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Full Length Research Paper

Design of permanent greenhouse structure by pultruded glass reinforced plastic

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Research activities have been taking on place in many ports of the world to develop or produce new greenhouse construction materials in order to grow more economic agricultural products. One of the new technological materials is the glass fiber reinforced plastic (GFRP) materials. GFRP materials are basically constituted of resin and continuous or chopped fiber and they are manufactured by using various manufacturing methods. The pultrusion process is a proven manufacturing method for obtaining lengths of high quality GFRP and became a competitive alternative to traditional structural materials. Factors in choosing GFRP materials for greenhouse applications are: lightweight, non-corrosive, chemically resistant, possess good fatigue strength, provide electrical and flame resistance. In this study, the structural behavior of the greenhouse structure, which is constructed using pultruded GFRP structural element, has been investigated. The mechanical properties of the pultruded GFRP sections have been computed using national and international standards. The proposed structures have been modeled using well known finite element program (SAP, 2000) to investigate the structural behavior under the static and dynamic loads. The pultruded GFRP box section and three different connection details have also been developed. The advantages and importance of GFRP profiles used in the greenhouse structure have been demonstrated.

Key words: Glass fiber reinforced plastic, greenhouse model, static analysis, dynamic analysis.

INTRODUCTION

One of the most important problems in Turkey is the size of the soil capital to keep the population in rural areas. Greenhouse prevents unemployment by providing more products. In addition, by keeping the population in rural areas is one of the measures to prevent unplanned urbanization (Nedim, 2004). Environmental conditions are not suitable for developing and growing the fresh vegetables and flower cultivation in every season of the year. Controlled environment plant production systems offer the possibility to provide large numbers of high quality crops with greater predictability. Crop quality and predictability can be achieved within efficient, cost-effective structures such as a well-designed greenhouse. The selection of the structural material has a tremendous influence on the crop production capability of the greenhouse system.

In the continuing quest for improved performance of structural materials scientists and engineers strive to produce either improved traditional or completely new materials. Composite materials are an example of the latter category. Within the past five decades there has been a rapid increase in the development of advanced composites incorporating fine fibers, termed fiber reinforced composites. These materials, depending on the matrix used, may be classified as a polymer, metal or ceramic matrix composites. The high cost of metal and ceramic matrix composite prevents their normal use in construction. The majority of composites used in the construction industry are therefore based on polymeric matrix materials. The factors in choosing polymeric composite materials for structural engineering applications are: the materials are lightweight, non-corrosive, chemically resistant, non-magnetic, provide electrical and flame resistance. Material surfaces

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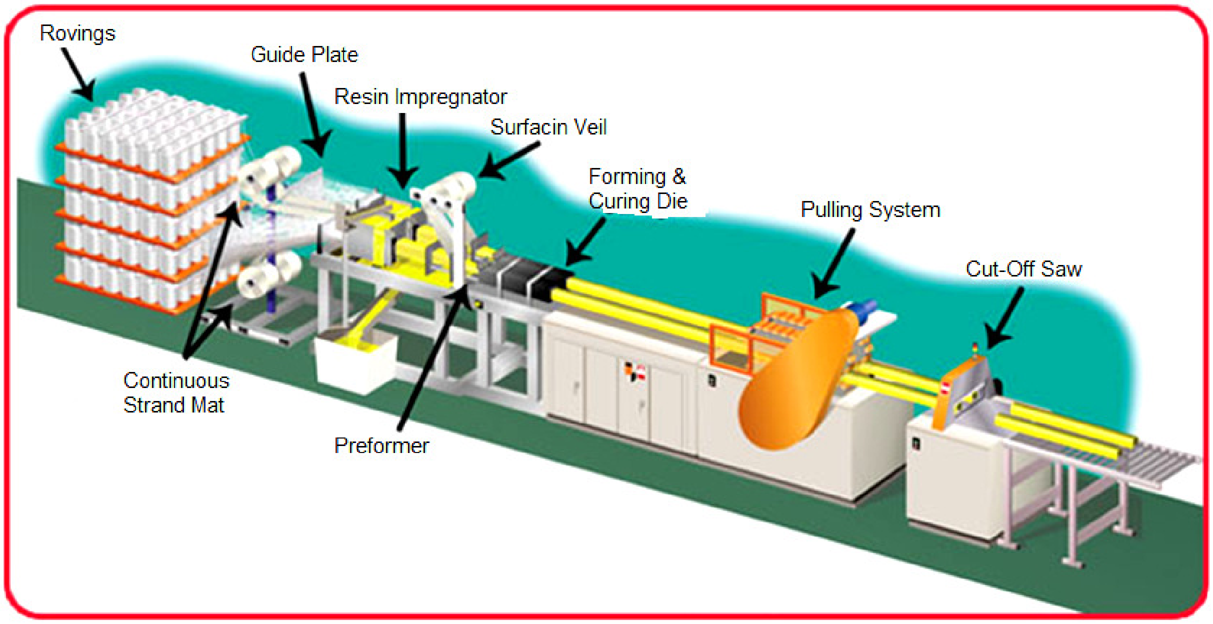

