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Core Conductive Yarn Based Integral Knitted ESD Garments Part I. Metallic Core Conductive Yarns Investigation

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Abstract. A research regarding the integral knitted structures for electrostatic discharge (ESD) protective garments with core conductive fibres is currently undergoing. The results of the research will be published in three papers. The current paper presents a study on the knitted structures made with metallic core conductive fibres. A number of 15 samples made with different types of fibres were manufactured and tested for their ESD characteristics. From the experimental results, conclusions were drawn about ESD performances of tested samples.

Introduction

Technological evolution has led to development of increasingly more performance electronic devices with high operating speeds which give them the ability to achieve multiple functionalities at the same time. This, together with minimization of electrical components, led to an increase in their sensibility, making them vulnerable to electromagnetic disturbances that may occur. Of these disturbances, electrostatic discharges (ESD) cause losses between 4 and 6% of annual gross sales of high tech companies and more than 45 billion $ per year in the global electronics industry [1]. Some studies have shown that about 30-50% of all malfunctions that occur on the manufacturing line are caused by some kind of electrical overstress, ESD being one of the main causes [2]. Currently there are two standards that define the requirements to be met in the manufacturing environment to protect the electrostatic sensitive devices (ESDS) against damages caused by ESD [3, 4].

The ESD is caused by the build up of electrostatic charge on objects. When this build up exceeds a certain level the charge is suddenly released to a nearby object and depends on different parameters, such as the resistivity of the charged object, the humidity of the environment, grounding, air gap between the two objects, etc. [5-7]. If the nearby object is an ESDS, depending on its magnitude, the discharge can damage the ESDS. Another problem associated with ESD is represented by the risk of explosions in flammable environments [8]. Most common discharges occur from the human operator's clothing which can be charged by routine activities. For example, the activity of walking on a polyethylene carpet can generate voltages of up to 12.000 V [9]. In the recent years the textile industry has seen a number of important changes both in the production flow by introducing automatic monitoring systems [10-12] and the destination of finished products. To overcome the problems raised by ESD, special protective garments, ESD garments, were designed to help the dissipation of charge and reduce the risk of producing discharges.

The studies regarding the essential performances of ESD protective garments lead to a number of contradictory requirements when defining the ideal ESD garments: (i) high conductivity to facilitate the dissipation process and to avoid charge accumulation and (ii) high resistivity to prevent fast dissipation and to limit the energy transfer during discharging [2]. They also must have good shielding properties to reduce the intensity of the electrostatic fields generated under the garment [13] and anti-static properties to not generate electric charge when come in contact with other materials [14]. These requirements can't be met at the same time by a garment, thus a compromise will be considered. In general is aimed to obtain a garment with dissipative properties that, according to Standard EN 1149-5:2008, must possess a half decay time of the electric field strength under 4 seconds, shielding factor greater than 0.2 or surface resistance less than $2.5 \times 10^9\ \Omega$ [15].

Over the past years researchers manufactured different ESD garments which were tested in order to analyse their ability dissipate charge and protect ESDS. The fabric used for the ESD garments consists in a base material (normally from polyester or cotton) with insertion of special fibres at different distances. These fibres can be classified in surface conductive and core conductive fibres.

Fabrics containing stainless steel, surface conductive carbon fibres and core conductive carbon fibres were manufactured and tested for their electrostatic properties [2, 16, 17]. Surface and volume resistances along with the charge decay time were used to determine the ability of the fabric to reduce the risk of producing an ESD. Also the propensity of the fabrics to generate electrostatic charge was tested by measuring the voltage on the body of a chair while a person performed some typical activities. Depending on how the conductive fibres were introduced into the fabric, the surface and volume resistances presented different values. The charge can be generated on the fabric through 3 different mechanisms, namely: triboelectric, corona and induction charging [18-20]. Analysing the charge decay times, different values were obtained, depending on the charging mechanism [16]. Another testing procedure consists in charging the material up to a predefined level and analysing the discharge current from the fabric to a passive ESD probe. Depending on the distance between the special fibres it was observed that as the distance decreases, much more charge is transferred but the peak current is smaller. The magnitude of the discharged current and the transferred charge decrease from the stainless steel to surface conductive and core conductive carbon fibre, which corresponds to the decrease of material's surface resistance [2]. Different tribocharging test methods revealed that the voltage per unit of transferred charge is slightly smaller for the fabrics with surface conductive fibres than the ones with core conductive fibres [17].

Fabrics made from polyester and stainless steel in different percentages were tested for their electrostatic properties, using a contact discharge test method [9]. This method analyses the ability of a fabric to attenuate an ESD. As expected, the attenuation increases with the quantity of the stainless steel and the density of the fabric. The influence of washing on the properties of an ESD garment can also be analysed [21-23]. Worse charge control properties can be observed after washing, mainly due to the loss of the conductive fibres or the cracks that appear on the surface conductive fibres. Also, comparing the woven fabrics with the knitted ones, the last ones are more suitable for washing since the decrease in their electrostatic properties is smaller [21].

