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Adhesion of aqueous polyurethane adhesive to human hair

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ABSTRACT

Adhesion of a water-based polyurethane adhesive to a human hair has been studied using the microbond test. Adhesion promotion using a silane coupling agent and air plasma treatment was compared. The results show that after air plasma treatment, the interfacial shear strength (IFSS) between the polyurethane and human hair was increased from 3.9 to 8.1 MPa. After immersion in an artificial sweat solution at 50 °C for 48 h, the retained interfacial shear strength was 6.4 MPa, and the control remained at 3.7 MPa. γ-Aminopropyltrimethoxysilane (APS), a silane coupling agent was not very effective at modifying the surface of the human hair for adhesion because the interfacial shear strength was at 4.5 MPa. Furthermore after ageing of in synthetic sweat, the interfacial shear strength fell to 3.5 MPa.

1. Introduction

In the wigmaking, the human hair is directly knotted onto a foundation, which is made of net or other material. To secure the hair knot strongly and avoid hair lost, the human hair also was stuck onto the foundation using the polymer adhesive [1]. Unlike vegetable fibres, such as coir, flax, hemp etc., which are mainly composed of hydrophilic cellulose, hair is hydrophobic, because its outer surface has adsorbed fatty acids, including sulphur containing amino acids, stearic acid, palmitic acid, oleic acid and 18-methyleicosanoic acid [2–5]. An effective surface treatment to improve the adhesion of hair to polymers has not been reported. Surface treatment with silane coupling agents or in plasma gases have been used commonly to improve the adhesion of carbon, glass or polymer fibres to polymeric matrices. The concentration of surface chemical functional groups on the fibres increases during these treatments. With silanes, an appropriate functional group can be introduced onto the fibre surface, which reacts with functional groups in the polymer matrix resin to enhance the interfacial adhesion in the fibre/polymer composite [6–10]. Plasma treatment can provide specific functional groups under the appropriate conditions [11–21]. Mostly an array of oxygen containing functional groups is introduced through oxidation to improve the interfacial properties of composites.

Acrylic polymer adhesives have been widely used for coating fabrics because of their excellent weather resistance, water and alkali resistance. However their extensibility and abrasion resistance is inferior to many polyurethane systems [22]. The use of aqueous polyurethane dispersions in coatings and adhesives for textiles has increased recently because of their non-toxic, non-flammable solvent-less and reduced polluting characteristics. They have excellent extensibility, abrasion resistance, and superior low temperature impact resistance [23].

In this work, a water based polymeric polyurethane adhesive was employed. To improve the interfacial adhesion between a polar adhesive and the non-polar surface of the human hair, it is necessary to modify its surface chemistry. Therefore two different types of surface treatment were chosen: one a silane coupling agent and the other an air plasma treatment. The microbond test was used to measure the IFSS between the adhesive and human hair. Single filament fragmentation and push-in tests are difficult to accomplish with human hair for various practical reasons [24]. However, the poor interfacial adhesion means that the stress transfer between the adhesive and human hair limits the spectral shift in Raman spectroscopy and the equivalent photoelastic response in the matrix. The microbond test was also used to assess the retention of adhesion after immersion in an artificial sweat solution at 50 °C for 48 h, since human perspiration is a likely corrosive environment for biomaterial applications of adhesives and coated human hairs in close proximity to skin.

2. Material and methods

2.1. Sample preparation

As-received human hairs (Fig. 1), with ~80 μm diameter were first rinsed three times with ethanol to remove organic contaminants from their surface. The excess ethanol was removed by rinsing with three batches of fresh water. Subsequently the hairs

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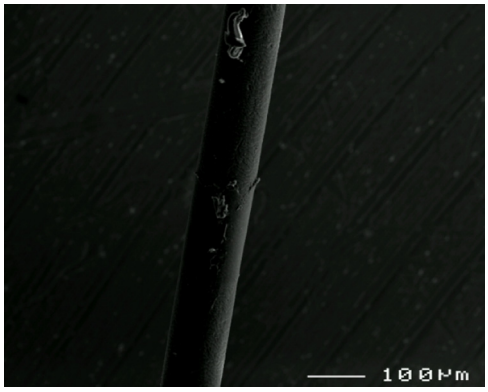

Fig. 1. SEM (JEOL 6400) micrograph of an un-cleaned human hair.

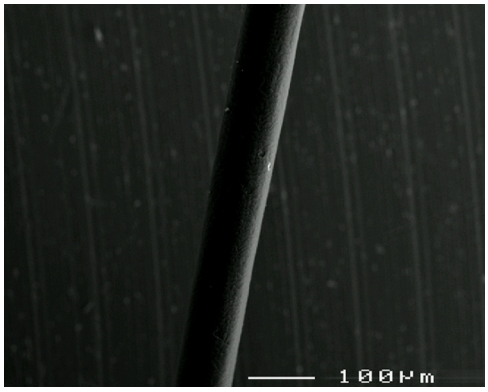

Fig. 2. SEM (JEOL 6400) micrograph of a cleaned control human hair.

were dried in a vacuum oven at 50 °C for 24 h. The surface morphology of the control hair is shown in Fig. 2. There are many layers of flat, thin cuticles laid out overlapping one another as roof shingles on the surface.