Figure 1. Pultrusion machine configurations (Strongwell, 2010).

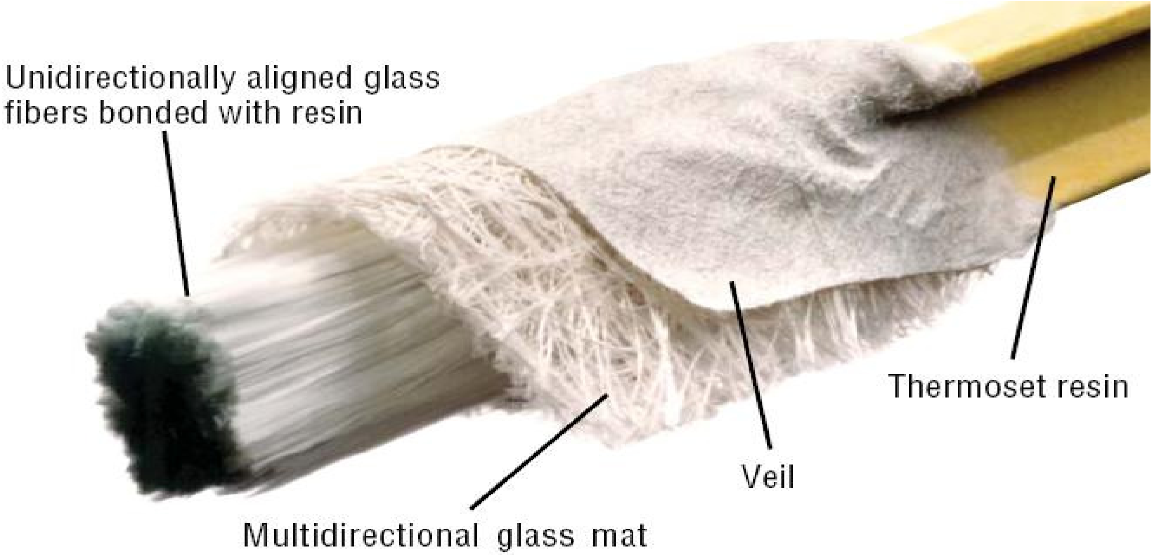

Figure 2. Details of GFRP profile (Strongwell, 2010).

are also durable and require little maintenance (Extren, 1998).

The mechanical performance of glass fiber reinforced plastic (GFRP) materials has been investigated, developed and applied to specific semi-structural applications. However, they have not been widely used as secondary or primary load-bearing structural elements. One historical reason for this is that the finished shapes of GFRP elements are not originally in the form of conventional construction sections, namely beams and columns. This problem has been overcome by the development of the pultrusion technique. The pultrusion process (Figure 1) is a proven manufacturing method for obtaining lengths of high quality fiber reinforced plastic components having consistently repeatable mechanical properties (Werner, 1984).

