness of the confinement system of 20 mm.

Table 1. Experimental program.

Series	**No. of spec.**	**H/D**	**Confinement**	f_{c0}	$f_{cm,m}$
				[N/mm²]	[N/mm²]
R	3	5	-	27.67	-
FB20	3	5	20 mm fine-grained concrete	28.72	92.53
2L20	3	5	20 mm fine-grained concrete, 2 layers carbon textile	30.76	94.96

2.2 Specimens Preparation and Test Setup

2.2.1 *Plain concrete*

In order to establish a reference as realistic as possible to an existing building component that requires structural retrofitting (low–strength concrete) such as column, all specimens were cast out of the same recipe designed for a scheduled compressive strength of 20 MPa. The cement content was 240 kg/m³ while the water/cement ratio was 0.75 and the maximum size of the coarse aggregate was 16 mm. With the aim to determine the mechanical properties of the concrete, three cylindrical specimens measuring 150 x 300 mm for every series were made out of the same batch and tested on the same day as the main specimens. The compressive strength of the core fco and the fine-grained concrete fcm,m is shown in Table 1. Furthermore, the specimens were provided with a steel reinforcement content of 2.36 cm²/m. Six rebars with a diameter of Ø12 mm as longitudinal reinforcement and every 10 cm cross-sectional reinforcement out of Ø6 mm curved rebars were used. The tensile strength of the steel rebars was 500 MPa and a young's modulus of 200 GPa. The concrete cover was 15 mm.

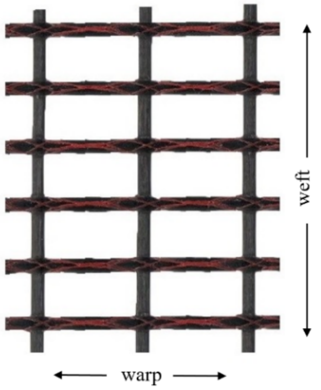
2.2.2 *Specimen preparation*

After the specimens were demolded, the surface needed to be prepared for the confinement. According to the approval for the reinforcement system used, the surface was blasted with sand until the aggregate with a diameter of > 4 mm was visible. The middle roughness of the surface was around 1 mm. 24 hours before confining, the specimens were prewetted and covered with foil. Furthermore, the surface was wetted again and cleaned of dust 20 minutes before confining. To ensure uniform loading, a concrete cap made from fine-grained concrete was placed at the bottom face of the specimen.

2.2.3 *Confining materials*

The Confining materials, which were used in the series, are already regulated in the general technical approval (Z-31.10-182 2016). It designates the use of the textile reinforcement TUDALIT-BZT1-TUDATEX, which is impregnated with a film-forming dispersion based on Styrene-butadiene rubber. According to the approval, only the yarns in the warp direction with the red knitting thread (Table 2) may be used for reinforcement. Important mechanical properties can be found in Table 2.

Table 2. Characteristics of the textile reinforcement TUDALIT-BZT2-V.FRAAS according to Z-31.10-182 (2016).

Properties of a coated yarn	**Carbon yarns in warp direction**	**Structure of mesh**
Number of filaments per yarn	3200/3300 tex	
Fiber cross-sectional area Textile Yarn	 140 mm²/m 1.8 mm²	
Tensile strength Mean value characteristic value	 1980 MPa 1890 MPa	
Modulus of elasticity Mean value characteristic value	 170 GPa 166 GPa	
Ultimate strain Mean value characteristic value	 1.28 % 1.24 %	
Coating	Lefasol VLT-1	

As a concrete matrix, the fine-grained concrete TF10 CARBOrefit® is used. This concrete has a maximum grain size of 1 mm and has been specially developed for the processing of carbon reinforcements in the hand lay-up and spray process. The concrete mixture, which is available as ready-mixed concrete, has a characteristic strength of at least 80 MPa. The compressive and flexural strengths of the concrete was measured using three prisms for each specimen were produced.

2.2.4 *Instrumentation of the specimens*

The specimens were stored for more than 28 days under constant climatic conditions (20 °C and 60 % relative humidity) until they were wrapped. After the first layer of fine-grained concrete thickness of 5 mm, the carbon mesh was applied and slightly pressed into the mortar. The textile was then wrapped around the specimens under slight tension, and the next layer of concrete was applied in parallel (Figure 1 (a)).

These processes of wrapping and applying the fine-grained concrete were repeated until the required number of layers was achieved. As a concrete cover, a final 5 mm layer of fine-grained concrete was applied. By using additional stencils, uniform total layer thicknesses of 20 mm could be realized. In addition, to prevent premature debonding failure of fibers, an overlap length of 50 cm was provided in the confined specimen. Furthermore, one layer of CFRP was applied to avoid a failure in the column head and foot (Figure 1 (c)).


(a) (b) (c)

Figure 1. (a) wrapping process; (b) specimens; (c) test setup.

