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Experimental Methods for the Analysis of Composites Materials Containing Textile

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Abstract

An important category of materials used to obtain a composite material is represented both by fibers and textiles. Yarns, weaves, knitted fabrics, are some of the textile products summarized in this paper. Laminated composite materials have properties that depend on the fiber strength of each layer and on the material's number of layers as a whole. There are many experimental methods that can be used for the analysis of these materials, among which we will study the conditioning of materials and the thermal and conductive properties of textile panels.

Key words: *composite, layer, yarn, weave, knitted fabric.*

Introduction

Composites materials are materials with anisotropic properties, consisting of several components, whose organization and development characteristics allow use of the best parts. From a technical standpoint, the term refers to composite materials possessing the following properties:
• are created artificially by combining different ingredients;
• are a combination of at least two chemically outstanding materials, which have a distinctive boundary;
• the properties of any component that can not be considered separately.

A major advantage of the composites is the fact that they are essential for the modulation properties and thus making possible the obtaining of a wide variety of materials, with applications in almost all fields of technical activity [1].

The ongoing developments registered in the textile sector, such as the discovery of new fibers: new materials to ensure adequate absorption of heat - made of PET fiber are dispersed microparticles of cesium, tungsten and oxygen (the last revelation of the Japanese company Sumitomo Metal Mining), fiber behavior improved by noble with silver, or nanoparticles or new construction insulation materials made of nonwoven materials as wallpapers Klima Tec Pro KV 600, made by German company Erfurt, which applied to the cold walls can reduce heating costs by 75% and new processing technologies, have led to the elaboration of new high performance composite materials, used mainly in the form of laminated plates.

By using the classic and consolidated textile technologies, such as weaving, knitting, sewing, braiding, obtaining nonwoven fabrics; layers of material are obtained, with an architecture in which fiber orientation can be in any direction, not only plan – figure 1. Due to the nature of the three-dimensional fibers, the architecture of the structures obtained is less exposed to delamination, therefore the impact resistance increases significantly [2]. In general, the mechanical properties of composite materials are mainly determined by three factors: the properties of fiber, matrix and interface, the fiber content and the fiber orientation distribution. For woven and braided fabrics, the position of the fibre at every point can be calculated with only a few geometrical parameters of the textile as an input [3].

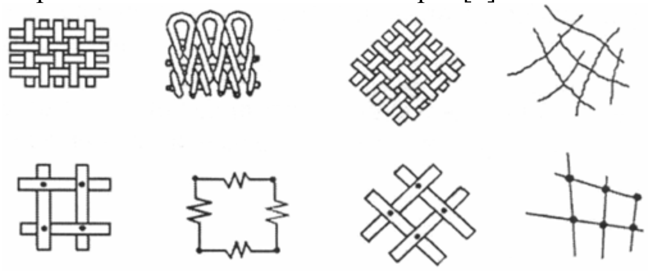


Fig. 1. Type of textile structures: weave fabric, knit, braid, nonwoven fabric

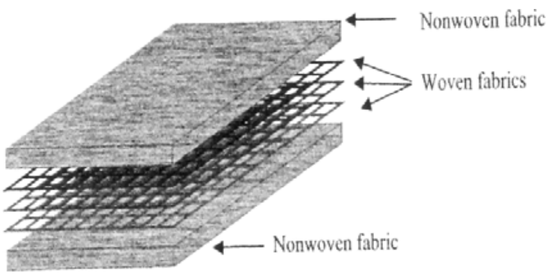


Fig. 2.

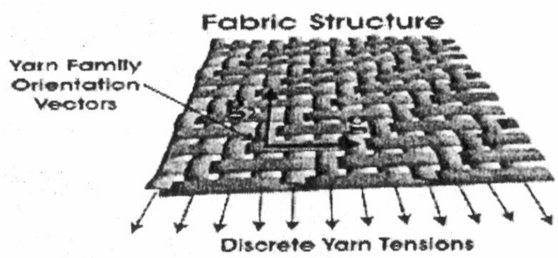


Fig. 3.

