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Long-Term Behaviour of Prestressed Basalt Fibre Reinforced Polymer Bars

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Abstract

The opportunity to use basalt fibre reinforced polymer (BFRP) bars as internal reinforcement for concrete could be beneficial in aspect of limiting the relatively high deformability. The information about long-term behaviour of such reinforcement under prestressing loading would be helpful to estimate prestress losses, which have to be expected. Obtaining such experimental data and analysing it could be used for further developing of the design principles and procedure for prestressed elements with BFRP reinforcement.

A testing rig (referred to as creep rig) has been build to evaluate the behaviour of BFRP rebars in constant loading conditions with a direct correlation to steel rebars and cables. All samples have been put in to equal tension of 16kN and have been monitored over a long period of time. The constant level of loading was kept and corresponding deformations have been measured. This study aims to investigate the behaviour of BFRP rebars under long term static loading.

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Keywords: BFRP; prestress; creep; long-term.

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1. Introduction

It has been discussed by Youssef T. et al. (2009) that GFRP bars are more susceptible to creep under constant long-term loading. As a result, GFRP reinforced structures can suffer deflection over long periods of time. In the research conducted by Youssef T., et al. (2009), GFRP reinforced concrete beams were tested for a yearlong sustained loading under flexure, along with a steel reinforced beam of similar design

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specifications. It was observed, that the presence of creep induced strain within the GFRP internal reinforcement dependent upon the diameter of the bars. 9.5 mm bar recorded 16% strain increased from initial loading, the 12.7 mm bar experienced 21% and the 15.9 mm bar recorded 24 % at one year of loading. However, it is interesting to note, that the 15.9 mm steel reinforced bar recorded a near negligible strain increased from initial loading.

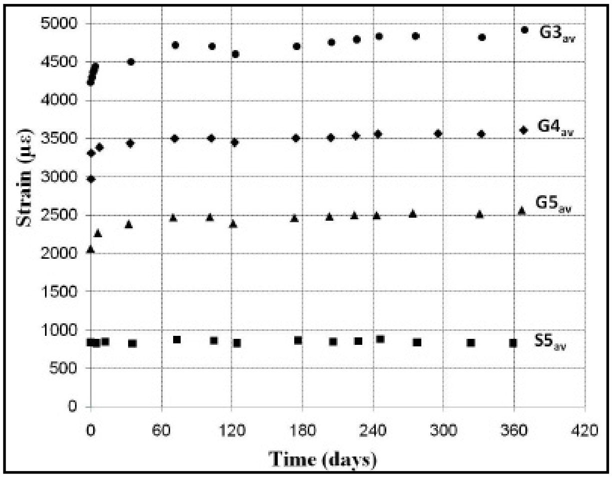

Figure 1. Creep Induced Strain Results of FRP Reinforcement.
(Youssef T. et al. 2009)

Figure 1 displays the results from the year long loading experimentation of GFRP internally reinforced Concrete beam conducted by Youssef T., et al. (2009). The readings plotted for the duration of the experiment, show gradual increase in strain., with a higher rate of increase in strain over the first 60 days. In order to understand the reason for this, further information is required in regards to particular changes in ambient temperature and humidity.

Hota. V. S. Gangarao, et al. (2007) comments of creep along with stress relaxation to be a result of the viscoelasticity of the resin in the GFRP composites. Literature reviewed by Hota. V. S. Gangarao, et al. (2007) suggests carbon possess less creep in comparison with glass and aramid fibres, and suggests that particle displacement which causes creep is more likely to occur at higher temperatures whilst under continuous stress. Static fatigue or creep rupture is the most extreme consequence of creep, where the GFRP bar would experience rupture as a result of reaching strain rupture limit when exposed to sustained stress for long periods of time. J.M. Lees (2001) supports the above by commenting that time to creep rupture is a product of the temperature, alkaline environment as well as size of initial stress, the type of fibre used, and the matrix bond. Further experimental research is recommended in order to gain complete understanding of creep phenomenon of FRP bars without exposure to concrete.

The above is also discussed by Webber A. (2008), where experimental research consisted of determining the ability of GFRP internal reinforcement to transfer loads to the surrounding concrete under sustained loading. Over 30 GFRP (wet concrete embedded) rebar samples were loaded in tension at different stress levels and different temperatures. Elongation recorded over loading periods was taken as the sum of creep strain and elastic strain of the rebar and the bond slip/failure between the concrete and rebar. Sheikh S.A. & Johnson D.T.C. (2008) suggests that key aspect of performance of internal reinforcement bars in terms of creep is related to the ability of anchorage systems to maintain constant levels of stress by exhibiting little or no anchorage slip.