In this method, a continuous E-glass fiber, which is popular in GFRP composite, reinforcement in the form of alternate layers of randomly oriented mat and layers of unidirectional roving bundles are pulled through a resin impregnator and then on through a heated die to form continuous prismatic members (Figure 2) similar in

Figure 3. Examples of pultruded GFRP profiles (Strongwell. 2010).

geometry to those produced by the steel industry as seen in Figure 3 (Mallick, 1997; Extren, 1998). The pultrusion process allowed GFRP to become a competitive alternative to traditional structural materials (steel, concrete, wood etc.). At the same time it provides a lower specific weight with respect to strength and good environmental resistance.

Having resolved fundamental manufacturing constraints through the development of the pultrusion process, the mass adaptation of GFRP sections as secondary and primary load bearing elements have been achieved (EUROCOMP, 1996) and they are used in a number of civil engineering applications as given in Figure 4 (Strongwell, 2010; Saribiyik and Akgul, 2010). However, pultruded GFRP sections have not been used and applied in greenhouse structures. Therefore, pultruded GFRP greenhouse structure has been modeled and analyzed under dynamic and static loads.

MATERIALS AND METHODS

Mechanical properties

Mechanical properties of the pultruded GFRP section have been determined to use in the numerical model of the greenhouse structure. The anisotropy and in homogeneity of pultruded GFRP material make the characterization of the engineering properties more complex. The material properties of GFRP depend on the

Figure 4. Examples of pultruded GFRP structures (Strongwell, 2010).

Figure 5. Pultruded GFRP tensile coupons with bonded steel tabs and failure modes.

fiber properties, matrix properties, volume fraction of fiber, packing of the fiber, and properties of the interface in the section. The elastic properties of the pultruded box section have been estimated using ASTM D3039 (2006) specimens and the transverse tensile properties have been evaluated using the validated short coupon geometry (Sarıbıyık, 2000; Gosling and Sarıbıyık, 2003).

Longitudinal standard ASTM D3039 coupons (250 × 15 mm) are cut from the box section (Figure 5). Plain rovings (contributing

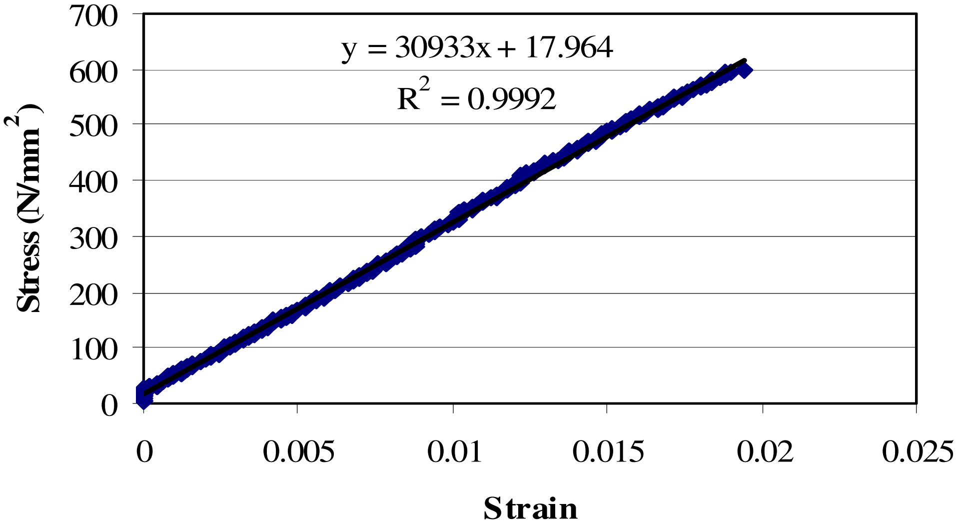

Figure 6. Tensile test specimen of stress-strain curve.

Table 1. Pultruded GFRP material characteristics.

