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PIEZOELECTRIC POLYMERS IN TEXTILE INDUSTRY

YUKSELOGLU S.Muge[1], ARSLAN A.Feyza [1]

[1] Marmara University, Faculty of Technology, Department of Textile Engineering, Goztepe, 34722 Istanbul, Turkey,

E-Mail:myukseloglu@marmara.edu.tr, feyza_yilmaz_92@hotmail.com

Corresponding author: Yukseloglu, S. Muge, E-mail: myukseloglu@marmara.edu.tr

Abstract: *In the Piezoelectric behaviour refers that conversion of mechanical impact to electrical power, or electrical impact to mechanical changing. The presence of piezoelectricity has been scientifically discovered in 1880 as a result of the work of Jacques and Pierre Curie brothers. They found that some naturally occurring crystals such as quartz and Rochelle salt produced a surface charge when subject to a compressive load. Piezoelectric energy has a wide range of application areas by providing sustainable energy. One of these areas is the textile industry which has been moving towards higher value added production in recent years.*

Piezoelectric materials are divided into four groups: piezoelectric crystals (quartz, rochelle salt, tourmaline, topaz etc.), piezoelectric ceramics (lead zirconate titanate, barium titanate, etc.), piezoelectric polymers (PVDF, odd numbered nylons etc.) and piezoelectric composites. Because of different characteristics of these piezoelectric materials, each of them is preferred with regard to projected purpose. This study reviews piezoelectric polymers and highlights its properties such as elasticity, lightness, strength, etc. where the desired characteristics are needed in textile products. These features make easier to use of piezoelectric polymers in smart textile applications. They are generally used to energize from human movements or different regions of the human body. Power generation can be achieved by various textile structures such as fibre, yarn, weaving and knitting. In this review some polymers, for example polyvinylidene difluoride (PVDF), Polyamide 11 (PA11), Polypropylene (PP), are especially chosen to give more detail on their piezoelectric characteristics which are considered in the textile applications.

Key words: *Piezoelectric, polymers, PVDF, Polypropylene, Polyamide 11.*

1. INTRODUCTION

Today, the innovation has an important role in battling competition in textiles where there is need for investment in research and development areas such as developing new products, new materials with different uses [1]. Piezoelectric polymers are one of those materials which may be used in various sectors.

The harvesting of waste energy from human movement or different regions of the human body has been turned over for obtaining electrical power to low-energy consumption devices such as wireless body worn sensors and wearable consumer electronics [2].

Piezoelectric polymers have been known more than 50 years and are extremely useful in monitoring vibrations and in controlling flexible structures. On the other hand, piezoelectric materials are used to measure the extent of deflection, frequencies of vibration, and control the structure through actuation. A piezoelectric polymer can damp vibrations passively and as the need arises, the stiffness of a material can be changed with an applied electric field that enhances damping effects [3].

Polymer-based fiber sensors have been recently realized through melt spinning of the piezoelectric polymers such as poly (vinylidene fluoride (PVDF), Polypropylene and Polyamide 11. When the fibers are deformed, typically compressed or subjected to axial strain, an electric potential is generated by the piezoelectric properties [4].

The ability of piezoelectric materials to convert electrical to mechanical energy and conversely mechanical to electrical energy has been exploited in an application closely related to power generation. Many investigations done piezoelectric polymers have already gone into the design and properties of piezoelectric transformers [5].

In the below section some of the piezoelectric polymers that are used in textile studies have been specified.

2. PVDF

PVDF (polyvinylidene fluoride) which is the first explored piezoelectric polymers was detected by Kawai in 1969 [6]. Since then, these piezoelectric materials with their flexible porperties have been attracted many researchers in textile studies. In most of the applications they either used thick or thin PVDF films [7-9] and some used bulk materials [10].

The dielectric constant of PVDF is about 12, which is four times greater than most polymers [11]. The material has four crystal phases at different processing conditions. Ferroelectricity and piezoelectricity specialty is provided by the polar β phase which is one of its crystal phases is formed under mechanical stress or high electric fields [12].

Hadimani et.al. [9] studied polyvinylidene fluoride (PVDF) fibres which were extruded in continuous melting process. Poling conditions of extruded fibers were set as 4:1 extension ratio, a temperature of 80^{o}C and 13 000 V high voltage on a 0.5 mm diameter fibre. After melting and poling processes of PVDF monofilament, piezoelectric power of PVDF fibres were measured 2.2 V under an impact force of 1.02 kg from a height of 5 cm [9].

Piezoelectric bicomponent fiber consist of sheath poly (vinylidene fluoride) fiber, conductive composite with carbon black(CB) and core component polyethylene (HDPE), which was searched. The mean power from a 25 mm length of bicomponent PVDF yarn was estimated as 15 nW [13].

‘’3D spacer’’ technology was used for manufacturing piezoelectric fabric that contain high β-phase (~80%) piezoelectric PVDF monofilaments as the spacer yarn interconnected between silver (Ag) coated PA66 multifilament yarn layers acting as the top and bottom electrodes. As a result of this work was produced power density in the range of 1.10 W μW cm-2 to 5.10 μW cm-2 at applied impact pressures of 0.02 MPa to 0.10 MPa [14].

(PVDF)/nanoclay composite nanofibers were fabricated by a “near distance-wheeling” electrospinning (NWS) method. Results of the free vibration test showed that voltage peak value of straight PVDF/nanoclay fibers was 2.76 V whereas it was 1.65 V for random PVDF/nanoclay fibers, and PVDF fibers was maximum 0.78 V [15].

3. POLYPROPYLENE

Polypropylene is one of the most widely used polymer in technical applications because it is easily available and less expensive as compared to other polymers that can be used for piezoelectric applications.

