Influence of GFRP Vertical Stirrups Using NSM Technique on Shear Behavior of Reinforced Concrete Beams with Recycled Coarse Aggregate

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Abstract. Shear strengthening with GFRP rods is the focus of this paper on concrete beams that contain aggregate replacement ratios of thermstone and bonza (pumice materials), obtained from the rubble of demolished buildings. A total of nine beams (2400×160×300mm dimensions) were loaded under a four-point bending load test. The parameters examined in this research were the replacement ratio of lightweight coarse aggregate (20% and 30% volumetric ratio), type of lightweight aggregate replaced by (thermstone or bonza) and strengthened in shear by GFRP rods using NSM technique. The characterization of the tested beams includes ultimate load, failure mode, load-deflection curve, load strain curves of stirrups, bottom longitudinal rebars, GFRP rods at the shear zone of concrete. The results showed that the use of GFRP rods to strengthen concrete beams was effective. As the failure mode was transformed from a shear failure in the reference beam that was cast using normal concrete to a concrete compression failure in the beams which was occurred when using suitable and sufficient amount of strengthening by GFRP rods for selected used lightweight aggregate replacement ratios.

1. Introduction

The density of concrete is considered an important factor that is always taken into consideration by civil and structural engineers, since it is considered as one of the important parameters to increase the stability of dams. There are no general limits for using recycled coarse aggregate in a concrete mixture. Numerous researchers recommend that (30%) as the maximum ratio for using recycled coarse aggregate as a replacement of coarse normal aggregate [1][2][3][4]. Many researchers were looking for an alternative to use as a coarse aggregate, one of the waste materials was used as a replacement for coarse aggregate in concrete. Thermstone and bonza (pumice material) were used in this research. RAC refers to Recycled Aggregate Concrete is defined as prepared concrete using recycled aggregates or a combination of recycled and natural aggregates [5]. Pradhan et, al[6], examined fourteen beams for the shear performance of recycled aggregate concrete (RAC), in the absence and presence of stirrups. The poor performance of (RAC) beams in shear although improved the properties of (RAC) by particle packing method, they found that the existing equations to predict the shear strength are not suitable for (RAC) beams, and they proposed an expression to predict concrete shear strength (\(V_c\)) of (RAC) beams by using the shear strength results of RAC beams without shear reinforcement. Abreu, et, al., [7], used recycled crushed concrete to produce recycled aggregate and they studied the effect of using this concrete in the production of coarse aggregate for another new concrete and so on. Arezoumandi, et,
al.,[8], replaced the coarse aggregate in two different proportions (50% and 100%) volumetric replacement. Nine full-scale beam specimens were tested. The results indicated that the replacement of natural coarse aggregates in a ratio exceeds 50% leads to poor bonding with concrete components. The recycled coarse aggregate used by Shatarat, et al. [9] was by crushing the remains of old reinforced concrete beams and slabs with a proportion of (50% and 100%). They treated the recycled coarse aggregate to improve its properties. The study proved that the treated aggregates slightly increase the beams shearing capacity. After comparing the results with the international design codes, it turned out that the codes are very conservative. Matias et al.[10] pointed out that the amount of demolition waste in the European Union is approximately 1 ton per capita and the overall amount produced is more than 450 million tons per year. The demand for construction materials which has been growing in recent decades, has the production of waste from demolition and rehabilitation work. This “construction–demolition” process has put a massive pressure on natural resources, especially natural aggregate, and has led to high levels of Construction and Demolition Waste (CDW). [10].

