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ENVIRONMENTAL PERFORMANCES OF DIFFERENT CARBON AND GLASS FIBRE REINFORCED POLYMER SHEAR STRENGTHENING SOLUTIONS OF LINEAR REINFORCED CONCRETE ELEMENTS

**S.G. MAXINEASA[1] D.N. ISOPESCU[1] I.S. ENTUC[1]
N. TARANU[1] L.M. LUPU[1] I. HUDISTEANU[1]**

Abstract: *It is well-known at this point that the construction sector has a significant environmental impact. From the tremendous quantities of raw materials consumed to the impressive amounts of greenhouse gases released into the atmosphere, the built environment is rapidly increasing the negative influence over the Earth's ecosystem. Therefore, civil engineering specialists should study and promote different solutions characteristic to the construction sector with respect to the environmental dimension of the sustainability concept. One answer to this issue can be represented by the use of fibre reinforced polymer (FRP) materials. The goal of the present paper consists in analysing the opportunity of using different carbon and glass fibre reinforced polymers applied by using the wet lay-up technique for shear strengthening of a linear reinforced concrete (RC) element. By considering the Life Cycle Assessment (LCA) methodology, the study shows that the main environmental advantage of polymeric materials consists in the opportunity of reusing an existing structural element by strengthening it with different FRP solutions. Therefore, composite materials can be regarded as a viable solution for the construction sector's sustainable development.*

Key words: *construction sector, environmental impact, sustainability, FRP, LCA.*

1. Introduction

Within the scientific community, it is now common knowledge that the present consumption rates are unsustainable, endangering the Earth's capacity to provide the necessary resources for future generations. Adding the tremendous amounts of greenhouse gases released into the atmosphere, it can be stated that limiting the

[1] "Gheorghe Asachi" Technical University of Iasi, Faculty of Civil Engineering and Building Services, Department of Civil and Industrial Engineering

negative ecological effects resulted from human daily activities, as well as improving the state of the natural environment represent the biggest challenge for the human race at the beginning of the XXI century [5]. Therefore, all industries should make supplementary efforts in order to analyse and understand the ecological footprint of their products, which is a highly important step that needs to be completed in order to find and implement the correct solution with the goal of minimizing the global environmental impact.

At the global scale, the efforts of implementing the environmental dimension of the sustainability concept are highly influenced by the construction sector. The activities related to this industry are responsible for almost 40% of the global greenhouse gases emissions and for approximately 50% of the consumption of extracted raw materials [1], [4, 5]. Taking into account that in the near future, it is expected that these values will rise at alarming rates, civil engineers should use more solutions specific to this field in order to minimise the impact of the built environment over the natural one.

It is considered that out of all life cycles of a construction, the materials manufacturing phase is responsible for an important environmental footprint. Also, if we are to take into account the significant amounts of materials consumed every year, it can be stated that the environmental performances of the built environment can be improved by considering different solutions in order to decrease the present consumption rates of traditional building materials. It is a fact that among all materials used in this sector, concrete is the most consumed one. The amount of concrete used every year is approximately two times larger than the sum of the quantities of the other traditional construction materials consumed. Thus, it is considered that concrete is the most used product specific to the built environment. In the last six decades, the concrete consumption rates have multiplied by approximately 10 times; presently, around 25 billion tons of concrete are being produced each year [1, 4, 5].

Taking into account all the above, reducing of the volume of concrete can be regarded as a solution for minimizing the construction sector's impact over the environment. The present paper tackles this option by analysing whether fibre reinforced polymer (FRP) materials can be used with the goal of reducing the ecological footprint of the build environment. In order to pursue this aim, various glass and carbon fibre reinforced polymers shear strengthening applications of a linear reinforced concrete (RC) element have been analysed. The evaluation has been undertaken in order to establish if strengthening and reusing an existing RC element that does not provide a certain level of structural safety can lead to a lower environmental impact than that exerted by demolishing the structural element and building a new one.

2. Analysed Case Studies

To achieve the goal of the study, the Life Cycle Assessment (LCA) methodology has been used. As defined by the international standards ISO 14040:2006 and ISO 14044:2006, an LCA study can be used in order to evaluate and interpret the environmental effects of a product during its life cycle [2, 3]. Taking into account that the authors wanted to assess the environmental implications resulted from the preoperation stage of the analysed products, the Cradle-to-Gate with options LCA type of study has been used by considering the following life cycle phases:

- raw material extraction;
- processing of raw materials;
- manufacturing the construction materials;
- transport to the building site;
- construction/assembling phase.