Characteristics	Unit	Value
Unit weight	(g/cm³)	1.75
Specific gravity	(g/cm³)	1.77
Longitudinal elastic modulus	(N/mm²)	29540
Transverse elastic modulus	(N/mm²)	7870
Poisson ratio	($\nu_{x,y,z}$)	0.34
Shear modulus	(N/mm^2)	3210
Longitudinal shear strength	(N/mm^2)	82.8
Transverse shear strength	(N/mm^2)	64.4
Longitudinal tensile strength	(N/mm²)	587
Transverse tensile strength	(N/mm²)	32
Bending strength	(N/mm²)	560

significant to the material properties) are assumed to be parallel to the central axis and subjected to edge effects. Therefore, the longitudinal specimens are extracted parallel to the member axis and remote from the edges of the box. Metal tabs (1 × 15 × 50 mm dimensions) are bonded to the gripping areas with Araldite. Coupons are cut in the orthogonal direction to establish the transverse material properties. Axial tensile load has been applied to the coupons at a rate of 2 mm/min (Mallick, 1997) using self-clamping jaws with rotational freedom about two axes. The load/strain data are recorded using an electronic data acquisition system at a rate of one reading per second. All coupons have been loaded to failure enabling a determination of tensile strength.

From the test record of each specimen, the elastic modulus has been calculated (Figure 6). The mean longitudinal elastic modulus is obtained as 29540 N/mm^2. The mean value of strength has been determined as 587 N/mm^2. The metal tabs prevented gripping damage to the specimen as expected when using the standard test method (Mallick, 1997). The mean value of the Poisson ratio is obtained as 0.34. The mean value of strength has been determined as 587 N/mm^2. Transverse samples of the pultruded GFRP section have been tested to determine the transverse elastic properties. The mean transverse elastic modulus is determined as 7870 N/mm^2. All the specimens failed in the gauge area as shown in Figure 5. The transverse strength of the box section has been determined as 32 N/mm^2.

Analysis and applications

The GFRP material properties required for the modeling of the greenhouse have been obtained from the experimental studies and summarized in Table 1. Shear properties were taken from literature (Javed, 2003). Finite element software package SAP 2000 is used to determine the structural behavior of greenhouse structure under the dynamic and static loading conditions. All the connection points are assumed to be rigid and the loads were applied to the pultruded GFRP structures as a combination in the software. Cross-sectional and perspective views of the application plans are given in Figures 7 to 9.

