Behavior of reinforced Concrete Beams with Steel slag Reinforced by Fiber Reinforced Polymers Bars

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Abstract-This paper presents experimental and numerical study of the flexural behavior of concrete beams with steel slag as a coarse aggregate partially replacement, and reinforced by glass fiber reinforced polymers (GFRP) bars by pultrusion process as a solution to overcome the corrosion problem. A series of 10 experimental beams are cast and tested up to failure under two-point load with 600 mm apart, where all beams had the same dimensions with width, depth, total length and clear span between two supports are 100 mm, 200 mm, 2000 mm and 1800 mm, respectively. Finite element analysis program (ANSYS) is used to develop a calibration models for simulation of the behavior of experimental beams to give confidence in the use of ANSYS. Then a series of 16 beams models with different parameters (flexure and compression reinforcement ratio and type and shear reinforcement) are used to study how different parameters affect on the behavior of a concrete beam with steel slag and investigate how GFRP should be applied in order to get maximum increase of load capacity. Experimental tests and numerical analysis results show that adding the steel slag to the concrete mixes as a coarse aggregate replacement, using GFRP bars and increasing of GFRP bottom main reinforcement ratio have a significant effect on the flexure behavior of concrete beams with steel slag reinforced by GFRP bars.

Keywords-Flexure, Behavior, Steel slag, Beams and GFRP bars.

I. INTRODUCTION

The Egyptian construction sector is one of the most promising sectors which are intended to achieve great gain to national gross domestic product. Reinforced concrete building materials were implemented a large scale development in recent years. Many of materials industries have evolved with the development of construction industry such as steel slag and fiber reinforced polymers. Steel slag is a by-product obtained either from conversion of iron to steel in basic oxygen furnace (BOF), or by the melting of steel scrap to make steel in the electrical arc furnace (EAF) [3]. The industrial wastes have been encouraged in construction industries because it contributes to reduce the usage of natural resources [2]. For many years, by products such as fly ash, silica fumes and steel slag were considered as waste materials. They have been successfully used in the construction industries, for the partial or full replacement of both fine and coarse aggregates, it is recommended that up to SSA 60% can be used as replacement of coarse aggregate [4,6]. The concrete casted with steel aggregate concrete was more durable than that prepared with natural basalt aggregate in terms of the chloride penetration resistance [5]. Recycling steel slag to use it in the concrete as natural aggregate replacement might prove an economical and environmentally friendly solution also this will encourage other investigations to find another filed of using the slag. As a replacement to steel reinforcement, Fiber Reinforced Polymers (FRP) bars have gained popularity due to their noncorrosive and non-metallic properties. FRP are light weight and have high strength-to-weight ratios 1.5 to 2 times the tensile strength of steel [1]. Glass fiber reinforced polymer GFRP has a very important role to play as reinforcement in concrete structures that will be exposed to harsh environmental conditions where traditional steel reinforcement could corrode [7]. FRP is the most corrosion resistance replacement of steel reinforcement in concrete, the corrosion reduces the life time of structures, causes high repair costs. With this combination between a by-product aggregate and non corrosion reinforcement we can offer a cost effective reinforced concrete section that can achieve very high compression, flexure strength and very high durability against corrosion if we compare with normal concrete section reinforced with steel bars.

The aim of this study is to investigate the behavior of concrete beams with steel slag as a coarse aggregate partially replacement reinforced by GFRP bars. Experimental tests were performed to investigate the behavior of beams. The ANSYS program is used to develop finite element calibration models to simulate of the behavior of experimental results. The load-deflection response of the experimental beam will be compared to Finite elements model result to calibrate the FE model for further use [8,9]. Then series of beam models were then used to study how different parameters affect on beam behavior to get maximum increase of load capacity.
II. EXPERIMENTAL PROGRAM

Tested beams are cast and tested up to failure under two point load with 600 mm apart as shown in figure 2, where all beams had the same dimensions with width, depth, total length and clear span between two supports are 100mm, 200mm, 2000mm and 1800mm, respectively. Beams are divided into four groups as shown in Table 1 to study the effect of some parameters on the behavior and predicting deflections of the concrete beams with steel slag as a coarse aggregate replacement reinforced by FRP bars [10] with stress strain curve as shown in figure 1 as follow:

1. The tensile reinforcement ratio (0.8 and 1.60% are used).
2. The compression reinforcement ratio (0.8 and 1.60% are used).
3. Shear span to depth ratio (a/d= 2, 3 and 4 are used).
4. The characteristic strength of concrete (fcu= 30 and 40 N/mm²)

The specimens were loaded with two-point load 600 mm apart in the middle third of specimens for group 1, 2 and 4, the specimens were loaded with two-point load 800 mm from the support for group 3 to study the flexure behavior of concrete beams with steel slag as a coarse aggregate replacement reinforced by FRP bars when exposed to pure bending moment.

