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USE OF CARBON FIBER IN CONCRETE STRUCTURES – STATE OF THE ART

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SUMMARY

The development of material production technology has led to the application of new materials in construction. Because concrete is currently the most commonly used construction material, which in addition to numerous advantages (water resistance, low maintenance costs, easy workability, low cost, etc.) also has certain disadvantages (low tensile strength and brittle fracture behavior). Reinforcement of concrete using discrete fibers, randomly distributed, is an acceptable solution for improving the ductility of concrete. Carbon fiber reinforcement (CFRP) has been widely studied in the last two decades, as it represents a suitable alternative for the reinforcement of existing (endangered) RC structures. The advantages of this material are reflected in the relatively simple application, increased performance of the RC structure, low weight of the elements, etc. The paper also analyzes the existing cases of application of this material, as well as the presentation of previous research in the field of structural reinforcement using carbon fibers.

Key words: Carbon fiber, Carbon fiber-reinforced polymer (CFRP), reinforcement concrete structures, reinforcement of existing structures, structural behavior of construCTIONS

1. INTRODUCTION

Reinforced concrete (RC) is the most important and most used composite material in construction, which achieved its development through the development of its component materials concrete and concrete steel. Namely, high-strength concrete (up to 200 MPa) with additives that improve properties in terms of weather deformation and high-strength steel, especially prestressing steel, are used today.

But with the advantages, including high load capacity and relatively simple processing at low cost, apart from shaping, there is also a major disadvantage; reinforced concrete is prone to corrosion. Concrete is highly alkaline and forms what is known as a passive layer on the reinforcing steel, protecting it from corrosion. Substances that enter the concrete from the outside (carbonation) can reduce the alkalinity over time (depassivization), so that the reinforcing steel loses its protection, and the steel reinforcement begins to corrode. This leads to cracking of the concrete, reducing the durability of the structure as a whole and its failure in extreme cases. This problem is particularly present in older RC structures, which were built before the introduction of the service life and limit state of durability in the analysis of the structure's usability (built from the middle of the last century to the eighties of the last century). The standards that are in force today do not cover in sufficient detail the aspect of durability of concrete in terms of the calculation model.

Improving the properties of concrete structures in terms of load-bearing capacity, usability and durability has led to the development and application of new materials. Thus, in the nineties of the last century, research began with the aim of developing the application of technical textiles to achieve better properties

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of the edge parts of concrete elements. Here we can single out the research carried out in Dresden and Aachen (Germany) funded by two institutions, the DFG Collaborative Research Centers SFB 528 and SFB 532. The previously mentioned research showed that the use of textiles as part of the concrete protective layer enables the reduction of the thickness of the concrete protective layer, which is particularly interesting. in aggressive environments (industrial zones and marine areas), where greater thicknesses of the concrete protective layer are necessary.

The use of fiber-reinforced polymer (FRP) materials in civil infrastructure for the rehabilitation and strengthening of reinforced concrete structures as well as for new constructions has become a common practice. The most effective technique for improving the shear strength of the damaged parts of the RC structure is the joining of fiber reinforced plastic (FRP) plates or sheets as cladding. External reinforcement with highly reinforced fiber-reinforced plastics (FRP) on concrete structural elements has gained great popularity in recent years, especially in rehabilitation works but also in new construction. Comprehensive experimental research conducted in the past has shown that this strengthening method has several advantages over traditional methods, particularly corrosion resistance, high stiffness-to-weight ratio, improved durability and flexibility.

According to existing standards, the minimum requirement for a concrete protective layer is 35 mm for external building elements, which leads to a total thickness of about 100 mm for facade panels. If the reinforcing steel is now replaced by non-metallic reinforcement, for example mesh reinforcement made of glass or carbon fiber, a thickness of only a few millimeters is sufficient to ensure durability and a strong connection between the concrete and the reinforcement. It is known that TRC enables the production of facade panels between 20 and 30 mm thick, which saves up to 80% in concrete. This has a direct impact on transport costs for precast concrete components, which can be reduced by up to 80%. Much smaller mounting elements are also sufficient for installation, which further saves costs. TRC is already used today in new construction, and it also serves the purpose of strengthening existing structures. In addition to the fact that they are not susceptible to corrosion, glass and carbon fiber reinforcements are particularly distinguished by their high strength, which is up to six times higher compared to reinforcing steel.

The use of carbon fiber reinforced polymers (CFRP) can now be considered common practice in the field of strengthening and rehabilitation of reinforced concrete structures. The effectiveness of this technique has been widely documented by theoretical and experimental research and applications on real structures. CFRP reinforcement provides additional flexural or shear reinforcement, and the reliability of this application of materials depends on how well they are bonded and can transfer stress from the concrete component to the CFRP laminate. Commercially available FRP strengthening materials are made of continuous aramid (AFRP), carbon (CFRP), and glass (GFRP) fibers.

This paper presents an overview of previous research in the field of carbon fiber application in constructions, and on this occasion a systematic division of the area was made into:

- Properties of carbon fiber (CFRP),
- Method of application in constructions,
- Experiences of the exploitatiON AGE.

2. PROPERTIES OF CARBON FIBERS (CFRP)

The previously mentioned researches have shown that the use of textiles as covering of concrete elements enables the reduction of the thickness of the concrete protective layer, which is particularly interesting in aggressive environments (industrial zones and marine areas), where greater thicknesses of the concrete protective layer are necessary. The main role of strengthening structures with carbon fibers is expected in the area of tensile load capacity. Of course, in addition to the tensile load capacity in reinforced concrete structures, there is the question of the contribution of carbon reinforcements in terms of durability and even ductility of the structures. In the presented works, tests were carried out with the aim of determining the final properties of carbon fibers and carbon tape reinforcement in terms of tensile load capacity, appearance and distribution of cracks in concrete, as well as the final load capacity of the structures themselves.

Research carried out in paper [1] provides guidelines for strengthening RC beams using FRP materials, where the types and methods of FRP strengthening are generally described. Research was conducted on 38 beam samples with the aim of providing the shear capacity. The samples are variably reinforced (the main load-bearing reinforcement, the spacing of the shear reinforcement and the method of strengthening with CFRP were used differently). The obtained research results showed that beams without reinforcement or with reinforcement in the support area were not satisfactory in terms of crack opening, beams with plates over the entire span had an explosive failure without warning, while all the remaining samples reinforced with CFRP strips failed in shear and where until the strips come off. All reinforced beams showed an increase in shear resistance from 19% to as much as 109% (depending on the type of reinforcement). Conclusions are given regarding the application of commercially available materials (SIKA) and an account of the increase in beam strength with regard to the method of application of CFRP reinforcement is given.

A general report by the **ACI Board (2002)** provides current knowledge on the application of FRP, as well as examination of the flexibility, shear strength, bond behavior and durability of all materials in use. Also, further in the paper it is emphasized that the common link between all FRP products described in this paper is the use of continuous fibers (glass, aramid, carbon, etc.) embedded in a resin matrix, an adhesive that allows the fibers to act together as a single element. The resins used are thermoset (polyester, vinyl ester, etc.) or thermoplastic (nylon, polyethylene terephthalate, etc.). FRP composites differ from the short fibers that are widely used today to reinforce non-structural cementitious products known as fiber-reinforced concrete (FRC). The production methods of combining continuous fibers together with the resin matrix allow the adaptation of the FRP material so that the optimized reinforcement of the concrete structure is achieved. The primary interest of the concrete industry in FRP reinforcement, as stated in the paper [2], is the fact that it does not usually cause durability problems such as those associated with corrosion of steel reinforcement. Depending on the constituents of the FRP composite, other deterioration phenomena may occur as explained in the report. It was emphasized that concrete elements can benefit from the following characteristics of FRP reinforcement: light weight, high specific strength and modulus, durability, corrosion resistance, chemical and environmental resistance, electromagnetic permeability and impact resistance.