The present study represent a part of a more elaborate study performed during a PhD thesis at the Faculty of Civil Engineering and Building Services, "Gheorghe Asachi" Technical University of Iasi, Romania [6]. The following case studies have been analysed:

- **case study no. 1** – unstrengthened RC linear element cast of C20/25 concrete, with a rectangular cross-section of 100x150mm, and a length of 1200mm (Figure 1a);
- **case study no. 2** – first shear strengthening system made by applying one layer of unidirectional glass fibres fabric by using the wet lay-up technique and epoxy resin (Figure 2b);
- **case study no. 3** – second shear strengthening system made by applying one layer of unidirectional carbon fibres fabric by using the wet lay-up technique and epoxy resin (Figure 3b);
- The structural behaviour of the analysed construction products has been studied at the Faculty of Civil Engineering and Building Services, "Gheorghe Asachi" Technical University of Iasi, Romania.
- The transportation phase was considered in the LCA analyses by using a Euro 5 diesel truck with a 3.3 tons payload capacity, and the transport distances presented in Table 1.
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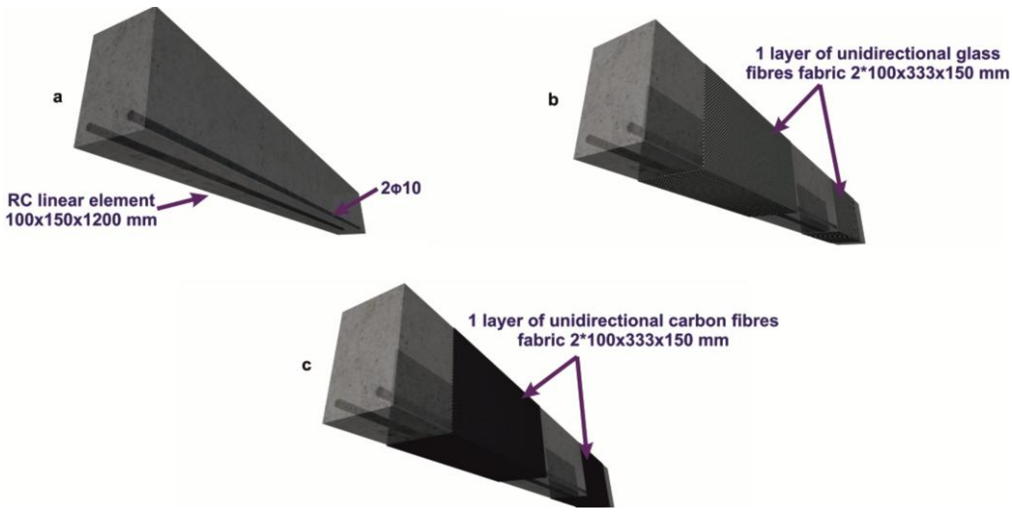

Fig. 1. *Analysed construction products.*
a. case study no.1, b. case study no. 2, c. case study no. 3

In order to quantify the environmental negative effects that are related to the assessed elements, the following impact indicators have been taken into consideration (Table 2):
- Global Warming Potential (GWP);
- Ozone Depletion Potential (ODP).

Transport distances used in the assessment Table 1

Material	**Distance [km]**	**From → To**
Fine aggregate	30	quarry → concrete mixing plan
Coarse aggregate	30	quarry → concrete mixing plan
Cement	165	quarry → concrete mixing plan
Steel reinforcement	25	steel mill → construction site
Concrete	15	concrete mixing plant → construction site
Glass fibres fabrics	1850	manufacturing unit → construction site
Carbon fibres fabrics	1850	manufacturing unit → construction site
Epoxy resin	1850	manufacturing unit → construction site

Environmental impact categories Table 2

Impact category	**Parameter**	**Unit**
Climate Change	Global warming potential (GWP) excluding the biogenic carbon	kg CO_2 equiv.
Ozone depletion	Ozone depletion potential (ODP)	kg. CFC-11 equiv.