Mehdizad Taleie S., et al. (2007) discuses the relaxation of CFRP materials to be an area of concern in prestressing as it is a phenomenon which can affect long term performance of an FRP reinforced structure. The three main aspects of stress relaxation are fibre relaxation, straightening of the FRP fibres and viscoelasticity of the matrix resin where the magnitude of the rheological affects largely depends on environmental conditions as is in creep. Fornusek J., et al. (2009) mentions of prestressing reducing the effect of lower modulus of elasticity in GFRP composites. Unique stressing experimentation was developed in order to study the stress decrease or relaxation experienced by GFRP composites in terms of internal reinforcement. GFRP material possessed 32GPa of elastic modulus and tensile strength of 655MPa. The tensile testing bed consisted of steel anchors with load cells to control force exerted and strain gauges to monitor relaxation. A force of 37 % of UTL (Ultimate Tensile Load) (240 MPa) was applied to the GFRP material for a period of 132 days.

The results of such investigation Fornusek J., et al. (2009) above confirms findings by Mehdizad Taleie S., et al. (2007), Fornusek J., et al. (2009) observed a loss of 3.9 % within the first 24 hours of stressing. The period that follows, exhibits a reasonably uniform loss in tension, indicating environmental conditions were kept constant. Loss of tension was recorded to be 7.3 percent after 28 days of sustained loading, with final loss recorded at 10.5%.

2. Experimental Program

The creep and experimental program itself are planned to run continuously and for a long period of time for determining creep effects. For the purpose of this publication the results commented on are those that show the behaviour of the materials under tension for the period of time at the initial stages of this work in progress.

The limit for prestressing of 16kN was decided upon due to the Ultimate Tensile strength (1200 MPa) of the bars and the diameter of the bars that were being used (6 mm). The applied load is estimated to be 50% of the ultimate tensile capacity of the BFRP bars.

Temperature was kept at 25°C ±2 in order that this did not affect the samples, this was controlled by a constantly air conditioned room.

2.1. Samples

A total of 3 BFRP samples where used, supplied by Magmatech. In addition 2 steel high yield-reinforcing bars, and one high tensile steel cable sample, in order to compare the creep effects of BFRP with steel. The samples are made in the following design scheme presented in Figure 2:

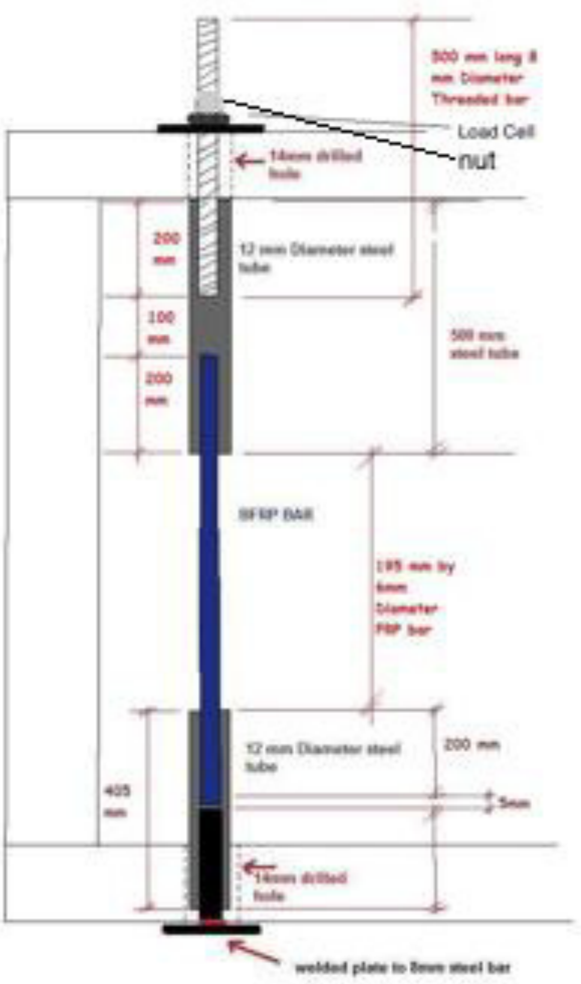

Figure 2. A diagram of a Sample

In order for the samples to be held in the tubing a strong epoxy resin was used, Weber.tec's EP Structural Adhesive. The threaded bar was also encased in the tubing, and then this is used in order to tension the material in question.

Table 1. Properties of the materials

Material	BFRP	Steel
Elastic/ Young's Modulus	50GPa	210GPa
UTL	1200MPa	400MPa

2.2. Creep Rig

The design is based on a rigid steel SHS frame capable of housing up to six bars for simultaneous testing. The design utilises the rigid frame principle with nuts used to exert the tensile load onto the threaded bars. To determine whether the chosen sections would be sufficient to support a load of 20 kN per bar, during the design stage of the testing rig the horizontal frames were taken to be simply supported with the vertical SHS frames as supports.

