Composite Materials for Greenhouse Applications

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This paper presents new composite materials used in extension of growth season of vegetable crops, in countries with a mild continental transition climate, for constructions type tunnel. Composite materials are realized from two components, namely textile materials with generated heat potential and polyethylene polymer foils, with a selection possibility of wave lengths in IR domain. For insurance of microclimate conditions, especially of thermal performance, the materials have been tested from electrical and mechanical point of views, following the generated heat flux and its elastic deformations for a known material width.

Keywords: tunnel, horticultural crops, composite materials

Vegetable crops in protected spaces represent a production sector with a high degree of intensity and production possibilities a lot higher than field vegetable crops. Choice of construction materials for the purpose of ensuring of a microclimate with controlled parameters represents one of the most important problems for creation of systems of durable, economical, forced vegetable cultures. The materials used in special constructions type greenhouse must ensure certain microclimate parameters, being designed according to the specific requirements of plants, such as temperature, light intensity, solar radiation and humidity [1-4]. The most used materials are:

- type glass and polymeric foils with selection possibility of certain wave lengths needed in the development process of plants and B) composite textile materials that can be obtained through weaving, knitting, in an alloy with plastics, glass or polymeric foils [5-7].

- a large ampleness in all vegetable producer countries is represented by usage of polymeric foils obtaining essential modification in technological process. The polyethylene foils replace successfully glass in solaria. They are more resistant to mechanical factors because of their flexibility, having the possibility of selective transmission of solar radiation and allow accomplishment of some complex and economical types of solarium. The synthesis of new additives able to improve the transmission of light and create the necessary microclimate for agricultural cultures in solaria covered with polymeric foils, has allowed extension of fields where protected agriculture can be practiced. The role of these additives is to select only certain wave lengths from solar light, needed for development of plants. The main advantages are productiveness and reduction of used agrochemicals [8, 9]. The visible domain spectrum contains radiations with wave lengths from the domain of 480-700 nm. Because of climatic and environment modifications with implications on ozone layer thickness the quantity of UV radiations is present in a lot higher ponderosity.

At the passing of electromagnetic waves specific to visible domain and UV through a transparent material type polymeric foils, the radiations change frequency by diminishing it, resulting an increase of wave length. Practically, the visible and UV radiations become infrared radiations with a thermal effect as high as the wave length. Foils for solaria covers allow and prevent selectively, the energy transfers between inside and outside of solarium, leading to a greenhouse effect. To retain a maximum of heat inside the solarium, the ideal foil should present maxim transmission of solar radiation and especially from IR domain, close and average that allows the air inside solarium to stay hot all day. Heat maintaining is being accomplished through the choice of certain additives of selective light transmission that will be incorporated in the polyethylene polymeric matrix [10, 11]. At the moment, following the last research, is well established what domains of solar spectrum influence positively or negatively, directly, the growth and development of plants. For this is recommended the visible radiation, of different wave lengths, between 380-760nm. So, the radiation with wave length of 440-475nm from red domain of solar spectrum determines plant elongation, and radiations from blue domain help at hormones development that balance phototropism. It has been observed, that generally, the main pigments from plants leaves: chlorophyll a, b, c and d, carotene, absorb radiations with wave length of 395-685nm, so a larger interval from violet-green to red-orange [9, 12-15].

- technical textile materials have known a spectacular development in the past decades, being used currently in all domains. Extension of usage domains and growth of performance level of technical textiles has lead to increase of their ponderosity in total volume of textile production in countries with developed economy. Composite textile materials represent a series of products perceived as a challenge to traditional concepts regarding to the role of technical textile materials, processes and products. In an

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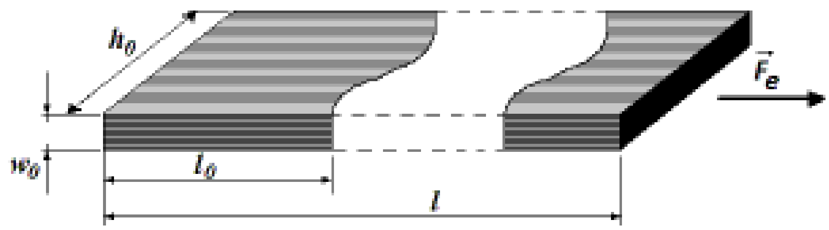

Fig.1. The phenomenon of deformation of the material under a force

increasing manner, is created the premise that composite textile materials used in agriculture find their place in a broader industry and a market for flexible engineering materials [16].

