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Shear Strength Study of RC Beams Retrofitted Using Vinyl Ester Bonded GFRP and Epoxy Bonded GFRP

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Abstract

Many of the existing reinforced concrete structures throughout the world are in urgent need of rehabilitation, repair or reconstruction because of deterioration due to various factors like corrosion, lack of detailing, failure of bonding between beam-column joints, increase in service loads, etc., leading to cracking, spalling, loss of strength, deflection, etc. The recent developments in the application of the advanced composites in the construction industry for concrete rehabilitation and strengthening are increasing on the basis of specific requirements, national needs and industry participation. The need for efficient rehabilitation and strengthening techniques of existing concrete structures has resulted in research and development of composite strengthening systems. Fiber Reinforced Polymer (FRP) composite has been accepted in the construction industry as a promising substitute for repairing and in incrementing the strength of RCC structures. FRP composites possess some outstanding properties such as: resistance to corrosion, good fatigue and damping resistance, high strength to weight ratio, and electromagnetic transparency. FRPs over the years have gained respect in terms of its superior performance and versatility and now are being used not only in housing industry but its potentials are being continuously explored for its use in retro-fitting and strengthening of damaged structural members. This paper focuses exclusively on shear behaviour of RCC beams and the Vinyl-Ester bonded GFRP and Epoxy bonded GFRP wrapped retrofitted RCC beams. Beams were retrofitted with 1.2 mm Epoxy bonded GFRP sheets and 0.9 mm Vinyl-Ester bonded GFRP sheets using epoxy resins. In all a total of 10 beams were tested and the respective readings were recorded. The beams were full-wrapped and strip-wrapped and tested for shear behavior analysis. Cracking and deflection of GFRP reinforced concrete beams are analyzed experimentally. It was concluded that the wrapping of GFRP sheets increases the ultimate load carrying capacity of RCC beams. Also a cost analysis was done in order to get a cost effective solution for the issue of retrofitting, which is a rising concern in the recent times.

Keywords: Glass Fibres, Vinyl Ester Bonded GFRP, Epoxy bonded GFRP, Shear Strength, RC Beams

1. Introduction

Retrofitting of shear concrete elements are traditionally accomplished by externally bonding steel plates to concrete. Although this technique has proved to be effective in increasing strength and stiffness of reinforced concrete elements, it has the disadvantages of being susceptible to corrosion and difficult to install. In the last decade, the development of strong epoxy glue has led to a technique which has great potential in the field of upgrading structures. Basically the technique involves gluing steel plates or fibre reinforced polymer (FRP) plates to the surface of the concrete. The plates then act compositely with the concrete and help to carry the loads. Also recent development in the field of composite materials, together with their inherent properties, which include high specific tensile strength good fatigue and corrosion resistance and ease of use, make them an attractive alternative to any other retrofitting technique in the field of repair and strengthening of concrete elements. FRP can be convenient compared to steel for a number of reasons. These materials have higher ultimate strength and lower density than steel. The installation is easier and temporary support until the adhesive gains its strength is not required due to the low weight. They can be formed on site into complicated shapes and can also be easily cut to length on site. FRP composites are different from traditional construction materials such as steel or aluminum. FRP composites are anisotropic (properties apparent in the direction of the applied load) whereas steel or aluminum is isotropic (uniform properties in all directions, independent of applied load). Therefore, FRP composite properties are directional, meaning that the best mechanical properties are in the direction of the fiber placement. Composites are similar to reinforced concrete where the rebar is embedded in an isotropic matrix called concrete. FRP composites possess some outstanding properties such as: resistance to corrosion, good fatigue and damping resistance, high strength to weight ratio, and electromagnetic transparency. FRP has found an increasing number of applications in construction either as internal or as external reinforcement for concrete structures. It is well known that FRP possesses a major advantage over conventional steel in reinforcing concrete structures. Civil structures made of steel reinforced concrete are normally susceptible to environmental attacks that lead to the initiation of an electrochemical process which leads to the corrosion of steel reinforcement. Constant maintenance and repairing is needed to enhance the life cycle of those structures. Bridge deck deterioration due to direct exposure to environment, deicing chemicals and ever-increasing traffic loads is one of the most common deficiencies in a bridge system. The use of FRP bars as an internal reinforcement for concrete bridge decks and also girders provides a potential for increased service life, economic, and environmental benefits.

