WET SPUN COMPOSITE FIBRES WITH ENHANCED THERMAL AND MOISTURE PROPERTIES BY INCORPORATING WASTE ALPACA POWDER

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ABSTRACT

We have investigated a sustainable approach to enhance both the thermal and moisture properties of the wet-spun polyacrylonitrile by using green natural alpaca fibre. The waste alpaca fibres were mechanically milled into powders and mixed with various weight ratios of polyacrylonitrile (PAN) polymer in dimethyl sulfoxide (DMSO). The Differential Scanning Calorimetry (DSC) and the Thermogravimetric analysis (TGA) revealed improved thermal stability of the composite alpaca/PAN fibres than the control PAN. Moreover, owing to the addition of alpaca the moisture properties of the composite fibres were increased substantially.

Key Words: GREEN NATURAL ALPACA; COMPOSITE FIBRES; THERMAL AND MOISTURE PROPERTIES; SUSTAINABILITY

1. INTRODUCTION

Nowadays textiles are not only using to their traditional clothing applications but in versatile areas such as automobile, medical, electronics, sports, and protection [1, 2]. However, the textile industry is considered as the second most polluting industry because of consuming a massive amount of fresh water, energy and releasing tonnes of effluents into the water stream [3]. In addition, a huge proportion of various fibrous wastes and increasing volume of second-hand clothing that are thrown into the landfill responsible for around 10% of total carbon emissions worldwide [4]. Furthermore, manufacturing non-biodegradable synthetic fibres from petrochemical sources also account for the adverse impact on environmental pollution [4]. Polyacrylonitrile, the most widely used synthetic-based textile fibre after nylon and polyester, is widely used in apparel industries and considered as the best precursor for the production of carbon fibres [5]. Nevertheless, the major drawbacks of the acrylic fibres are high flammability, low thermal stability, and moisture properties [6, 7]. Although for reducing the flammability, application of different types of flame retardant halogenated co-monomers with acrylonitrile monomer was reported, these are not free of toxic and hazardous chemical involvement [6]. Nonetheless, the thermal stability and the moisture properties of the acrylic fibres were overlooked. On the other hand, to support the ecofriendly and sustainable approaches to improve the properties of the textile fibres especially from the synthetic origin, researchers are currently focusing on applying natural waste materials to reduce the extensive use of chemicals and upkeep the waste management [8]. As natural fibres are biodegradable, biocompatible, low cost and environment-friendly, these are used as fillers in producing composites for versatile applications in aerospace, reinforcement, and interiors [8]. Alpaca, a proteinaceous wool-like natural fibre with some essential innate characteristics, is discarded into a landfill while producing waste during the dehairing process [9]. Hence, to utilize the inborn properties of alpaca fibres, our group have already produced particles of around 2.5 µm from waste alpaca fibres [9]. After evaluating the powder particles, we have found that both the thermal stability and moisture properties of the particles has been increased without altering the protein structure of the parent fibre [9]. Therefore, in this study, we have incorporated the alpaca powders into the polymeric structure of PAN by a solution spinning technique and studied the thermal and moisture properties of the composite fibres.

2. MATERIALS AND METHODS

2.1 Materials

Waste alpaca fibres were collected from Nocturne Alpacas, Buckley, VIC 3240, Australia. Polyacrylonitrile (M_w 150,000 g/mol) and dimethyl sulfoxide (DMSO) were purchased from Sigma-Aldrich and Merck, respectively.

2.2 Alpaca powder fabrication

The collected waste alpaca fibres were cleaned with commercially available detergent and water, followed by drying in a conventional oven at 60^0C. Using milling process, the fibres were then converted into powders, as discussed previously [9].

2.3 Wet spinning

The control PAN fibres were prepared with 18 wt % dope solution concentration. The alpaca/PAN composite fibres were wet spun with 20 wt % solid content in the dope solution. The alpaca powders were dispersed into PAN at 10 %, 20 %, and 30 % weight ratios. Dimethyl sulfoxide (DMSO) was used as a solvent. A laboratory scale DISSOL wet spinning machine was used for the production of continuous fibres. The spinneret diameter was 100 µm with 100 holes and the coagulation bath was a mixture of DMSO and water (65:35) at room temperature. Figure 1 represents the wet-spun control PAN and alpaca/PAN composite fibres with different alpaca ratios.