Such a geometrical calculation of the fibre position in a knitted fabric is not easy to accomplish. The aim of study was to show how orientation tensors – figure 3, can be used in the analysis of knitted fabric composites. This on-axis orientation was used in the evaluation of tensile test data. With respect to quantitative predictions, the use of orientation tensors simplifies the calculation of the Voigt/Reuss elastic model greatly [4].

In particular knitted products with a 3D geometry offer an alternative to laminated plates, the great deformability, the possibility of ventilation - air permeability and a low price. The rhombic and hexagonal variants have been studied as geometric shapes for the 3D knited fabric, the yarn type used being the monofilament PET. Additional yarns have been used, to ensure contact between the layers [5].

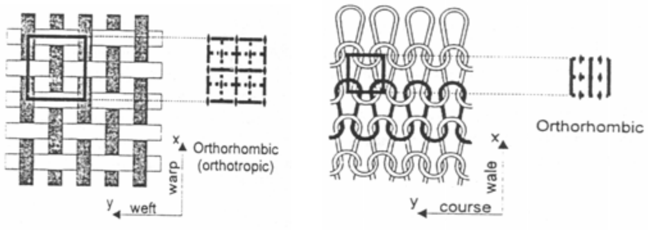
Weaving

The process of weaving involves crossing of two systems of yarns called warp - located along the fabric and weft - located across the fabric, at right angles - figure 4. a [6].

Current weaving processes have been adapted and new processes were developed to produce multilayer with the appropriate yarn architectures, structurally efficient and cost effective composites structures.

An experimental program has been designed to characterize the mechanical properties, failure modes and mechanisms of such structures, to produce design data and to validate the various models. The emphasis has been on the design and production of multilayer woven composites where the warp and the weft yarns are straight and uniformly distributed to minimize resin-rich areas. These yarns are held together by relatively thin binders inserted in either the warp or the weft direction.

The final architecture of the composite is dependent both upon the initial yarns geometry adopted during weaving and also upon the effect of downstream manufacturing stages. An optimal binder path length was sufficient to reduce crimping to an acceptable level. It was also found that an existent weft binder "locking length" can determine warp crimping. This depends on warp tension, warp density, yarn bending stiffness and the coefficient of friction between the warp and weft yarns [2].



a. b.

Fig. 4. Fabrics: a – weave; b - knit

Knitting

Knitted fabric is a textile product that is obtained by successive or simultaneous looping of one or more systems of yarns, process after which a mesh is obtained, which is horizontally organized in rows and vertically in strings – figure 4. b [6].

Among the various textile processes, yarn knitting is ideally suited to the manufacture of components with complex shapes. The use of advanced knitting machines allows the production of near net-shape fabrics that can then be formed into the composite component by a liquid molding technique. The use of near net-shape fabrics has the advantages of minimum material wastage and a reduced production time, both of which should lead to a decrease in the cost of component manufacture.

The strength and stiffness of knitted composites is much lower than that of woven composites because of the looped structure of the knit, however its bearing strength and impact resistance and tolerance is superior to woven composites [2].

Experimental characterization of the mechanical properties included: in-plane tension, transverse compression, in-plane shear and out-of-plane bending tests. The results demonstrated that these properties were dependent on the knit architecture defined in terms of the loop length components and fabric tightness. As expected it was found that compared to woven composites, the knitted composites had relatively poor tension and compression properties. However, they had comparable bearing properties and superior energy absorption and impact resistance and tolerance. The amount of deformation was increased, the composite tensile strength and stiffness improved marked in the direction in which it was deformed; in some cases there was a decrease in strength in the non-stretch direction. A simple test regarding the knitted fabric's stretching, along with standard mixtures, can help in the determination of stiffness and thus, offers a good estimate of the composite's stiffness [2]. An overview and description of these types can be found in paper[7].

3-D knitted fabric can provide a cost-effective alternative for existing sandwich structures – figure 5. Additionally, they also provide a cheap and easy way to produce complex double-curved surface. This was not possible until now, or was difficult to achieve with the more common sandwich panels. The excellent deformability of 3D-knitted fabrics is a direct result of the looped structure of the yarns. Because of this, the yarns can bend freely and can slip over each other. Another advantage of the 3D-knitted composites is the relatively high impact resistance caused by the presence of many pile fibers. We also find a good damage tolerance for these composites, due to the specific nature of the integrally knitted structure. And finally, these complex structures also seem to have some interesting ventilation properties [4].