2. Shear strengthening of reinforced concrete beams
Reinforced concrete beams can become deficient during their service life and need strengthening and repair. Strengthening the structural elements in bending may result in shear failure rather than giving the desired load-carrying capacity. "Strengthening", includes modifications in a building to increase its load capacity, hardness, ductility and stability [11]. Numerous methods are available for designers to choose among shear strengthening techniques. Such as external addition of stirrups, jacketing, external plate bonding using epoxy or bolts and bonding external Fiber Reinforced Polymer (FRP) segments [12]. Mostofinejad, et. al.[13] used four beams (2000×300×200mm dimensions) strengthened in shear with near-surface mounted (NSM) laminates technique. They have studied the effect of using different compressive strengths and presence of stirrups in the beams. Rahman et. al.,[14], studied the behavior of reinforced concrete beams strengthened with (NSM) technique with steel bars to obtain a quick and economic strengthening solution. Seven beams were tested (2000×125×250mm dimensions), ultimate loads, mode of failure, strain behavior and deflection have been studied. Sharaky, et. al.,[15], studied the numerical and the experimental behavior of reinforced concrete beams strengthened by near-surface mounted (NSM) with (GFRP) rods with and without anchor end. Nine strengthened beams were tested with (2200×150×250mm dimensions). The results showed that the load carrying capacity for the reinforced concrete beams strengthened by bottom (GFRP) bars is high when compared to beams strengthened with side (GFRP) bars.

3. Sustainability of lightweight aggregate
Sustainability became a standard term with the definition of the Brundtland Report (World Commission on Environment and Development, 1987). Sustainability now is an integral part of the agenda of governments and companies, and their aims have become central to the work of research laboratories and universities worldwide [16]. It is an action looking for satisfying current needs and leave coming generations the possibility to satisfy their requests, it is the main conception of science capable of discovering the solution for the related problem [17]. Because of the huge quantity of concrete produced every day even a slight decrease in the use of raw materials in concrete mixtures will lead to significant benefits to the environment[18]. The best solution for achieving sustainability in concrete production is the use of waste materials and construction waste residues, [19]. Recently, the concept of sustainability has evolved, in addition to the physical and mechanical properties of materials, taking into consideration economic and environmental issues, to obtain a successful and sustainable innovative product, [20].

4. Test specimens
In this study, nine beam samples were tested with a 2400mm length, 160mm width and 300mm height. The beams were designed to have high flexural capacity and to ensure failure occurs in the shear zone. Three 16mm bars (had a 580MPa yield strength) were used as reinforcement for flexural, and 6mm stirrups bar (250MPa yield strength) @200mm, with two 8mm (420MPa yield strength) top bars. The beams have been loaded by four-point bending test as shown in figure 1. Five concrete mix types were used in this research. The first specimen was normal concrete beam without any replacement of coarse
aggregate, and without strengthening, used as a reference sample, to compare the beam failure mode and the decrease in the load carrying capacity due to partial replacement of natural aggregate with thermstone or bonza. The second type of beams was cast with 20% of coarse aggregate replacement with thermstone (volumetric ratio). The third type of beams was cast with 30% of coarse aggregate replaced with thermstone (volumetric ratio). The fourth and the fifth types of beams were cast with the coarse aggregate with (20% and 30%) with bonza respectively. For mixtures containing a proportion of lightweight aggregates, (ranging from second to fifth mixes), two beams were cast for each mix type, one was strengthened with GFRP rods and the other one was unstrengthened to compare the effect of shear strengthening with GFRP rods. Table 1 shows details of the tested beams considered in this research. Table 2 shows the lightweight aggregate replacement ratios used for the beams and their properties.

Table 1. Details of tested beams considered in this research

| Beam No | Lightweight coarse aggregate replacement | Volumetric replacement ratio (%) | Steel stirrups details | Spacing of Strengthening |
|---------|------------------------------------------|---------------------------------|------------------------|-------------------------|
| B1      | No replacement                           | 0                               | 6mm@200mm              | Without strengthening   |
| B2      | Thermstone replacement                   | 20                              | 6mm@200mm Ø6mm@ 200mm vertical GFRP |
| B3      | Thermstone replacement                   | 30                              | 6mm@200mm Ø6mm@ 200mm vertical GFRP |
| B4      | Bonza replacement                        | 20                              | 6mm@200mm Ø6mm@ 200mm vertical GFRP |
| B5      | Bonza replacement                        | 30                              | 6mm@200mm Ø6mm@ 200mm vertical GFRP |
| B6      | Thermstone replacement                   | 20                              | 6mm@200mm              | Without strengthening   |
| B7      | Thermstone replacement                   | 30                              | 6mm@200mm              | Without strengthening   |
| B8      | Bonza replacement                        | 20                              | 6mm@200mm              | Without strengthening   |
| B9      | Bonza replacement                        | 30                              | 6mm@200mm              | Without strengthening   |