Table 1. Tested beam groups

<table>
<thead>
<tr>
<th>group</th>
<th>parameters</th>
<th>beam</th>
<th>concrete</th>
<th>Fcu [N/mm²]</th>
<th>R.F.T.</th>
<th>Bottom RFT</th>
<th>Top RFT</th>
<th>stiruups</th>
<th>shear span [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>bottom</td>
<td>B1</td>
<td>ordinary</td>
<td>30</td>
<td>steel</td>
<td>2Ø10</td>
<td>2Ø10</td>
<td></td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>R.F.T.</td>
<td>B2</td>
<td></td>
<td>30</td>
<td></td>
<td>2Ø10</td>
<td>2Ø10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ratio</td>
<td>B3</td>
<td></td>
<td>30</td>
<td></td>
<td>2Ø10</td>
<td>2Ø10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B4</td>
<td></td>
<td>30</td>
<td></td>
<td>2Ø10</td>
<td>2Ø10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Top</td>
<td>B5</td>
<td>33% steel slag</td>
<td>30</td>
<td>FRP</td>
<td>4Ø10</td>
<td>2Ø10</td>
<td>0 ø8 at 150mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R.F.T.</td>
<td>B6</td>
<td></td>
<td>30</td>
<td></td>
<td>2Ø10</td>
<td>2Ø10</td>
<td>0 ø8 at 150mm</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>shear span to depth</td>
<td>B7</td>
<td>steel slag</td>
<td>30</td>
<td></td>
<td>2Ø10</td>
<td>2Ø10</td>
<td>4Ø8</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B8</td>
<td></td>
<td>30</td>
<td></td>
<td>2Ø10</td>
<td>2Ø10</td>
<td></td>
<td>800</td>
</tr>
<tr>
<td>4</td>
<td>Fcu</td>
<td>B9</td>
<td></td>
<td>30</td>
<td></td>
<td>2Ø10</td>
<td>2Ø10</td>
<td></td>
<td>600</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B10</td>
<td></td>
<td>40</td>
<td></td>
<td>2Ø10</td>
<td>2Ø10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Stress-strain curve of used GFRP bar
Figure 2. Flexure tests of concrete beams

2.1 Results of Experimental Program
Table 2 shows the results of the tested beams in the experimental work in this study, the table includes the values of the first cracking and the fracture loads and its corresponding mid-span deflection.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B1</td>
<td>Control</td>
<td>steel</td>
<td>12.00</td>
<td>40.41</td>
<td>1.268</td>
<td>22.804</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>N.A.</td>
<td></td>
<td>10.00</td>
<td>41.00</td>
<td>3.552</td>
<td>42.226</td>
</tr>
<tr>
<td></td>
<td>B3</td>
<td></td>
<td></td>
<td>10.15</td>
<td>42.50</td>
<td>3.442</td>
<td>40.638</td>
</tr>
<tr>
<td></td>
<td>B4</td>
<td></td>
<td></td>
<td>12.02</td>
<td>50.04</td>
<td>5.174</td>
<td>38.992</td>
</tr>
<tr>
<td>2</td>
<td>B5</td>
<td>S.S.</td>
<td>FRP</td>
<td>10.15</td>
<td>42.50</td>
<td>3.442</td>
<td>40.638</td>
</tr>
<tr>
<td></td>
<td>B6</td>
<td></td>
<td></td>
<td>9.01</td>
<td>41.84</td>
<td>3.558</td>
<td>36.026</td>
</tr>
<tr>
<td>3</td>
<td>B7</td>
<td></td>
<td></td>
<td>11.03</td>
<td>42.46</td>
<td>8.318</td>
<td>39.172</td>
</tr>
<tr>
<td></td>
<td>B8</td>
<td></td>
<td></td>
<td>11.01</td>
<td>42.46</td>
<td>8.31</td>
<td>39.164</td>
</tr>
<tr>
<td>4</td>
<td>B9</td>
<td></td>
<td></td>
<td>10.15</td>
<td>42.50</td>
<td>3.442</td>
<td>40.638</td>
</tr>
<tr>
<td></td>
<td>B10</td>
<td></td>
<td></td>
<td>7.02</td>
<td>38.22</td>
<td>4.826</td>
<td>41.356</td>
</tr>
</tbody>
</table>

