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A practical fabrication method of the gecko-inspired easy-removal skin adhesives

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Abstract

Easy-removal skin adhesives require a robust reversible adhesion. This requirement is addressed in this study with the fabrication of PDMS micro-patterned surfaces that inspired by gecko feet. The design of these gecko-inspired structures were aimed to maximize the ratio between pull-off strength and peel strength. They were fabricated using the laser cutting technology which is typically used for industrial manufacturing applications. Several kinds of PDMS specimens in triangular, square and hexagonal patterns, as well as triangular, square, diamond and circular cross-sections were made. The wetting properties of the gecko-inspired surfaces were evaluated by contact angle measurements. Pull-off strength and peel strength measurements were performed against a silicon skin substitute. Multiple attachments were achieved on a range of preloads.

The averaged pull-off strength under a preload 10 N for 10 s can reach up to approximately five times of peel strength when the peel angle is 30 degree. Also compared with conventional Band-Aids, a slight enhancement in attachment ability and a significant decrease in peel strength between the skin and the adhesives were consistently observed. Therefore, the fabrication of the gecko-inspired structures on the micro-molding of PDMS appeared to offer a near-practical way for manufacturing an easy-removal skin adhesives, albeit in its present form with a comparable adhesion strength and a decreased peel strength. The originality of this work is the reverse de-molding approach based on the combination of the cost- and time-efficient laser cutting methods and the Teflon film as the mold material, which avoid the limitation caused by taking PDMS structure out of the molds, so that provide more variations of the tip geometry. As such, a further development of this fabrication method might be of significant interest in a number of practical applications in skin tissue industrial design.

Keywords: Novel adhesives; Structure property relations; Biological adhesion; Fabrication technique

1. Introduction

In the development of wound dressings, the normal challenge for adhesives is to hold the wound dressings and human skin together, at the meantime, to allow the wound dressings to be removed without damage from the skin [1]. If a dressing incorporates an adhesive that is too ‘aggressive’, then tissue damage may occur on its removal, which is known to increase the size of wounds and subsequently delay healing [2]. Nevertheless, insufficient adhesion could lead to exudate leakage, which could adversely affect patients’ quality of life and have cost implications, particularly in the case of chronic wounds. Therefore, it is important to balance between the strong bond (high pull-off strength) and the easy removal (low peel strength between the skin and the tape).

Furthermore, geckos are capable of attaching and detaching their adhesive toes seamlessly easily in milliseconds while running on vertical and inverted surfaces, which is undoubtedly a challenge no conventional adhesive is capable of meeting. This is due to the fact that the adhesive on gecko toes differs dramatically from that of conventional adhesives in terms of the structure. Several findings have been reported on the design principles of different patterns [3] and cross sections [4]. In addition, the effect of the geometrical parameters of pillars [5] and the roughness of the substrate [6] on the strong

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attachment and easy-removal properties have been analyzed to establish a design map for bio-inspired fibrillary surfaces [5].

Several researches have reported on the fabrication of gecko-inspired structures, such as electron-beam lithography of polyimide [7], nano-moulding using silicon rubber [8], polyimide and polyurethane [9]. Deep reactive ion etching, self-assembly, anodic oxidation, and angle etching have also been explored to fabricate templates of synthetic gecko-foot hairs [10–12]. Nevertheless, the wound dressings, as one of the most commonly used product on a daily basis, it is essential to manufacture in a practical and cost-effective way. The fabrication of gecko-inspired structures described in this paper is using a standard laser cutting technique commonly used in the manufacturing industry. Unlike the laser-cutting technology from previous study [13], we applied PTFE films as the mold material, which owns extraordinary properties which fit in this case: 1) Safety issues for laser cutting; 2) Excellent non-sticky property; 3) High heat resistance. Additionally, we applied a reverse de-molding approach during fabrication, which avoid the limitation caused by taking PDMS structure out of the molds, so that provide more variations of the tip geometry. By testing on various kinds of micro-molded PDMS arrays, the feasibility of this fabrication method was evaluated.

2. Specimen fabrication

2.1. Materials and methods

Briefly, the micro-patterned surfaces were obtained by molding the mixture of uncured PDMS (Sylgard1 184; Dow Corning, Midland, MI, USA) and the curing agent (10:1 weight ratio) in the molds made by laser cutting.