Figure 1. Details of the selected beams for the test.
5. Materials
Ordinary Portland cement available in the local market has been used to produce the concrete mixtures approved for this research. Natural coarse aggregate of 4.75-19 mm was used. The samples were taken according to ASTM specifications. Sieve analysis was done for samples and the obtained gradients were within the limits of the specifications. For fine aggregate, the samples were also taken according to the ASTM specifications, and the results of the sieve analysis of the samples used were within the limits of the ASTM specifications. The lightweight aggregate was obtained from the remains of the broken thermstone and bonza, where it was re-crushed to a size similar to the size of the natural coarse aggregate. The sieve analysis was done and the sizes that passed through the sieve were 19 mm, and remained on the sieve 4.75 were taken.

6. Concrete mix design
The approved reference mixture was 1: 1.8: 2 with a water-cement ratio of 0.38, where the compressive strength was 35MPa at 28 days. Two proportions of coarse aggregates were replaced with lightweight aggregates of thermstone or bonza with volumetric ratios of (20% and 30%). The compressive strength at 7 and 28 days was tested using standard compression cylinders measuring (150 × 300 mm) in addition to test the flexural and splitting tensile strength at 28 days, as shown in table 2. It is certainly normal for the density of the concrete to decrease when replacing the natural aggregate with lightweight aggregates such as thermstone and bonza. The amount of decrease in density depends on the type of the lightweight aggregate replaced and also the percentage of aggregate replacement. It was found that the maximum reduction in density was only 6.2%, table 2.

| Mix No. | Type of aggregate replacement | Volumetric replacement ratio (%) | Density (Kg/m³) | f′c after 7 days (MPa) | f′c after 28 days (MPa) | Modulus of rupture at 28 days (MPa) | Splitting tensile strength at 28 days (MPa) |
|---------|-------------------------------|----------------------------------|-----------------|----------------------|----------------------|-----------------------------------|------------------------------------------|
| 1       | No replacement                | 0                                | 2407.9          | 30.84                | 35.26                | 3.95                              | 3.45                                     |
| 2       | Thermstone replacement        | 20                               | 2327.1          | 27.34                | 33.58                | 3.80                              | 3.37                                     |
| 3       | Thermstone replacement        | 30                               | 2333.2          | 22.86                | 31.50                | 3.55                              | 3.23                                     |
| 4       | Bonza replacement             | 20                               | 2345.9          | 26.77                | 31.83                | 3.65                              | 3.33                                     |
| 5       | Bonza replacement             | 30                               | 2257.9          | 22.25                | 26.28                | 3.30                              | 3.07                                     |

7. Strengthening style
The style of Near-Surface Mounted (NSM) strengthening was used for shear strength by applying Glass Fiber Reinforced Polymer (GFRP) bars. The diameter of used glass bars was 6mm with (400 MPa) breaking strength. The style of strengthening was achieved by using vertical (GFRP) bars with a spacing of 200mm c/c at the shear span. The selected NSM technique for this research was done as follows: Firstly, grooves of (12×12mm) were made on both sides of the beam according to the specific locations, a thin layer applied on the grooves of primer base (which was the consisted of a mixture of two materials produced by the DCP company). It was left for 24 hours to dry, then the GFRP bars were glued to the surface of the beams with an adhesive, (Sikadur-31) which was used as an adhesive to attach the GFRP bars to the concrete surface as a second layer (it comes in the form of a 2-component thixotropic epoxy adhesive). Finally, the grooves that the GFRP rods were installed in them were filled with the glue. Figure (2) shows pictures of the installation stages of the GFRP rods to the beams.
8. Installation of strain gauges