2.1. Effects over the natural environment in case study no. 1

The first case study evaluates the environmental impact of the unstrengthened RC element (Figure 1a). In order to analyse this structural component, the amounts of materials presented in Table 3 have been considered.

Quantities of component materials used in case study no.1 Table 3

Impact category	**Quantity [kg]**
Fine aggregates	12.24
Coarse aggregates	22.86
Cement	5.4
Water	2.7
Steel reinforcements	1.73

Figures 2 and 3 present the resulted values describing the environmental impact of the unstrengthened RC linear element. It can be observed that the carbon footprint (Figure 3) of the element is highly influenced by the mixing stage. The amounts of cement and steel reinforcements used also have an important impact in the case of the GWP parameter.

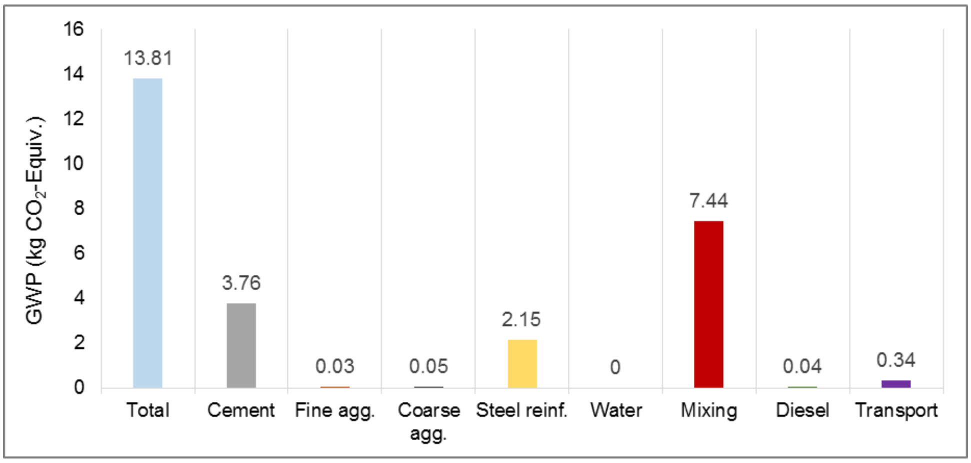

Fig. 2. *Global warming potential in case study no. 1*

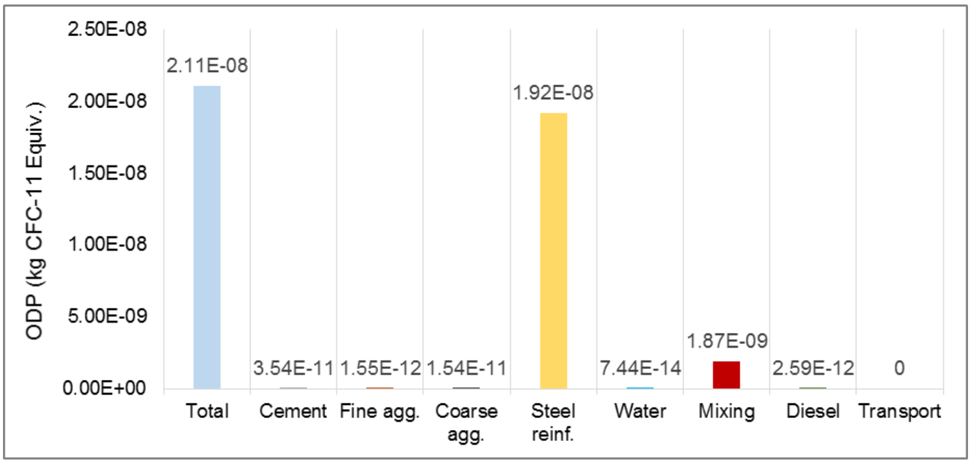

Fig. 3. *Ozone depletion potential in case study no. 1*

In the case of the Ozone Depletion Potential impact category, the volume of steel bars used has the most important influence over the overall result. Also, the mixing stage has a significant effect over the total impact of the element over the stratospheric ozone layer.

2.2. Effects over the natural environment in case study no. 2

The environmental performances of the strengthening made by using glass fibres unidirectional fabrics and epoxy resin are determined in Case study no. 2. The analysis considers the amounts of component materials presented in Table 4.

