A Review of Concrete Structure in Terms of Deterioration and Strengthening with Analysis of Recent Technology

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Abstract—**In this paper the components of concrete structure, which are steel and concrete, and corrosion will be discussed. Followed by a description of the old technique that was used to strength and repair reinforced concrete structures. Then this essay presents a state-of-the-art technique that is fiber reinforced polymer and reviews of its manufacturing methods. Next, the positive and negative aspects of using fiber reinforced polymer sheets as increase shear and flexure capacity will be analyzed. Finally, a brief summary will be concluded.**

Index Terms: **concrete structure, strength, fiber reinforced concrete polymer (FRP), repair.**

I. INTRODUCTION

Concrete structures are the most widely used for building constructions. Commonly reinforced concrete is composed of concrete, that made by mixing cement with water, aggregate and sand, and steel. Steel and concrete work together effectively in resisting the external load. Whilst concrete has high compressive strength and low tensile strength, the embedded steel is provided to resist the tension and shear forces. It is a well–known fact that many concrete structures around the world approach the end of their service life as well as some of them affected by aggressive environment conditions, such as a devastating earthquake in Japan in recent years. Consequentially, these structures are more likely to need to be rehabilitated and retrofitted.

A. Old technique

In the past the popular method to repair and strength concrete structural elements was by bonding of steel plates to reinforced concrete members. However, the limited use of this technology in civil engineering applications due to corrosion, the heavyweight of steel plates and the difficulties to install, led a lot of researchers to develop novel material.

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Recently, in order to reveal emerge technique, extensive research projects have been conducted to focus on fiber reinforced concrete polymer. Because of these research projects which indicated that fiber reinforced concrete polymer may has superior properties, at present, there are tremendous research carrying out in this area.

The use of concrete as a construction material is widespread. In general, Portland cement alongside with sand, fine aggregate, coarse aggregate and water are the most common contents of concrete. In addition, concrete sometimes needs some further materials, e.g. additives and admixtures, in order to enhance particular characteristics of concrete such as workability, durability and time of hardening. Particularly in structural aggressive environments, such as chemical factories [1]. In fact, there are many other materials used as construction material such as wood and steel. Interestingly, compared with concrete, the percentage of steel consumption around the world does not exceed one to ten. Moreover, recently the demand for concrete in the world has been estimated to be at least 4.5 billion tons every year [2]. It is believed that water is the only other material which is consumed by human beings in such massive quantities [1].

Concrete is different to many materials, such as steel and wood, in that it has an ability to withstand water action without crucial deterioration. Hence, it is useful material to build structures which are subjected directly to water, for instance, retaining walls [2]. Another advantage of concrete is that structural elements could be easily formed into irregular shapes as well as that it requires a lower grade of skilled labor to build compared to other materials [3]. It is widely accepted that concrete is the cheapest material as a direct consequence of the cost and availability of its components [3].

However, even though plain concrete has a significant compressive strength, it has a small value to resist tensile and flexure strength [4]. These values are roughly one-tenth and one - fifteenth its compressive strength, respectively [4]. Because of these figures some reinforced concrete codes such as the American Concrete Institute (ACI 318) states that concrete is of little consequence in terms of tensile and flexure strength and is not taken into account in structure design. To compensate for this weakness and resist the tension, engineers provide concrete structures with other material.

This compensation can be carried out by embedding steel bars in concrete, which is known as "reinforced concrete" [5,6].

In terms of loads, reinforced concrete has an adequate performance in carrying heavy loads, which are subjected on concrete structure [1]. While concrete is responsible for compression, tensile strength is compensated by steel bars [1]. The tensile strength of steel is approximately equal to 100-140 times the tensile strength of plain concrete [2]. Furthermore, in order to increase the bond and stem the slippage between steel and concrete, projections are rolled on steel bars [7].

B. The deterioration of reinforced concrete buildings

Nevertheless, according to Mehta and Monteiro [2], corrosion is a considerable problem that frequently faces civil engineers. Also, Broomfield [8] argues that industrialized countries encounter the most serious problem when corrosion of steel in the infrastructure is appearance. The more reinforced concrete that is in direct contact with chloride ions, oxygen, seawater and water, the more corrosion may occur [8]. As steel corrodes, the resulting bar occupies an area far greater than that the original size. McCormac and Nelson [9] concluded that this expansion generate pressure towards concrete is more likely to cause significant crushing and cracking of concrete, and may result in the loss of bonding between plain concrete and bars. Concrete structure plays an important role as a corrosion protection material for embedded steel [9]. Therefore, in order to design reinforced concrete members, the designers should take into account the possibility of the highly aggressive environments, which may cause corrosion, as guidelines and specifications provide a specific minimum concrete cover requirement [2]. For instance, the American Concrete Institute Building (ACI 318) [5] recommended a minimum concrete cover of 2.5 cm for slabs and beams and 5 cm for foundations and walls.