Two types of strain gauges (Tokyo Measuring Instruments Lab.) were used, one for the steel with a length of (5 mm) and the other for concrete with a length of (30 mm) with their adhesives obtained from the same corporation. Strain gauges were fixed at six locations of the beam that was strengthened with GFRP bars, and at five locations for the beam that was unstrengthened with GFRP bars, as shown in figure 3. Two of the gauges were mounted to the stirrups at the left and right side of the beam, and one was mounted to the middle longitudinal bottom reinforcing steel bar. Two gauges were mounted on the concrete surface at the shear zones. They were inclined at an angle of 45° normal to the direction of the shear cracks. The last strain gauge was fixed on the second GFRP bar located at the right end of the strengthened beam. The data were collected by the (data acquisition) that was connected with a computer and the strains were recorded during the test for all load stages.

**Figure 2.** Stages of installing GFRP bars

**Figure 3.** Locations of strain gauges for a typical tested beam
9. Results and discussion
For the results to be arranged and easy to compare, they have been divided into different categories, load carrying capacity, load deflection curves, load strain response and mode of failure.

9.1. Load carrying capacity
Table 3 shows that for unstrengthened beams B6, B7, B8 and B9, the percentage decrease in the load carrying capacity relative to the reference normal concrete beam B1 ranges between (5.4% and 13.5%). Therefore, it can be concluded that unstrengthened beams with replacement ratios of (20% and 30%) can be successfully beams used in construction concrete practice. Also, when observing table 3, it can note that the maximum load for the strengthened beams was obtained for beam B4, where the maximum load was equal to 185kN with a different type of failure mode (concrete crushing) when compared to unstrengthened beam B8 (shearing failure). The maximum deflection value was increased by 47.4% (from 19mm for the reference beam B8 to 28mm for beam B4). As for beam B2, the gain in the load capacity was 11.8% compared with unstrengthened beam B6 (the load capacity 165 kN for beam B6 and 184 kN for beam B2). While the gain in the load carrying capacity for beams B5 and B3 was (5.9% and 9.4%) compared to the unstrengthened beams (B9 and B7) respectively. Whereas, the decrease in the maximum load as a result of coarse aggregate replacement with lightweight coarse aggregate was equal to 13.5% at beam B7 compared with beam cast with normal concrete B1, (185kN for B1 to 160kN for B7). As for beam B6, the decrease in the maximum load as a result of coarse aggregate replacement with lightweight aggregate was 10.8% compared to the normal concrete beam B1, (185kN for B1 to 165kN for B6). Whereas, the decrease in the maximum load of beams B8 and B9 which were cast with partial lightweight aggregate replacement (bonza) compared with normal concrete beam B1 was 5.4% and 8.1%, respectively.

9.2. Load deflection response
All deflections were measured up to the failure load. The deflection was measured by (LVDT) that was connected with the data acquisition. The location of (LVDT) was at the midspan of the tested beam. That is clear in figure 4 and table 3. The highest deflection value for the strengthened beams was occurred at beam B4 (28mm). It is interesting that all the maximum deflection values for the strengthened beams were higher than the maximum deflection value of the corresponding unstrengthened beams with the same aggregate replacement ratio. The gain in deflection for the beam B4 was 47.4% compared with the unstrengthened beam B9 that cast using the same concrete that has the same lightweight aggregate replacement ratio. While the gain in deflection of the strengthened beam B2 was equal to 29% compared to the unstrengthened beam B6 which was cast with the same type of concrete. Whereas the beams B3 and B5 which were cast with strengthened concrete with a 30% lightweight coarse aggregate replacement ratio (Thermstone and bonza respectively) they had gains in deflection of (9.6% and 11.1% respectively), compared with unstrengthened beams B7 and B9 that were cast with the same type of concrete. Also, it can be noticed that the shape of all the deflection curves is almost linear until the load level becomes close to the peak value. Referring to the available elastic equations for deflection, it can be noted that the variable in these beam samples is the value of modulus of elasticity (E), which is inversely proportioned to the value of the deflection, and that the value of (E) is directly proportional to the specific density of the concrete. Therefore, it is noticed that the decrease in the specific density of concrete leads to an increase in the deflection values, before reaching the failure load. As the gain in the maximum load, the statement applies to the maximum deflection at the failure load, it was found that beams B2 and B4 have the higher gained maximum deflection due to the strengthening by GFRP bars where the 20% of coarse aggregate replacement with thermstone and bonza, respectively. As shown in table 3.
a. Unstrengthened beams with thermstone aggregate replacement

