Hierarchically Branched Gecko Like Structures Imprinted Using Porous Alumina Templates

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ABSTRACT

This work presents the methodology to fabricate hierarchical nano-structures of various geometrical parameters to mimic closely gecko's hierarchical adhesion system. We have developed a new approach to create high aspect ratio branched structures on thermoplastic stiff materials. The gecko like structures are fabricated by capillary force assisted nanoimprinting making use of a tiered branched nanoporous anodized alumina (NPAA) template. Thermoplastic polymers are structured by placing the polymer film in contact with the template while is heated above its glass transition temperature. The polymer rises into the cavities of the NPAA template and the structures are released upon cooling. Frictional adhesion tests show that hierarchical structures provide enhanced adhesion compared to the linear counterparts.

Keywords: dry adhesive, gecko mimetic adhesive, hierarchically branched nanostructures, nanoimprinting

1 INTRODUCTION

Geckos' ability of climbing surfaces, whether wet or dry, smooth or rough, has attracted great attention, in particular for the possibility to produce dry adhesives based on the same principles. The gecko's remarkable ability to move on vertical surfaces derives from the tissue structures on the gecko's foot which is composed of nearly 500,000 keratinous hairs called setae. Many of the bio-mimetic structures developed to date make use of linear polymer pillars [1-3], and in some cases hierarchical micron size structures [4] with slanted geometry [5]. However, the performance of these structures is not always as effective as gecko's setae. A major limitation is that these pillars do not mimic exactly the morphology of the gecko's adhesive system.

2 EXPERIMENTAL

We have developed a new approach to create high aspect ratio hierarchical structures on thermoplastic stiff materials. In this process, we make use of a tiered branched NPAA substrate as template. This template is fabricated by a two step aluminum anodization process that allows creating a tiered structure of pores within pores. Details of the fabrication of the template have been provided before [6]. The fabricated templates are clean in DI water and used without any additional treatment. To imprint the structures, free standing thermoplastic polymers such as polycarbonate (PC) or Poly(methyl methacrylate) are used. The films are placed in contact with the templates by applying a small pressure and subsequently are heated above their glass transition temperature. The polymer fills into the cavities of the NPAA template driven principally by capillary forces. The gecko structures are released upon cooling by mechanical peeling off the template.

The frictional adhesion of the gecko like structures was measured against a smooth glass surface implementing a pulling test. A preload of 30 mN applied as weight was initially applied onto tapes of 1cm^2 in area. An Instron mechanical testing system was employed to measure the pulling force proportional to the frictional adhesive force.

3 RESULTS AND DISCUSION

An example of the gecko like structures obtained by this process is given in Fig 1. As shown in the figure, well defined two tier branched gecko structures were obtained. The first tier has dimensions of 250 nm in width and 3.5 µm in height. The second tier includes four fibrils with average dimensions of 90 nm x 0.8 µm. The structures formed on stiff polycarbonate had sufficient structural stability and did not show signs of collapse. In addition as the method to produce the structures is dry, the pillars did not clump or bunch. This phenomenon is typically seen when the template is removed by wet etching and bunching occurs during the elimination of the solvent due to surface tension.

Recent theoretical studies have revealed that hierarchical structures can increase adhesion strength either by reducing structural stiffness or by allowing increased height or aspect ratio without collapse [7]. The improvement in adhesion can therefore be attributed to the more conformal geometry of the hierarchical gecko structures. To prove this theory, the frictional adhesion of gecko tapes with and without branches with the same longitudinal dimension (2µm height x 200 nm width) was measured and compared. Initially, the adhesive force of pristine PC films was measured resulting of low adhesion values in the order of 1.5 10^2 N/ m^2 . The frictional adhesive force of gecko tapes is shown in Figure 2. The adhesive force obtained for PC films with linear pillar structures is indicated by the dotted line. The adhesive force showed values in the order of 5.5 10^2 N/ m^2. The adhesive force of PC films with branched structures is indicated by the continuous line. The adhesive force values obtained were greatly improved with maximum adhesion values of 1.65 10^3 N/ m^2. These results demonstrate the increase in adhesive performance generated by the branched pillar structure. This result can be attributed to the fact that branched structures offer better conformal contact to a surface and make more effective and a higher number of contacts to a surface than linear structures for the same aspect ratio, hence adhesion is enhanced.

4 CONCLUSION

A methodology to fabricate gecko mimetic adhesives using stiff polymers and self-assembled tiered branched NPAA as templates was developed. This methodology allows fabricating gecko like structures without complicated clean room procedures and at low cost. The mimetic topographic features include highly dense branches of high aspect ratio nano pillars These hierarchical structures are to date the closest to resemble the gecko foot hairs in terms of a) aspect ratio, b) branched hierarchy and c) having broad fibril bases. The dry adhesive force measurements confirmed that the branched geometry is beneficial to increase adhesive force versus the linear geometry.

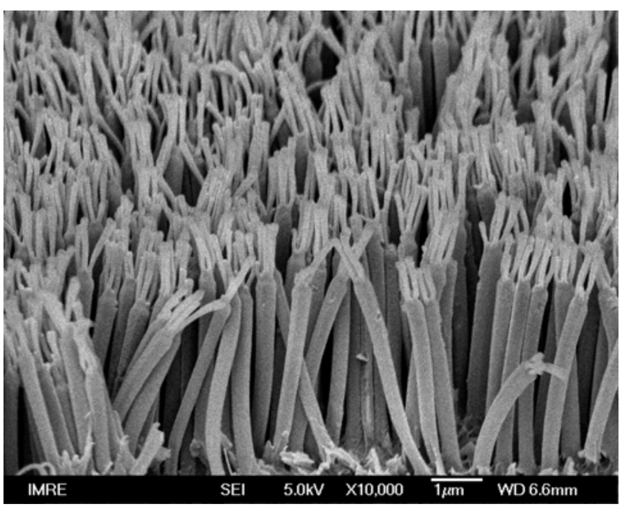

Figure 1: Tiered branched polymeric gecko like nanostructures fabricated in Polycarbonate.

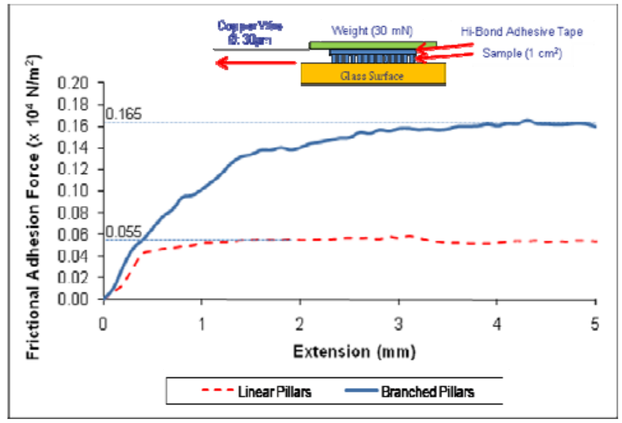

Figure 2: Frictional adhesion strength of linear pillars and tiered branched pillars measured by the pulling test.

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