Charge decay is much faster if corona discharges are generated along the conductive fibres [24]. This is because the corona discharges generate ions that help neutralize the charge. However a high density of charge is necessary on the fabric to generate corona discharges, which can increase the risk of generating an ESD. When a low humidity percentage of the environment is expected, bellow 30%, the fabrics used for ESD protection must be carefully chosen because the charge dissipation properties can be reduced significantly. A fabric that can successfully dissipate the charge at 50% relative humidity, it may have difficulties at lower percentages of relative humidity [25].

In this context, a prototype exhibiting superior ESD protection capacity, compared with the solutions currently available on the market, based on core conductive fibres integral knitting structure is presented. The research based on integral knitted structures with core conductive fibres will be presented in three papers. This paper is focused on studying the influence of fibres with metallic conductive core on the ESD properties of the prototype. In the second paper the influence of the carbon fibres will be analyzed and in the third the influence of knitting parameters and non-conductive fibres within the fabric on the ESD properties will be investigated.

Experimental part

Although the core conductive fibres have the lowest spread on ESD garments manufacturing (due to their dissipative-insulating surface, which doesn't provide a continuous electric path) the use of the integral knitting technology will lead to a continuous structure of conductive core. The ESD garments manufacturing will ensure both high surface resistance due to dissipative-insulating surface of fibres, and high conductivity as a result of overall continuity of the conductive core of the fibre through the entire product (garment).

The high protective capacity will be given by the general structure of the product, which can be equivalently seen/assumed as a conductive core with a dissipative material layer at the surface. The continuous conductive core through the entire product, uncut/uninterrupted by the sewing process of constituent parts, as a consequence of continuous knitting/integral knitting, will facilitate the charge dissipation process, avoiding charge accumulation on the external dissipative layer.

The dissipative layer, which covers the core, will be of high electrical resistance, limiting the charging process and energy transfer in case of an eventual discharge. The ESD protective garments currently available on the market are guaranteed to preserve their ESD properties for a maximum number of 50 washes. This limitation is due to conducting fibres, used to manufacture the garments' structure, which are subject of corrosion during interaction with washing environment. The proposed structure of the innovative ESD garments will overcome this limitation, ensuring a complete protection of the conducting part by the coating layer.

Based on the comparative study of composite fibres' performances on the market, 15 different types of fibres with a conductive core were selected for testing (Table 1). The samples made using patented knitting technique were tested from the dielectric and surface resistivity point of view. The knitting was made using two parallel fibres, one of 100% PNA fineness Nm 28/2 and one with the conductive core. From the structural point of view, it was opted for a 1x1 patented structure. Knitted samples were made using a manual linear machine VKTM, fineness 5E. The samples were relaxed in a dry environment for 72 hours, to eliminate any dimensional variation. The structure parameters of the knitted samples determined by measurements are: knits' density and the mass per unit of surface measured for a 5 cm unit of length (Table 1).