RESULTS AND DISCUSSION

The greenhouse structural elements are computed using

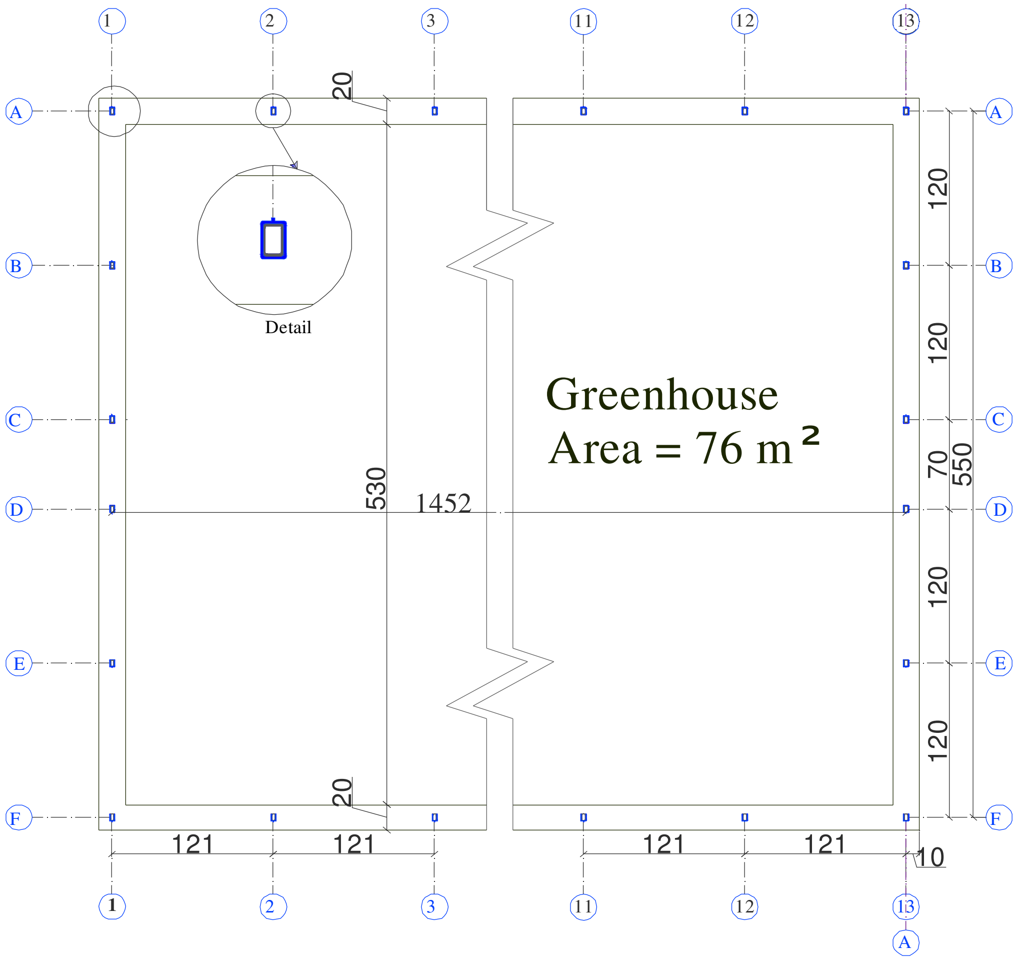

Figure 7. GFRP Greenhouse application model (dimensions are cm).

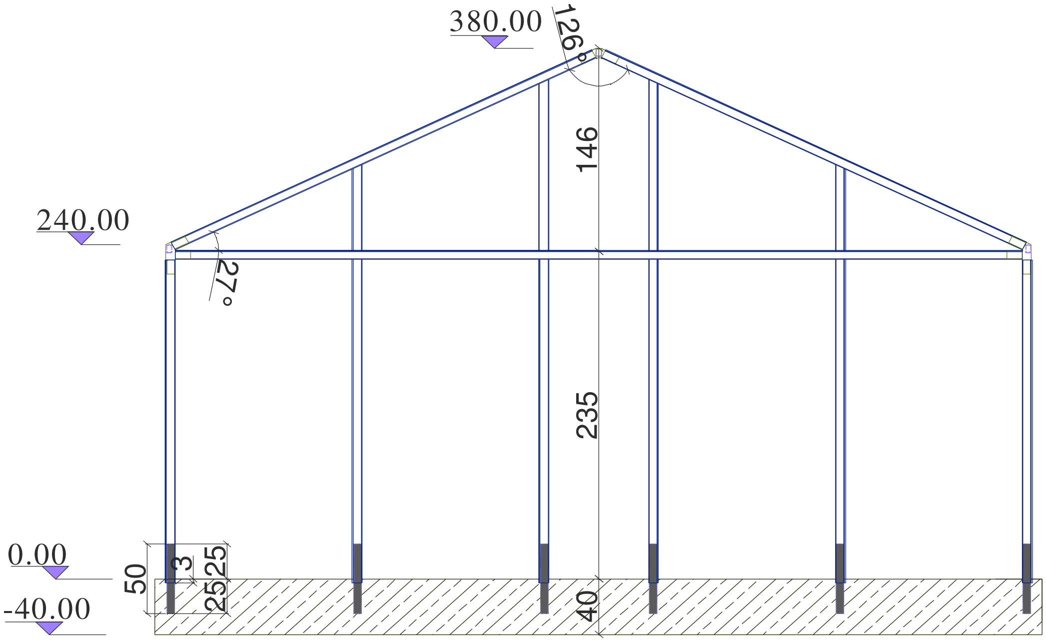

Figure 8. GFRP greenhouse application model A-A section(dimensions are cm).