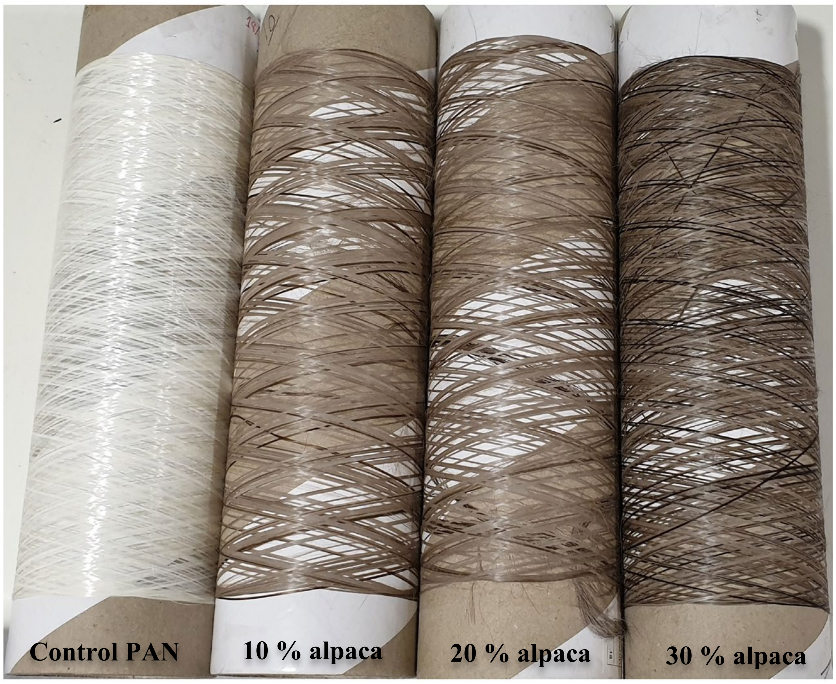

Figure 1. Control PAN and alpaca/PAN composite fibres

2.4 Thermal properties

The thermal properties of all the fibres were tested by using both the differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA). Differential Scanning Calorimetry (DSC) test was carried out by DSC Q200 (TA Instruments, USA). The samples (5 mg) were heated from ambient temperature to 400^{0}C at a heating rate of 10^{0}C/min in a nitrogen atmosphere. The thermogravimetric analysis (TGA) was carried out by using TGA Q50 (TA Instruments, USA), where the samples (5 mg) were heated from room temperature to 600^{0}C at a heating rate of 10^{0}C/min in a nitrogen atmosphere.

2.5 Moisture properties

The moisture properties (%) of the fibre samples were measured according to ASTM D2495-07 (reapproved 2012) [10]. Each sample was conditioned at 20 ± 2 ^{0}C and 62 % ± 2 % relative humidity for 48 hrs. The conditioned samples were weighted and dried at 110^{0}C for 4 h in an oven. The samples were then reweighted and the moisture regain (MR) and moisture content (MC) were calculated by Equation (1) and Equation (2), respectively:

$$MR\ (\%) = (M-D) / D * 100 \quad (1)$$
$$MC\ (\%) = (M-D) / M * 100 \quad (2)$$

where, M is the weight of the conditioned sample and D is the weight of the oven-dried sample.

3. RESULT AND DISCUSSION

3.1 Thermal stability analysis

The DSC and TGA analysis of control PAN and alpaca/PAN composite fibres are shown in Figure 2 (a & b). The control PAN fibres showed an exothermic peak at around 296^{0}C that is typical for the PAN fibres (Figure 2a) [11]. However, while adding alpaca into the PAN system, it was revealed that the decomposition temperature shifted to about 315^{0}C, which could be possible due to the efficacious interaction between the protein part of alpaca and the nitrile group of PAN [11]. It resembles that the polypeptide chains from the proteinaceous structure has fitted with the flexible molecular chain of polyacrylonitrile that limits the easy movement of PAN and ultimately increases the decomposition temperature of the alpaca/PAN composite fibres [12]. On the other hand, from Figure 2b, it was found that the thermal disintegration of the composite fibres has been increased compared to the control PAN fibres. The primary decomposition temperature of the control PAN fibre was around 290^{0}C that stands for the degradation of the nitrile (C-N) bonds [11, 13]. Nevertheless, the thermal degradation temperature of the composite fibres with 10 %, 20 % and 30 % of alpaca, was found to be enhanced in between 305^{0}C and 315^{0}C that could be because of the presence of protein content into the matrix [11]. Hence, this upsurge in the decomposition temperature of the alpaca/PAN composite fibres will certainly increase their thermal stability than that of pure PAN fibres.