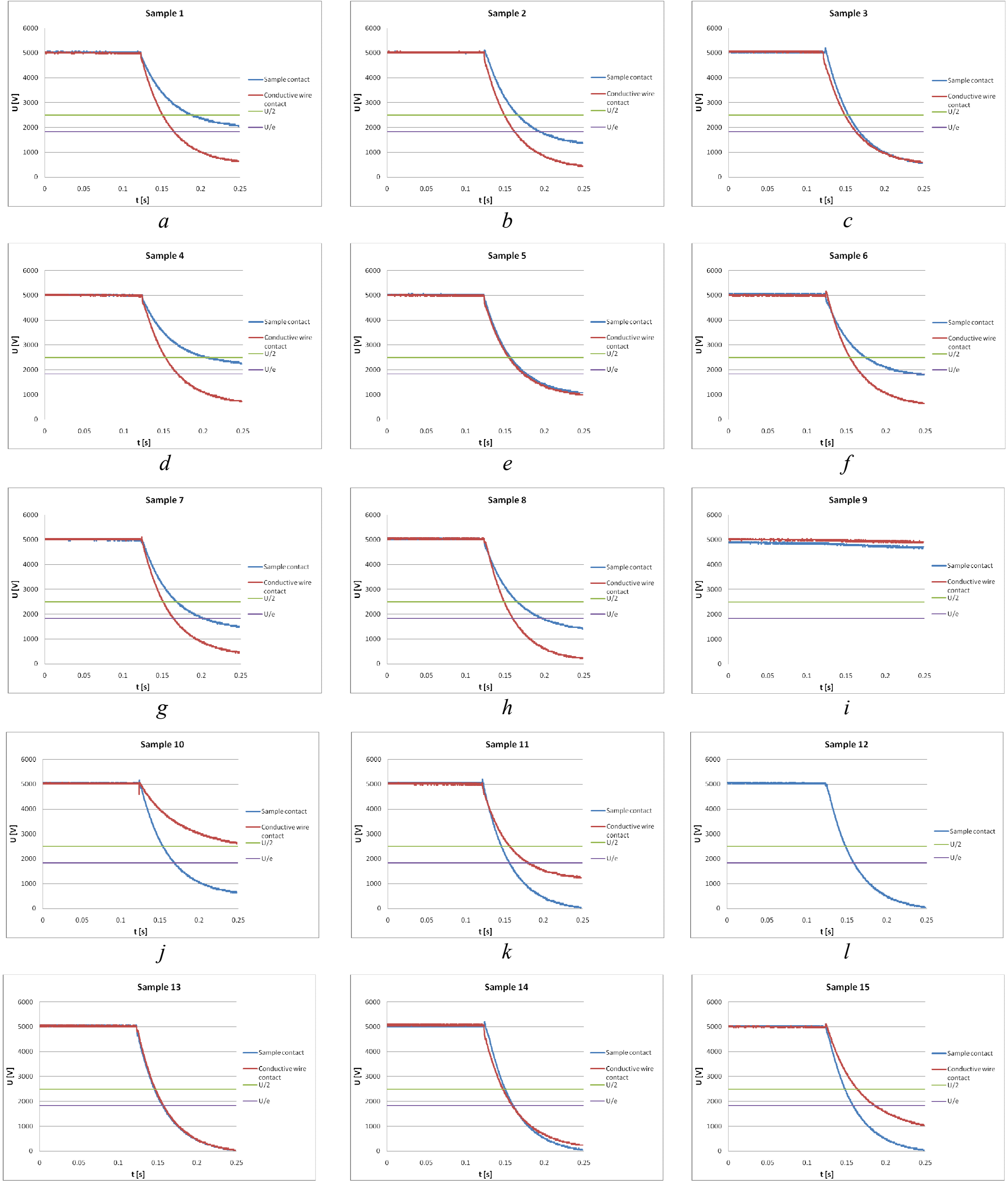
Table 1. Description and structure parameters of tested samples

Sample no.	Fibre's description	Sample densities	
		Do (line/5 cm)	Dv (row/ 5cm)
1	Enamelled 0.15 mm monofilament copper core coated with double layer of silk	14	21,0
2	Enamelled 0.193 mm monofilament copper core coated with single layer of silk	12	21,5
3	Enamelled 0.14 mm monofilament copper core coated with polyester	15,0	21,5
4	Enamelled 0.1 mm monofilament copper core	15,0	18,5
5	Enamelled 0.12 mm monofilament copper core	15,0	18,0
6	Enamelled 0.15 mm monofilament copper core	15,0	21,0
7	Enamelled 0.19 mm monofilament copper core	15,0	21,5
8	Enamelled 0.2 mm monofilament copper core	15,0	21,5
9	Multifilament conductive core: 5% stainless steel fibre + 95% polyester fibre	15,5	19,5
10	Copper monofilament + polyester multifilament	15,5	21,0
11	Multifilament conductive core: 30% stainless steel fibre + 70% polyester fibre	15,5	19,5
12	Multifilament conductive core: 28% stainless steel fibre + 72% polyester fibre	16,0	20,0
13	Multifilament conductive core: 20% stainless steel fibre + 80% polyester fibre (2 filaments)	15,0	21,0
14	Multifilament conductive core: 20% stainless steel fibre + 80% polyester fibre (1 filament)	15,5	20,0
15	Cotton + 0.035 mm stainless steel	15,5	20,0

Results and discussions

Charge decay time measurements. To determine the charge decay time for the knitted samples, a measuring stand using a Charge Plate Monitor (CPM) type 268A-1T manufactured by Monroe Electronics, a discharge electrode, an ESD switch normally open, an oscilloscope and a set of electrostatic insulators was used. CPM has an internal 5 kV power source and an electric field sensor. Through the high voltage power source, the CPM's plate is charged up to a certain potential in regards with the ground. Being in contact with the charged plate, the tested material will also be charged at the same potential. After disconnecting the power supply, the discharge stage is started by connecting the electrode to the ground. The discharge signal is viewed and recorded via oscilloscope and will be used to determine the charge decay time. All insulator items used within the measuring stand were made of polycarbonate. It was intended to separate the charging area from the discharging area for the tested samples.

The results regarding the charge decay time are presented individually for each sample in figure 1 and represent the evolution of the discharge voltage. Centralization of data and parameters that characterize the discharge process are presented in Table 2.



a *b* *c*

d *e* *f*

g *h* *i*

j *k* *l*

m *n* *o*

Fig.1. Charge decay times for tested samples

The charge voltage used for every sample was set to 5 kV. Determinations were made in two different conditions:

- the discharge electrode connected to the sample's dissipative surface (CD);
- the discharge electrode connected to the fibre's conductive core (CC).