b. Unstrengthened beams with bonza aggregate replacement

c. Strengthened and unstrengthened beams with thermstone aggregate replacement

d. Strengthened and unstrengthened beams with bonza aggregate replacement

Figure 4. Load deflection relationships of tested beams

Table 3. Maximum load and maximum deflection with mode of failure of tested beams.

| Strengthened Beam No. | Lightweight coarse aggregate volumetric replacement ratio | Maximum load (kN) | Gain in load compared to unstrengthening beam (%) | Decrease in load carrying capacity of strengthened beams relative to reference beam B1 (%) | Maximum mid-span deflection (mm) | Gain in deflection compare to corresponding unstrengthened beams (%) | Mode of failure |
|-----------------------|--------------------------------------------------------|-------------------|-----------------------------------------------|------------------------------------------------------------------------------------------------|---------------------------------|------------------------------------------------------------|----------------|
| B1                    | 0% (normal concrete)                                   | 185               |                                               |                                                                                                |                                 |                                                           | shear          |
| B2                    | 20% thermstone                                          | 184               | 11.5                                          |                                                                                                | 24                              | 29                                                        | Concrete crushing |
| B3                    | 30% thermstone                                          | 175               | 9.4                                           |                                                                                                | 25                              | 9.6                                                       | Concrete crushing |
| B4                    | 20% bonza                                              | 185               | 5.7                                           |                                                                                                | 28                              | 47.4                                                     | Concrete crushing |
| B5                    | 30% bonza                                              | 180               | 5.9                                           |                                                                                                | 21                              | 11.1                                                     | Concrete crushing |
| B6                    | 20% thermstone                                          | 165               | 10.8                                          | 18.6                                                                                           |                                 |                                                           | Shear          |
| B7                    | 30% thermstone                                          | 160               | 13.5                                          | 22.8                                                                                           |                                 |                                                           | Shear          |
| B8                    | 20% bonza                                              | 175               | 5.4                                           | 19.0                                                                                           |                                 |                                                           | Shear          |
| B9                    | 30% bonza                                              | 170               | 8.1                                           | 18.9                                                                                           |                                 |                                                           | Shear          |
9.3. Shear force in concrete stirrups and GFRP bars

For the strain occurred in the stirrups, figure (5 a, b, c and d) shows that the strains for left and right stirrups of the tested (strengthened and unstrengthened) beams, respectively. The shear strength of concrete and steel stirrups can be calculated using the following simplified equations:

\[ V_c = \lambda \frac{f'c}{6} \times b_w \times d \]  \hspace{1cm} (1)

where \( \lambda \) is the modification factor to reflect the reduced mechanical properties of lightweight concrete relative to normal weight concrete [21]. The value of \( \lambda \) equals to 1 for normal concrete, and equals to 0.75 for concrete contained full lightweight coarse aggregate. This value can be calculated by the interpolation for (20% and 30%) lightweight aggregate replacement ratios, which equal to (0.95 and 0.925 respectively). For stirrups shear strength, it can be calculated based on the following expression:

\[ V_s = \frac{A f_y d}{s} \]  \hspace{1cm} (2)