The 3-D knittings that have been used consist of two grids of knitted beams interconnected by curved pile fibers that are oriented vertical to the films. Currently, only hexagonal and rhombic cell structures have been produced. In these 3-D knits, the piles form a hexagonal or rhombic “honeycomb core” structure, while the films show an open hexagonal or rhombic framework. In this way, a highly deformable sandwich structure with good ventilation properties can be formed. However, it is also possible to knit completely closed surfaces. This option is welcomed if one wants to produce composite parts that have a smooth surface on the outer side. In this case, it is unnecessary to laminate an extra top film so that delamination problems are avoided. Another benefit is the reduction of processing steps. For the moment, all 3-D knittings are based on plain PET-monofilaments, whose intrinsic stiffness is responsible for keeping the two films at a distance. Hence, it will not be possible to replace the monofilaments entirely by i.e. glass rovings, which are more favorable for attaining high mechanical properties in the final composite. To evaluate the 3D knitted sandwich material, a comparison is made with PMI-foam and polypropylene-honeycomb. Extra yarns can be incorporated into the sides to reinforce the film. So far, trials with the insertion of multifilament polyester have been carried out. The knitting procedure is still the same, except that now a multifilament is taken together with the PET-monofilament for knitting the films. One of the advantages of the yarns is that when several layers of knitting have to be laminated, the contact area between adjacent layers is larger compared to the original knitting structure. Consequently, there is a better adhesion between different layers.

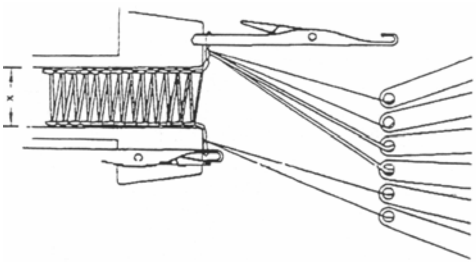


Fig. 5. Device for making 3D knit
X – space between layers

As a sandwich material, the 3D knitted composites can be used in a wide range of application where lightweight construction is of prime concern. The 3D knitted scaffold adds a few new features. First, the extremely open structure opens up possibilities for applications in which ventilation is required, i.e. ventilation grids. These can be used for shielding off engines or heat dissipating appliances. Especially in wet conditions these composites could be useful because of their corrosion resistance [8].

Sewing

Sewing is one of the oldest industrial methods of joining materials together. The first sewing machines were invented over 200 years ago, and the current form of the sewing machine has remained largely unchanged for over 100 years.

Sewing is the ideal way of joining textile surfaces together because it retains the textile characteristics of these surfaces. The seam is flexible, just like the textile parts it does not lead to distortion of the textile architecture and does not change the nature of the fabric’s links, as would be the case with welding or gluing.

There are five basic classes of stitch that can be sewn using different sewing machine. These are: the simple stitch, the double stitch, the double triplock stitch, the overlock stitch and the interlock stitch [9]. The international standard ISO 4915 gives an overview of the different stitching types. Different types of stitch are presented in figure 6 [10].

Regardless of the reason, stitching is widely used in the production of composite components. There has been considerable interest in composites produced by stitching layers of woven fabric and subsequently impregnating the preform with resin using a liquid molding technique. There are three main reasons for the use of a thick seam in composite structures.

1. A major motivation for stitching is the potential to greatly reduce the cost of component manufacture by reducing RTM tooling costs and to reduce the number of components in the structure, hence reducing the assembly costs.
2. Sewing is an effective method for joining composite structure to provide high through thickness strength and resistance to peel loads.
3. Sewing improves interlaminar tenacity and in some cases improves impact resistance and tolerance [9].