Determined parameters which define the discharge process have the following meanings:

- $t_{1/2}$ represents the time after which the 5 kV voltage at which the samples were initially charged decreases by half as result to the discharge (half-time);

- $t_{1/e}$ represents the time after which the 5 kV voltage at which the samples were initially charged decreases to 1/e of its value as result to the discharge (37% time);
- U_{125} represents the voltage recorded at the sample's surface after a period of 125 ms has passed from the beginning of the discharge (residual voltage after 125 ms);
- r_{125} represents the ratio between the residual voltage after 125 ms and the initial charge voltage.

Table 2. Measured parameters characterising the discharge process

Sample no.	$t_{1/2}$ [s]		$t_{1/e}$ [s]		U_{125} [V]		r_{125} [%]		Electrical resistivity [Ω]
	CD	CC	CD	CC	CD	CC	CD	CC	
1	0.0657	0.0278	-	0.0426	2040	640	40.8	12.8	1.4×10^{14}
2	0.0432	0.0257	0.0718	0.0377	1360	440	27.2	8.73	9.6×10^{11}
3	0.0305	0.0448	0.0432	0.0303	560	600	11.11	13.16	2.3×10^{14}
4	0.0808	0.0298	-	0.0446	2240	720	44.8	14.52	1.4×10^{14}
5	0.0337	0.0323	0.0543	0.0509	1080	1000	21.6	20.16	1.9×10^{14}
6	0.0519	0.0308	0.1161	0.0456	1800	640	36	12.8	6.6×10^{13}
7	0.0451	0.0278	0.0804	0.0412	1520	480	30.4	9.6	3.2×10^{14}
8	0.0426	0.0257	0.0715	0.0358	1400	240	27.78	4.76	1.2×10^{14}
9	-	-	-	-	4720	4920	96.72	98.4	$< 2 \times 10^{5}$
10	0.0306	-	0.0442	-	640	2640	12.7	52.8	9.2×10^{11}
11	0.0236	0.0388	0.0338	0.0651	40	1240	0.82	26.96	$< 2 \times 10^{5}$
12	0.252	-	0.0353	-	40	-	0.8	-	$< 2 \times 10^{5}$
13	0.0225	0.024	0.0321	0.034	40	0	0.79	0	$< 2 \times 10^{5}$
14	0.0269	0.0241	0.0371	0.035	40	240	0.8	4.76	$< 2 \times 10^{5}$
15	0.0248	0.0405	0.035	0.063	40	1040	0.8	20.8	$< 2 \times 10^{5}$

Analysing the results it can be noticed that the samples made with copper core fibres present good ESD properties. These are strongly enhanced if the conductive core is electrically connected to the discharge electrode.

The samples made with multifilament fibres also present good ESD characteristics. These depend on the percentage of existing conductive fibres in the total mass of the fibre. For multifilament fibres the residual voltages after 125 ms were smaller than those measured for samples with monofilament fibres.

Surface resistivity measurements. Measuring the surface resistivity of textiles used in ESD applications may not be indicative for a part of the used composite structures. If the measured surface is homogeneous and doesn't depend on the direction of measurement, then the measurement of surface resistivity can provide useful information in terms of ESD characterisation. If the composite structure is made from materials with different resistivity (conductive-dissipative, conductive-insulating, dissipative-insulating) then the surface covered by the measurement electrodes has a strong influence on the measurement results.

Using core conductive fibres in the knitted structures leads to obtaining a surface from a single material, the one used to make the surface layer. Although the knitted structure is composite and made from two materials with different resistivity, the surface (fabric's exterior) is unicomposite and is suitable for surface resistivity investigations.

As the samples are made with fibres with a conductive core, there won't be any of the problems mentioned above and it will be possible to determine the surface resistivity. The results of surface resistivity measurements are presented in Table 2. Analysing these results reveals that while samples made with monofilament conductive core fibres show a high surface resistivity, the order of 10^{14} ohm, the samples with multifilament conductive core fibres show a lower surface resistivity, less than 10^{5} ohm.

Conclusions

It is found that very good ESD properties (small charge decay time and high surface resistivity) are found in samples made with monofilament copper core conductive fibres. A superior charge decay time for this category is obtained when connecting directly the metal core to ground. The samples with multifilament fibres, although have a low charge decay time, their surface resistivity is small, which increases the risk of occurrence electrostatic discharges that can cause malfunctions of electrical devices.

Considering these, the results suggest using monofilament core conductive fibres, indicating that an investigation of the possibilities to reduce the residual voltage values using different types of knitting structures must be made. This investigation will be the subject of a future research paper.

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