2. Material Investigation

As the name implies, FRP composites are materials made of fiber reinforcements, resin, fillers, and additives. The fibers exhibit high tensile strength and stiffness and are the main load carrying element. The resin offers high compressive strength and binds the fibers into a firm matrix. The additives help to improve the mechanical and physical properties as well as the workability of composites. Glass fibre reinforced polymer (GFRP) is used in this investigation for the purpose of retrofitting. Following are some of the charecteristics of this versatile fibre. Glass fibre reinforced polymer (GFRP), also known as glass fibre reinforced plastic is a fibre made of a plastic matrix reinforced by fine fibres made of glass. The plastic matrix used is epoxy or thermoplastic. The GFRP is the least expensive but has lower strength and significantly lower stiffness compared to other alternatives. The glass fibres are divided into three classes -- E-glass, S-glass and C-glass. The E-glass is designated for electrical use and the S-glass for high strength. The C-glass is for high corrosion resistance, and it is uncommon for civil engineering application. Of the three fibres, the E-glass is the most common reinforcement material used in civil structures. It is produced from lime-alumina-borosilicate, which can be easily obtained from abundance of raw materials like sand. The fibres are drawn into very fine filaments with diameters ranging from 2 to 13 X 10^{-6} m. The glass fibre strength and modulus can degrade with increasing temperature. Although the glass material creeps under a sustained load, it can be designed to perform satisfactorily. The fibre itself is regarded as an isotropic material and has a lower thermal expansion coefficient than that of steel. Following are the different constituents of Glass fibre reinforced composite.

2.1 Vinyl ester bonded fibre reinforced polymer

Vinyl ester bonded fibre reinforced polymer - Vinyl ester bonded fibre reinforced polymer (VE-FRP), also known as vinyl ester bonded glass fibre reinforced plastic is a fibre made of a plastic matrix reinforced by fine fibres made of glass. The plastic matrix used is vinyl ester. The resin system forms an integral part of the FRP constituents. The resin is perhaps one of the most important constituents which effects the performance of the composites. The two classes of resins are the thermoplastics and thermosets. A thermoplastic resin remains a solid at room temperature. It melts when heated and solidifies when cooled. The long-chain polymers do not chemically cross-link. Because they do not cure permanently, they are undesirable for structural application. Conversely, a thermosetting resin will cure permanently by irreversible cross-linking at elevated temperatures. This characteristic makes the thermoset resin composites very desirable for structural applications. The most common resins used in composites are the unsaturated polyesters, epoxies, and vinyl esters; the least common ones are the polyurethane's and phenolics.

2.2 Unsaturated Polyesters

The unsaturated polyester amounts to about 75% of all polyester resins used in USA. It is produced by the condensation polymerization of dicarboxylic acids and dihydric alcohols. The formulation contains an unsaturated material such as maleic anhydride or fumaric acid, which is a part of the dicarboxylic acid component. The formulation affects the viscosity, reactivity, resiliency and heat deflection temperature (HDT). The viscosity controls the speed and degree of wet-out (saturation) of the fibres. The reactivity affects cure time and peak exothermic (heat generation) temperatures. High exotherm is needed for a thin section curing at room temperature and low exotherm for a thick section. Resiliency or flexible grade composites have a higher elongation, lower modulus, and HDT. The HDT is a short-term thermal property, which measures the thermal sensitivity and stability of the resins. The advantages cited in the unsaturated polyester are its dimensional stability and affordable cost. Other advantages include ease in handling, processing, and fabricating. Some of the special formulations are high corrosion resistant and fire retardants. This resin is probably the best value for a balance between performance and structural capabilities.

2.3 Epoxies

The epoxies used in composites are mainly the glycidyl ethers and amines. The material properties and cure rates can be formulated to meet the required performance. Epoxies are generally found in marine, automotive, electrical and appliance applications. The high viscosity in epoxy resins limits it use to certain processes such as molding, filament winding, and hand lay-up. The right curing agent should be carefully selected because it will affect the type of chemical reaction, pot life and final material properties. Although epoxies can be expensive, it may be worth the cost when high performance is required.