This paper presents new composite textile materials used in horticulture for extension of growth season for vegetable crops, designed as the prototype. These materials aim achieving fundamental functions in microclimate creation through insurance of a high level of technical and functional parameters described through indicators of temperature, humidity and solar radiation.

Experimental part

Structure of proposed composite materials in extension of growth season of vegetable crops for countries with a mild continental transition climate

Composite materials presented in this paper can be used for single greenhouses type tunnel for vegetable crops following the insurance of microclimate conditions through two components that make the composite material: knitted textile material that has the controlled heating capacity (a) and polymeric foil with possibility of selection of certain wave lengths needed in the process of plants development(b).

a. The textile materials have been created on flat knitting machines Shima Seiki, of gauge 10 E, using as raw material polypropylene monofilament yarns of fineness 286 dtex and with interlock knit structure with filling yarn. Polypropylene yarns have been obtained through incorporation of thermal additives improving thermal and mechanical properties, with the following characteristics: work temperature 85°C, maxim work temperature 150°C. In interlock knit structure have been introduced electrical conductive filling yarns made of Nichrome, Kanthal, Manganin, copper with purpose of heat generation.

b. In the technological process of obtaining foils from olefin polymers, there have been used for delay of thermo-oxidation and prolongation of usage duration, stabilizers type antioxidant and light stabilizers. Choice of stabilizers for polymeric foils used in constructions type solarium and tunnel must concord to degradation mechanisms, namely thermo - oxidative degradation. Thermo – oxidative degradation of polymeric foils and also their ageing represent complex phenomenon where contribute a myriad of factors such as temperature, exposure time to destructive agents actions. Foils made of low density polyethylene, obtained through technology of extrusion laminating, that have incorporated additives with role of selective light transmission in IR domain have been applied through thermo-adhesion on the knitted material presented in section a).

Results and discussions

Mechanical measurements

In the exploiting process, the composite material is degraded, phomenum known as “ageing”, because of a complex of mechanical, physical and chemical factors that act both from outside and inside. Operation of frequency, wind and hail action leads to a mechanical degradation represented by fissures, orifices and loss of flexibility. Materials are described from a mechanical point of view, with a myriad of properties determined in static or dynamic conditions such as elasticity and formability, resistance to break and elongation, resilience and resistance to strain.

If a material is under the action of an outside force and does not broke immediately, but takes over that force, changing its form and linear dimension, but maintains the same volume, we can say that this material is bending. As we can see from figure 1, if after the clearing out of force, the material gains its previous form we can say that it has suffered an elastic temporary deformation that has taken place only during force action. The material deformation phenomenon under the action of a force is presented in figure 1. So, the materials property of elastic deformation under action of an outside force is called elasticity according to Hook’s law of proportional relation between elastic force and relative elongation. According to the model presented in this subchapter we can establish the variation of elastic force and relative elongation in the proportionality interval for elastic deformation, for proposed composite material.

Determining the Young’s modulus for the composite material

The composite material obtained through thermo-adhesion of two components has been subject to break with a constant deformation gradient, being deformed gradually until the moment of breaking down. Tests have been realised on the electronic dynamometer Instron 3345, according to SR EN ISO 527-2/1996, resulting the stress – strain diagram (fig. 2).

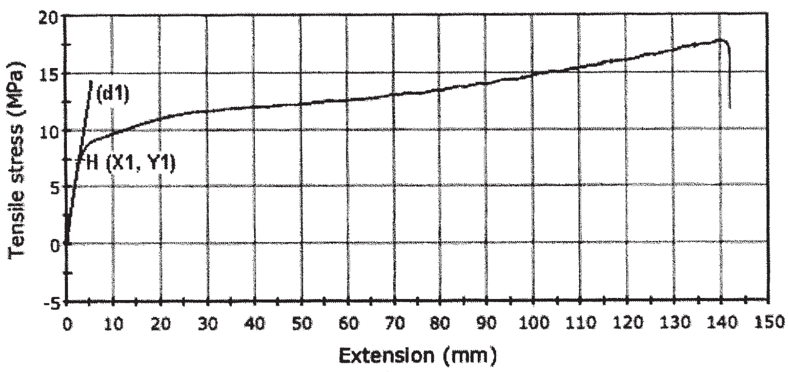

Fig. 2. Stress -strain diagram of composite material

The tested samples dimensions are:

l_o = 0.1m (100mm);
h_o =0.04m (40mm); (1)
w_o = 0.0025m (2.5mm)

where:

l_o = initial sample length,
h_o = sample width;
l_w = sample depth;

