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TEXTILE REINFORCED COMPOSITES WITH INTEGRATED SENSORS

Abstract

Smart textiles progressively play a significant role in the European textile sector and help the textile industry in its transformation into a competitive knowledge driven industry. Nowadays, the integration of electrical and electronic systems within fabrics *and composites* is completely viable with t*extile sensors which find usage in many areas including transport industry, medicine and sports. In the case of high performance textile reinforced composites, textile sensors can be integrated during the weaving process. After integration in the reinforcement they not only act as a part of structural material but also have actuating, sensing, and microprocessing capabilities. In this paper, sensor yarns were developed from E-glass/polypropylene (GF/PP) commingled yarn and implemented during weaving of 2D structures at the ARM loom due to checking the thermo-forming consolidation behavior as important factor for several future applications.*

Keywords: smart textiles, conductive polymers, sensor yarns, 2D weaving fabrics, composites

1. INTRODUCTION

When electronics are combined with textiles the resultant is commonly referred to as "smart" textiles which have a promising realm in science and technology because of commercial viability and public interests [1-3]. Smart textiles progressively play a significant role in the European textile and clothing sector and help the textile industry in its transformation into a competitive knowledge driven industry [4]. For textile reinforced composites one possible solution is to use intelligent textile materials and structures, which provide real possibility for *on line* and *in situ* monitoring of structural integrity. Such intelligent materials are made by coating or treating textile yarns, filaments, or fabrics with nanoparticles or conductive and semi conductive polymers giving them specified performance [5].

Sensors or conductive yarns embedded inside the textile reinforcements during the weaving process have to present all the characteristics of traditional textile materials: flexibility, lightweight and capability of adopting the geometry of the reinforcement. Therefore, it is important that sensors integration does not modify their general behavior [6]. Textile materials are very flexible and easily deformable in all directions, and sensors used should be able to support, often all at the same time, tensile, shear, bending and even compression deformations [7].

Two sub-classes of sensors that may be integrated into textile structures based on conductive polymers are intrinsically conductive polymers (ICP) and conductive polymer composites (CPC) [7,8].

Intrinsically conductive polymers (ICPs), also known as conjugated polymers and synthetic metals, are the class of polymeric materials that can conduct electricity.

Different types of conductive polymers such as poly(pyrrole), poly(aniline) and poly(3,4 ethylenedioxythiophene) can be prepared with a broad range of conductivities i.e. from 10^{-10} to 10^{+5} S/cm. Among the wide range of conjugated polymers already developed perhaps the diethoxy substituted thiophene poly(3,4-ethylenedioxythiophene) or PEDOT is one of the most promising conducting polymer because of its many advantageous properties such as excellent transparency in the visible range, high conductivity (>300 S/cm) and good thermal stability [7]. Polystyrene sulfonic acid (PSS), a water-soluble polyanion, can be used during the polymerization of PEDOT as a charge balancing dopant. The water-soluble PEDOT:PSS complex has electrical and film-forming properties, shows high conductivity, transparency and possesses great environmental stability. However, PSS itself is a nonconducting material, which limits the conductivity of the PEDOT:PSS complex to the 1-10 S/cm range [9].

Extrinsically conductive polymers (ECPs), conducting polymers (CPs), or conductive polymer composites (CPCs) are obtained by blending, generally by melt mixing, an insulating polymer matrix, thermoplastic or thermosetting plastic, with conductive fillers like carbon black (CB), carbon fibres or nanotubes, conductive polymers or metallic particles. Its conductivity values are much lower than the conductivity values of ICPs [7,8].

In this work, sensor yarns inserted during the weaving process of 2D structure were presented and validated before and after 2D structures consolidation [9].

2. EXPERIMENTAL PART

2.1. Sensor yarns production

Sensor yarns of one meter total length were made from E-glass/polypropylene (GF/PP) commingled yarn with fineness of 842 tex and GF/PP mass content of 71:29 produced by P-D Fibreglass Group, Germany. Aluminum roll to roll mechanism with plexiglass bath was developed for sensor yarns production to obtain even coating thickness and uniform distribution 1).

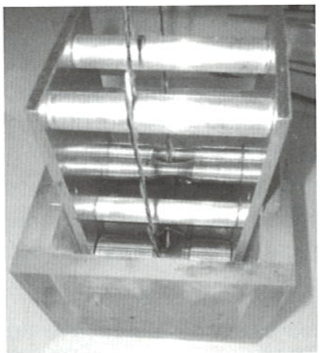


Figure 1. Roll to roll coating procedure: conductive coating process [9]

Coating speed of 0.2 m/min was taken during the process due to later slower drying of coated yarn at temperature of 170°C and distance less than 5 cm from the coated area. It is possible to produce ten or even more sensor yarns in one seria taking into account its final quality. Procedure was done at the Ecole Nationale Supérieure des Arts et Industries Textiles, ENSAIT, Roubaix, France.