It is noticeable in figure 5 that the starting of increasing the strain values for most beams occurs when the load reaches a level of about (40-50 kN). Where these load values are close to the values computed using equation 2 for concrete shear strength \( V_c \) shown in table 4. The total shear strength carried by the stirrups and concrete that is calculated in the 6th column of table 4 was within the limits ranging between (51 to 60 kN). These limits of shear forces are the starting load levels of transferring the shear force to the GFRP rods. Whereas, if these loads were multiplied by two to obtain the total applied load, the limits of total loads would be (102 to 120), and these are approximately the same levels of load at which the GFRP rods start to resist the shear forces as shown in table 4 and figure 5.
Table 4. Values of shear forces in strengthened beams resisted by concrete, stirrups and GFRP rods.

| (1) Beam No. | (2) Lightweight coarse aggregate volumetric replacement ratio | (3) f'c at 28 day (MPa) | (4) Vc calculated by equation (1) (kN) | (5) Vs calculated by equation (2) (kN) | (6) Vc+Vs calculated by equations (1&2) (kN) | (7) Experimental shear force at failure (P/2) (kN) | (8) The estimated shear force carried by GFRP bars (kN (col.7-col.6)) |
|--------------|---------------------------------------------------------------|--------------------------|----------------------------------------|----------------------------------------|---------------------------------------------|-----------------------------------------------|-------------------------------------------------|
| B2           | 20% thermstone                                                | 33.58                    | 38.25                                  | 18.27                                  | 56.52                                       | 92                                            | 35.48                                           |
| B3           | 30% thermstone                                                | 31.5                     | 36.08                                  | 18.27                                  | 54.35                                       | 87.5                                          | 33.15                                           |
| B4           | 20% bonza                                                     | 31.38                    | 36.97                                  | 18.27                                  | 55.24                                       | 92.5                                          | 37.26                                           |
| B5           | 30% bonza                                                     | 26.28                    | 32.95                                  | 18.27                                  | 51.22                                       | 90                                            | 38.78                                           |

9.4. Strain in longitudinal reinforcement

All the beams were reinforced to resist large bending moment values to ensure that bending failure does not occur. By noting figure 6 which illustrates the strains occurred in the main reinforcing middle bottom bar of the beams when applying the loads collected by data acquisition, it can be noted that the strains have almost the same pattern as that of the strain occurred in the reference beam which had a linear response until approaching the failure load. Because the main reinforcement in the beams was designed to resist high moments and loads, therefore the strains in the main reinforcing bars remained within the elastic range.

If the internal moment that occurred in the main reinforcement is calculated using the recorded strain values obtained from the test:

\[
\sigma = E \times \varepsilon
\]

\[E = 200000 \text{ MPa (for steel)}\]

\[F (force) = \sigma \times A_s\]

\[Hence, F = E \times \varepsilon \times A_s\]

\[M (moment) = F \times (d - \frac{a}{2})\]

\[M = E \times \varepsilon \times A_s \times \left(d - \frac{a}{2}\right)\]

\[a = \frac{A_s \times E \times \varepsilon}{0.85 \times f'_c \times b}\]

substitution in equation (8):

\[M = E \times \varepsilon \times A_s \times \left(d - \frac{A_s \times E \times \varepsilon}{2 \times 0.85 \times f'_c \times b}\right)\]

The applied moment can be calculated by the following equation:

\[M = \frac{P}{2} \times 0.8\]

If the moments computed by equations 9 and 10 are compared with the applied moment at all load stages and for all beams, the results will be as shown in figure 7.

It is interesting in figure 7 that the value of the moment computed using the recorded strain on the main reinforcement was slightly less than the applied moment calculated using equation (9) at early stage of loading, then the two curves were coincided. This is due to the concrete resistance to moment before reaching the concrete cracking stage. This reduces the strain values on the rebar in the pre-crack stage. By observing figure (6 a & b), which represents the strain value at mid-span of the main reinforcement for strengthened and un strengthened beams, the linear pattern of the strain curve is clearly visible, which reveals the stress in the main reinforcement was within the elastic load-stage at different stages of loading for all tested beams.
a. Strengthening beams

b. Unstrengthening beams

Figure 6. Load strain relationship of main reinforcement

a. Beam (B1)

b. Beams (B2 and B6)

c. Beams (B3 and B7)

d. Beams (B4 and B8)

e. Beams (B5 and B9)