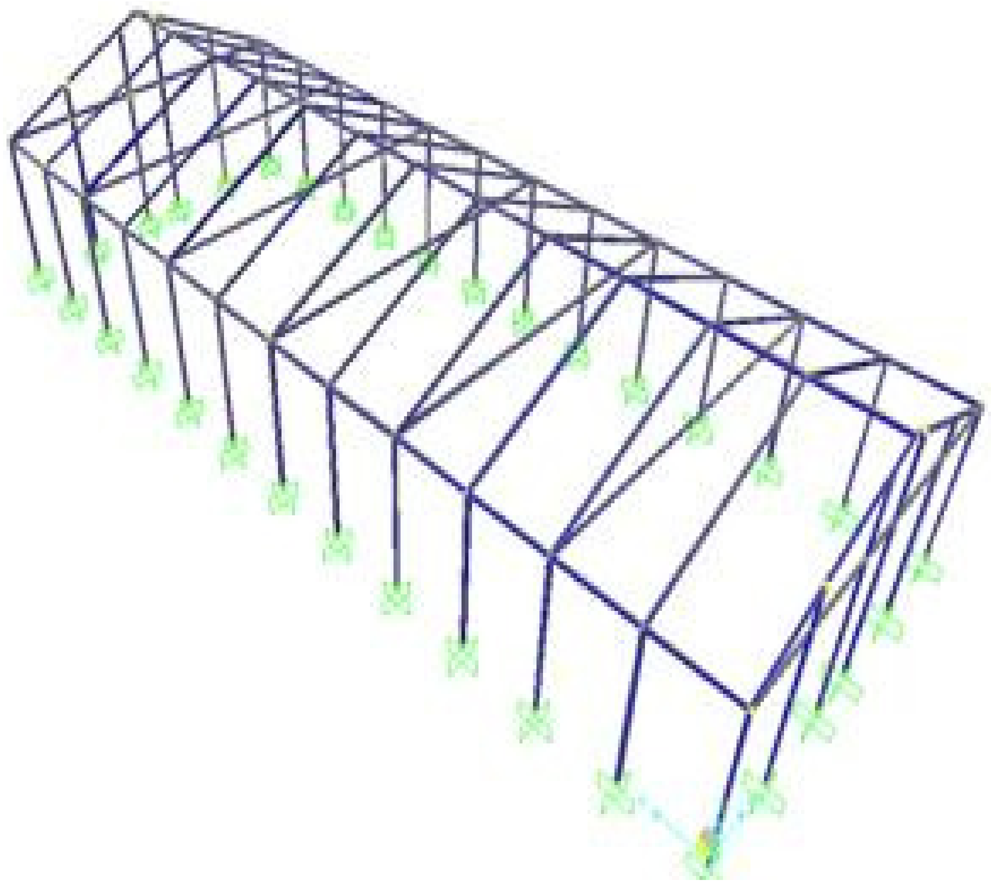

Figure 9. Perspective of GFRP greenhouse application model.

SAP 2000 finite element analysis. The elements behaviors under dynamic and static loads are determined. The maximum tensile and compressive strength of 105 N/mm^2, shear strength of 4.6 N/mm^2 and bending strength of 88 N/mm^2 are found. The results are compared with the materials characteristics given in Table 1. All the results are found to be under the limit values. Therefore, the Greenhouse model is constructed to the land of Sakarya University, Pamukova Vocational High School. In this region the agricultural land is fertile, processing area is close and the climate conditions are suitable for greenhouse structures.

Ease of installation technique and assembly details are developed. GFRP box profile in application is selected as steel box profiles available in the industry. Therefore, GFRP box profiles (Figure 10) are connected using steel connector on the roof (Figure 11) and on the end of the column (Figure 12) parts of the GFRP structure.

CONCLUSION AND RECOMMENDATIONS

Pultruded GFRP structural elements are used as column and beam in the greenhouse construction design. Determined mechanical properties were used to model structural system using SAP 2000 finite element software package. The material behaviors under dynamic and static loads are determined. According to this:

(i) The longitudinal elastic modulus is obtained as 29540 N/mm^2, strength is determined as 587 N/mm^2 and Poisson ratio is obtained as 0.34. The transverse elastic modulus is determined as 7870 N/mm^2 and strength of the box section is determined as 32 N/mm^2. All the specimens failed in the gauge area as required in test standard.

(ii) Greenhouse structural elements are examined under the maximum dynamic and static load combinations. The maximum tensile and compressive strength of 105 N/mm^2 and bending strength of 88 N/mm^2 are found. The results are under the limit material charecteristics of GFRP.