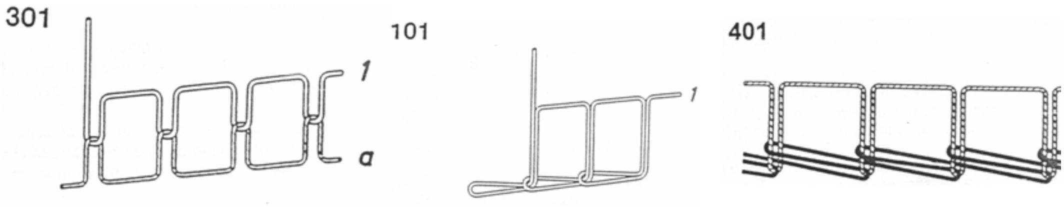


Fig. 6. Stitch type: 301 – simple stitch; 101 – chain stitch; 401 – double chain stitch; 1 - thread to the needle; a – spool of thread

By sewing the layers together an additional crimp of the fabrics might occur. This crimp might reduce the mechanical properties of the composites, therefore it should be avoided. To determine the eventually occurring additional crimp the thickness of the textiles after the stitching was measured. For this a thickness tester was used which gives as result the thickness of the textile related to its length. The figure shows the measurement of the thickness of the textile in a stitched zone. The single yarns of the tested fabric which lay perpendicular to the testing direction are clearly visible. In the area of the stitching row the thickness of the textile increases. That means that no additional crimping by stitching occurred [10].

It is essential that their mechanical properties are characterized, in order to facilitate their use for structural applications. Within the Cooperative Research Centre – Aerospace Structures (Australia) stitching program, Dransfield et al [11] and Mouritz et al [12] have reviewed the improvement of the delamination resistance of CFRP by stitching, and the Effect of stitching on the in-plane mechanical properties of FRP composites. The study it is for carbon panels and glass panels, for aerospace and non-aerospace applications [2].

The stitching process caused spreading and consequent misalignment of yarn about the stitch. Misalignments of up to 30^0 were recorded for heavy stitch yarns. The area around the stitch then becomes a resin rich pocket. It has generally been found that under tension, compression and flexure the stiffness and strength of the stitched panels is lower than that for the unstitched panels.

Braiding

Processes originally developed for the textile industry are being used in the manufacture of composites structural components. One of these techniques is two-dimensional braiding, which has the capability to fabricate near net-shape performs of the desired structural part, while providing the required yarns reinforcement. In combination with a resin infiltration process, such as Resin Transfer Molding (RTM), producing low-cost, high-quality components with improved damage tolerance and resistance is possible. Consequently, there is growing interest in the design, manufacture, and performance characterization of braided composites.

Their mechanical properties: the tension and compression stiffness of the braided composites were similar to that of comparable composites made by the other methods. Their tensile and compressive strength were reduced considerably. This was attributed to fibre damage due to the braiding process. Tension tests on fibre tows revealed a 20% reduction in tension strength resulting from fibre damage during braiding [2].

Experimental Methods

Several ways of obtaining composite materials containing textiles were presented. Due to their peculiar properties, we obtain products with broad applicability both. Therefore, specific methods will be needed for testing these materials.

Conditioning

In determining the characteristics of textile products, are important conditions for the microclimate in which they were processed. Thus, standard conditions, the physico-mechanical tests carried out enforcing the parameters characterizing the ambient environment, the following values: temperature of the 20ºC±2ºC, the relative humidity of 60%± 5%; pressure 101325N /m² [13]. For conditioning is used the oven, desiccator or thermohygrostate.

For the samples conditioning, the physio-mechanically tested materials must be kept in standard atmosphere, until steady state is established between the water molecules absorbed and transferred. The speed at which this balance is achieved depends on the nature of the textile material's fibers. In most cases, the steady state is reached after 24 hours, for technical items the duration increased to 48-72 hours. The material is considered to have reached steady state, in standard atmosphere, when after successively weighing them twice, in a time interval of one hour, they do not exhibit a difference greater than 0.1% from the first weighing. It is recommended that the steady-state is achieved by absorption, not by desorption. For this reason, is indicated that the drying of the material is done at 40-50 °C and 7-20% relative humidity for one hour. This operation is known as preconditioning.

The drying of the samples can be achieved in the oven. The figure 7. a is a schematic diagram of a laboratory oven ITM, with a capacity of 50 dm^3, provided with a housing 1, with well-insulated walls - 2, door - 3 provided with a protective metal cover – 4 and closing handles - 5. Drying is done with hot air introduced into the sample chamber through the outlet openings - 6. The right side of the heating block is equipped with a centrifugal fan to ensure air circulation inside the oven. On the side wall - 8 there is located a thermometer pocket - 9, fine temperature control system -10, control lamps - 11, the main switch - 12.