Paper [2] states that there are three sources for commercial carbon fibers: resin as a by-product of petroleum distillation, PAN (polyacrylonitrile), and rayon. The properties of carbon fibers are controlled by the molecular structure and degree of freedom from damage. Carbon fiber formation requires processing temperatures above 1830F (1000°C). At this temperature, most synthetic fibers will melt and evaporate, acrylic will not, and its molecular structure is retained during carbonization at high temperatures. There are two types of carbon fiber [2]: high modulus **Type I** and high strength **Type II**. The difference in properties between types I and II is the result of the difference in the microstructure of the fibers. These properties are derived from the arrangement of the graphene (hexagonal) layer networks present in graphite. If these layers are present in three-dimensional bundles, the material is defined as graphite. If the bond between the layers is weak and two-dimensional layers occur, the resulting material is defined as carbon. Carbon fibers are two-dimensional.

The paper [2] also presents a table showing the typical physical and mechanical properties of commercially available composite fibers for reinforcement. It can be noted here that the characteristics of carbon fiber products are significantly higher than those of glass or aramid fibers. The differences in tensile modulus and tensile strength are especially pronounced, where carbon fibers are up to 50% more resistant than glass or aramid fibers.

In paper [3], experimental research was carried out on RC beams with the purpose of formulating the behavior of RC beams before and after the installation of carbon fibers in order to increase the strength of damaged beams. Tests were carried out on the load to failure of concrete beams of concrete grades M15, M25 and M35. Materials used to strengthen the beams, i.e. carbon fibers, are initially loaded at 60% and 90% of the ultimate strength of the control beam. Experimental results showed that the technique of strengthening RC beams using carbon fibers will increase the ultimate strength of the beams by up to 30%. The average increase in strength of the beam with carbon fibers is greater than that of the control beam. Some of the conclusions drawn are that the load capacity can be increased by 35 to 45% by applying carbon fiber reinforcement, but also that the development of cracks before and after the installation of carbon fiber reinforcement did not change. All test samples showed large damage at the ultimate load as well as a significant increase in ductility.

Bašanović L. (2019) worked on the area where the concrete was reinforced with fibers, i.e. concrete with a proportion of fibers that are irregularly and randomly distributed in the concrete mixture with the aim of improving the physical and mechanical characteristics of concrete. The paper gives a brief overview of the application of fibers in construction, as well as the application of additives in concrete in the form of micro fibers. In the work itself, no experimental research was applied, leaving the possibility for further research in that direction.

Böhm R., Thieme M., WD, Wolz DS (2018) this paper describes the necessary production steps for the development of carbon fiber (CF) reinforcement: (1) production of cost-effective CF using new carbon fiber lines and (2) fabrication of CF-ribs with different geometry profiles. PAN/lignin-based CF was found to be currently the most promising material to meet future market demands. However, significant research needs to be undertaken to improve the properties of lignin-based CF, i.e. PAN/lignin. In the work, the authors also deal with the creation of a countertype of the production technology of carbon fiber reinforcement. It is emphasized that 10% of the world's total energy consumption is needed for the construction and dismantling of buildings, and that current buildings only have a limited lifespan of about 40 to 80 years.

The use of carbon fibers for reinforcement, as stated in this paper [8], requires that the carbon fibers must reach the minimum mechanical properties of steel. The minimum stiffness requirements of CFRP-based strengthening systems can be calculated by a simple rule of thumb that takes the typical fiber volume for either thermoset matrix systems (typically around 60%) or thermoplastic matrices (typically around 45%). The authors state that in order to achieve the required tensile strength value of around 500 MPa for CRFP reinforcing steel, carbon fibers must have a tensile strength of approximately 830 MPa for thermoset matrix systems. Also, the authors emphasize that the stiffness requirements for CF resulting from the direct replacement of steel with CFRP defined by the minimum Young's modulus are already fulfilled by both industrially available and experimental-scientific carbon fibers.

In order to evaluate the mechanical properties of the reinforcement types and the influence of the production process on the properties, comparative tests were performed. The comparison was made using established strengths because stress measurements to determine Young's modulus are highly questionable due to the different external geometries of different types of reinforcement.

At the end, a number of conclusions were drawn, and it was said that the new carbon fiber production process enables the development of cheaper carbon fibers. Five different production processes have been developed for the realization of different surface geometry profiles. In particular, the so-called spiral pultrusion - as a production process for the production of reinforced structures with surface profiling in one mold step - has been identified as efficient enough to be successfully integrated into the industrial process of rebar production. At the same time, the helical pultrusion process still offers design freedom with respect to surface contours and fiber orientation, allowing for even greater potential to optimize reinforcement bar design.

In the paper [9], the author conducted an experimental study with the use of carbon fibers for reinforcement with the aim of obtaining the most correct application procedure of reinforcement, which would lead to an increase in resistance to bending, shearing and stiffness. This paper presents the procedure for increasing/decreasing the percentage of substrates reinforced by different types and methods of application of CFRP materials. Two commercially available CRFP materials produced by SIKA were used in the work, and tests were carried out on five exemplary models of RC beams. The data collected for the deflection shows a 300% improvement in the utilization of the reinforced elements between the fifth and first beams at different loads. It is similar to all beams compared to each other at specific loads. In addition, when conducting the test, the increase in member stiffness was one of the most important factors that differed from one sample to another. All samples showed three stages: re-opening of cracks, cracking and crushing. Crack phases are improved with the application of CFRP laminates at various locations. The more anchorages and wraps used, the better the specimen performed in terms of shear, bond, flexural strength and time to complete failure of the reinforced elements. In the end, it was concluded that the use of CFRP material is one of the most powerful techniques for strengthening RC elements. Reinforcement of concrete with CFRP leads to an increase in load capacity as well as an increase in stiffness. When anchorage is considered, better performance and usability of the structure is considered. The strength and stiffness of the members increase with increased use of CFRP laminates, thus avoiding crushing or complete failure of members without warning. In this work, it was concluded that the application of CFRP laminates whenever necessary, taking into account anchorage and stiffness, actually leads to an increase in beam strength and provides additional load-bearing capacity.

Cheng-Tzu Thomas Hsu et al. (2006) investigate the shear behavior between concrete and CFRP polymer with carbon fibers in their work. A total of 27 samples were tested in this research. Test variables include the maximum compressive strength of the concrete, from 4000 to 12000 psi. This test setup was shown to be able to investigate the direct shear condition between CFRP laminates and concrete. Based on the test results so far, empirical formulas have been developed for calculating the compressive strength and slip ratio of different concrete compressive strengths. Such a relationship allows further understanding of the transfer mechanism of CFRP laminates and concrete. The paper also discusses the influence of salt water on the ultimate shear strength of the CFRP strengthening system. The paper describes in detail the characteristics of the materials used in the test with their physical and mechanical characteristics, and also describes the correct procedure for installing CFRP strips. In order to further understand the direct shear strengthening behavior with CFRP, a new test method established by Bian, Hsu, and Wang 1997 was also used; Hsu, Bian, and Jia 1997 This new experimental method not only measures the compressive strength of CFRP reinforcement, but also reveals the compressive strength and slip relationship of the system. Knowing the exact ratio is crucial for determining the bond development length of CFRP reinforced beams. Nine samples were tested for the effect of salt water on the ultimate strength of the CFRP connection. Seawater has been observed to have some effect on the epoxy curing process. It was found that the final push-off strength of the specimens immersed in seawater was 30% lower than that of the control specimens. Based on the conducted research, the following conclusions were drawn: A new direct direct shear test procedure was proposed, which is capable of studying the punching and sliding strength of CFRP strips and concrete; The present test results show that the ultimate direct shear or compressive strength of the CFRP reinforcement system increases almost linearly with the maximum compressive strength f c of concrete and the tensile splitting strength f sp of concrete; The use of a binder or epoxy resin in seawater or saltwater affects the ultimate shear strength and effectiveness of the epoxy resin CFRP strengthening system.