(iii) The shear strength of greenhouse structural elements, specially columns, is determined as 4.6 N/mm^2. Applied shear force could be reduced because of the less density of the pultruded GFRP.

(iv) GFRP profiles have significant advantages in permanent greenhouse construction, including its lightweight, non-corrosive, chemically resistant, resistant to moisture, easy assembly, high benefit/cost ratio.

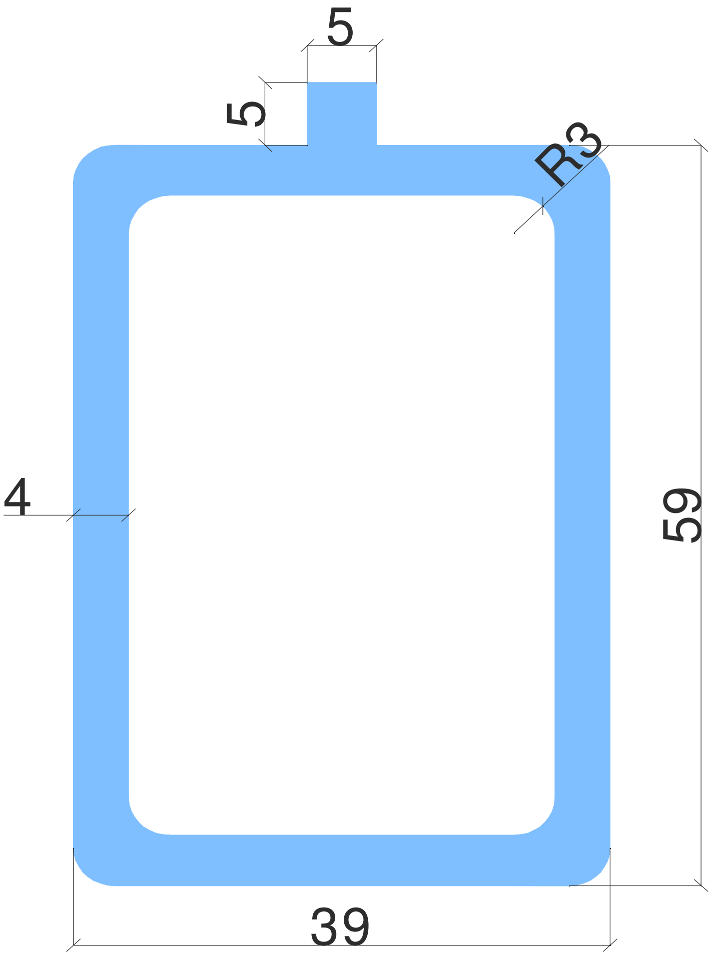

Figure 10. Details of the GFRP profile (dimensions are mm).