2.4 Vinyl Esters

The vinyl ester resins were developed to take advantage of both the workability of the epoxy resins and the fast curing of the polyesters. The vinyl ester has higher physical properties than polyesters but costs less than epoxies. The acrylic esters are dissolved in a styrene monomer to produce vinyl ester resins, which are cured with organic peroxides. A composite product containing a vinyl ester resin can withstand high toughness demand and offer excellent corrosion resistance.

2.5 Polyurethanes

Polyurethanes are produced by combining polyisocyanate and polyol in a reaction injection molding process or in a reinforced reaction injection molding process. They are cured into very tough and high corrosion resistance materials, which are found in many high performance paint coatings.

All the twelve beams are tested under simply supported end conditions. Two points loading is adopted for testing. The testing of beams is done with the help of hydraulic operated jack connected to load cell. The load is applied to the beam with the help of hydraulic jack and the data is recorded from the data acquisition system, which is attached with the load cell. The value of deflection is also obtained from the data acquisition system. Out of these twelve beams 4 are control beam, which are tested after 28 days of curing to find out the safe load which is taken as load corresponding to deflection of L/250 i.e. 15 mm

2.6 Phenolics

The phenolic resins are made from phenols and formaldehyde, and they are divided into resole and novolac resins. The resoles are prepared under alkaline conditions with formaldehyde/phenol (F/P) ratios greater than one. On the contrary, novolacs are prepared under acidic conditions with F/P ratios less than one. Resoles are cured by applying heat and/or by adding acids. Novolacs are cured when reacting chemically with methylene groups in the hardener. The phenolics are rated for good resistance to high temperature, good thermal stability, and low smoke generation.

3. Details of the RC beam Model for Shear Analysis

The specimen that is the model frame is designed following the standards and provisions of Indian code of practice IS 456: 1958. The material chosen are concrete compressive strength Fck = 20 N/mm^2 . and the grade of steel chosen is Fe 415 N/mm^2. The dimensions of the Reinforced Concrete Beam is as shown in figure – below :

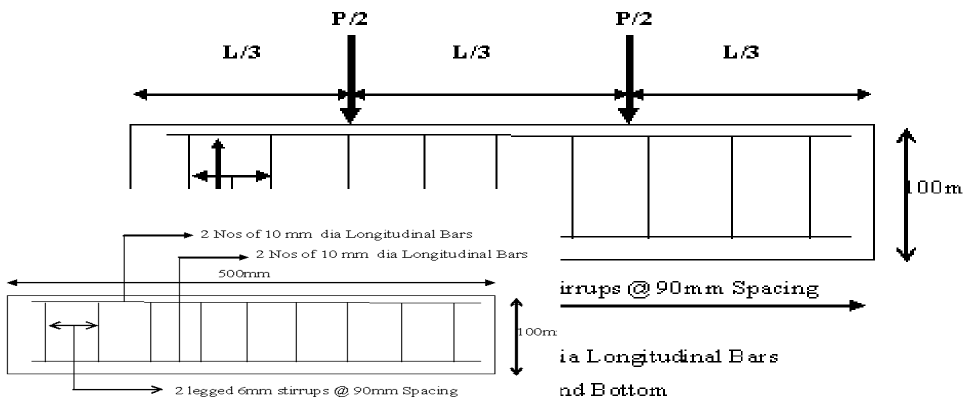
Details of RC Beam Cross Section: Length = 500 mm, Width = 100 mm, Depth = 100 mm

Details of the Reinforcements :

Longitudinal Bars at top : 2 nos of 8mm dia Bars each

Longitudinal Bars at bottom : 2 nos of 10mm dia

Bars each Stirrups : 2 Legged 6mm dia stirrups at 90 mm C/C.



4. Experimental Investigation

4.1 Testing Arrangement

All the twelve beams are tested under simply supported end conditions. Two point loading is adopted for testing .The testing of beams is done with the help of hydraulic operated jack connected to load cell. The load is applied to the beam with the help of hydraulic jack and the data is recorded from the data acquisition system, which is attached with the load cell. The value of deflection is also obtained from the data acquisition system. Out of these twelve beams 4 are control beam, which are tested after 28 days of curing to find out the safe load which is taken as load corresponding to deflection of L/250 i.e. 15 mm. To determine the increase in the shear strength of the beams after retrofitted with Vinyl Ester bonded Glass Fiber Reinforced Polymer, beams are designed in such a manner that they are deficient in shear and hence fail in shear. When the beams are tested, shear cracks are seen over the beams which shows that they are failing in shear. Two Controlled Specimens are tested for shear, two full wrapped Vinyl Ester bonded GFRP are tested for shear and two strip wrapped Vinyl Ester bonded GFRP are tested for shear.

