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Durability Control of UV Radiation in Glass Fiber Reinforced Polymer (GFRP) - A Review

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Abstract. Glass Fiber Reinforced Polymer (GFRP) was commonly used as outer layer, and it may expose to the ultraviolet exposure and prone to UV radiation. UV radiation will lead to degradation of the GFRP itself and it will reduce the quality and function of GFRP. This paper is a review of past studies on UV Radiation of Glass Fiber Reinforced Polymer (GFRP) in transmission line tower. A study on UV radiation toward coupling steel laminates of GFRP pultruded show the load carry the capacity of the joint was found to be increase, it was due to polymerization of the adhesives. While, a study of UV radiation on GFRP show during the aging process GFRP show signs of plasticization and after 6 months the tensile strength of GFRP show substantial descending pattern and the tensile modulus were found less affected compared to tensile strength. Glass Fiber Reinforced Polymer (GFRP) has a good potential as a material to resist UV radiation.

Keywords: GFRP, Ultra Violet radiation, tensile modulus, tensile strength

INTRODUCTION

In the civil engineering applications, it is important to find solutions with alternative materials and technologies that are effectively offers better excellent mechanical performances in the structural construction industry. Nowadays, composite materials are increasingly utilized in engineering structures industry. Composite material is a combination of two or more materials for better properties than used it as a single component. Composite materials have many advantages such as high strength and high stiffness. Other than that, composite materials have low density than bulk materials which allowed weight reduction in finishing part. The reinforcement part is usually fiber that stronger, harder and stiffer than the matrix [1].

Glass Fiber Reinforced Polymer (GFRP) is a material that can fulfill the requirement to ease the installation procedure, saving of production time and decrease the environmental pollution. Due to increasing in population, it is important to produce and improve better products in order to sustain growing population every day. Despite using lower strength and modulus of natural fiber, an alternative material such as synthetic fibre which is Glass Fiber Reinforced Plastics (GFRP) was being developed due to presence of hydroxyl and other polar groups in various constituents of natural fiber [1].

Due to the lack resistance of composite structures that was extremely exposed in aggressive environments fail within a short period. Mechanical degradation and damaging in structural integrity can happen under some circumstances, causing from surrounding environments. Any aggressive environment will irreversible changing the

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property in polymer matrix chain. The degradation of fiber interface was causes by the acid and alkali environments on the surface of the glass fibers. The environmental factors would fasten the rate of mechanical degradation during installation and storage.

UV RADIATION IN GLASS FIBER REINFORCED POLYMER (GFRP)

GFRP was commonly used as outer layer, and it may expose to the ultraviolet exposure and prone to UV radiation. The harmfulness of ultraviolet (UV) radiation to human health and polymer degradation have become an attention recently in engineering industries. UV radiation will lead to degradation of the GFRP itself and it will reduce the quality and function of GFRP. A study on UV radiation toward coupling steel laminates of GFRP pultruded show the load carry the capacity of the joint was found to be increase, it was due to polymerization of the adhesives. While, a study of UV radiation on GFRP show during the aging process GFRP show signs of plasticization and after 6 months the tensile strength of GFRP show substantial descending pattern and the tensile modulus were found less affected compared to tensile strength. A. Kashi et. al. investigated the effect of marine environmental condition on durability of RC-corroded columns strengthened with FRP sheets by using 3 methods which were directly wrapping FRP and wrapping FRP after replacing damaged concrete with repair mortar, and after removing damaged concrete [2]. The method 3 was by applying repair mortar around GFRP sheet. It was found that the method 3 has a better performance of retrofitted columns in marine environmental conditions compared with the other two methods. The stiffness increased obtained by coupling steel laminates to GFRP pultruded profiles was investigated. Based on past research, three different epoxy adhesives were used and compared [3]. After the UV radiations, the load carrying capacity of the joints was instead increased due to further polymerization of adhesives. It also showed better effects on the mechanical responses of the joints than those registered in the aging conditions separately analyzed. Monitoring the effects of seawater ageing in glass fiber reinforced polymer (GFRP) composites using quantum dots (QDs) was proposed by using a simple and innovative method. After 6 months the tensile strength of GFRP composite showed a substantial descending trend and the tensile modulus was less affected than tensile strength in seawater or water [4], . J. M. L. Reis, F. D. F. Martins, and H. S. Costa discover that for particular composite, the stiffness of the tensile specimen is not significantly affected by the ageing time, but the ultimate tensile stress (UTS) is affected by the ageing time [5]. Two types of cement based mortar, namely polymeric and self-compacted, were applied on the sheets. A. Kashi, A. Akbar, and F. Moodi concluded that the bond strength of the polymeric mortar to GFRP sheets was more than those with self-compacted mortar [6].