In [12] , an overview of previous research in the field of fiber reinforcement is given. As stated in the paper, reinforcing concrete using discrete fibers, randomly distributed, is an acceptable solution for improving the ductility of concrete. The addition of fibers in concrete affects most properties. These improvements in material properties opened the way for more research in this area to explore its advancement into untapped areas. Experimental results quantitatively reveal its improvement in various parameters such as tensile strength, flexural strength, toughness, ductility, corrosion resistance, resistance to cyclic and dynamic loads, crack resistance, etc.

Grujić B. (2016) addressed the topic in her doctoral dissertation modeling of the physical and mechanical properties of fiber-reinforced concrete with application in constructions. The subject dissertation investigated and analyzed the possibilities of obtaining improved physical and mechanical characteristics of micro-reinforced concrete with variations in the types and amount of steel fibers used in the mass of concrete. The selected steel fibers, as well as the amount of fibers used, greatly influenced the quality of the physical and mechanical characteristics of micro-reinforced concrete. At the same time, the paper presents a rheological-dynamic analysis of the subject concrete on a standard cylinder-shaped sample. The procedure for making samples of fiber-reinforced concrete is detailed, which is particularly significant from the aspect of the influence of the fiber shape factor, the time of making the mixture, and the coarseness of the aggregates and the fiber content on the consistency of the concrete. Microreinforcement mainly contributes to a significant increase in the ductility (toughness) of concrete, both when using steel and when using other artificial fibers: polymer, carbon, glass and others. The eventual increase in compressive strength due to the addition of fibers depends on a number of parameters, the most important of which are: type of fibers, amount of fibers, shape factor (L/D) and composition of the concrete matrix. The obtained results showed that there is an increase in the compressive strength of concrete elements reinforced with microfibers compared to standard concrete samples, approximately 3.7 - 9.4% for microfibers with curved ends. Flat microfibers have a slight increase in compressive strength (approx. 0.5-1.5%). A similar behavior occurs in the tensile strength test, where the increase is expressed from 56 – 100 % for samples reinforced with microfibers with curved ends. Other samples (straight microfibers) have an increase in tensile strength of approx. 30%.

In the paper [14], FRP reinforcement for concrete structures, a review of the available literature and current knowledge in the field of fiber-reinforced polymers (FRP), which are used to strengthen concrete structures, was carried out, especially on structures subject to aggressive environments or the influence of electromagnetic fields. This paper also reviews the production process, material properties, field of application and specifics of designing concrete elements reinforced with FRP composites. With a primary focus on internal reinforcement, the paper discusses recent practices of FRP application on RC elements in construction. The paper contains descriptions with a table showing the physical and mechanical characteristics of various FRP materials. Application supports are described, but it is said that there is not enough reliable experimental data on the long-term degradation of the mechanical properties of FRP materials. Therefore, common design practice is based on increased values of safety factors, which lead to higher costs of FRP-reinforced elements and make such structures economically inefficient. Also one of the main disadvantages, which is mentioned in this paper, is that most of the materials used for the production of FRP are not resistant to specific environmental conditions. For example, fiberglass is not resistant to alkalis; UV radiation is harmful to the mechanical properties of most polymer resins. The authors suggested that further research should be directed towards experimental investigations of long-term mechanical processes that take place in concrete elements with FRP reinforcement, and the development of a standard form of internal FRP bars and anchoring measures for external reinforcement, but also towards the development of design procedures for the application of combined internal and external reinforcements .

Katar M. Ihab (2017) reviews the latest research in the field of carbon composites in RC structures. The paper contains comparisons of a group of building materials that are mainly used for finishing from certain aspects and properties such as: stiffness and strength of materials in relation to weight, stiffness and strength of materials of the same thickness, weight/density, processing, thermal expansion, conduction heat, temperature resistance, long-term effect and implementation of the production process. The author provides a historical overview of the development of carbon fiber applications, with graphic representations of fiber textures. The results obtained during the research were collected and presented in tables. Analyzing the results, the study found that CFC received the second highest score among other materials after steel, although it had high scores among other materials, especially in specific properties: stiffness / strength to weight and thickness ratio, thermal expansion. On the other hand, CFC obtained lower results in other properties, such as: processing, temperature resistance and carrying out the production process, especially compared to steel and wood. Meanwhile, CFC scored average among most other materials in properties: weight/density, thermal conductivity, and long-term performance. As a result, CFC was assigned the second rank among other construction materials, but still by a small margin after steel, and not as expected before the experiment itself.

Navya HA, Patil Nayana N. (2018) investigated the behavior of M25 concrete reinforced with carbon fiber doses of 0%, 0.75%, 1.00% and 1.25% of the concrete mass, with the aim of determining the strength and durability characteristics. The mechanical properties, compressive and tensile strength, as well as bending resistance, were studied. The test samples were also subjected to the effects of acids and sulfates and were tested for their durability. The results show that there is an increase in compressive strength, tensile separation and flexural strength of carbon fiber reinforced concrete. The inclusion of 1% carbon fiber showed the maximum increase in strength and can be considered as the optimal dose. Compared with conventional concrete, the crack width also decreased in carbon fiber reinforced concrete. Some of the most important conclusions of this research are:

- As the carbon fiber dosage increases from 0% to 0.75%, 1% and 1.25%, workability decreases. However, the slump test for conventional concrete and carbon fiber reinforced concrete with 0.75% carbon fiber was found to have the same values,
- The compressive strength of M25 concrete for different amounts of carbon fibers of 0.75%, 1.00% and 1.25% compared to conventional concrete increased by 46.80%, 59.90% and 32.40%. The maximum percentage increase in compressive strength was achieved at 1.0% fiber dosage, and it was found to reduce by 1.25% the fiber content,
- It was observed that there was an increase in the tensile strength of CFRC for different dosages of 0.75%, 1% and 1.25% and they were found to be 28.1%, 56.30% and 9.40% more than with conventional concrete. The maximum percentage increase in tensile strength was achieved at 1.0% fiber dosage, and it was found to reduce more than 1%,
- Compared with conventional concrete, the flexural strengths for M25 grade CFRC for different carbon fiber percentages of 0.75%, 1.00% and 1.25% increased by 88.50%, 107.69% and 78.46% . The maximum increase in flexural strength was achieved at 1.0% fiber dosage, and it was found to reduce more than 1%,
- Carbon fiber reinforced concrete is more resistant to acid and sulfate attacks compared to conventional concrete. The highest resistance was observed in the case of CFRC with 1.0% carbon fiber, as indicated by the lowest percentage losses in weight and compressive strength.

3. METHODS OF APPLICATION IN CONSTRUCTIONS

As stated by the authors in [2], in the 1960s, corrosion problems began to appear on RC bridges and highway structures. Road salts in colder climates or sea salts in coastal areas accelerated the corrosion of reinforcing steel. Corrosion spreads and causes the concrete structure to break. The first solution for rehabilitation was the installation of a galvanized layer applied to the reinforcing bars. This solution soon fell out of favor for various reasons, but mainly due to the electrolytic reaction between the steel and the zinc-based coating, which led to a loss of corrosion protection.

In the late 1960s, several companies developed electrostatic-spray with fusion (powder) on steel oil and gas pipelines. In the early 1970s the US Federal Highway Administration funded research to evaluate over 50 types of coatings for steel reinforcing bars. This led to the current use of epoxy-coated steel rebars.