The material of the molds was the market-existing PTFE tapes. Several laser cutting trial sessions were operated to determine the proper laser powers corresponding to the specific sizes of the holes. As shown in Fig. 1A, when the laser power was 9 kW, most of the holes were not cut through; while when the laser power was higher than 10 kW, or the distance between two holes was not enough, the Teflon tape was burned. Therefore, the laser power for the 0.1 mm Teflon tape was decided as 10 kW. Besides, when R is less than 200 um, the laser cutting machine could not recognize the pattern completely, so the holes were cut randomly.

Molds were divided into two parts, as shown in Fig. 2. The top layer was for the backing layer of adhesives, and the bottom layer was for the micro-patterned structures. The thickness of PTFE films were 2 mm for the backing layer and 0.1 mm for the structured layer, respectively. The lower molds were made by initially designing a range of 2D vector masks of different concepts suitable for laser cutting on a width of 13 mm PTFE tape. Markers were a positive type, which defined the region of the pillars themselves directly. Holes were cut through the entire thickness of PTFE, which defines the length of the pillars.

The PTFE tape was fixed to a wood plate (Fig. 1B). The purpose of this substrate was to provide a mechanical support for the thin stretchable Teflon tape. The laser power was set as 10 KW, which can both cut through the holes and not burn the Teflon. The upper mold was etched in the same way. In this instance, the laser power was 30 KW. Then the two layers

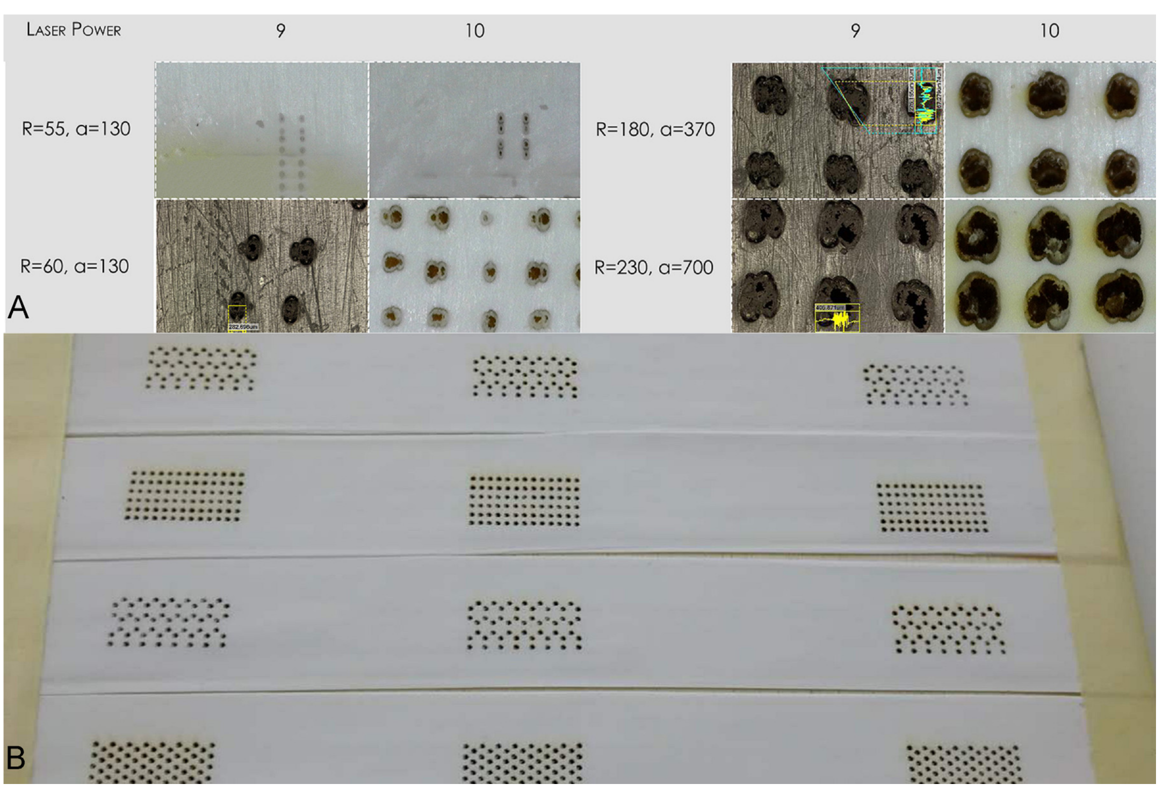

Fig. 1. A) Microscope images of Laser cutting trial sessions. R represents the radius of the holes, 2w represents the spacing between two holes B) The molds fixed on the wood plate made by laser cutting.