Cracking and corrosion, lead to loss of flexure and shear strength, compressive strength and durability of concrete structure [2]. Consequently, this damage in building structure is more likely to be retrofitted to meet the specifications. It should be noted that many reinforced concrete structures nowadays in many regions are need to be renovated or replaced [10]. Dong et al. [11] revealed that there are many reasons behind this deterioration. As concrete structures approach the end of their life, loads and corrosion Increase [11]. Moreover, construction errors or aggressive environment conditions can be the fundamental reason for structure deterioration such as a devastating earthquake in Nepal 2015.

However, the deteriorated structure needs a huge amount of money for rehabilitation. For good example, the cost of the renovation of concrete parking structures has been estimated to be in the order of 4 – 6 billion dollar in the Canadian budget [12]. Additionally, the Highway Agency in the UK (1999) indicated that around 75% of the bridges and motorways are in need of repair as they are subjected to corrosion damages that cost 600 million pounds sterling [12].

II. FIBER REINFORCED POLYMER (FRP)

A decade ago, the technology of retrofitting and strengthening structure using the bonding of steel plates to reinforced concrete was a popular method [13]. Nevertheless, due to their heavyweight, and difficulties to install on irregular surfaces of concrete structures, extensive research has been conducted to develop alternative material [13]. Recently, Fiber reinforced polymer systems (FRP) are demonstrated by many researchers as a state- of-the-art technology. Today, one can hardly keep pace with research that is carried out in fiber reinforced polymer [13]. FRP regimes have crucial potential for various structure field applications, it could be used as one of structural concrete components by adding to concrete during mixing in low volume dosages between 0.5%-2.0% of volume of concrete (ACI Committee 544, 2008, p.2), or as a repair and strengthening material for reinforced concrete elements [5,10].

The first fiber reinforced polymer emerged in the 1930s, that was investigated at the Swiss Federal Laboratory for materials testing and research [13,14]. Fiber reinforced polymers are formed by embedding fibers in a resin matrix. While fiber provides strength and stiffness, polymeric resins are used to protect and transfer loading between fibers as well as are responsible for the bonding adhesive between fiber reinforced polymers and concrete [3]. The common resin matrixes are Polyester, Epoxy, Vinyl Ester, Urethane [13].

In terms of fiber reinforced polymer composites classification, there are four commonly types based on the kinds of fiber namely: glass fiber reinforced polymer (GFRP); carbon fiber reinforced polymer (CFRP); basalt fiber reinforced polymer (BFRP) and aramid fiber reinforced polymer (AFRP) [15]. CFRP composites have superior properties compared to other fibers composites, that characterized as having high modules of elasticity (350- 650 Gpa) and high strength (2500- 4000 Mpa) [16]. However, CFRP is considered as the most expensive type of fibers and it is more brittle compared with GFRP [16]. It may be noted that glass fiber reinforced polymer is the most commonly used as an alternative material of steel reinforcement in civil engineering [16]. The important features of widely used are the low cost as well as high chemical resistance and high tensile strength [16].

In order to produce fibers, there are six manufacturing methods for fiber reinforced polymer composites, namely: hand lay-up, compression modeling, resin transfer modeling, injection modeling, filament welding and pultrusion. Pultrusion is more likely to be the most common method of FRP manufacturing. Regarding to Pultrusion process, there are a number of different stages to ensure that fibers are in the correct condition for using as shown in figure 1. The first stage of the process begins when the continuous strands draws from creels. Having been drawn they are put through a risen tank so that it is saturated with resin. After this process, the produce passes through the heated die. Finally the end produce is pulled [16].

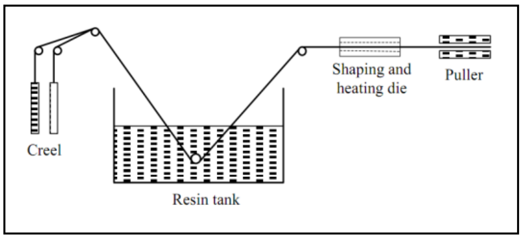

Figure 1. Pultrusion Process.

In order to lengthen the structural lifespan and retrofitting, extensive research has been conducted to provide an efficient strengthening approach. The criteria for engineers to embrace new material are that corrosion resistance, weight, cost, the way of installing, carry loads, resist flexure and shear force [10]. Many researchers believe that Fiber reinforced polymer externally bonded or sometimes called sheets has many advantages to strength and repair concrete structure members, such as beams, columns and slabs.

Fiber reinforced polymer sheets have become an accepted modern technique within civil engineering in terms of retrofitting and strengthening because of their lightweight, excellent corrosion resistance, a high tensile strength to weight, ease to remove and install and consider as a good non magnetization [17]. This means that it have a potential to use in special structures for instance hospitals that use magnetic resonance devices. Moreover, Fiber reinforced polymer sheets have potential to withstand against flexure and shear forces [17].