Increasing use of composite especially in structures and transportation vehicles urge researcher to explore more on effect of UV resistant composites in order to minimize the harmful effect to human and degradation of polymer-based composite materials. Many researches recently focused on finding the functions of composite structures by utilizing hollow glass fiber reinforced polymer (HGFRP). An investigation was conducted on magnetic fiber composites by filling ferromagnetic substances into hollow glass fiber reinforced polymer (HGFRP) [7].

QUALITY CONTROL OF GLASS FIBER REINFORCED POLYMER (GFRP)

Quality Control in Manufacturing

The quality control in manufacturing which consist of production of resin and fiber is the important step to check the product’s final quality. In the process of producing raw material, the constraint parameter may gradually change. Some parameters must be examined first to avoid failure that will causes profile collapsed such as fiber distribution, surface tack, resin and fiber content and flow characteristics. This is because the process is quite difficult and need extra precautions to handle [8].

There was some researcher studied the quality control in manufacturing of composite structures. Szymanski studied the composite material which was used in the aviation industry. Manufacture diagram of composite element with polymer matrix was presented and the quality process in every stage was discussed briefly [9].

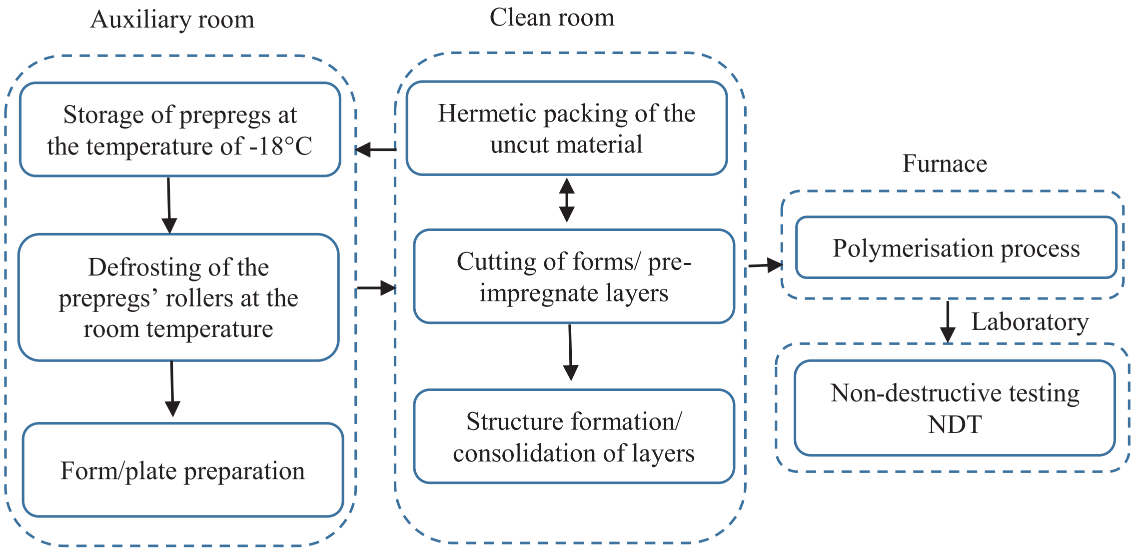

FIGURE 1. Manufacture diagram of composite element [9]

Nowadays, the most common technology used in the manufacturing industry of composite structures is the pre-impregnated method. The pre-impregnate is the method of reinforced impregnated with a specific amount of incomplete cycle of polymerisation resin, then protection film will protect one or two sides. Pre-impregnates usually occurred in the form of unidirectional continuous fibres called a tape or rowing [9]. This method also occurred in the form of bi-directional woven fibers called fabrics. Syzmanski stated that in the perspective of using pre-impregnated method in aviation industry especially in manufacturing of composites will minimize the quantity of porosity below 1 %. Other than that, it will increased the high mechanical properties, the quality of the surface of composite and the full control on the curing process either in temperature and pressure [9].