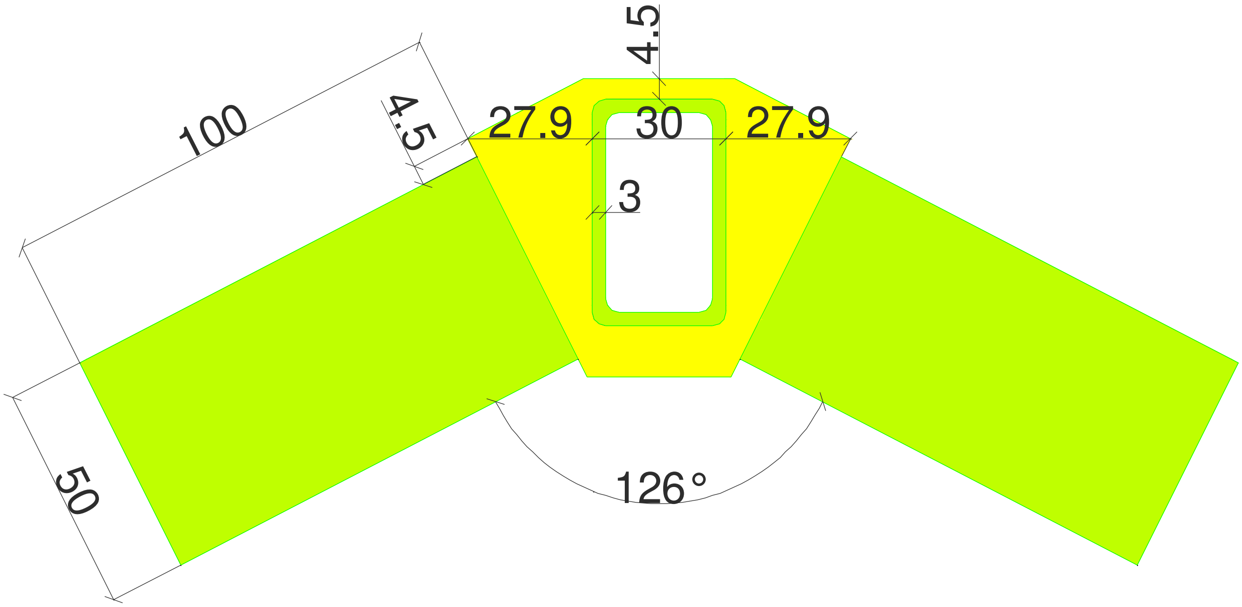

Figure 11. Connection element on the roof (dimensions are mm).

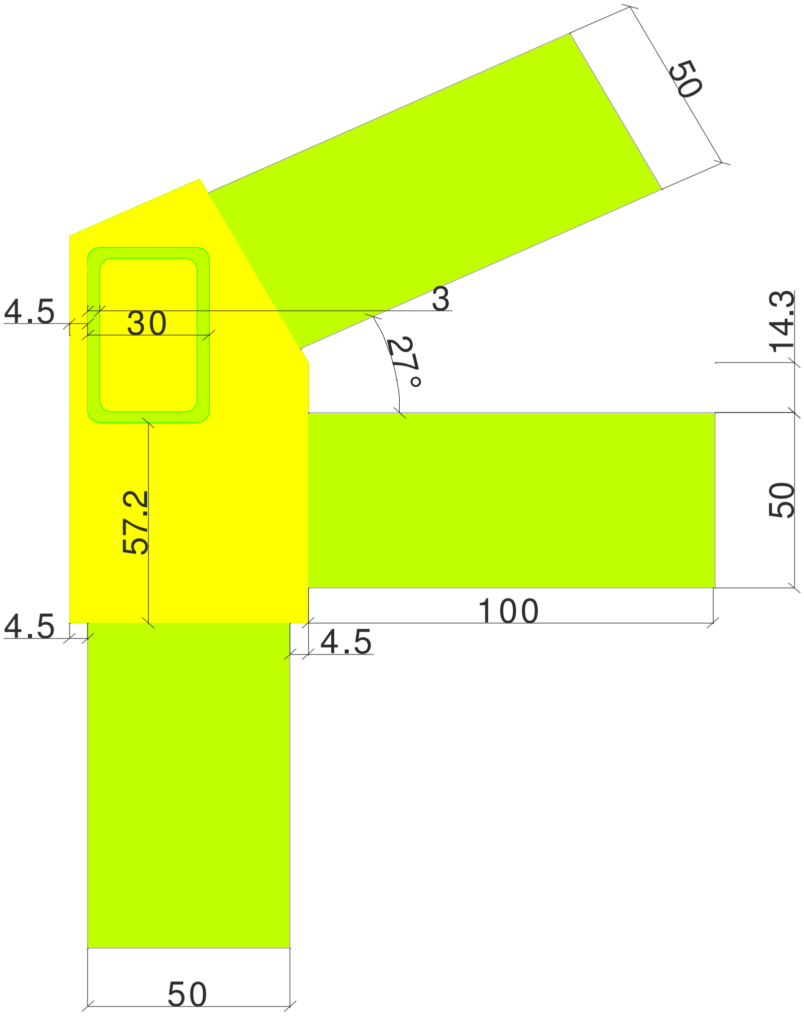

Figure 12. Connection element at column-beam joint (Dimensions are mm).

Therefore, the pultruded GFRP materials are strongly recommended to be used in the permanent greenhouse construction.

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