Piezoelectric isotactic polypropylene (iPP) monofilaments were producted on different draw ratios such as 1:1, 2:1, 3:1, 4:1, 5:1, 6:1, 7:1. Voltage responds were analyzed for different draw ratio and the peak voltage was found that 264 mV on 2:1 draw ratio [16].

Voltage response of varying the weight ratios (1%, 3% and 5%) of tourmaline in polypropylene polymer was examined. After monofilament meltspinning processes of PP/TM (1%, 3% and 5%) seperately, tourmaline added PP filaments were woven as 70 mm x 100mm. The recorded peak voltage values were measured 1.46 V for PP/ TM %1, 2.84 V for PP/ TT %3 and 3.92 V for PP/ TT %5 on ossiloscope [17].

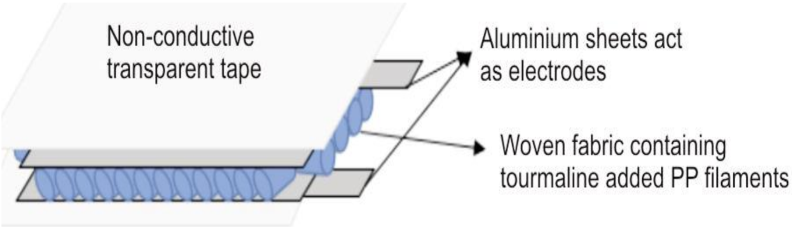

Fig.1: *PP/TM piezoelectric woven textile layer sandwiched between two aluminium sheets [17]*

The effect of addition 0%, 0.01%, 0.1% and 1% weight ratios of multiwalled carbon nanotubes (CNTs) on the piezoelectric properties of polypropylene (PP) monofilaments was investigated. CNT enhanced piezoelectric properties of the PP filament [18].

Patel and Uzun [19] reported various piezoelectric smart materials and their applications in their study. They have stated that although PVDF piezoelectric materials are relatively inexpensive, the repeatability of the material to generate consistent voltage can prove to be a challenging factor. Conversely, PP may generate least amount of energy, it showes good promise as an engineering material due to its flexibility, cost effectiveness and repeatability characteristics.

4. POLYAMID 11

In the past twenty years, the odd-numbered polyamides are well known ferroelectric polymers. Especially studies were focused on polyamide 11 (PA 11) due to its relatively low water absorption, its excellent mechanical and piezoelectrical properties. In one of those studies [20], piezoelectrical properties of PA 11 has shown better piezoelectrical properties and were thermally more stable than PVDF and to its copolymer with trifluorethylene (PVDF-TrFE). Wu et al [21] studied the effect of draw ratio on the ferroelectric and piezoelectric properties of PA11; they have observed that as the draw ratio of the films increase from 1:1 to 3,5:1, the piezoelectric strain coefficient d'_{31} measured at 25 °C remained uchanged and roughly was 1.1 pC/N but the piezoelectric stress coefficient e'_{31} increased from 2.1 to 4.9 mC/m^2 . On the other hand, at 120 °C, d'_{31} was increased from 3.8 to 20 pC/N and e'_{31} from 0.5 to 27 mC/m^2 .

PA 11 is a high-performance semicrystalline polymer, which was found the triclinic α-form, the monoclinic β-form and three hexagonal or pseudo-hexagonal forms (γ, δ, and δ' -forms) with different crystal lattices [22]. On the other hand, at room temperature the odd-numbered nylons have shown lower piezoelectric constants than PVDF [11].

In one study, PA 11 piezoelectric mono-filament was successfully extruded via a continuous process on melt spinning apparatus. Result of applied 1.02 kg force from 10 cm height to PA 11 monofilaments was a peak voltage about 3.24 V [23].

Some researchers [24] discovered crystal morphology of PA11/clay blends of nanocomposites; they used polarized light microscopy (PLM), small angle scattering (SALS) and differential scanning calorimetry (DSC) for that and PA 11 can crystallize into well-formed spherulites. Both isothermal and non-isothermal crystallization methods showed an increased crystallization rate with the addition of clay.

Datta et al [25], used PA 11 nanowire arrays to observe their vibrational energy harvesting applications; they have reported their fabrication and properties of vertically aligned and self-poled piezoelectric PA 11 nanowires with a melting temperature of around 200 ^{o}C. They have indicated that the produced nanogenerator exhibited an excellent fatigue performance and high temperature stability which this low cost piezoelectric polymer offers nanowire-based energy harvesting at temperatures well above the room temperatures.

5. CONCLUSIONS

This review indicates that it is possible to design textile-based piezoelectric structures using PVDF, PP and Polyamid 11 polymers. At the table given below we have compared the physical and piezoelectric properties of PVDF, PP and Polyamid 11.

Table 1: *Comparison of some physical and piezoelectric properties of some polymeric materials*

Polymer	**Density (g/cm^3)**	**Tensile modulus of elasticity (MPa)**	**Tensile strength (MPa)**	**Tg (^{o}C)**	**Tm (^{o}C)**	**Max use Temp (^{o}C)**	**d_{31} (pC/N)**
PVDF	1.78	2200	60	-35	175	80	20-28
PP	0.91	1000	37	-10	161	80	128± 1
PA 11	1.06	340	48	68	195	185	14

In the near future, we believe that further studies will take place on varies types polymeric yarns, woven and knitted fabrics or nonwovens with a different type of conductive electrodes may be ideal to optimize the piezoelectric output for smart textile applications. With these high quality piezoelectric materials, it may also be possible to develope high performance energy-harvesting textile structures for future applications in multi diciplinar sectors such as for environmental aspects or for human health.

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