It is emphasized that research into the use of resin in concrete began in the late 1960s with a program at the Bureau of Polymer Impregnated Concrete Records. Unfortunately, the steel reinforcement could not use polymer concrete due to incompatible thermal properties. This fact led Marshall-Vega (later renamed Vega Technologies and currently reformed under the name Marshall-Vega Corporation) to produce glass rod for FRP reinforcement. The experiment succeeded and the resulting composite rebar became the polymer concrete reinforcement of choice. Despite earlier research into the application of FRP reinforcement in concrete, the commercial application of this product in conventional concrete was not recognized until the late 1970s. Then research began in earnest to determine if composites were a significant improvement over epoxy-coated steel. During the early 1980s, another pultrusion company, International Grating, Inc., recognized the product's potential and entered the FRP reinforcement industry.

The same authors [2] talk about how in 1986 the first highway bridge using composite reinforcement was built in Germany. Since then, bridges have been built across Europe, and more recently in North America and Japan. The US and Canadian governments are currently investing significant sums in product evaluation and further development. The biggest markets seem to be in the transportation industry. The paper states that at the end of 1993, there were nine companies actively selling commercial FRP rebars.

Structures such as bridges and columns built entirely from FRP composites have shown exceptional durability and effective resistance to the effects of environmental exposure. Modern FRP bonding has been established worldwide as an effective method applicable to many types of concrete structural elements such as; columns, beams, slabs and walls. It was there in 1991 that the first on-site repair with FRP joints was carried out. Since then, strengthening with externally bonded FRP composites has been studied worldwide. This sudden increase in the use of FRP composites was achieved after the 1995 Hyogoken Nanbu earthquake in Japan. By 1997, more than 1,500 concrete structures worldwide had been strengthened with FRP cladding joints. In Figure 1. the on-site application of CFRP is presented. Another form of application is the use of FRP bars instead of steel reinforcing bars or prestressing strips in concrete structures.

Figure 1. Strengthening of the RC structure using carbon (CFRP) strips [4]

Alferjani MBS, Abdul Samad AA, Elrawaff S. Blkasem, Mohamad N. (2013) in their paper gave an overview of 10 papers on the topic of using carbon fibers reinforced with polymers as reinforcement of RC beams in the shear area. Here, the area of application of carbon fiber is emphasized, as well as the history of application. In the paper itself, an overview table of data obtained by experimental and numerical research with the results of structural failure at ultimate load is provided. The conclusions were drawn that a greater number of layers of CFRP reinforcement on the beams is unnecessary and that the use of FRP material in structures enables variations in the safety factor depending on the environmental conditions and the type of stress.

Khalifa et al. (1999) conducted a test on three RC T-beams to investigate the anchorage performance of surface-mounted FRP reinforcement. The first beam was the reference beam, the second one was strengthened with CFRP without end anchorage, and the last one was strengthened with CFRP with end anchorage. The anchoring system, called the U-anchor, uses a GFRP bar placed in a groove on the edge of the beam and serves as an end anchor. They found that shear strength increased when reinforced with CFRP, but failure was governed by CFRP debonding when CFRP was used without end anchorage. However, in the specimen where anchorage was used, the shear capacity of the member increased quite a bit and ultimately no FRP debonding was observed.

Adhikary et al (2004) performed tests on eight RC beams reinforced in shear with CFRP strips using two different wrapping schemes; U-wrap and two sides of the beam. They investigated the effectiveness of cross layers over each other, vertical and horizontal; the main parameter, the fiber alignment direction (90°, 0° and 90° + 0°) and the number of layers (1 and 2). They observed that the maximum shear strength was obtained for a beam with full U-wrapped strips having vertically aligned fibers. Horizontally aligned fibers also showed enhanced shear strength compared to beams without CFRP. On the other hand, they found that the lowest concrete stress was for the same load range among all beams. A fully U-wrapped beam of one layer of CFRP with vertically aligned fibers achieved a maximum 119% increase in shear strength. Also, they compared with experimental values using models to predict the contribution of web shear to the shear resistance of CFRP bonded beams.

Al-Amery (2006) tested six RC beams with different combinations of CFRP strips and strips in addition to an unstrengthened beam serving as a control test. CFRP strip for flexural strengthening and with CFRP straps for shear strengthening or with a pair of CFRP sheets and straps, for total strengthening. They determined that the CFRP strips used significantly reduce the slippage of the joint between the CFRP strips and the concrete section. CFRP straps used to anchor CFRP strips increase the bending strength by up to 95%. only a 15% increase was achieved using CFRP strips alone. The results of the tests and observations showed that a significant improvement in the strength of the beam was achieved by joining CFRP strips and straps. That is, a more ductile behavior was obtained because debonding was prevented.

Anil (2006) improved shear capacity of RC T beams using unidirectional CFRP composites and compared experimental and analytical used ACI Committee report. From the results, it was observed that the stiffness of the beams is very close. It was also observed that the strength and stiffness of the specimens improved with the use of unidirectional CFRP. On the other hand, the analytical tensile load capacity showed a 20% lower value than the experimental bearing load, thanks to the successful anchoring performance.

Bencardino et al (2007) presented an experimental and analytical investigation of the shear strengthening of reinforced concrete rectangular beams wrapped with carbon strips (CFRP). The main variables include external anchorages with different lengths in the form of U-shaped steel ties. The results showed that the anchorage system improves the strength and deformability properties of the CFRP beam. Also, the anchoring system changes the mode of failure of the reinforced RC beam under a predominant shear force, without increasing the load capacity, to a more ductile failure with a significant increase in the load capacity almost to bending failure.

Jayaprakash et al. (2008) made an experimental investigation of the shear strengthening capacity and failure mode of precracked and uncracked RC beams externally bonded with bidirectional carbon fiber reinforced fabric (CFRP) strips. Twelve RC T-beams were produced with different internal longitudinal and shear reinforcements. These beams are subjected to two types of loading: three-point and four-point bending systems. Beams are classified into three categories, namely; control, pre-repaired and repaired and initially reinforced (ie untreated) beams. The overall increase in shear strength of the pre-rehabilitated and initially strengthened beams ranged between 13% and 61% greater than their control beams. It was found that the application of CFRP strips in pre-rehabilitated beams achieved better performance compared to originally strengthened beams. It was also observed that all reinforced beams reached premature bending failure due to the presence of an excessive amount of shear reinforcement.

Jayaprakash et al (2008) conducted tests to study the shear capacity of precracked and uncracked reinforced concrete beams with bidirectional CFRP strips on the outside. The experimental program consisted of six samples that were classified into two categories; named BT and BS, each category had eight beams, four control beams, six precracked/repaired beams and six initially strengthened specimens. Based on the results, it was observed that the outer CFRP strips act as shear reinforcement similar to steel forks. They also showed that increasing the ratio of longitudinal tension reinforcement and the spacing of CFRP strips affect the shear capacity. This research showed that the orientation of CFRP strips not only affects the cracking pattern but also affects the shear capacity.

Godat et al. (2010) studied to gain a clear understanding of size effects for carbon fiber reinforced polymer (CFRP) beams. Their experimental research investigates the shear performance of rectangular reinforced concrete beams strengthened with CFRP U-strips, as well as one fully wrapped with CFRP strips. All beams were strongly reinforced in the bending region, no steel ties were placed in the right shear range of interest, but in the left shear range they were placed to ensure that failure would occur in the shear range. From these results, they noted that CFRP's larger beam size improves shear capacity less. They investigated the crack behavior of these samples. Their research presented a comparison of test results and predictions from design guidelines.

Bukhaari et al. (2010) studied the shear strengthening of reinforced concrete beams with carbon fiber reinforced polymer (CFRP) sheets. Seven, two span continuous reinforced concrete rectangular beams.

One beam was not strengthened (control beam), and the remaining six were strengthened with different arrangements of CFRP sheets. They studied fiber orientation (0/90 and 45/135) as the main variable. Tests have shown that it is useful to orient the fibers on the CFRP strip at 45° so that they are approximately perpendicular to the shear cracks.