Analysing Figure 4, it can be observed that the carbon footprint of the assessed shear strengthening system is mostly influenced the amount of epoxy resin used, while the surface preparation works and the glass fibres fabrics have an important effect over the global warming phenomena. In the case of the ODP parameter (Figure 5), the epoxy resin is responsible for almost 99% of the total environmental impact.

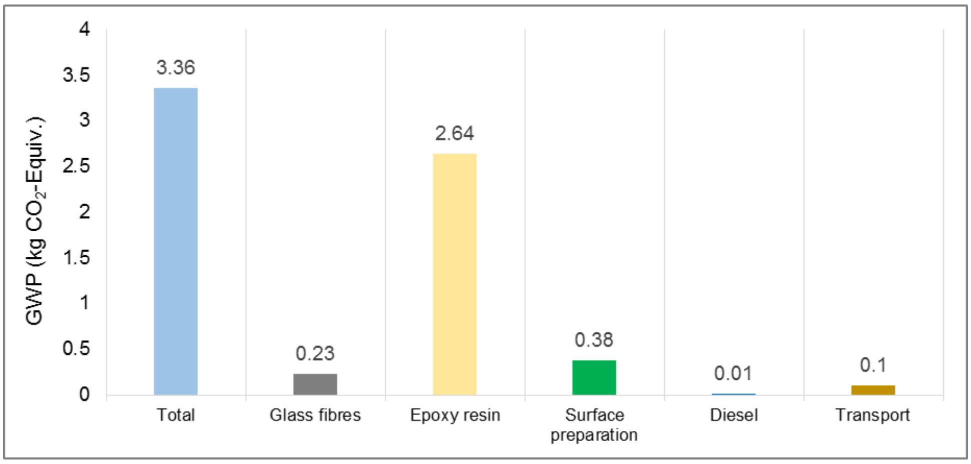

Fig. 4. *Global warming potential in case study no. 2*

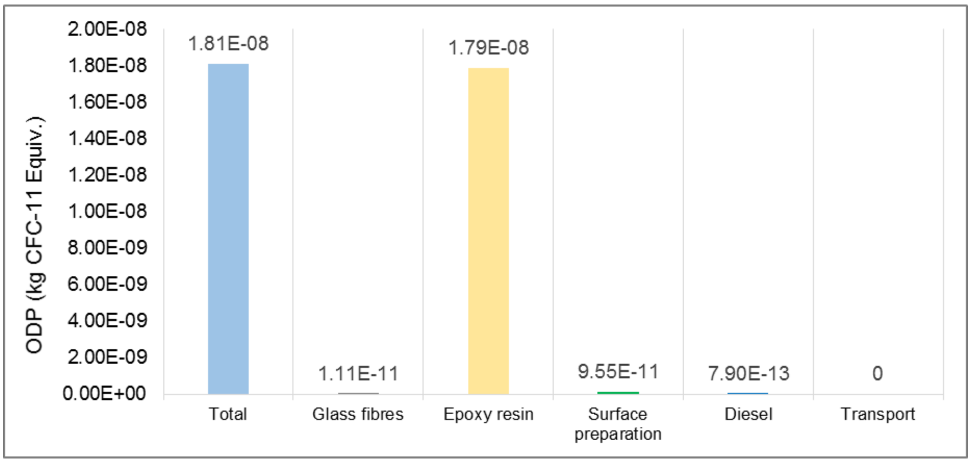

Fig. 5. *Ozone depletion potential in case study no. 2*

Quantities of component materials used in case study no. 2 Table 4

Impact category	**Quantity [kg]**
Glass fibres	0.1146
Epoxy resin	0.32

2.3. Effects over the natural environment in case study no. 3

The last case study determines the environmental impact of the carbon fibres fabrics and the epoxy resin which form the last considered shear strengthening application. Table 5 shows the quantities of component materials used in the LCA evaluation.

Analysing the resulted values, it can be observed that the amount of epoxy resin and carbon fibres consumed has the highest impact over the total carbon footprint of the assessed product (Figure 6). In the case of the GWP parameter, the surface preparation works have an important negative effect. Figure 7 shows that the amount of epoxy resin used is almost solely responsible for the total impact in the case of the ODP environmental indicator.