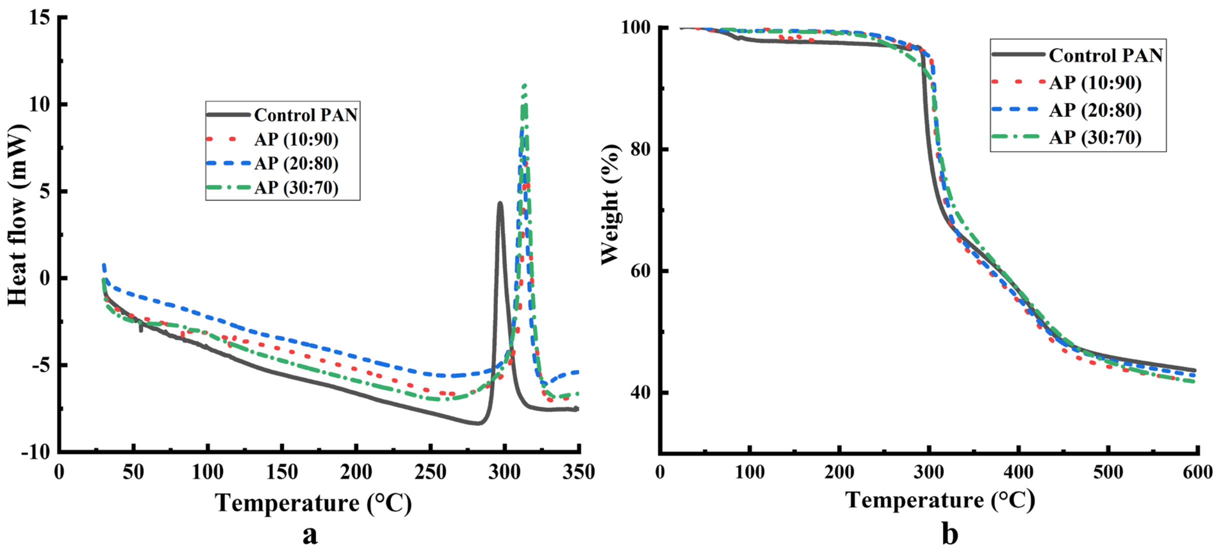

Figure 2. Thermal analysis of control PAN and alpaca/PAN composite fibres (a) DSC & (b) TGA

3.2 Moisture properties

The moisture properties of all the fibres are illustrated in Table 1. It was observed that the moisture properties of the fibres having alpaca, inclined progressively compare to the pure PAN fibres. It is well-known that synthetic fibres exhibited lower moisture properties than their natural counterpart [14]. Typically, the moisture regain of PAN fibres ranges between 1.5 % and 2.5 % whereas it is from 14 % to 16 % for alpaca fibres [5, 7]. In our study, we have found that the moisture regain and moisture content of the acrylic fibre was nearly 1.94 % and 1.90 %, respectively. However, because of incorporating alpaca into the PAN structure the moisture regain and moisture content of the composite fibres was gradually increased compare to the PAN fibres. It has previously been reported that while alpaca fibres were converted into powders, the crystallinity of the powder particles was reduced and moisture absorption ability was increased [9]. Therefore, as we have used the alpaca particles and these were successfully embedded into the polymeric structure of PAN, this enhancement in moisture absorption of the composite fibres are expected.

Table 1. Moisture properties of control PAN and alpaca/PAN composite fibres

Sample	Moisture regain (%)	Moisture content (%)
Control PAN	1.94 ± 0.10	1.90 ± 0.10
AP (10:90)	3.17 ± 0.12	3.07 ± 0.11
AP (20:80)	4.96 ± 0.16	4.73 ± 0.14
AP (30:70)	6.12 ± 0.14	5.77 ± 0.12

4. CONCLUSION

In recent years, the textile industry is considering as one of the major polluters of the environment because of using various toxic chemicals, a huge amount of fresh water, producing tonnes of effluent and consuming energy. In this regard, there has been an increase of re-using textile wastes by following convenient, non-hazardous and user-friendly ways to reach the goal of a sustainable world. In this study, the main aim was to reduce the synthetic petrochemical content of acrylic fibres in an eco-friendly manner and enhance the thermal and moisture properties of the composite fibres. From the DSC and TGA analysis, it has been found that without any chemical treatment and by using natural fillers it is possible to produce thermally stable fibres that could possibly reduce the flammability of the fibres. Moreover, with the enhanced moisture properties, these fibres could be applicable in apparel industries from the comfort point of view.

5. REFERENCES

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