HK Lee, SH Cheong, SK Ha, and CG Lee (2011) investigated the behavior and performance of deep reinforced concrete shear beams strengthened with CFRP strips. A total of fourteen reinforced concrete deep T-section beams are assumed to have shear failure. The specimens are reinforced with longitudinal steel and forks near the mid-span. They also studied variables such as reinforcement length, fiber direction combination of CFRP sheets and anchorage using U-wrapped CFRP strips, these variables have a significant influence on the shear performance of reinforced deep beams. Their tested experimental results of T-section beams were considered deep beams, since the ratio of shear span to effective depth (a / d) is 1.22. On the other hand, the crack patterns and the behavior of the examined deep beams during the four-point load tests were observed.

Alferjani MBS, et al. (2014) also compared works in the field of strengthening RC beams using carbon fibers. This paper reviews 10 articles and attempts to address an important issue encountered in the shear strengthening of carbon fiber reinforced beams. One of the conclusions drawn is that there are no design guidelines for the optimization and selection of CFRP tape/laminate thickness for strengthening RC beams. A beam strengthened with multiple layers of CFRP laminates unnecessarily increased the strengthening time and costs compared to a single layer CFRP laminate.

The importance of the study for beam strengthening using CFRP laminates in the strengthening system provides an economical and versatile solution for extending the service life of reinforced concrete structures. From the reviewed literature, it is evident that epoxy resin is suitable for strengthening the removal.

Ascione L., Mancusi G. and Spadea S. (2010) presented experimental results on ten (10) samples of RC beams in order to highlight the special properties of concrete elements reinforced with CFRP bars and stirrups. A comparison between experimental evidence and theoretical predictions is also presented. In this regard, predictions are established using force balance and strain compatibility equations, assuming the following hypotheses:

- preservation of the cross-section plane;
- perfect reinforced concrete connection;
- no shearing deformations.

Further, for the comparison of experimental values, partial factors and environmental factors are assumed to be unique. Finally, research conclusions are given stating that the prediction formula proposed by CNR-DT 203 for estimating shear deflection loads appears to greatly overestimate the actual strength of FRP-reinforced members. The moment-curvature relationship of FRP-reinforced elements is basically linear in both pre-cracking and post-cracking stages, no corresponding contribution in terms of stress reduction or better stiffness appears. Experimental results significantly assess the reliability of prediction formulas, both for deviations and for crack width. Neglecting the effects of reduced stresses in the calculation of bending or member failure leads to good agreement with experimental data. The experimentally observed cracking phenomenon is more important than the theoretical one. The authors state that more experimental research is needed in the future in order to better predict the actual mode of failure.

Dan S., Bob C. (2018) and colleagues conducted experimental research with the aim of analyzing the behavior of modern and effective solutions - for the rehabilitation of reinforced concrete frame structures. In the paper, experimental researches of carbon fiber-reinforced polymer (CFRP) were carried out, which are used as a solution for strengthening frame constructions made of reinforced concrete (RC), which are assumed to be existing structures, and which were tested as non-reinforced and as (CFRP) reinforced structures. The experiment focused on RC frames, and single RC frames were constructed, all according to the Romanian codes from 1970, according to which dimensioning for seismic influences is inadequate for today's influences on the structure. Experimental investigations carried out on the RC frame structure highlighted some main aspects of the CFRP strengthening system: a slight increase in the resistance capacity by 5% at the ultimate load-bearing stage and a reduction of the top displacement by 27% at the serviceability stage.

Song and Hwang, (2004) investigated the mechanical properties of concrete reinforced with high-strength steel fibers, with different fiber content (volume fraction 0 - 2%). The researchers proposed different relationships from the test results to predict the compressive strength, split tensile strength and modulus of rupture of high strength steel fiber reinforced concrete, knowing the values of high strength concrete and the volume of added fibers. It was seen that the compressive strength increases with the fiber content up to V f = 1.5%, as shown in Figure 1. The change in tensile strength and modulus of rupture followed a linear relationship with the fiber volume fraction. Both strength parameters increased with fiber content (Figure 2).

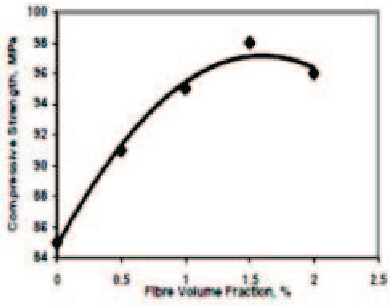

Figure 2 . Relationship between compressive strength and fiber volume fraction [13]

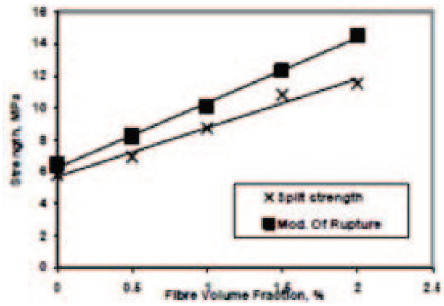

Figure 3. The relationship between tensile tensile strength, splitting modulus and fiber volume [13]

Balendran et al (2002) conducted a series of experiments to investigate the effectiveness of fiber inclusion in improving the mechanical properties of concrete with respect to concrete type and sample size. Light aggregates and limestone concrete with and without steel fibers were used in the research. It was observed that the small volume of steel fibers increased the cylinder splitting tensile strength and the modulus of rupture, although it had little effect on the compressive strength itself. The effectiveness of fiber reinforcement depends on the properties of the concrete matrix in question. With the same fiber type and volume, the improvement in tensile strength and flexural strength was much greater for lightweight concrete than for normal weight concrete. There was no effect of size on the tensile breaking strength of normal weight prism and lightweight aggregate plain concrete. In the case of fiber-reinforced concrete (both normal and lightweight), the size effect was not significant when the sample size exceeded the critical (transitional) size of 150 mm. The toughness indices of fiber-reinforced concrete are not very sensitive to sample size. On the other hand, for normal weight fiber-reinforced concrete, the toughness indices became smaller when the sample size increased. Therefore, the effect of size on toughness should be considered when designing the ductile behavior of fiber-reinforced structures. Further research is needed to examine the effect of size on toughness.

Bencardino et al (2008) presented compression test results on cube and cylindrical specimens of plain and fiber reinforced concrete with fiber volume of 1%, 1.6% and 3%. The compressive strength was evaluated experimentally and the corresponding stress-strain curves were also recorded on the cylindrical specimens to highlight the role of the fibers in the response after reaching the ultimate load. The results of the strength test show that the shape of the test specimen affects the value of the compressive strength. The results of the experiment also emphasized that with proper mix design, consistent quality fiber concrete can be produced in the field. Therefore, the results confirm that the most significant contribution of fibers in concrete is a significant improvement in behavior after reaching the ultimate load capacity, both in compression and tension. This is mainly because the fibers continue to resist crack growth and propagation after the first crack appears and allow the concrete to withstand very high stresses, five to six times the value of ordinary concrete. Increasing the fiber content improves post-peak behavior and an extended softening branch is observed. SFRC samples with fiber contents of 1.6 and 3% show, at a strain of 0.01, residual stresses of about 74 and 78% of their peak stresses. At these amounts of fibers, the ultimate stress at failure reaches values three to five times the ultimate stress values.

Job Thomas and Ananth Ramaswamy (2007) presented their results with an experimental program and analytical evaluation of the influence of fiber addition on the mechanical properties of concrete. The obtained models are based on the regression analysis of 60 test data for different mechanical properties of concrete reinforced with steel fibers. The study showed that fiber-matrix interaction significantly contributes to the improvement of mechanical properties caused by fiber incorporation. Therefore, the following conclusions were drawn from their study: there was only a small increase in compressive strength, modulus of elasticity and Poisson's ratio (less than 10%) in various types of concrete due to the addition of steel fibers; The maximum increase in tensile strength, namely tensile strength and modulus of rupture due to the addition of steel fibers has been shown to be about 40% in various types of concrete and is the basic justification for the use of fibers in concrete. The post-cracking response is significantly improved by fiber dosages throughout the different classes of concrete. It has been shown that the highest stress increase corresponding to the peak compressive strength in various types of concrete is about 30%. Enhanced peak stress capability is another significant benefit derived from the use of fibers. The proposed strength prediction models can be used to estimate the strength properties of SFRC based on the concrete and fiber class index $(RI = V_f L_f / \varphi_f)$.