4.2 Retrofitting of the beams using vinyl ester bonded GFRP and Epoxy Bonded GFRP by full wrapping and Strip wrapping technique

For proper bonding between the beam and the sheets, the surface of the sheets is roughened using brush or using some other roughening materials. Roughening can be done with the help of sand paper or hard brush or small chisel. Once the beam surface is roughened, the Vinyl Ester resin is prepared. The Vinyl Ester is prepared in the ratio of 1:5 where 1 part of hardener is used with 5 parts of resin. The mixture is then mixed thoroughly. Proper care should be taken that the mixture is used as soon as possible so that the Vinyl Ester doesn't sets. After the Vinyl Ester is mixed complete, the Vinyl Ester is applied to be roughened end of the sheets using brushes. After the Vinyl Ester is properly applied in the sheets, the sheets are fixed on all the sides of the beams, whose surface was cleaned using a brush. Some pressure is given on the surface for proper fixing of the sheets. Likewise sheets are wrapped on all the faces of the beam for the full wrapping technique. For strip wrapping technique After the Vinyl Ester is mixed complete, the Vinyl Ester is applied to be roughened end of the strips using brushes. After the Vinyl Ester is properly applied in the strips, the strips are fixed on all the sides of the beams(whose surface was cleaned using a brush) at a distance of 10cm centre to centre. Some pressure is given on the surface for proper fixing of the strips. Likewise strips are wrapped on all the faces of the beams at a distance of 10cm centre to centre. And the same procedure is repeated for applying epoxy bonded GFRP sheets to RCC beams for both full wrapping and strip wrapping technique. After the beam is completely retrofitted, the beams are kept for drying and setting properly for 24 hours. After that 2 number of Vinyl ester GFRP retrofitted beam retrofitted using full wrapping technique and 2 number of the Vinyl ester GFRP strip wrapped beams are tested and consequently then the 2 number of Epoxy bonded GFRP beams retrofitted using full wrapping technique and then the two number of Epoxybonded GFRP retrofitted using strip wrapping technique are then tested in the same manner in which the control specimens were tested.

4. Interpretation of the Experimental Results and Conclusions

Retrofitted RCC beams, retrofitted using the full wrapping technique has shown an increase by about 10.01%, and retrofitted using the strip wrapping technique has shown an increase by about 19.75%, over the shear strength of normal RCC Beams. The shear strength of the Epoxy bonded GFRP retrofitted RCC beams, retrofitted using the full wrapping technique has shown an increase by about 12.47%, and retrofitted using the strip wrapping technique has shown an increase by about 14.1% over the shear strength of normal RCC Beams. 3. Beam Retrofitted by Vinyl Ester Bonded GFRP & Epoxy Bonded GFRP strip wrapping technique shows an enhanced increase in strength in comparison to beams Retrofitted by full wrapping technique using Vinyl Ester Bonded GFRP & Epoxy Bonded GFRP full wrapping technique . That's because in strip wrapping technique the placement of the fibres are such that it crosses a large number of shear cracks, and hence resists the transfer and also delays the transfer of the cracks from one end to the other. The 1st crack strength of the Vinyl ester bonded GFRP retrofitted RCC beams in Shear retrofitted using the full wrapping technique has shown an increase by about 52.9%, and retrofitted using the strip wrapping technique has shown an increase by about 70.58%, over the shear strength of normal RCC Beams. The 1st crack strength of the

Epoxy bonded GFRP retrofitted RCC beams in Shear retrofitted using the full wrapping technique has shown an increase by about 52.9%, and retrofitted using the strip wrapping technique has shown an increase by about 29.76%, over the shear strength of normal RCC Beams. It can be concluded that Vinyl Ester bonded GFRP sheets when used for retrofitting performs better, that is enhances the shear carrying capacity of the structure more, as compared to structure retrofitted using Epoxy Bonded GFRP. Generally Vinyl Ester Bonded GFRP gives about 10% more strength to the structure as compared to strength given by retrofitting using Epoxy bonded GFRP. The cost of Vinyl Ester Bonded GFRP was Rs. 1500 and that of Epoxy Bonded GFRP was Rs.1300. Hence the cost of retrofitting using Vinyl ester Bonded GFRP will be higher as compared to the cost of retrofitting using Epoxy bonded GFRP.