Where: N.A. = Concrete with normal dolomite aggregate
S.S. =Concrete with 33% steel slag as a coarse aggregate replacement

III. NUMERICAL ANALYSIS

3.1 Calibration Model
The use of finite element to create the calibration model using experimental load-deformation behavior of a concrete beam B3 from experimental program, ANSYS was used as the FE modeling package [8]. The width, depth, total length and clear span between two supports of the beam tested were 100mm, 200mm, 2000mm and 1800mm, respectively. Tested beam had tensile reinforcement 2#10 mm FRP bars and ø8mm@15cm stirrups. The element types for concrete, steel plates and reinforcement bars were solid 65, solid 45 and link 180, respectively as shown in figures 3, 4, 5.
To simulate the experimental test, a Static analysis type is utilized. The finite element model for this analysis is a concrete beam reinforced by FRP bars under two vertical loads. The load–deflection curve is considered the key aspect in studying the beam behavior as it involves response parameters including beam ultimate loads, and maximum deflection. Therefore, correlating the load–deflection relationships of the finite element results with that of the experimental ones is considered an effective mean to verify the model.

The entire load-deformation response of the model produced compares well with the response from experimental work as shown in figure 7. This gave confidence in the use of ANSYS. The approach was then utilized to analyze a series of concrete beams with steel slag as a coarse aggregate partially replacement reinforced by FRP bars.

Analysis were carried out on 16 beam models, divided into four groups, where all groups have the same width, depth, total length and clear span between two supports of 100, 200, 2000, 1800 mm respectively to study the effects of some parameters on the behavior of the reinforced concrete beams with steel slag as a coarse aggregate reinforced
with GFRB bars using ANSYS software and compare it with the reinforced concrete beam models reinforced by steel bars with the same parameters, as shown in table 3. The studied parameters include:

1. The tensile reinforcement ratios are (0.8, 1.20, 1.60 and 2.10 % are used).
2. The tensile reinforcement types (GFRP, and Steel).
3. The compression reinforcement ratios are 0.8, 1.20, 1.60 and 2.10 % are used).
4. Shear reinforcement ratios(0.2, 0.33 and 0.4% are used).

Table 3. Details and reinforcement of Beam models for Groups 1, 2, 3&4

<table>
<thead>
<tr>
<th>No</th>
<th>Beam</th>
<th>Var.</th>
<th>Group</th>
<th>Bottom reinforcement</th>
<th>Top reinforcement</th>
<th>Stirrups</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B1</td>
<td>Bottom reinforcement ratio</td>
<td>1</td>
<td>2@10mm (0.8%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
</tr>
<tr>
<td>2</td>
<td>B2</td>
<td>FRP Bars</td>
<td>3@10mm (1.2%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>B3</td>
<td>Steel Bars</td>
<td>4@10mm (1.6%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>B4</td>
<td></td>
<td>5@10mm (2.1%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>B5</td>
<td>Bottom reinforcement ratio</td>
<td>2</td>
<td>2@10mm (0.8%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
</tr>
<tr>
<td>6</td>
<td>B6</td>
<td></td>
<td>3@10mm (1.2%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>B7</td>
<td></td>
<td>4@10mm (1.6%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>B8</td>
<td></td>
<td>5@10mm (2.1%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>B9</td>
<td>Top reinforcement ratio</td>
<td>3</td>
<td>2@10mm (0.8%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
</tr>
<tr>
<td>10</td>
<td>B10</td>
<td></td>
<td>2@10mm (0.8%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>B11</td>
<td></td>
<td>2@10mm (0.8%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>B12</td>
<td></td>
<td>2@10mm (0.8%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>B13</td>
<td>FRP Bars</td>
<td>4</td>
<td>2@10mm (0.8%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
</tr>
<tr>
<td>14</td>
<td>B14</td>
<td></td>
<td>2@10mm (0.8%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>B15</td>
<td></td>
<td>2@10mm (0.8%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>B16</td>
<td></td>
<td>2@10mm (0.8%)</td>
<td>2@8mm (0.8%)</td>
<td>Ø8@150mm</td>
<td></td>
</tr>
</tbody>
</table>

3.4 Results of Numerical Analysis

Table 4 shows the results of the numerical analysis models, the table includes the values of the max loads ($P_{max}$) and deflections at max loads.