From figure 1 there can be established the following relations:

$$S = h_0 \cdot w_0 \quad (2)$$

where: S= cross section:

$$\varepsilon_r = \Delta l / l_0 = (l - l_0)/l_0; \quad (3)$$

where:

ε_r = relative elongation;
l = sample length under action of force F_e;
F_e = elastic force;

OH zone described by stress - strain diagram (fig. 2.) is a line segment and represents the proportionality Young where, point $H(x_1,y_1)$ represents the end of the proportionality Young area. Line (d1) described by segment OH goes through origin O of axes and can be described by equation:

$$y = m_1 x \quad (4)$$

where: $m_1>0$ represents the line decline ($m_1=tg(\alpha_1)$, where α_1= <(xOH) – angle made by line (d1) with axe, Ox.

For OH section from diagram we can define:

$$f_1(x) = p \cdot x \quad (5)$$

with $x \in [0; x_1]$ and $p \in \Re, p > 0$

Point $H(x_1, y_1)$ determines inclination:

$$p = y_1 / x_1 \quad (6)$$

According to equations (3), (5), (6), on this interval, the elastic force is:

$$F_e|_{OH} = f_1(\varepsilon_r) = (y_1/x_1) \cdot \varepsilon_r \quad (7)$$

In this area of stress -strain diagram, acts Hook's law described through equation :

$$\Delta l / l_0 = (1/E) \cdot (F_e / S) \quad (8)$$

We can emphasize the formula of elasticity module of Young, for the composite material described through equation:

$$E = p/(h_0 \cdot w_o) = (1/(h_0 . w_0)) \cdot (y_1/x_1), \quad (9)$$

for: h_o= 0.04m (40mm); w_o = 0.0025 m (2.5mm); H(4, 7.5) we have E = 0.018

In design of composite materials used in applications type tunnel, for horticultural crops, the thickness of material influences directly the wave length that passes through it. So, through this model we can calculate elasticity module, respective designed material deformation for a given thickness.

Electrical measurements - Assessment of thermal flux generated by composite materials

In order to test the heating properties of the materials a measurement system was developed. A personal computer is controlling the system using two USB ports (USB0 and USB1). First USB port is used to command a programmable power supply. This device is a EA-PSI 6032 device and can generate up to 32Volts and 3Amps. The electrical heating wire is connected to the output of the power supply. This is the "power circuit" of the system. Two temperature transducers (TS1 and TS2) are fixed within the heating conductor in order to measure the real wire-temperature. These sensors are AD590 type and they are integrated circuit temperature transducer that produces an output current proportional to absolute temperature. The temperature range is large (-55 to 150°C) and the output current is linear (1μA/°C). A data acquisition board is used to measure the temperature sensors signals. This board is a National Instruments bus-powered M series multifunction board for USB and has up to 400kS/s and up to 32 Analog Inputs. Secondary USB port of the computer is connected with the DAQ board.

The system uses two temperature sensors because we needed the confirmation that the electrical wire is heated uniformly and the material texture has no influences in this. In the measurement results only one temperature is presented because these tow sensors indicated very closed values of temperature.

Four types of electrical heating conductor were tested: kanthal, nichrome, manganin and copper. These tests are performed just to observe how the heating textile materials acts, for further tests and implementation only dedicated heating material (as kanthal, nichrome or cupro-nickel alloys) will be used. Figure 3 presents the measurement results for tested conductors. In all cases the textile materials maintain their physical properties (dimension, elasticity and shape) even the higher temperature was around 145°C.