Cucchiara et al (2004) investigated that the inclusion of fibers in an adequate percentage can change the brittle failure mode that characterizes shear failure to a ductile failure mechanism, thus increasing energy dissipation. It also confirmed the possibility to achieve similar performance by using reinforcing fibers instead of increasing the amount of transverse reinforcement in the form of forks. Testing was done for two ranges of shear to effective depth ratios to study the behavior in two different failure modes. In the case of FRC beams, a more progressive cracking process with reduced crack widths was observed. It was also possible to compare the ultimate strength by using steel fibers as shear reinforcement in the appropriate amount instead of the forks, although the simultaneous use is more appropriate because the forks allow a greater ability to deform beyond the elastic limit. Additionally, the presence of fibers has been shown to be more effective in beams where failure in the absence of adequate reinforcement governs the effect of the beam.

Rao and Rama Sheshu (2006) tried to investigate the useful possibilities of steel fibers in reinforced concrete elements with either longitudinal reinforcement or transverse reinforcement, as well as the potential of these fibers in concrete to act as longitudinal reinforcement or transverse reinforcement in a beam where either reinforcement was not present. They conducted tests of the torsional behavior of RC beams as torsional stiffness; torsional stiffness and torsional toughness of members play a vital role in the analysis of buildings exposed to seismic and wind loads. The pure state of shear stress due to torsional loading induces the main diagonal tensile stress which is mainly responsible for failure of ordinary concrete member under pure torsion. It was seen that the addition of steel fibers at about 1.2% improves the torsional toughness of the non-fiber beam by about 200% and the torsional stiffness by 148%. This indicates that a single type of reinforcement does not help to improve the torsional strength of beams beyond the occurrence of the first visible cracking moment. Therefore, it can be concluded that the ultimate stress strength of beams with one type of reinforcement can be limited to the torsional strength of unreinforced fibrous or non-fibrous elements. The presence of fibers forces the beam to behave ductile to some extent delaying the crack progress. However, the fibers present in the matrix improve the torsional toughness and torsional stiffness of the members. The steel fibers thus improve the breaking moment of the members to a noticeable extent, which improves the performance of the member in aggressive environments.

Rao and Rama Seshu, (2005) developed an analytical model to predict the moment response and SFRC members subjected to pure torsional loads by considering the softening effect of concrete. The addition of steel fibers only slightly improves the maximum torque capacity, but improves torque and torsional toughness to a greater extent. The durability of FRC was confirmed by experiments that corrosion in SFRC is less, compared to steel bars. The study clearly indicated that the main factor that facilitates corrosion is the rupture of the tight bond of the fiber-cement matrix, which is caused by the slippage of the fibers that follow the crack opening. The flexural strength of cracked specimens also increases due to corrosion as the surface roughness causes difficulty in sliding which ultimately results in an increase in strength.

Rapoport et al. (2002) investigated the relationship between permeability and crack width in steel fiber-reinforced cracked concrete. They also examined the influence of steel fiber reinforcement on the permeability of concrete. This indicates that fiber-reinforced concrete is subject to inelastic (irreversible) deformation compared to unreinforced concrete. From the test results, it can be seen that at higher levels of cracking, the reinforcing steel fibers clearly reduce the permeability, which is most likely a consequence of the stitching and multiple cracking that the steel fibers have. It is possible that a higher volume of fibers will further reduce the permeability of cracked concrete. However, at some fiber volume, an optimal level can be reached, above which more fibers will increase throughput.

Nataraja et al. (2005) investigated the resistance of OPC and SFRC to the influence of compressive strength for a relative comparison of the response of these mixtures. The addition of steel fibers has been shown to significantly improve the impact resistance of concrete and is therefore a suitable material for structures exposed to impact loads. A drop weight impact test, also known as a repeated impact test, was performed to assess impact resistance. The number of blows for first cracking as well as the number of blows for ultimate failure increased with increasing fiber volume fraction for all mixtures. Plain concrete specimens failed to brittle failure because they do not possess significant cracking resistance, and the concrete only resisted a few additional impacts after cracking. In the case of ordinary concrete mixes of 30

MPa, the specimens failed immediately after the opening of the first crack, and the broken pieces touched the positioned gears of the device with the addition of several impacts. In the case of the 50 MPa mix, the specimens resisted several additional impacts before contacting the girders. However, in the case of SFRC, this increase in crack resistance is approximately 40% to 60%, depending on the fiber content. The increase in the number of blows for the first crack is significantly higher in the case of SFRC.

Singh and Kaushik (2003) presented a study on the fatigue strength of steel fiber reinforced concrete. Tests of steel fiber-reinforced concrete are mainly limited to determining the limit of its bending capacity for different fiber types/volume fractions/ratio. The obtained fatigue equation can be used to obtain the flexural fatigue strength of steel fiber reinforced concrete for the desired level of resistance. However, more research is needed to determine how fiber type and ratio affect results.

Song et al (2005) investigated the impact resistance differences of high strength steel fiber reinforced concrete (HSFRC) and high strength concrete (HSC). Studies already show that hook-ended steel fibers have good potential for enabling concrete to withstand higher impact loads and that the fibers provide at least a five-fold increase in impact resistance, compared to straight steel fibers. It was also reported that steel fiber concrete is six times better at receiving impact loads than "ordinary" concrete.

Khaloo and Afshari, (2005) investigated the effect of length and volume of steel fibers on the energy absorption of concrete slabs of different concrete strengths by testing 28 small reinforced concrete slabs (SFRC) under load. The presence of steel fibers in the concrete did not significantly affect the final strength of the panels, which manifests itself with the appearance of large cracks. The fibers did not significantly affect the flexible characteristics of the panels before cracking. Also, the increase in fiber content reduced the growth rate of total energy absorption. The panels did not show any visible cracks before reaching ultimate strength. Ordinary panels failed under load without any significant warning. The addition of fibers does not significantly increase the ultimate flexural strength of SFRC panels. However, the panels' ability to absorb energy has improved. The energy absorption of panels with a fiber volume of 0.5% was about 12 times higher than a regular concrete panel. Panels with 1.0% fiber volume experienced energy absorption about 2 times higher than the 0.5% fiber panel. For this reason, experiments recommend the use of fiber volumes in the range of 0.75 - 1.75. Longer fibers (ie fibers with a higher aspect ratio) provided greater energy absorption. The absorption of the 35 mm fiber was about 1.2 times that of the 25 mm fiber. Increasing the strength of fiber concrete increases the energy absorption capacity. The test also concludes that fibers have a similar effect on the behavior of slabs of different concrete strengths.

Altun et al. (2007) investigated the influence of steel fibers on different classes of concrete. By searching the relevant literature, it can be noted that the optimal SF dosage for SFARC beams should be within 1 - 2.5% of the absolute volume. A dose of SF less than 1% becomes ineffective, and doses greater than 2.5% also become ineffective mainly due to physical difficulties in ensuring a homogeneous distribution of fibers within the concrete, which causes a significant drop in compressive strength when compared to ordinary concrete for the same class. Here, it is believed that SFARC beams having steel fibers in a dose of about 30 kg/m^3 should be suitable or even a common practice, because firstly, crack formation, crack size and crack propagation in beams according to bending moments are significantly better, secondly, the ultimate capacity a little better in bending, and thirdly and most importantly, the toughness is much higher than in an RC beam with the same usual reinforcement, but without steel fibers. Therefore, it is clearly stated that a dosage of steel fibers of 30 kg/m^3 is recommended.