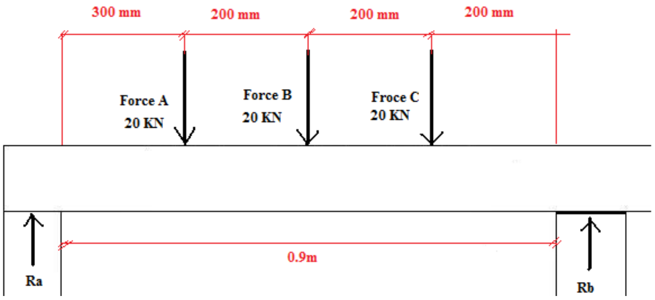

Figure 3. Forces Acting on Section, note this is half the rig

The nut is tightened to apply the load simultaneously with loading preventing torque effects. Once required load has been obtained and measured via individual load cells (Novatech F313 Low Profile Donut Load cell), an additional plate and nut are introduced to secure and to act as an additional resistance to the tension of the sample. The threaded bar is be secured using a nut as seen in Figure 4.

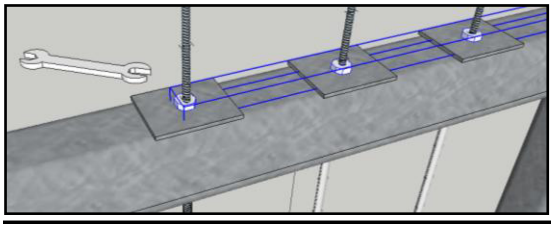

Figure 4. Upper section threaded bar & Nut System.

Each sample is made up of upper and lower anchorage steel tube to house the steel, BFRP rebars and threaded bars. The upper anchorage steel tube has a 100mm space between the FRP rebar and the threaded bar, this space is filled with Styrofoam. The reason for this is that a set of three strain gauges will be attached to the tubing on the 100mm gap as seen in Fig 5, the readings from these three strain gauges are used to obtain an average strain developed on the steel tube at the desired load (16kN)

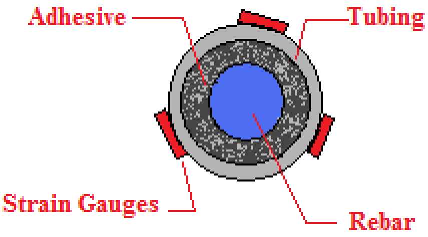

Figure 5. Upper Steel Tube with Strain Gauge Set up.

2.3. Testing

Testing of the FRP samples was carried out in three stages; initial loading, keeping the desired load level and monitoring of sample.

National Instrument’s Labview was employed for data logging in addition with the National Instruments devices NI USB 9162 and NI 9219. The devices use 4 channels which can carry the information form the load cells and strain gauges and place the data in an easily accessible formats (graph or txt file) and can use full, half or quarter bridges. The Demec gauge and measurements were recorded in Excel so that elongation/ contraction of the materials could also be monitored in real time.

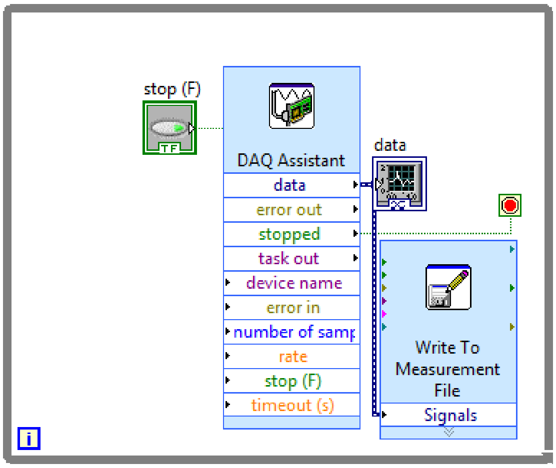

Figure 6. A Simple program for data logging in Labview

2.3.1. Stage 1 – Initial Loading

As the measuring cell is a compressive load cell, to measure the tensile load, the plates are used to oppose the tension incurred by twisting of the nut and apply the compressive load on the frame as seen in Figure 8 Loading begins with fixing tightly the nut with a washer against the upper plate, a 17mm spanner is used to do this. Creep is dependent on rate of loading as well as the amount of force. Loading was carried out at a rate of 2 kN every 15 minutes till 16 kN was reached. Possible transferring of torsional stresses during the process of loading was prevented using limitations of the rotational effects. Initially the readings were taken every 15 minutes for each sample and initial elongation was recorded as 0 kN.