Figure 7. Moment curves obtained from applied moment and actual strain values

9.5. Average surface concrete strain at beam shear zone

The direction of the strain gauges which was normal to the direction of the cracks led to a decrease in the strain value being recorded, since with the starting of the cracks, the strain value is almost approximately constant. Figure 8 shows the average strains at the surface of the concrete at the shear zone of the tested beams on the left and right sides for strengthened beams (B2, B3, B4 and B5) and the unstrengthened normal concrete beam (B1).
9.6. Mode of failure

It can be observed that there was no shear failure occurred at all strengthened beams that contained lightweight aggregate replacement ratio, except for the beam B4 (with a 20% bonza ARR) as there was a shear failure after concrete crushing. At the beginning, failure of this beam was a compression failure that occurred when the load reached (180 kN). As the load was increased, a debonding occurred at the upper limb of one of the GFRP rods, leading to a shear failure. Whereas the failure of beam B1 that was cast with normal concrete and the failure of unstrengthened beams that were cast with proportions of lightweight aggregate was shear failure mode, as shown in figure 9.

- **a.** (B1) shear failure
- **b.** (B2) concrete crushing failure
- **c.** (B3) concrete crushing failure
- **d.** (B4) concrete crushing with shear failure
- **e.** (B5) concrete crushing failure
- **f.** (B6) shear failure
- **g.** (B7) shear followed concrete crushing
- **h.** (B8) shear failure
- **i.** (B9) shear failure

**Figure 9.** Failure modes of tested beams
9.7. Strains in GFRP
The load-strain relationships of the GFRP rods are shown in figure 10 for the beams that were strengthened with GFRP rods. It is clear from figure 10 that the beginning of transferring the loads to the GFRP rods had started when the load reached a level of about 100 kN, and the strain values before reaching this load level are almost negligible. This means that the value of the shear force reached about 50 kN when the loads were transferred to the GFRP bars. If these values were compared with the values of the calculated shear forces for stirrups and concrete (Vs and Vc), the values would be close to the calculated values as shown in column 6 of table 4.

Figure 10. Load-strain relationship at GFRP rods for strengthened beams

10. Conclusions
The following conclusions can be drawn from the results of the experimental tests.

- For unstrengthened beams, when the coarse aggregate was replaced by 30% of lightweight aggregate, the maximum load decreased was only (8.1% and 13.5%) for bonza and thermstone, respectively.
- When replacing 20% of the volume of coarse aggregate with lightweight coarse aggregate, the maximum load of the unstrengthened beams, compared with beams cast with normal concrete, was reduced by (19% and 18.6%) depending on the type of replaced coarse lightweight aggregate (bonza and thermstone) respectively.
- When the beams were strengthened by GFRP bars (that cast with concrete had 30% of lightweight coarse aggregate replacement), the gain of the maximum load was (5.9% and 9.4%) depending on the type of lightweight aggregate used (bonza and thermstone), respectively.
- For beams cast by concrete contained 20% of lightweight coarse aggregate replacement, and strengthened with GFRP rods, the gain of maximum load was (5.7% and 11.5%), depending on the type of lightweight coarse aggregate used (bonza and thermstone), respectively.
- Compressive strength tests indicated that the increase in the amount of lightweight replacement in the mix resulted in a slight decrease in compressive strength. The same conclusion applies to splitting and flexural tests.
- It was found that by replacing 30% of the natural coarse aggregate with lightweight aggregate decreased the compressive strength by (10.6% and 25.5%) for thermstone and bonza, respectively.
- Test results show that by replacing 30% of the natural coarse aggregate with lightweight aggregate decreased the concrete density by only (7.26% and 6.23%) for thermstone and bonza, respectively, which gives an indication of possibility for using this concrete in construction works.
- The concrete compression failure that occurred in most of the strengthened beams gives an impression that the reinforced beams have reached the highest load that the beams can carry for the adopted strengthening pattern in this research.
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