The above results show that three conductors can be heated up over 120°C. The difference in supplying power values are because of the electrical resistance of conductors (0.86Ω for copper, 33.33Ω for manganin and 80Ω for kanthal). The low resistance of copper imposes

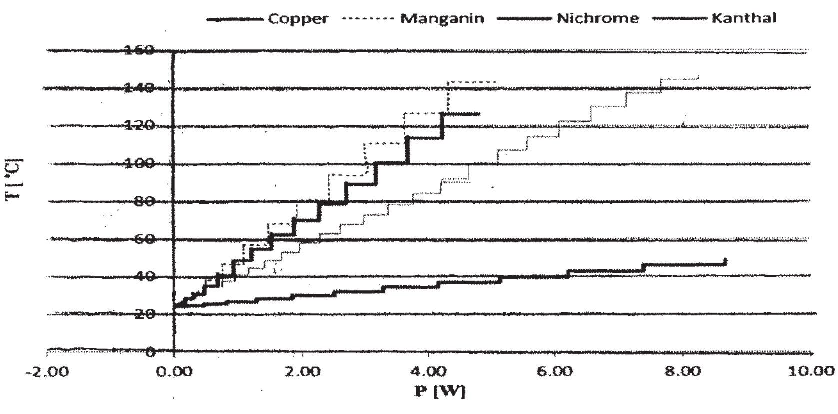

Fig. 3. Temperature vs. absorbed power of heating materials

greater supply power but at lower voltage values. The high temperature (160°C) was achieved with a voltage of 3V and 3.16A current. In case of manganin because of a greater value of resistance, the same temperature was achieved with 13V and 0.39A.

Heating system testing

A small greenhouse (scale 15:1) was designed to test the heating capability of the electro-conductive textile material. The measurement system used to test the material was improved by adding one more temperature sensor. A picture of the system is presented in figure 4.

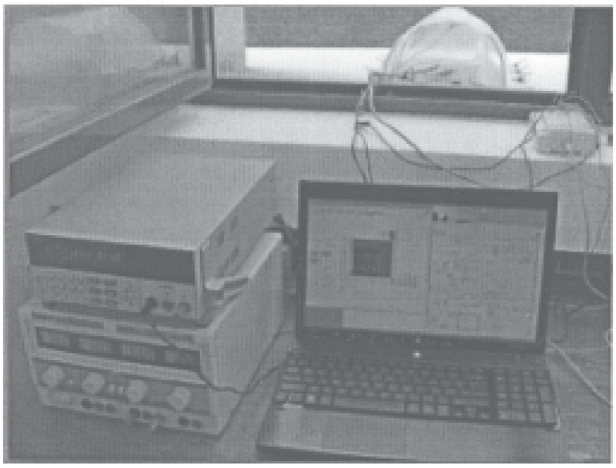

Fig. 4. Heating system testing in case of a miniature greenhouse (scale 15:1)

In this case three temperature sensors are used. One sensor measures the temperature below the textile material; one sensor measures the temperature above the textile material, at the top limit of the greenhouse and the third sensor measures the electrical wire temperature.

The wires were powered with different currents in order to see how the above and the below temperatures changes. The tests were performed in December, 2012 and the outdoor temperature during the tests was -1…0°C. In figure 5 TEMP1 is the outdoor temperature, TEMP2 is the temperature below the textile material and TEMP3 is the electrical wire temperature. This picture presents the heating process of the greenhouse ambient as an effect of the electrical wire heating. It can be observed that in few minutes the ambient temperature can grow with few degrees. For example if the wire is heated up to 23°C the ambient temperature is increasing from -1 to 2°C in approximately 3 min.

In figure 6 TEMP1 is the temperature below the textile material, TEMP2 is the temperature above the textile material and TEMP3 is the electrical wire temperature. In this picture the heating "quantity" is presented. It can be observed that the ambient temperature is not the same below the textile material and above. For example, if the wire is heated up to 100°C the ambient temperature increases with a value of 5°C in 8-9 min.