Figure 7. Samples in the Creep Rig before applying load

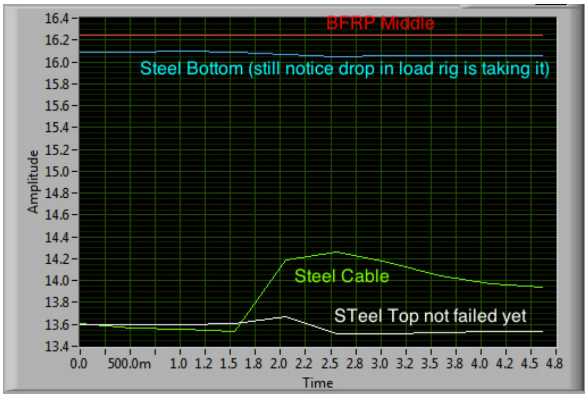

Figure 8. Graph of loading during initial stages

2.3.2. Stage 2 – Desired Load Level Reached

Once desired load Level was reached (16 kN), the specimen is left to adjust and at each monitoring event observe any movement of the frame, anchorage, or the threaded bar and adjust the load if necessary. At this stage readings are taken for the following.

- Load level in KN from load cell for each of the samples separately.
- Changes in strain/deformation from mechanical DEMEC gauge.

2.3.3. Stage 3 - Monitoring

Samples are loaded to 16 KN, and monitored every 24 hours. After a period of 24 hours, readings were repeated again, the first reading is from the load cell, it was noticed the load does decrease as expected. In turn, the load was again increased to 16 KN as previously and readings taken after that.

Readings on the electro resistant strain gauges were taken along with temperature, focusing on increases in strain on the BFRP rebar at 16 KN of load. The process is then repeated over the following days, to determine functionality, the same sequence then to be carried on a weekly basis for the following 4 months in future tests.

3. Analysis & Results

Over the 30 days period the expected behaviour for steel reinforcing bar and cable was seen in Figure 9, however as BFRP is unknown the results seen where of interest as this differ from hat was hypnotised with GFRP. Steel cable over the period has constantly elongated, we can see the cable is stretching, and there will be dislocations of the metallic atoms, (see Figure 9). Also for steel rebar there is slight elongation from over the first day of loading, however the material quickly reaches a plateau and the tension is kept well in the rebar.

BFRP has a very similar behaviour to that of steel rebar. The initial elongation of 0.5mm and then the BFRP plateaus much like the steel, and even retains its load better than steel.

It is important to keep the load as close to 16 kN as possible, so to find the creep at that level. Therefore each day the load was adjusted. The load lost each day was recorded for the first 30 days and the average value was calculated from the results obtained. Over a long period of time the materials establish themselves and hold their loads better. This is (Figure 9) an average for the first 30days, so one should bear this in mind when prestressing with these materials, that there will be prestress loses of equivalent to the results seen.

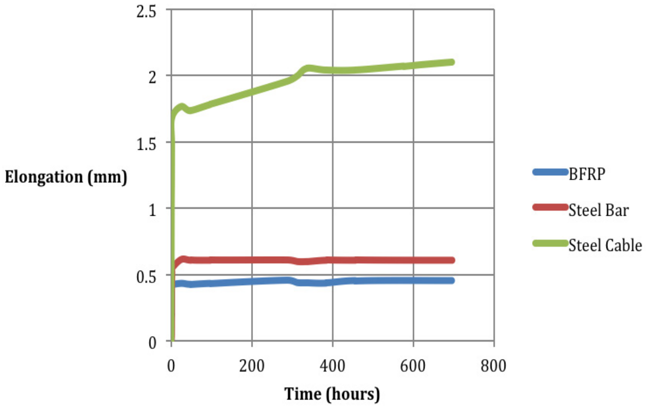

Figure 9. The Change in Elongation of Materials over Time (30days)

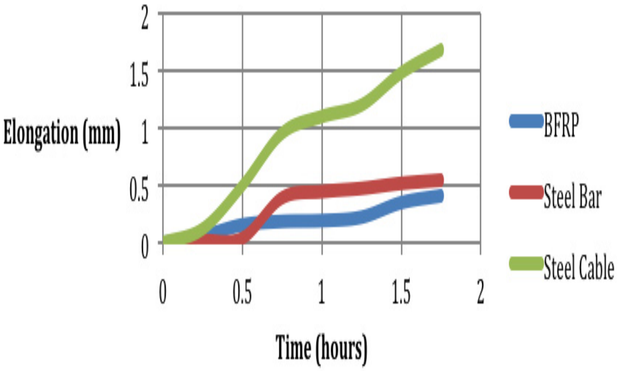

Figure 10. Change in elongaion of the materials for the intial loading (After this time they begin to plauteu)

The most sensitive period for the materials (in particular Steel rebar and BFRP) was the intial loading. After intial loading from those materials the eliongation plateaus, except for steel cable.

4. Conclusions

- Prestress Loses are seen to be equal or less with BFRP and Steel in comparison to steel cable.
- BFRP Creep is a different behaviour to that of Steel as to the recorded time and stages of loading the creep results for BFRP and steel are close to each other.

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