In recent years, many studies have been conducted to focus on fiber reinforced concrete that uses to increase shear and flexure capacity. An experimental investigation was carried out by Attari et al. [18], to study the flexure strength of concrete beams using various fiber reinforced polymer sheets. In particular, glass and carbon fiber reinforced polymer are considered with different configurations. Seven beams were conducted as specimens for Attari et als. [18], experimental work. Additionally, the experimental results revealed that applying glass fiber reinforced polymer is much more effective than carbon fiber reinforced polymer in terms of increasing flexural strength [18].

In addition, Buggio, et al. [10], investigate the effectiveness of using various configurations and types of commercially manufactured fiber reinforced polymer sheets to strengthen shear critical reinforced concrete beams. Externally bonded fiber reinforced polymer sheets namely carbon, glass fiber reinforced polymer and type of fiber reinforced polymer anchors were used to increase the capacity of shear strength. Buggio, et al. [10], highlighted that applying external fiber reinforced concrete increased the shear strengthening. However, this research emphasized that the full depth of a U wrap is a much more effective way to increase shear capacity than the partial depth of a U wrap. Unsurprisingly, the experimental results revealed that fiber reinforced polymer anchors enhanced the stiffness and shear capacity [10]. It should be noted that, while a lot of research focused on shear strengthening, this study is one of few studies which have used fiber reinforced polymer anchors as the anchoring mechanism to secure externally bonded FRP sheets [10].

Unlike many research such as Buggio, et al. and Attari et al. [10,18], research are conducted on either shear or flexure strength, Dong et al. [11], addressed reinforced concrete beams using glass fiber reinforced polymer (GFRP) and carbon fiber reinforced polymer (CFRP) as external sheets to strengthening flexural and flexural–shear. Dong et al. [11], have examined and applied the combination between flexure and shear strengthening configuration. Additionally, they assumed some arrangements of sheets that bound onto a beam surface, such as a U- wrap shape and a L shape [11]. They concluded the experimental results and emphasize that using (GFRP) and (CFRP) sheets can significantly enhance the flexural and shear capacity of the beams strengthen. Clearly, and as expected, Dong et al. [11], revealed that using the flexure-shear strengthening configuration is much greater asset than the flexure strengthening in enhancing the durability.

In an attempt to find an adequate equations to calculate the shear strength which depend on externally bonded fiber reinforced polymer Monti et al. [19], proposed some equations. Theses equations are used to compute the shear capacity of a U wrap and complete wrapping [19]. Twenty four beams with same properties were used. The cross section of beams where 250 mm x 450 mm for width and depth respectively, and 2.80 mm as span for beams. The main reinforcement was 4 Ø 20mm bottom and 2 Ø 20mm top. The thickness of externally bonded carbon fiber reinforced polymer sheet was 30mm.it should be mentioned that the questions developed demonstrated good correlation with other experimental works that available in the literature [19]

However, as a matter of fact, fiber reinforced polymer system is still impeded to be as a prime material for shear and flexural strengthening [17]. Because of insufficient experimental data, the researchers still carry out experimental works to explore satisfactory and reliable guidelines for the reinforced concrete structure design in terms of the flexure and shear strengthening using fiber reinforced polymer systems [17]. Dong et al. [11], supported Belarbi et als. [17], research by claiming that the acceptance and using of an stat-of-the-art technique as a develop material rely on the availability of comprehensive design codes and guidelines with clears specifications.

In addition, Belarbi et al. [17], indicated that the limited use of fiber reinforced polymer sheets for repair and strengthening as a direct consequence of its high initial cost. On the other hand, Hollaway and Leeming [20]concluded that while the initial cost of externally bonded fiber reinforced polymer is high, the total cost including labour and maintenance compared with other approaches is cheaper.

III. CONCLUSION

All in all, this paper has attempted to give an overview of reinforced concrete structure in terms of deterioration and strengthening with analysis of the emerge technology. While concrete components were presented, the function of providing the embedded steel to concrete has been discussed. This essay emphasized that concrete is a considerable material to strengths the compression but to use concrete successfully, steel is required to resists the tension. In addition, the advantages of utilizing the reinforced concrete for example, the potential to resist the water action, were addressed. On the other hand, corrosion, which may be a crucial problem that faces engineers, was discussed. The old technique, that was commonly used to cope with concrete structures deterioration, has been indicated. Moreover, the state-of-the-art technique, that uses to repair and strength concrete structures, was demonstrated.

In terms of strengthening and retrofitting methods, it could concluded that fiber reinforced polymer system is more likely to be an efficient approach. Its manufacturing process was involved. This paper has tried to provide some an emerge summary of recent research projects on fiber reinforced polymer strengthening of concrete structures, focused on flexure and shear strengthening. However, this review has some limitations. While there are numerous research projects undertook on fiber reinforced polymer regime, due the words limitation, a few studies were concluded. Last but not least, In future, potential studies should continue to focus on fiber reinforced concrete to develop it and provide clear guidelines.

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