Latex Appretan® 96100 50wt% (Clariant) was taken to insulate the sensor yarns for first and last coating steps. Mixture of Poly (3, 4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) CLEVIOS™ P FORM. CPP105D 1.3wt% (Heraeus) and Latex Appretan N96100 50wt% (Clariant) was used for conductive coating of yarns (two or three roll to roll coating layers). PEDOT:PSS/Latex solution in a ratio of 20:80 was prepared at ambient temperature. The ratio corresponds to the percolation threshold concentration studied earlier. Copper wires (Conrad), Φ 0.2 mm, were ligatured around the yarn in conductive coating area at distance of 5 cm as the effective sensor length. Additionally, conductive drops were applied only at places where wires were inserted to obtain its better connection with yarn. Length of copper wires is 1 m per each sample (Figure 2).

Figure 2. Sensor yarn

2.2. Sensor yarns implementation during the weaving of 2D structures

Pretests were made by insertion of four sensor yarns in weft (Figure 3) and four sensor yarns in warp direction during the weaving of 2D structures, 4-end satin weaves with repetiton at the ARM loom. GF/PP commingled yarn was used for the fabrics production as well.

Figure 3. 2D structure with integrated sensors in weft direction [9]

Two stacks composed of three layers of 2D weaving fabrics with the middle layer with integrated sensor yarns were consolidated at the heating press under following conditions; temperature of 185 °C and pressure of 20-30 bar during 5 min (Figure 4) [9].

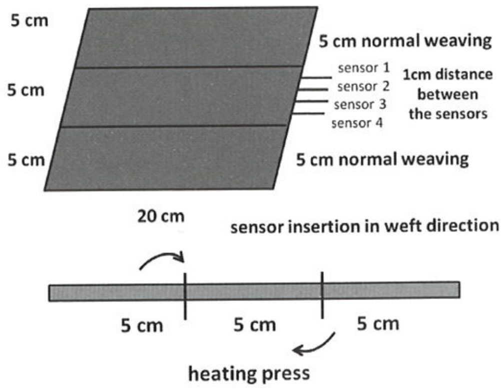


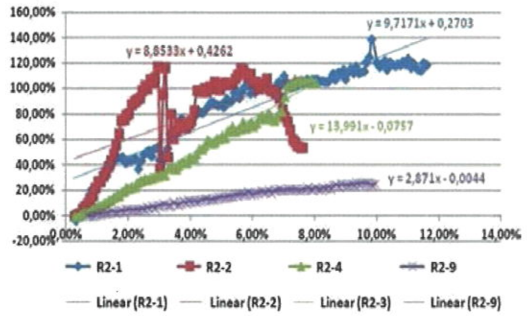
Figure 4. Scheme of weaving step and 2D structure arrangement for consolidation [9]

3. Results

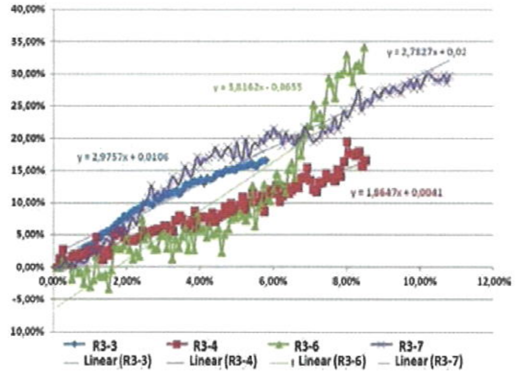
Initial resistance of sensor yarns was measured after sensors development using a Keithley system and resistance box. Electromechanical tests of two and three roll to roll conductive coating GF/PP sensor yarns were done at MTS device by using speed of 100 mm/min with a pre-load of 0.5 N.

The electromechanical measurement is a combination of a strain and a resistance measurement made at the same time during a tensile test. The aim of electromechanical tests is to find the "k" factor, Eq. (1), between resistance variation and elongation:

$$\frac{\Delta R}{R0} = k \cdot \frac{\Delta L}{L0} \tag{1}$$



MEAN k= 8.8581
Stand. deviation 4.580
a.)



MEAN k= 2.8598
Stand. deviation 0.801
b.)

Figure 5. Electromechanical tests – graphs with $\frac{\Delta R}{R0}$ as y axes and $\frac{\Delta L}{L0}$ as x axes of sensor yarns: a) two roll to roll conductive coating layers, b) three roll to roll conductive coating layers [9]

According to electromechanical results three roll to roll conductive coating can be taken as better solution for sensor yarn production (Figure 5).

Initial resistance of sensor yarns after sensors development was measured also before and after consolidation of 2D structures with integrated sensors.

The aim is to develop sensor yarns workable after fabric consolidation and it is important to find better solution for its final validation. Tensile test at quasi-static speed and on-line monitoring of sensors can be done in that case.

4. CONCLUSION

Sensor yarns based on PEDOT:PSS were made from E-glass/polypropylene commingled yarn by new developed roll to roll procedure. It is possible to produce ten or even more sensor yarns in one seria taking into account its final quality. Two roll to roll conductive coating can be enough for sensor yarns preparation, but according to electromechanical results three roll to roll conductive coating can be taken as better solution. Mostly sensors work after its production and integration in 2D structures before consolidation, while its validation after consolidation of 2D fabrics has to be improved.

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