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Specimen	Load at First Crack (KN)	Deflection At first crack (mm)	Failure Load (KN)	Deflection at failure (mm)	Percentage increase in load carrying capacity (%)
Control Specimen-1	55	2.1	95	5.08	-
Control Specimen-2	70	2.71	79.7	4.94	-
Vinyl Ester Bonded GFRP FULL 1	55	1.41	126.7	7.02	4.88
Vinyl Ester Bonded GFRP FULL2	75	2.76	139.1	7.66	15.15
Vinyl Ester Bonded GFRP STRIP 1	70	2.77	115	4.51	23.68
Vinyl Ester Bonded GFRP STRIP 2	75	2.52	110	4.93	15.79
Epoxy Bonded GFRP FULL 1	75	3.86	108.7	5.31	14.42
Epoxy Bonded GFRP FULL 2	55	1.83	105	4.44	10.52
Epoxy Bonded GFRP STRIP 1	52.5	4.13	109.8	7.87	15.57
Epoxy Bonded GFRP STRIP 2	57.8	3.87	107	5.89	12.63

Table 1. Experimental Values of the load carrying capacity, deflection etc , obtained for the control specimen as well as the Full Wrapped Retrofitted and the Strip Wrapped Retrofitted Specimens.

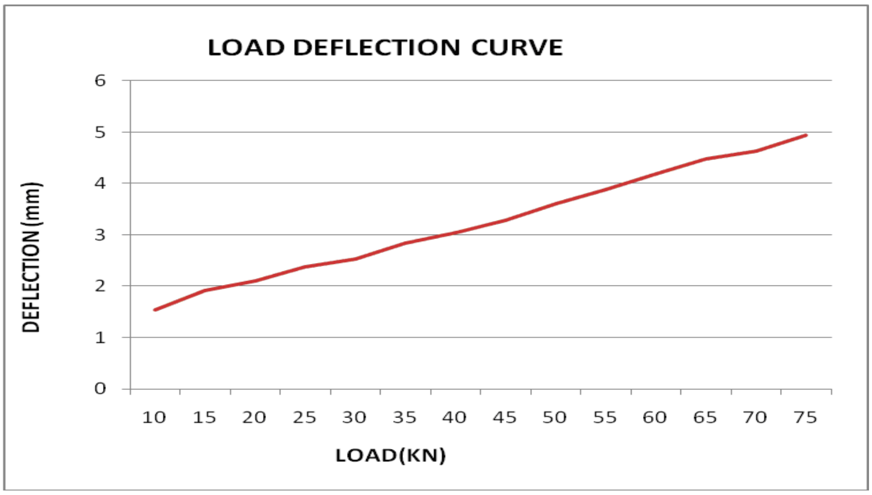

Figure 1. Mean Load Deflection Curves for Control Specimen-1 and Control Specimen-2

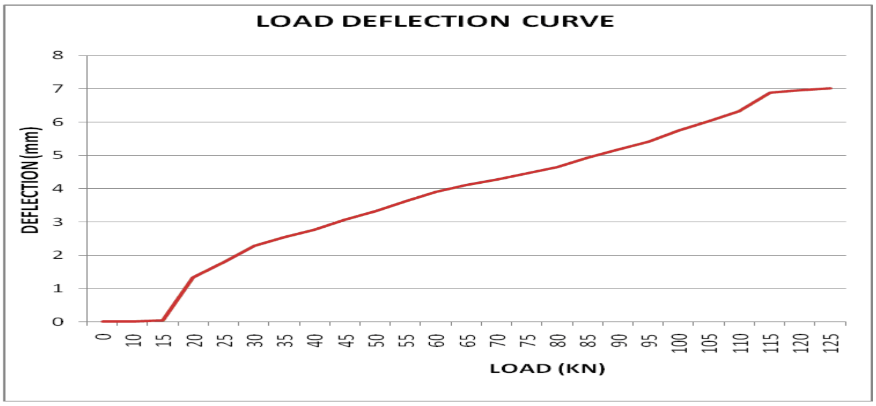

Figure 2. Mean Load Deflection Curves for Vinyl Ester Bonded GFRP FULL 1 and Full 2