It is very important to prepare and conduct thorough quality control for every stage especially during the manufacture process of composite structures of the pre-impregnate [10]. The pre-impregnate is a controlled and expensive material which was sensitive to external elements. The polymerisation process is the most important stage especially during the manufacturing of composite structures [9]. It is necessary to seal tight the element in a vacuum bag, to avoid leakage because outside air will enter the vacuum bag and the air will diffuse into the composite inside. This will cause voids in the composite structures in case of insufficient pressure inside the vacuum bag.

Quality Control after Manufacturing

Inspection is the important steps after manufacturing the profile. Based on EN 13706-2:2002, it is essential to check on geometric tolerances such as colour, size and appearance [8]. Although after manufacturing process, nothing else can be done to improve the quality of a cured laminate, but Quality Checking (QC) procedures is essential procedure to verify that the specified process has been successfully performed. One or more coupon specimens in each component batch were collected to be cured and tested. However, the purpose of collecting coupon specimen was to verify that the laminate followed the cure cycle but not to indicate the component produced.

There was a few testing that was conducted by past researchers using coupon specimens, one of the testing is Barcol test [8]. The level of resin cured in laminate were measured by the Barcol test. Other than that, flexural test was also conducted to indicate the tensile and compressive properties of the fiber. Furthermore, flexural test possible to verify the types of fibres used [11]. Room temperature on interlaminar shear strength (ILSS) and elevated temperature ILSS were essential to measure the cohesive and adhesive strength of the fiber to the interface of the resin and to verify that the resin was correctly formulated and cured sufficiently.

The final stage of the quality control was non-destructive tests (NDT). Based on this test, defects that occurred at the previous stages were detected. Selecting the material discontinuities and assessing material properties without affecting the performance properties can be done by using the non-destructive testing techniques. The non-destructive test for composite using resonant, thermovision, interferometric, radiographic and ultrasonic methods [9]. Eventually, the most accurate non-destructive method for testing composite is an ultrasonic method, which was applied in the composite elements for more than 80%. Scanning the entire material volume possible by automated the process of ultrasonic tests in order to accelerate and improve the quality of non-destructive tests.

GFRP REPAIR

Glass Fiber Reinforced Polymer (GFRP) is a lightweight material that can be utilized as a repair material and retrofit material efficiently in concrete applications. Unrepaired damage of structures may cause failure on structural which lead to costly repair and loss of lives. Nowadays it is important to find an alternative technique to strengthening the damage especially material that is low in cost and has shorter duration for repair. Utilizing fiber reinforced polymer (FRP) sheets to strengthen the reinforced concrete (RC) beams have been investigated and studied. Various compositions to strengthening the materials can be integrated to maximize the increase in strength and repair [12]. In [12], Baggio et al. presented that the effectiveness of using glass fiber reinforced polymer (GFRP) to boost up the shear capacity of reinforced concrete (RC) shear critical beam. The experimental testing was using nine RC shear deficient slender beams to be tested [12]. It was found that by applying the FRP sheets increased the overall shear capacity [12]. Besides, it was discovered that the full depth u-wrapped FRP sheets performed better rather than the partial depth u-wrapped FRP sheets. The advantages of using FRP anchors further in repairing material will improved the shear capacity and the ductility of failure and then changed the mode of failure from a shear failure to flexural failure. This will slow down the debonding with the existence FRP anchors.

Haddad et. al investigated the coupling effect of water recurring on concrete one-way slabs that was repaired using carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) that was heated at 600°C for 2 hours. The slab was then tested under four-point loading. Furthermore, the repairing using advances composite material was to increase the flexural capacity of heat-damaged slabs. It was discovered that upon heating then cooling the slabs, the RC slabs undergo extensive map cracking and upward cambering without spalling [13]. Other than that, it was found that the control slab, heat-damaged slab and water recurred slabs showed a flexural failure mode that well distributed hairline cracks that was spread from the repair layers. Furthermore, it was discovered that the prior to failure of composites, GFRP experience yielding failure of steel.

Shaw & Andrawes presented that externally bonded FRP laminates when used as supporting shear and flexural reinforcement in RC and prestressed beam became a constructive material. Bridge girders having the problem degradation of the ends beam exposed by the content of the salt which will reduce the shear strength of the beam. Based on past study, the effect of shear capacity of the beams was determined by tested three-point bending concrete cover damages that was imposed on small scale prestressed concrete beam. The experimental testing was using a quick setting mortar repair to substitute the damaged cover concrete and to test its potential to retrieve the shear strength of the beam. Shaw & Andrawes justified that using only the mortar repair is not enough to regaining back the original stiffness and strength of the beam. The researcher found that the mortar repair must be used with externally bonded glass and carbon FRP laminates to retrieve back the strength of the beam [14]. Unfortunately, it was discovered that the GFRP laminates able to retrieve the original strength of the beam but showed no recovery in stiffness.