2.2.5 *Test Procedure*

All tests were carried out using a servo-hydraulic compression testing machine with a maximum load carrying capacity of 6,000 MPa. The tests were done on deformation-controlled mode, primarily to allow accurate analysis of the processes of load transfer to the reinforcing layer and failure. The test speed was set at 0.01 mm/s according to empirical values. The test setup is shown in Figure 1 (c).

3 EXPERIMENTAL RESULTS

An increase in the load-bearing capacity in relation to the unconfined specimen was achieved for all the confined specimens up to 68 %. As a result of the increase in the cross-section and the higher strength of the fine-grained concrete compared to the core concrete, an increase in the load-bearing capacity of the specimens reinforced only with fine-grained concrete can be also achieved. Through a good surface preparation by means of sandblasting, a good bond between the old and new concrete was created, which leads to a constant overall stiffness of the specimen. This could be useful for components with low reinforcement requirements. At the same time, the structure can be repassivated without increasing the cross-section size. The load-displacement diagram

(Figure 2) shows a constant increase of the load with no significant transition from the core concrete to the fine-grained concrete layer. It should be mentioned that for the calculation of the multi-axial compressive strength fcc, the load-bearing part of the steel reinforcement was excluded. The most important test results are tabulated below.

Table 3. Experimental results.

Label	**Age**	**H**	**F_{max}**	**Δ F**	**Strength increase**	f_{c0}	f_{cc}	f_{cc}/f_{c0}	$f_{ct,fl,m}$	$f_{cm,m}$
	[d]	[cm]	[kN]	[kN]	[%]	[N/mm²]	[N/mm²]		[N/mm²]	[N/mm²]
R-1	107	100.7	1125.2			27.68	-	-	-	-
R-2	107	101.0	1115.6	1107.1	0	27.68	-	-	-	-
R-3	107	100.8	1080.5			27.68	-	-	-	-
FB20-1	106	100.3	1332.0			28.72	31.83	1.11	5.84	92.20
FB20-2	106	100.4	1322.6	1299.7	17	28.72	31.27	1.09	5.09	92.02
FB20-3	106	100.4	1244.5			28.72	28.80	1.00	5.81	93.38
2L20-1	103	100.3	1892.4			30.76	49.42	1.61	6.09	97.80
2L20-2	104	100.1	1794.9	1847.8	67	30.76	42.37	1.38	4.52	91.27
2L20-3	104	100.4	1856.1			30.76	48.27	1.57	5.95	95.83

With uniform total layer thickness and two effective textile layers, the load-bearing capacity was significantly increased. These results show a noticeable load redistribution after the failure of the core concrete to the confinement system. Consequently, the maximum load increases again. The process is characterized by audible cracking and longitudinal cracks along the yarn in the weft direction.

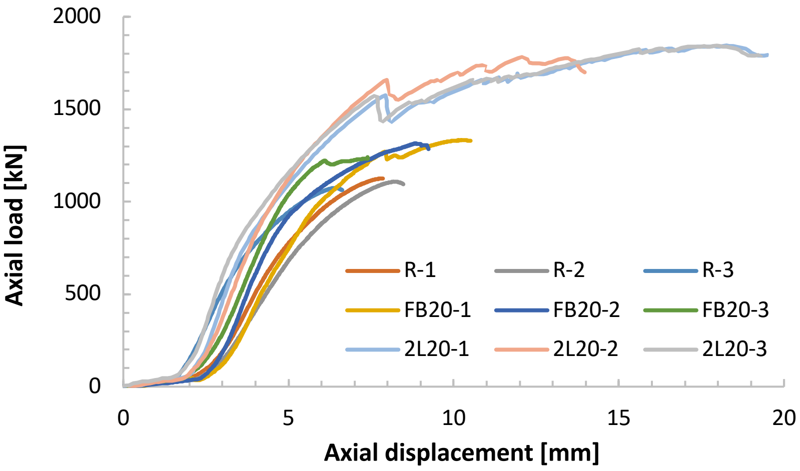


Figure 2. Load-displacement diagram.

4 SUMMARY

In this paper, a part of a more extensive experimental program is presented. The strengthening of the specimens through TRC increased the load-bearing capacity compared to the unreinforced specimens. The collected results show that an increase in the load-bearing capacity can also be achieved with just a layer of high-strength fine-grained concrete. Typical behavior for TRC could be observed. After the axial compressive strength of the core concrete is reached, the textile can be gradually activated by reaching the tensile strength of the fine-grained concrete characterized by elongated cracks. The compressive load acting on the component can thus be converted into the textile. A renewed absorption of the load is then the consequence.

The project is currently investigating additional tests and an empirical model to predict the peak strength in TRC-confined columns, and results will be published in subsequent papers.

Acknowledgments

The authors would like to thank the University of Applied Sciences Leipzig (HTWK Leipzig) for the sponsorship of this research. Additionally, PAGEL Spezial-Beton GmbH & Co. KG is gratefully acknowledged for providing the fine-grained concrete mixture.

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