Hatami F. et al. (2013) conducted research on an eccentrically loaded RC column with and without reinforcement. Stiffness, failure force and energy absorption of RC columns were tested. The results showed that by increasing the axial load, the deep cracks in the RC column without the CFRP layer were widened, and the bending stiffness was reduced until failure. After fracture, the tensile force in the longitudinal reinforcement increased slightly. Also, the behavior of RC columns without CFRP reinforcement showed that the maximum curve was in the middle of the column and that the maximum transverse stresses were recorded in the compression zone. The authors determined that the presence of CFRP reinforcement can increase the axial load capacity of the RC column by up to 108%, while an increase in the longitudinal displacement of 13% was measured for the CFRP sample compared to the unreinforced (control).

Also, along the way secant stiffness sample In 300 it was is 14.83 kN/mm, a for S 300-DD pattern about 34.5 kN/mm what is showed increase of 132.64% in relationship on unreinforced sample ar elative absorption energy sample In 300 it was is equal to 1273 kN/mm, a for S 300- DD pattern is was about 2977 kN/mm , what is increase of 133.9% in relationship on unhardened sample .

Jingjing Zhang and colleagues (2017) addressed the area of durability of RC structures reinforced with carbon fibers, as well as determining the mechanical resistance of the fibers themselves. The authors proposed a test in which chopped carbon, aramid and hybrid carbon-aramid fibers (1:1) were added to concrete in order to fully utilize the high strength and toughness of the fibers and improve the properties of concrete. The influence of different types and mixing ratio of fibers on the mechanical properties and durability of concrete was analyzed using axial compressive strength, static modulus of elasticity and carbonization tests. A calculation model, based on axial compressive strength, carbon dioxide concentration and carbonation time of concrete, was developed with existing models for calculating the depth of carbonation and verified using experimental data. The results showed that the compressive strength, elastic modulus and anti-carbonation capacity of fiber-reinforced concrete initially increased and then decreased with increasing fiber content and were better than plain concrete. The compressive strength and modulus of elasticity of hybrid fiber-reinforced concrete with a mixing ratio of 1% increase the most among all tested concrete samples, and the anti-carbonation capacity of carbon fiber-reinforced concrete with a mixing ratio of 1% is the best, and the proposed method can be taken to evaluate the practical properties and durability of fiber concrete in practical engineering.

In paper [18] , the application of CFRP strips on RC structures was investigated . From the results shown, it can be seen that the reinforced beams were stronger compared to the corresponding control beams. This difference becomes more pronounced in the shooting zone. The load/displacement curve is more pronounced for group 2 beams where the initial cracking load of beam CB-2 is lower than CB-1. It can also be noted that the load deflection curves of reinforced beams with end anchorages are stiffer compared to beams without end anchorages. The curves for the reinforced beams showed an identical response in the initial stage of loading, but as the load increased the beams without end anchorages began to deviate more due to excessive cracking at the ends and the tendency of the envelope to overturn. This effect is more pronounced in beams of group 2. From the tests of RC beams reinforced with CFRP sheaths along their length with and without anchorages, the following conclusions can be drawn: RC beams wrapped with CFRP at the bottom and extended on the sides intended for anchorages and without ends, improved structural performance of beams in terms of stiffness, load capacity and ductility; CFRP-strengthened RC beams were found to have the occurrence of fine cracks uniformly distributed along the span and a higher first crack load as high as 20.9% in WSAB-1 and 79.5% in WSAB-2 compared to their control beams; The ultimate bearing capacity of reinforced beams increased to a maximum of 16.7% compared to the corresponding control beam in Group 1, while in Group 2 it increased to a maximum of 20.8%; Reinforced beams tested at a lower a/d ratio were found to fail in shear and compression, even though they had adequate shear reinforcement. The difference in failure modes in reinforced beams with a smaller a/d ratio is due to the presence of end anchorages. However, beams tested with a higher a/d ratio fail to flex as expected. It has been observed that the use of CFRP sheaths results in a significant increase in the stiffness and ductility of RC beams, along with an increase in the load-carrying capacity of reinforced RC beams with end anchorages.

Koutas N. Lampros, Tetta Zoi et al. (2019) gave a state-of-the-art overview of the reinforcement of concrete structures with textiles. The paper states that there has been a significant improvement and upgrading of the textile materials themselves, where the characteristics have been improved from the aspect of detheorization, suffering from the effects of the environment, from the consequences of non-maintenance, etc. The advantages (high strength-to-weight ratio, corrosion resistance, easy and quick application, etc.) as well as the disadvantages of using FRP (textile) materials (high prices of epoxy resins, poor performance at high temperatures, poor adhesion to the substrate, etc.) are listed.), and new methods of strengthening with textiles are described, where in fact a new material is applied - textile reinforced concrete (TRM). This paper provides an overview of the use of the TRM system for strengthening, where certain segments of the load-bearing structure are analyzed in particular. The paper also provides an overview of methods for strengthening RC beams or plates from the aspect of bending and from the aspect of shearing, where the methods are described, general behavior due to strengthening, modes of failure, influence of parameters on the effect of strengthening, aspects of dimensioning, strengthening against shearing, improvement of concrete with the aim of increasing load and bearing capacity (deformation), seismic strengthening of RC structures, etc.

Litvinov A. (2010) dealt with the area of application of carbon fibers in his master's thesis in constructions. The purpose of this research was to investigate production technologies, properties of carbon fibers, construction methods, and to compare carbon fibers and structures, using carbon fibers with traditional materials and structures, and to discover the reasons for their application in construction. In addition to all that, the task was to create a calculation tool in Excel to evaluate the effect of carbon fiber reinforcement on the structure. In the paper itself, an overview of the use of carbon fibers in construction is given, so examples of the use of carbon fibers in the form of reinforcement of concrete elements, production of prefabricated elements (wall panels), use in bridge construction, etc. are given. At the end, a calculation was given in the software (Excel) with the aim of determining the effect of reinforcement. The calculations, which were made by the reinforcement manual in accordance with SP 52-101-2003, show a high efficiency of carbon fiber reinforcement. The main drawback of this work is the absence of experimental research on real samples and comparison with software.

Luiz Antônio Melgaço Nunes Branco and colleagues (2014) performed experimental research on concrete samples loaded under pressure reinforced with carbon tapes, with the help of the ABNT NBR 5739 standard and analysis of variance (ANOVA) - Brazilian standard. The obtained test results are shown in the tables, where it can be seen that the average strength values increased in all three types of tested concrete with the addition of laminated carbon fiber composite as reinforcement. The addition of carbon fibers enabled low-strength concrete to have an efficiency factor of 258.60, or 62.10 and 2.70 for medium- and high-strength concrete, which shows that the most effective reinforcement is for low-strength concrete, justified by lower tensile strength. The pictures show the brittle behavior of the reinforced concrete samples, where it is evident that the failure occurred in the carbon reinforcement, while the concrete section remained relatively undamaged. From the obtained results, it was established that the increase in strength was caused by the use of composite material in three classes of resistance. However, it was also observed that the efficiency factor of carbon fiber reinforcement is significantly higher at the lowest specific strength. As the resistance of reinforced concrete increases, the percentage of increase in performance of the applied system decreases (258.6% for low strength and 22.7% for high performance).