Many bridges and structures that are supported on steel columns or piles due to increasing load requirement and due to rusting showed an insufficient strength. The situation whereas increasing in load requirement but eventually decreasing in capacity can cause unexpected buckling of the piles. Kaya et. al studies the effectiveness of using glass fiber reinforced polymer (GFRP) for retrofit of buckled steel piles or columns. The experimental testing consists of forming on site GFRP jacket that was filled with wide concrete. Different degrees of thirteen buckled short steel columns were repaired. The steel column then tested to failure under axial compression. Other than that, the researcher conducted monotonic compression to analyse the quick repair technique and emergency repair of different levels of rusting on buckled steel columns and bridge piles. Kaya et. al concluded that the installation of concrete filled GFRP jackets to quickly repair the corroded and buckled short steel columns or piles can be an effective technique to construction industry [15].

Temporary repairs called to be happened when heat treatment was applied on buckled steel construction elements especially in disaster situation. Aydin et. al studied to change the temporary modifications which was applied to structural element into permanent modifications using additional process. The methodology consists of two methods which were through experimental and numerical investigation. The researcher repaired the elements by gluing fiber-reinforced polymer to treat the deficiency that observed. It was discovered that by affixing the GFRP plates to steel structures after heat treatment can accomplish the objective to change the temporary to permanent repairs. In [16], a formula has been developed to calculate the buckling stress of steel plates that are treated by using heat treatment and GFRP reinforced.

Mahfouz et. al studied the behaviour of concrete members that have been repaired using externally affixing advanced composite materials. The experimental testing starts with an analysis of tensile properties of glass GFRP sheets, and then continued to investigate the repaired concrete cylinders, columns and beams by using GFRP sheet. The researcher developed the preliminary design formulas to predict the possibilities of repaired member loading capacity. The results stated that the strength limit state for beam improving in the form of flexural and shear load when bonded externally to concrete members. Besides, the serviceability limit state also increased in the form of reduced cracks. The results shown that the strength and ductility of RC circular column increased with GFRP [17].

Yaqub et. al investigated the seismic performance of repaired post-heated RC square columns with unidirectional GFRP. The experimental testing was classified into three types which is un-heated, post-heated and repaired post-heated columns with GFRP jackets. The parameters used were the type of fibers used, the impact of heat damaged columns, the main fibres orientation and the attainable peak drift ratios. The results from past research shown that by wrapping the column with single layer of GFRP impressively increased the ductility, shear capacity, the ability of energy dissipation. Besides, the results also shown that it will slow down the rate of strength and stiffness. Furthermore, it was presented that the lateral strength of post-heated columns regained up to the original strength level of un-heated columns wrapped with a single layer of GFRP [18]. Nevertheless, it was found that the GFRP wrapped post-heated columns doesn't returned to original stiffness level of the un-heated columns. Other than that, the un-heated and post-heated columns was found failed in shear meanwhile the control failure mechanism of the GFRP wrapped post-heated columns was successfully shifted from column shear to flexural failure [18].

Many reinforced concrete structures were experience degradation process such as spalling of concrete and extreme deflection. Khot studied the various degree of RC beam damage which was repaired with single and double layer of GFRP using load carrying and energy absorption capacity as a reference. The results shown the most effective ways to repair damage of RC beam is by applying double layer of GFRP to its tension face. The past researcher concluded that the effectiveness of using GFRP plates effect the load carrying capacity and performance such as failure mode, deflection and crack pattern of damaged strengthened GFRP beams [19].

Despite of repairing concrete using GFRP, GFRP sheets also are widely used to repair structures in the marine environment. In [20], investigated the effects of cement based coatings when exposed to marine environments for strengthening the durability of GFRP sheets. A real condition of marine environments simulator was designed to conduct the experimental testing. Kashi et. al applied two types of cement based mortar, namely polymeric and self-compacted on the sheets [20]. The results showed increasing on the ultimate strength of the wrapped layers of GFRP by using the polymeric mortar when compared with specimens without the protective mortar. The self-compacted mortar has a better curing on marine environments but inversely reduce the polymeric mortar's durability. The researcher presented that the polymeric mortar has greater bond strength with GFRP sheets more than with self-compacted mortar.

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