Polyamide based soft materials for piezoelectric energy harvesting: a divergence from commodity applications

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Abstract: The textile and fibre industries are well versed with the properties and uses of polyamides. These materials have found extensive applications in different sectors of conventional and technical textiles. A relatively less explored characteristic of this class of polymer, is their response to external mechanical stimuli. The odd-numbered nylons possess this unique feature of converting mechanical stimuli into electrical output, or vice-versa, which is referred as piezoelectricity. Nylon 11, an odd-numbered nylon, is gaining prominence in this field of piezoelectric energy harvesting. This property is exclusively observed in odd-numbered nylons due to the parallel arrangement of dipoles in the polymer chains, resulting in a polar nature. On the contrary, even numbered nylons have anti-parallel arrangement of dipoles that impart these polymers a non-polar nature. The dipoles in this polymer comprise of the NH-CO groups. Nylon 11 is a polycrystalline material. The different crystal phases of nylon 11 are α, γ, δ, etc. All the crystal phases do not yield piezoelectric behaviour. The α phase of nylon 11 has a zig-zag conformation of polymer chains with very strong hydrogen bonding. This leads to the formation of a closely packed structure. The extensive hydrogen bonding between the polymer chains in this phase restricts the movement of dipoles, which suppresses the response of this phase to external excitation. The δ' phase of nylon 11 is loosely hydrogen bonded state of the polymer. This renders the δ' phase responsive to external stimuli due to easy rotation of dipoles. Thus, tuning the crystal phase of nylon 11, as per end use, becomes a subject of expertise. Electrospinning is a technique for preparation of nanofibers. This technique has been reported to produce δ' phase nylon 11 nanofibres using suitable solvent mixture. The simultaneous stretching and quenching of the polymer during electrospinning helps to stabilize δ' phase of nylon 11. The performance of this polymer is inferior compared to other established polymers in this field. Hence it has been formed into composites to improve its performance. However, blending with incompatible materials leads to problems of phase separation, which in turn hampers the overall properties of the composite. Therefore, surface modifications are carried out on reinforcement to establish compatibility between incompatible filler and matrix components. This adds up to the steps of composite manufacturing. Thus, selecting materials of similar chemical nature will help to overcome the issues of incompatibility and phase separation. Amino acids have a similar nature to the polyamides. Glycine is an amino acid that has appreciable piezoelectric properties. Hence, it was used to blend with nylon 11, to form electrospun nanofibrous webs. Interestingly, it was observed that glycine helped to promote the δ' phase formation of nylon 11, while it itself stabilized in its piezoelectric β form. However, beyond a certain concentration of the amino acid, it stabilized the α phase of nylon 11, by aiding in extensive hydrogen bonding between the polymer chains. The optimized composition of nylon 11/glycine produced an output voltage of 11.2V in response to 1.3N applied force. The d_{33} coefficient of the nanocomposite fibre was found to be 7.1 pm/V, which was double that of the pristine polymer. Further, the ability of the nanocomposite to harvest energy from biomechanical movements indicates its competence to be used for flexible wearable applications. This brings forth the contribution of nylon 11 as an energy material to mitigate the problem of energy crisis. This work shows the potential of nylons in the energy sector, beyond conventional textile applications.

Keywords: *nylon 11, glycine, nanofibre, piezoelectric, flexible wearable.*

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