Figure 7 b presents an electric diagram for the elements that provide heating and circulation of the air inside the oven. The parts of the electrical system are: I - power supply system network; II - power and protection system with fuses of 6 A; III - Electric motor power system m of 40W at 220V voltage signaling h_2; IV - temperature control system; V - supply system of the heating source, with electrical resistance R 400W. After oven-drying the specimens, the actual cooling takes place in desiccator.

A desiccator, figure 8. consists of a glass bowl - 1 and cover - 2, operated by the handle - 3. The bottom of glass vessel - 1 allows the depositing of a solution of sulfuric acid or ammonium nitrate, which provides the standard atmosphere. Specimens E are placed on the porcelain plate - 4 provided with holes.

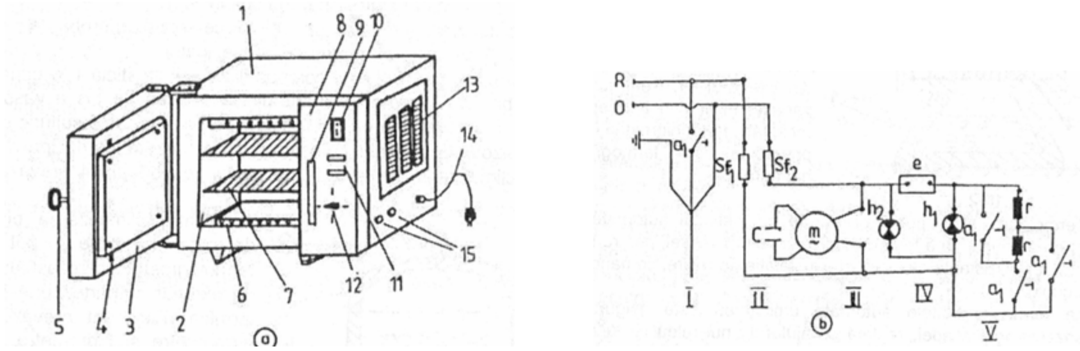


Fig. 7. Oven: a: 1- housing; 2,8 – walls; 3 – door; 4 – metal cover; 5 – handles; 6,14 – outlet; 7 – grill; 9 – thermometer pocket; 10 – temperature control system; 11 – control lamps; 12 – switch; 13 – resistance b: I – power supply system network; II – power and protection system with fuses; III – electric motor; IV – temperature control system; V – supply system of the heating source

Termohygrostat conditioning may be used (i.e. TH-1 type M1), which externally provides a very good insulation, being equipped with thermometers and hygrometers for humidity and temperature control, and thermographs and hygrograph to control their changes [14].

Changing the moisture content of textile materials involves changes in physical and mechanical characteristics, particularly for the natural fibers rather than for the synthetic ones. Humidity can be expressed as:

- real humidity - being the amount of water that the fabric contained in a given time, expressed in % relative to the product's weight when dry;
- normal humidity - is the same report, for the conditioned material;
- legal humidity (peak) R - represents the percentage of moisture allowed in conventional commercial transactions [15].

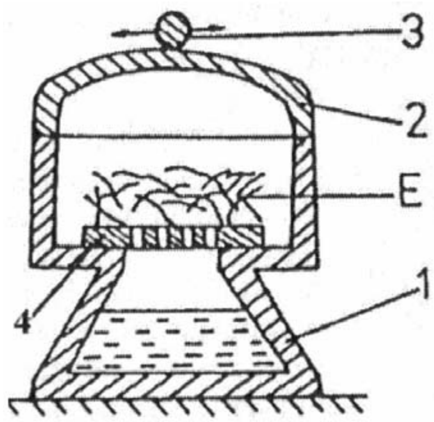


Fig. 8. Desiccator: 1 – glass bowl; 2 – cover; 3 – handle; 4 – holes; E - sample

Insulating layer of fibrous material is recommended to have 500-600g/m² weight.