1 wt% of γ-Aminopropyltrimethoxysilane A-1110 (APS) coupling agent (Momentive Performance Materials, USA) was hydrolytically dissolved for 5 min in distilled water at pH 4 by adding acetic acid. It was considered the protonation of the amine group to limit the hydrogen bonding of the silane at pH 4 [25]. The individual hairs were treated with APS solution by immersing them for 15 min at room temperature, followed by rinsing three times with distilled water at 50 °C to remove the weakly physisorbed silane oligomers [26,27], and drying in vacuo at 50 °C for 24 h. The cleaned human hairs were also treated in an air plasma at 50 W for 5 s (Fig. 3). There was no difference in the surface morphology after air plasma treatment, compared with the control.

A water-based polyurethane colloidal dispersion was diluted with an equal weight of distilled water to give a viscosity of 20 mPa s at 25 °C, which was measured using an AR 2000 Rheometer (TA Instruments), then mixed with a polycarbodiimide crosslinker Permutex XR-5580 in the ratio of 100:2 by weight, which was delivered by Stahl (Holland). Microbond specimens were prepared by placing a droplet of the blended polyurethane emulsion onto the hole in a card containing a threaded hair using a needle, as described elsewhere [21], dried at room temperature for 30 min, then cured at 70 °C for 6 h. Fig. 4 shows a POLYVAR optical micrograph of a typical polyurethane disc shaped droplet on a single hair, which has a different shape from the conventional ellipsoid. Liu et al. [21] showed by a finite element analysis that disc-shape droplets can be used for interfacial analysis despite their contrasting shapes.

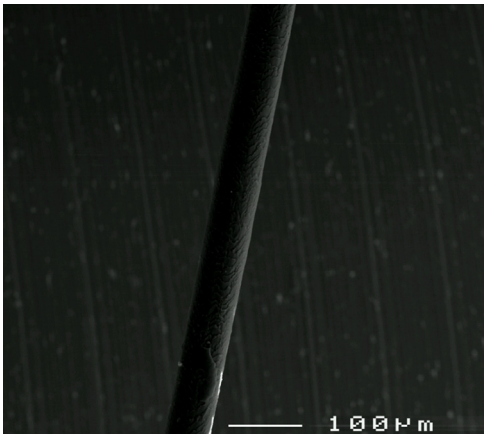

Fig. 3. SEM (JEOL 6400) micrograph of a human hair after air plasma treatment.

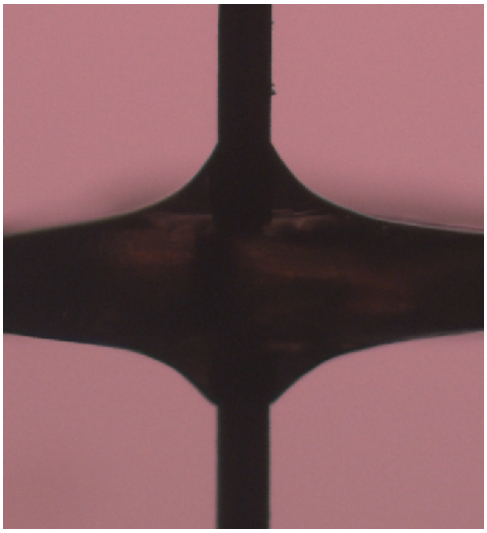

Fig. 4. Optical micrograph of a disc shaped polyurethane droplet on a single human hair of 0.8 mm diameter. The diameter of the fibre can be used as the scale bar.

2.2. Microbond test

Fig. 5 shows the arrangement of the microbond test. Caliper blades were used to restrain the disc-shaped droplet. A load was applied through the movement of the upper grips, a 10 N load cell was used to measure the applied force. The samples were tested at a displacement rate of 0.5 mm/min. The distance between the caliper blades was set to be 120 μm during the testing. Much care was taken to ensure that the single hair was aligned along the loading direction. During the test, the droplet was loaded through the caliper blades to induce a shear load between the hair and the polymer matrix. Two typical force–extension curves are shown in Fig. 6. The force was recorded by the load cell, and HTES-Series Software was used to plot a force–extension graph. The force increased until it reached a maximum value, F_m, before falling to a low level which represents the frictional force, F_f, as the droplet slides. In Fig. 6(a), the force reached a maximum value before abruptly dropping to a constant value, indicative of friction. In Fig. 6(b), the force decreased gradually to a low level. The deformation of the droplets was not observed during testing. For a sample with a weak interfacial adhesion between the hair and polyurethane adhesive, the bare surface of the hair was exposed by debonding (Fig. 7(a)). Its corresponding load–extension curve during the microbond test is shown in Fig. 6(a). However with stronger interfacial adhesion, some residual polyurethane remained