Mohammad Reza M., et al. (2009) conducted torsional load research on three groups of rectangular beams, consisting of sixteen samples with different amounts of torsional reinforcement. The aim of this research was to assess the impact different ratios of torsional reinforcement on the torsional behavior of reinforced beams. Wrapping of carbon fiber reinforced concrete (CFRP) beams consisted of various configurations, including anchored U-wrap, full wrap, and strip wrap. This study showed that the contributions of CFRP to the torsional strength of reinforced beams, which have an identical volumetric ratio of CFRP reinforcement, are quite dependent on the total amount of torsional reinforcements. CFRP contributions will increase as the torsional reinforcement of the steel increases. The experimental results show that increasing the steel reinforcement by 37% and 94% increases the CFRP contribution to the torsional strength up to 54% and 91% for reinforced beams with one CFRP layer; and up to 60% and 111% for reinforced beams with two CFRP layers, respectively. In this work, the influence of the number of CFRP layers was also investigated. It was found that the increase in the CFRP contribution to the torsional strength of beams strengthened with one layer and two layers of CFRP strips is close for different ratios of steel reinforcement compared to the increase in the total amount of steel reinforcement.

Mosallam AS (2000) investigated the strength and ductility of reinforced concrete frame joints strengthened with quasi-isotropic laminates with the aim of establishing new techniques for strengthening damaged parts of the frame. Six cyclic tests were performed on samples reduced twice, simulating the beam-column connection of a typical RC structure. The test results showed that the use of complex layers led to a significant increase in the stiffness, strength and ductility of these connections. The ductility and hardness of the reinforced samples increased by 42% and 53%, respectively, compared to the control samples.

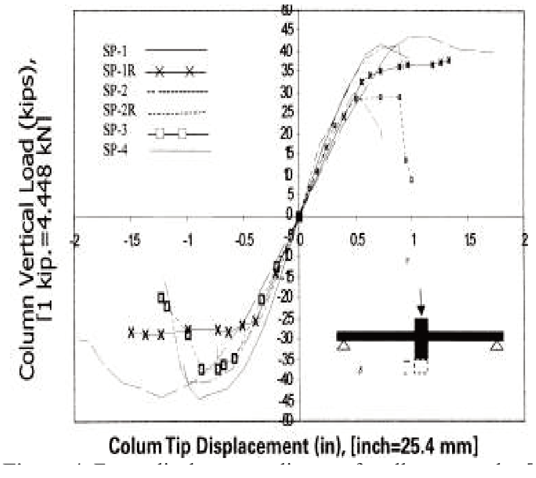

Figure 4. Force-displacement diagram for all test samples [26]

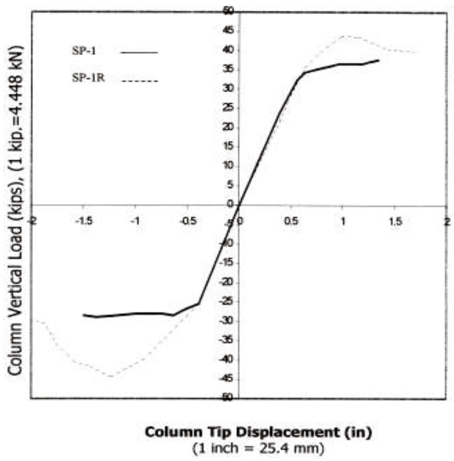

Figure 5. Force-displacement diagram for SP-1 and SP-1R [26]

From the presented diagrams and research results (Figure 4 and Figure 5), it can be seen that the use of the composite system not only restored the original capacity of the damaged sample, but also improved the ultimate load capacity by an additional 53% in the stressed zone and about 18% in the tightening. Also, the displacement at the ultimate load increased by about 29% in tension and 36% in the compression zone compared to the ultimate displacement before the damaged control specimen SP-1. Experimental results showed that the use of quasi-isotropic polymer composite laminates increases both the rotational stiffness and the ultimate strength of the reinforced concrete instant connections. The use of quasi-isotropic glass ± epoxy composites contributed to a significant increase in stiffness, strength and ductility of the repaired joint. For example, a 42% increase in the ductility of the repaired specimen (SP-1R) was achieved (3.40 vs. 2.4 for the control specimen SP-1). Cohesive failure was achieved in all tests.

Norris T., H., Ehsani RM (1997) presented the results of an experimental and analytical investigation of the behavior of damaged RC beams reinforced with carbon strips (CFRP). Carbon strips are glued with epoxy glue in the tension zone of the RC beam with the purpose of improving the shear and bending strength of the beam. In this paper, the authors consider the application of carbon strips wrapped around AB beams with the aim of increasing shear and bending resistance. These strips are made of high-strength carbon fibers, and since carbon-epoxy composite systems are not susceptible to corrosion, the problem of corrosion in reinforced concrete is automatically solved with the use of this material.

Analysis of the behavior of the bending resistance of the tested beams revealed the occurrence of deformations only after a load of 31 kN. By comparing the result of the reinforced beam with the control beam, it can be seen that the load at which the stress in the reinforcement was allowed was higher in the reinforced beam, which means that the internal forces are distributed to the carbon fibers and the reinforcement. Carbon fiber reinforced beams show higher ultimate strength than control beams at increasing loads up to 138 kN before sudden failure. This type of failure occurs due to the CFRP strips tearing off from the concrete.

The shear resistance of the tested beams investigated in this paper shows that with the application of CFRP reinforcement, the shear strength increases, regardless of the orientation of the carbon reinforcement. There is also a direct relationship visible between the increase value and brittle failure. In both cases (shear and bending) when the carbon reinforcements were installed perpendicular to the cracks, the results gave higher stiffness with brittle failure. When two layers of carbon reinforcement were used, where the second layer was installed perpendicular to the first, they usually showed the appearance of cracks and the failure still occurred suddenly, because the carbon reinforcements (part of them) were perpendicular to the cracks. The authors' conclusions in this paper show that CFRP reinforcements can increase the bending and shearing capacity of existing AB beams. The strength gain value as well as the fracture behavior model is related to the orientation of the carbon reinforcement. When CFRP reinforcements were placed perpendicular to the cracks, a large increase in stiffness and strength was observed, and brittle failure occurred due to cracking of the concrete as a result of stress concentration near the ends of the CFRP. When carbon reinforcements were placed parallel to the cracks, a smaller increase in shear strength and stiffness was observed.

4. CONCLUSION

Considering that the use of carbon fibers is increasingly prevalent in constructions, this paper systematizes previous research in this area with the aim of emphasizing the advantages and disadvantages of using carbon fibers. The most common application of carbon fibers in practice so far has been for the purpose of additional strengthening of structures, especially in the tension zone, where the application of carbon fiber reinforcement has proven to be extremely useful in terms of improving tensile load capacity, etc. In this paper, an overview of the author's research is given, and in one place, aspects with the possibilities of applying carbon reinforcements in constructions can be seen.

Based on the extensive analysis, it can be concluded that when reinforcing RC elements with carbon fibers, the main attention should be paid to the following factors:

1. Long-term degradation of mechanical properties. Depending on the type of CFRP reinforcement, the long-term strength can be reduced two to three times (compared to the short-term value). The maximum reduction in strength is associated with CFRP; however, other fibers are also sensitive to the effect of time. Moreover, creep is characteristic of most polymer resins applied in CFRP,
2. Correct selection of CFRP material due to environmental influences. Most of the materials used to make CFRP are not resistant to special environmental influences,

3. The characteristics of the adhesion bond is the leading criterion for the analysis of deformation states. In most cases, the design of CFRP RC elements is based on the application of increased safety factor values. However, recent research by the authors [8] revealed that such a methodology is too rough because deformations mainly depend on the bond properties of CFRP composites. Therefore, it can be said that, in order to increase the effectiveness of the application of structural composites, the sizing practice had to be based on experimental tests related to the joint properties of certain FRP materials,
4. Finally, carbon fiber composites are widely used as an addition to building structures. The main advantages of using this material are the achievement of higher tensile strengths and low weight, but there are still problems with cost.

Note: The work was done as part of the research carried out as part of the doctoral studies in the narrower scientific field of Civil Construction.

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