Nonwoven materials containing fibers recovered from waste, have a higher content of air, due to manufacturing process, which provides a loose layer, but also because of texture fibers, therefore, should be considered and taken into account that aspect.

Thermal Properties and Conductivity of Textile Panels

Thermal insulation capacity is a particular feature of textile materials, which can be determined by several laboratory methods. For example, the plate measurement system, type Dr. Boock, presented in figure 9.

Thermal insulation capacity is given by the parameter called the coefficient of thermal conductivity λ, whose value is calculated with:

$$\lambda = q \cdot d / \Delta Q \cdot W \quad (1)$$

expressed in kcal /m$\cdot h \cdot$°C; where: q - specific heat flow is expressed in kcal /m$\cdot h \cdot$°C; d - sample thickness is expressed in mm; ΔQ - the difference between temperatures recorded at the contact between the two plates and the surfaces of the specimen, expressed in °C; W – represents the constant, in conformity with the heat resistance of the air layers formed between the plates and surfaces of the fabric specimen.

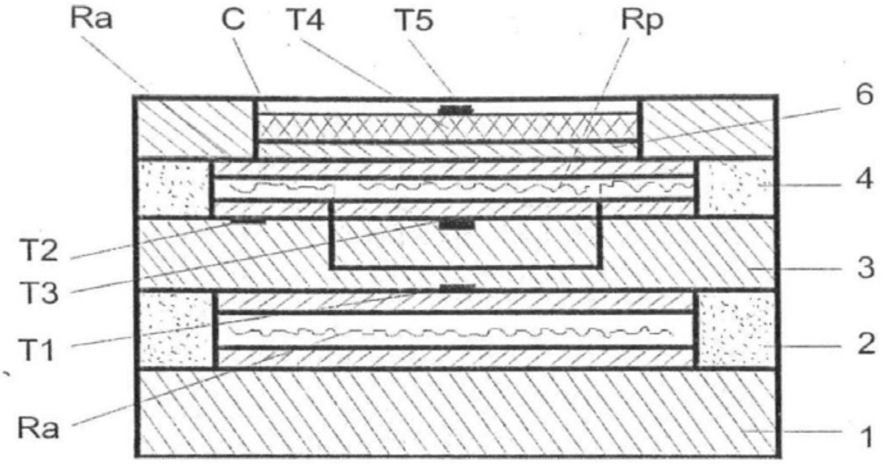
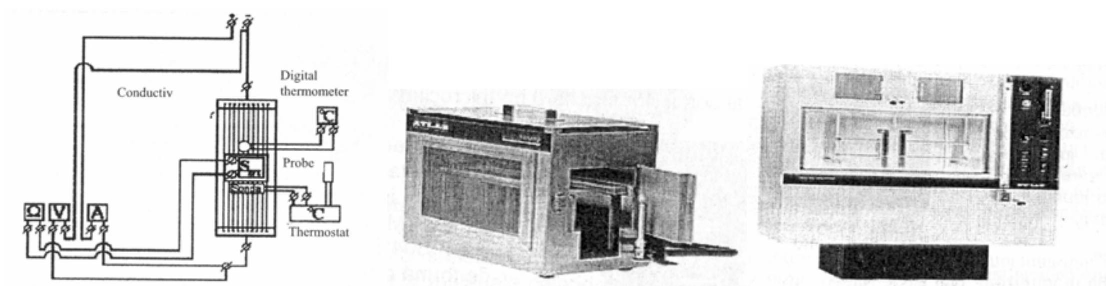


Fig. 9. Type Dr. Boock device plates: R – resistors; T – transducers; 1 – layer of asbestos tiles; 2,4 – layers of diatomaceous earth powder; 3 - layer of asbestos flakes, 6 – copper plate

Thermal conductivity coefficient can be expressed in terms of: U - potential difference, I - intensity of electric current, A - sample area through which the heat flows - the difference in temperature recorded at the two sides of the textile material [13].

$$\lambda = U \cdot I \cdot d / \Delta Q \cdot A \quad (2)$$

The installation presented in figure 10. a. has been used to determine the electric resistance of the panels and the temperature released near the panel at a 2 cm distance from the panel edge.



a. b. c.