Table 4. The Results of the Tested Beams of Groups 1, 2, 3&4

<table>
<thead>
<tr>
<th>No</th>
<th>Beam</th>
<th>Parameters</th>
<th>Group</th>
<th>Initial crack load [Kn]</th>
<th>Max load [Kn]</th>
<th>Max deflection [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B1</td>
<td>FRP Flexure reinforcement ratio</td>
<td>1</td>
<td>12.11</td>
<td>42.712</td>
<td>25.790</td>
</tr>
<tr>
<td>2</td>
<td>B2</td>
<td></td>
<td></td>
<td>13.21</td>
<td>43.99</td>
<td>31.200</td>
</tr>
<tr>
<td>3</td>
<td>B3</td>
<td></td>
<td></td>
<td>14.54</td>
<td>50.432</td>
<td>32.327</td>
</tr>
<tr>
<td>4</td>
<td>B4</td>
<td></td>
<td></td>
<td>19.88</td>
<td>54.314</td>
<td>26.253</td>
</tr>
<tr>
<td>5</td>
<td>B5</td>
<td>Steel flexure reinforcement ratio</td>
<td>2</td>
<td>9.9</td>
<td>29.988</td>
<td>35.900</td>
</tr>
<tr>
<td>6</td>
<td>B6</td>
<td></td>
<td></td>
<td>11.85</td>
<td>39.99</td>
<td>37.010</td>
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<td>7</td>
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<td></td>
<td></td>
<td>12.65</td>
<td>42.23</td>
<td>38.317</td>
</tr>
<tr>
<td>8</td>
<td>B8</td>
<td></td>
<td></td>
<td>17.51</td>
<td>48.492</td>
<td>31.074</td>
</tr>
<tr>
<td>9</td>
<td>B9</td>
<td>Steel compression reinforcement ratio</td>
<td>3</td>
<td>10.52</td>
<td>36.746</td>
<td>21.974</td>
</tr>
<tr>
<td>10</td>
<td>B10</td>
<td></td>
<td></td>
<td>10.61</td>
<td>37.502</td>
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</tr>
<tr>
<td>11</td>
<td>B11</td>
<td></td>
<td></td>
<td>10.66</td>
<td>39.036</td>
<td>25.387</td>
</tr>
<tr>
<td>12</td>
<td>B12</td>
<td></td>
<td></td>
<td>11.12</td>
<td>39.854</td>
<td>24.327</td>
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<tr>
<td>13</td>
<td>B13</td>
<td>Shear reinforcement</td>
<td>4</td>
<td>10.52</td>
<td>32.886</td>
<td>21.01</td>
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<td>14</td>
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<td></td>
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<td>37.484</td>
<td>22.907</td>
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<td>B15</td>
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<td></td>
<td>10.63</td>
<td>40.094</td>
<td>29.4</td>
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<td>16</td>
<td>B16</td>
<td></td>
<td></td>
<td>10.66</td>
<td>41.892</td>
<td>29.1</td>
</tr>
</tbody>
</table>
IV. ANALYSIS AND DISCUSSION

4.1 The tensile reinforcement type and ratios:

4.1.1 Crack patterns

The first crack appeared in the tension zone at the middle of the beam of B3 and B4, the number of cracks increased as the load increased and the cracks propagated upwards towards the compression zone until failure, as shown in figures 8 and 9.

![Figure 8. Crack Pattern of Beams B3](image)

![Figure 9. Crack Pattern of Beams B4](image)

4.1.2 Load-Deflection Relationships

The descending branch of the load-deflection curve is not investigated in these tests because the testing machine is load controlled as shown in figure 10.