Conclusions

In countries with mild continental transition climate, the development of new materials for special constructions type greenhouses and tunnels is essential in development of organic production of vegetable crops. The proposed composite materials have been realized so they can improve the temperature conditions from microclimate by:

- greenhouse effect generation using polymeric foils with selection transmission of solar radiation. The second component of composite material, the polymeric foil with possibility of selection of certain wave lengths contributes to thermal performance by greenhouse effect. Greenhouse effect is the physical phenomenon that characterizes the role of transparent object of different materials used at tunnels and greenhouses covers. A transparent material in visible and infrared domain close to solar radiation allows the radiant radiation from sun and limits the loss of same radiation in outside environment;

-by heat flux generated by textile material;

To ensure the exchange of gas between proposed microclimate and environment regarding carbon dioxide and oxygen, on the length of composite material there are areas where the polymeric foil has not been applied through thermo-adhesion, permeability to air through textile materials being comprised in the interval 49- 55(m^3/ min . m^2).

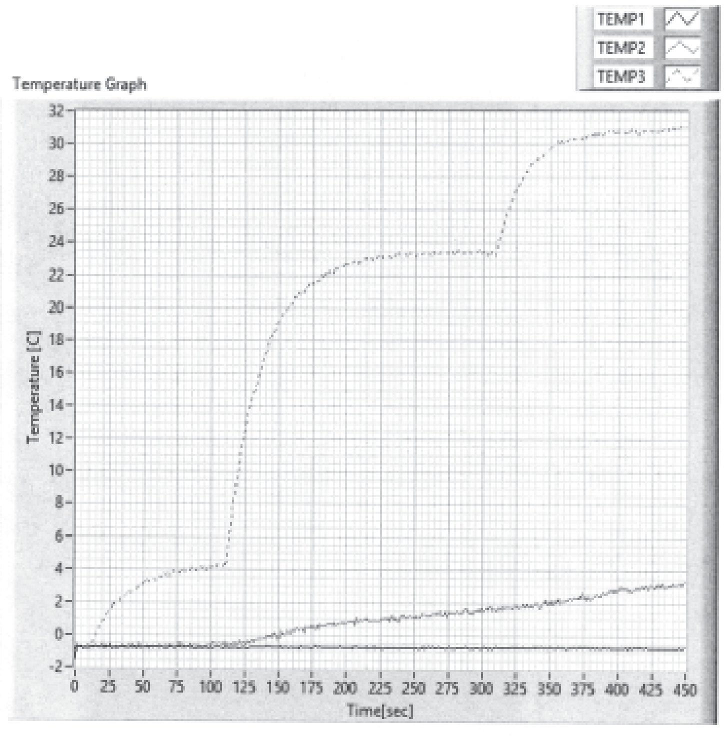

Fig. 5. Heating the ambient

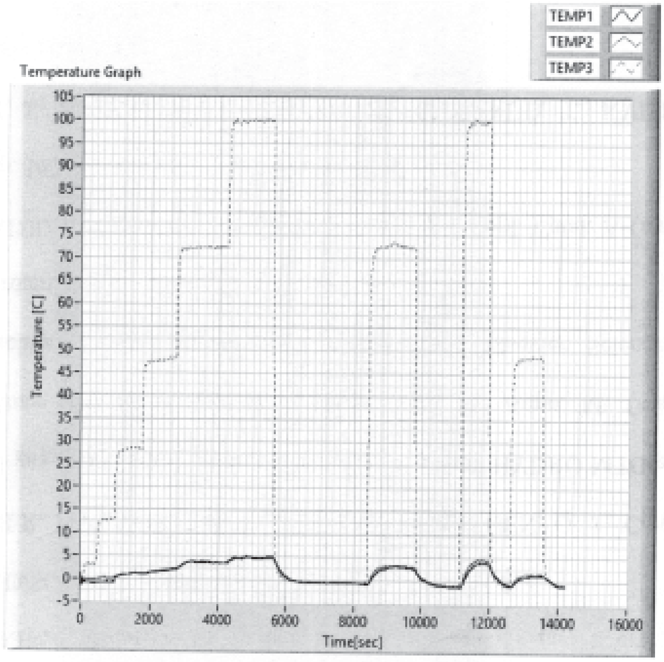

Fig. 6. Different heating processes

The establishment of elastic deformations by action of outside forces through described mathematical model contributes to a functional design of composite materials for applications in constructions type tunnel. So, the base element offered by model is represented by the link between material rigidity (elasticity module) and composite material width that is desired to be realized for applications type greenhouse and tunnel.

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