Fig. 10. a – installation for electric resistance; b - horizontal flame chamber HMV; c - horizontal and vertical or inclined flame chamber - HVFAA

The stand for testing the temperature sensors is made up of the following components: one conductive textile panel P, one temperature sensor, one thermo resistor - digital thermometer for measuring the panel temperature, one adjustable source of continuous current, one digital millivoltmeter for measuring the voltage supplied by c.c. source, two digital multimeters / one for measuring the intensity of the electric current and the other for measuring the value of the electric resistance, one thermostat for adjusting the value of the temperature of the conductive panel to the temperature of the probe. After analyzing the behaviour of the panels during these tests, conclusions are: the conductive yarn panels allow heating within the limits imposed by the thermal comfort; a restrictive domain must by established for the temperature variation; avoiding the change of the electric resistance due to the stresses during the wearing will require its fixing on a rigid carrier. This shortcoming can be reduced by using other yarns for the carrier, because these panels have a relatively small mass can be easily attached to different machines [16].

Flammability testing is called resistance to fire. Depending on how they are implemented in different types of devices, test samples can be positioned horizontally – figure 10. b. or vertically or inclined – figure 10. c. Testing the resistance to fire of materials was achieved with a horizontal flame chamber HMV, figure 10. b. Due to the exposure risks involved, the testing must be done in accordance with the requirements imposed by standards such as ASTM D5132, DIN 75200, and ISO 3795. The advantages of this test system:

• The chamber is made of stainless steel and its top surface can be separated from the rest of the compound;

• The flame can be adjusted as required;

• The support on which the test sample is placed in made of stainless steel also;

• The device is equipped with on-off timer.

With the horizontal and vertical or inclined flame chamber - HVFAA figure 10. c., flammability flame spreading and ignition can be tested. Determination is flame under standard ASTM D 5207. Testing can be horizontal, vertical or inclined at 45°, 60°, fitted with sliding door access, gas control system and three manual settings [13].

Other thermal tests were achieved through thermo gravimetric analysis (TGA) and performed on all composite samples. TGA measurements were completed in an ATI/Cahn high/mass TGA. In the TGA, samples were heated from room temperature to 335° at a rate of 2° per minute. Module output in TGA shows a continuous decrease in sample weight, depending on the increasing temperature [17].

Conclusions

Starting from the fiber, textile composite materials are used in woven, knits, woven fabrics and nonwoven fabrics. Further studies aimed at discovering new materials to ensure adequate absorption of heat - made of PET fiber are dispersed microparticles of cesium, tungsten and oxygen (the last revelation of the Japanese company Sumitomo Metal Mining), fiber behavior improved by noble with silver, or nanoparticles or new construction insulation materials made of nonwoven materials as wallpapers Klima Tec Pro KV 600, made by German company Erfurt, which applied to the cold walls can reduce heating costs by 75%.

In determining the characteristics of textile products, are important conditions for the microclimate in which they were processed. Thus, standard conditions, the physico-mechanical tests carried out enforcing the parameters characterizing the ambient environment, the following values: temperature of the 20ºC±2ºC, the relative humidity of 60%± 5%; pressure 101325N /m² [13]. For conditioning is used the oven, desiccator or thermohygrostate.

The study of the thermal conductivity depends on many factors and parameters: thickness of plates, structure as function of porosity, air permeability, weight per unit area and fiber conductivity. A high mass results in a low thermal resistance, thermal conductivity and high heat transfer. Thermal resistance increases with the increase in material thickness. A positive correlation exists between thermal resistance and the high air permeability and fiber composition.

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Metode experimentale de analiză a materialelor compozite cu conținut textil

Rezumat

O categorie importantă de materii prime utilizate la obținerea materialelor compozite o constituie atât fibrele cât şi produsele textile. Sunt prezentate pe scurt produsele textile: fire, țesături, tricoturi. Materialele compozite stratificate au proprietăți ce depind de rezistența fibrelor, a fiecărui strat şi de numărul de straturi ce formează materialul în ansamblu. Pentru studiul acestor materiale se folosesc multe metode experimentale, dintre care vom studia condiționarea materialelor şi proprietățile termice şi de conductivitate ale panourilor textile.