![Figure 10. Load-deflection chart for B3 and B4 (Experimental work)](image)

Load-Deflection Charts from the finite element model was determined, for the beams in Group 2, the steel reinforced concrete beams B5, B6, B7 and B8 tend to exhibit greater midspan deflections than beams in Group 1 as shown in figure 11, 12, 13 and 14. This indicates that, for the same area of reinforcement, GFRP bars tend to reveal different behavior than steel bars. For GFRP reinforced concrete beams, the midspan deflection tends to decreased as the reinforcement ratio achieve 1.6% as shown in figure 16.
4.2 The compression reinforcement ratios:

4.2.1 Crack patterns

The first crack appeared in the tension zone at the middle of the beam, the number of cracks increased as the load increased and the cracks propagated upwards towards the compression zone until failure, as shown in figure 17.

4.2.2 Load-Deflection Charts

The compression reinforcement ratios:

<table>
<thead>
<tr>
<th>Compression (FRP)</th>
<th>Compression (Steel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Load-Deflection Charts for experimental and Finite element model was determined at the mid span of the beams in Group 3 as shown in figure 18 and 19 as follow:
For B3 and B6 (Experimental) for Group 3 (Ansys) 

From load – deflection curves shown in Figure 18 and 19, it was noticed that, the maximum load of (B10) is about 102% of (B9). The maximum deflection of (B10) is about 100.67 % of (B9), the maximum load of (B11) is about 104% of (B10). The maximum deflection of (B11) is about 98.4 % of (B10) and the maximum load of (B12) is about 102% of (B11). The maximum deflection of (B12) is about 85.8 % of (B11). It could be concluded that the increasing of compression reinforcement ratios has an insignificant effect on maximum load of tested beams.

4.3 Shear reinforcement ratios
4.3.1 Crack patterns
The increasing of transverse reinforcement ratio increases the ductility of tested beams, hence, reduces the number of cracks and their widths as shown in figures 20.

Figure 20. Crack Pattern of Beams B8

4.3.2 Load-Deflection Charts
From the finite element model was determined at the mid span of the beams as follow: The increasing of transverse reinforcement ratios increases the ductility of tested beams, hence, increases the maximum loads with a small amount as shown in figures 21 and 22.
From load–deflection curves shown in Figure 22, it was noticed that, the maximum load of (B14) is about 113% of (B13). The maximum deflection of (B14) is about 109% of (B13); the maximum load of (B15) is about 107% of (B14). The maximum deflection of (B15) is about 128% of (B14); the maximum load of (B16) is about 104% of (B15). The maximum deflection of (B16) is about 99% of (B15). It could be concluded that the increasing of shear reinforcement ratios has an insignificant effect on maximum load of tested beams.

V. CONCLUSIONS

This study investigated the flexural behavior of concrete beams with steel slag as a coarse aggregate replacement reinforced by locally produced glass fiber reinforced polymer (GFRP) bars. Within the scope of the experimental program considering the materials used, comparison of the experimental results with the values calculated using the calibration model and other numerical models resulted in the following conclusions:

1. Using of GFRP bars has advantages compared to steel bars reinforcement in the concrete beam contained EAFSS coarse aggregate.
2. The increasing of flexure reinforcement ratios from 0.8% to 2.1% has a significant effect on maximum load and deflection of tested beams.
3. Ultimate load is greater in case of EAFSS coarse aggregate concrete beam reinforced by GFRB bars than the Ultimate load of dolomite aggregate concrete reinforced with steel bars in all tested beams.
4. The increasing of compression reinforcement ratios has an insignificant effect on maximum load and deflection of tested beams.
5. The maximum deflection of tested beams is increasing when increase compression reinforcement from 0.8% to 1.6% then decreasing at 1.8%.
6. The increasing of shear reinforcement ratios has a non significant effect on maximum load of tested beams, the maximum deflection of tested beams is increasing when increase shear reinforcement ratio from 0.2% to 0.33 then decreasing at 0.4%.

1. RECOMMENDATIONS FOR FUTURE WORK

1. Long term deflection of EAFSS coarse aggregate concrete beam reinforced by GFRB bars should be studied.
2. High density concrete contained EAFSS coarse aggregate and reinforced by GFRB bars prevention and absorption of the nuclear rays must be investigate for shielding purpose.

VI. REFERENCES