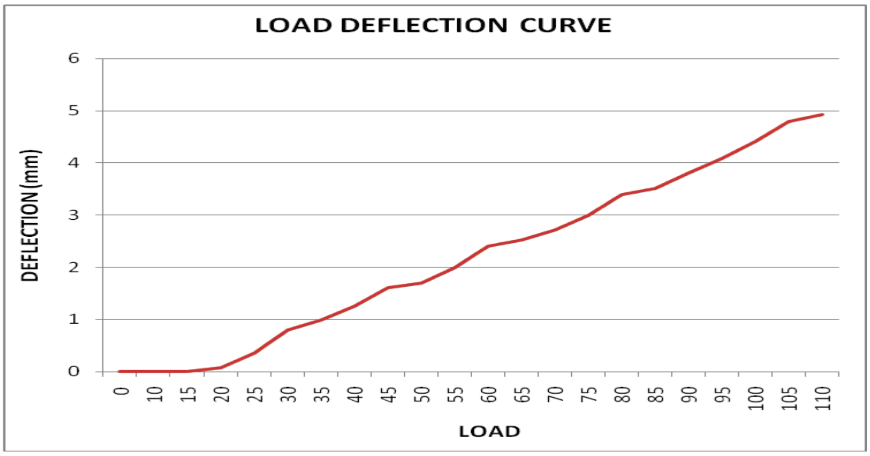

Figure 3. Mean Load Deflection Curves for Vinyl Ester Bonded GFRP STRIP 1 and STRIP 2

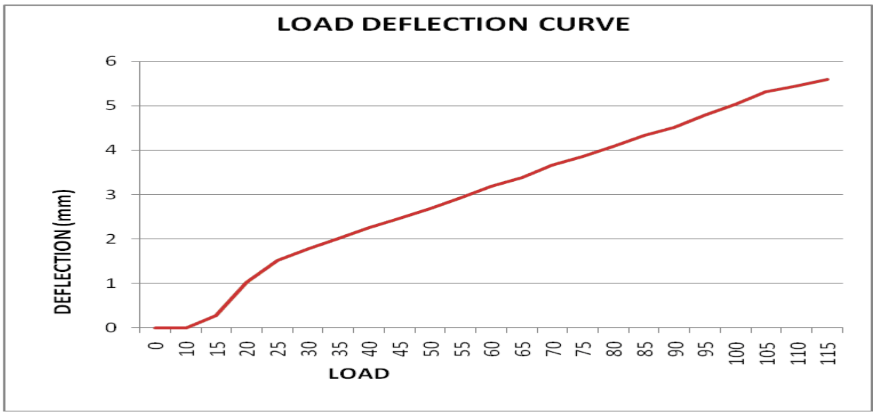

Figure 4. Mean Load Deflection Curves for Epoxy Bonded GFRP Full 1 and FULL 2

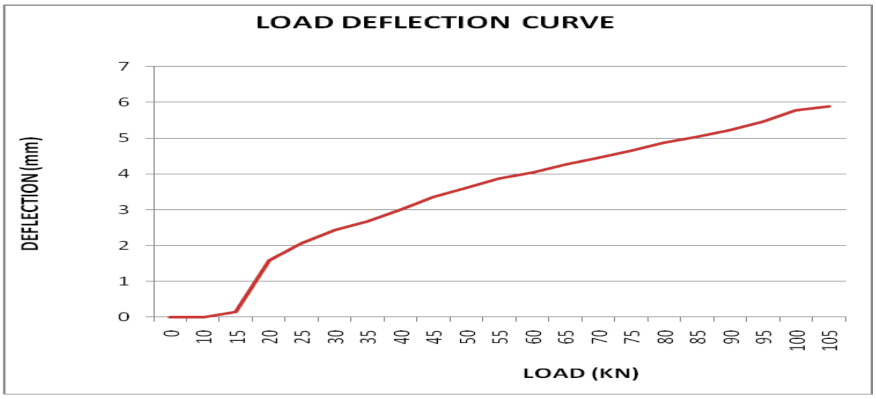

Figure 5. Mean Load Deflection Curves for Epoxy Bonded GFRP STRIP1 and STRIP 2