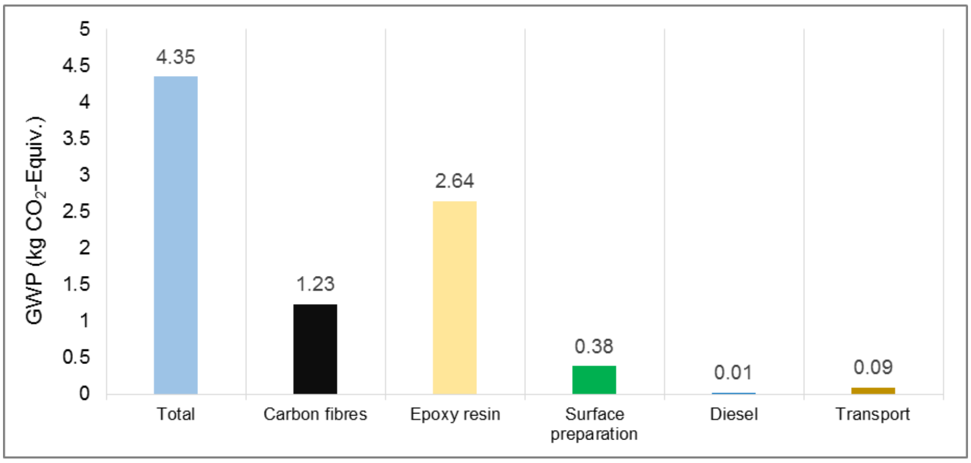

Fig. 6. *Global warming potential in case study no. 3*

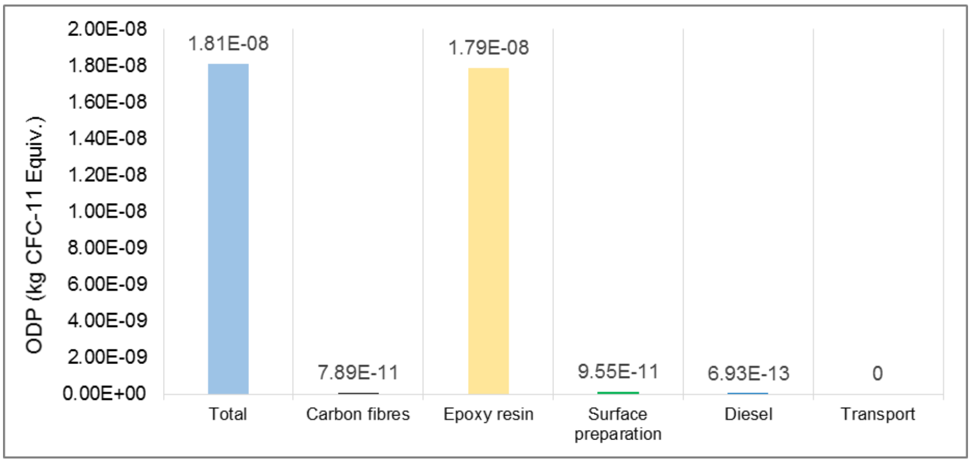

Fig. 7. *Ozone depletion potential in case study no. 3*

Table 5

Quantities of component materials used in case study no.3

Impact category	**Quantity [kg]**
Carbon fibres	0.0613
Epoxy resin	0.32

3. Conclusions

The aim of the present paper is to determine whether strengthening, by using different FRP strengthening applications, and reusing an existing RC linear element can lead to a lower environmental impact than that obtained in the case of demolishing the old element and constructing a new one. Table 6 illustrates a comparison of the values of the total environmental impact of the analysed construction products. As can be seen, the strengthening solution assessed in the second case study (based on using the glass fibres fabrics) represents the most environmentally friendly solution, followed by the FRP application studied in case study no. 3. The unstrengthened RC linear element has the highest impact over the natural environment.

Environmental impact results Table 6

Impact category	**Case study no. 1**	**Case study no. 2**	**Case study no. 3**
GWP [kg CO2-equiv.]	13.81	3.36	4.35
ODP [kg CFC-11 equiv.]	2.11E-08	1.81E-08	1.81E-08

The present paper shows that strengthening and reusing an RC linear element that does not properly satisfy structural conditions can be considered a viable solution with respect to the natural environment. Therefore, FRP materials can have an important role in the efforts of minimizing the environmental footprint of the construction sector, and thus in the global sustainable act.

Acknowledgements

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