Lifting-Force Maximization of a Micropatterned Electroadhesive Device Comparable to the Human-Finger Grip

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ABSTRACT: Electroadhesion device allows one to pick up almost all of the objects regardless of their shape or type of materials by means of the electrostatic Maxwell force, which is developed due to the dielectric-induced polarization on the subject surface. In this study, we propose the modeling methodology and its experimental verification that could maximize the lifting shear force of the electroadhesive device to reach well over the human-finger grip force, say, ca. 8.9 kPa, which has not been achieved yet in this device system. In this study, we maximized the lifting force up to 33.05 kPa for paper objects by scaling down the electrode pitches in the scale of micrometers while avoiding the voltage breakdown using the boundary-edge-length modeling methodology [Choi, K.; et al. ACS Omega 2019, 4, 7994–8000]. The developed model equation expressed adhesion lifting force as a function of the boundary edge length, applied voltage, and impedance, demonstrating that the model equation agreed well with the experimental output of our device and allowed the lifting force well over the human-finger grip. The in situ charge-transfer resistance measurement value of the impedance analysis (\( R_{CT} \)), indicating the amount of polarization, was decreased in the order of paper and glass, and it was clearly related to the enhanced lifting force of the two types of objects (23.9 and 50.0 kPa, respectively). Hence, the impedance analysis could quantify the magnitude of polarizations and the amount of induced charges of objects while in contact with the device.

KEYWORDS: micropatterned electroadhesive device, electroadhesion, induced polarization, areal adhesion force, voltage breakdown

INTRODUCTION

In daily lives, small objects are picked by the precision grip of two fingers (index and thumb). The ratio of the grip and load forces is a function of the finger-surface friction, more specifically since the effective lateral pressure is a function of the normal clamping force and friction coefficient. Following the Amonton’s law (Coulomb’s law) for various objects, the fingertip manipulates the parallel change in the tangential and normal forces in such motions as shaking, lifting, and transporting handheld objects. The tangential force of two fingertips of a young healthy adult is equivalent to the one grasping an object weighing 200 g (2.7 N), which is equivalent to 8.9 kPa with an assumption that the contact area of each fingertip is 300 mm\(^2\). Various artificial precision grips have been developed to simulate this amazing capability of fingertips. In this sense, one of the most promising technology may be based on the electroadhesion principle, which could allow lifting up almost all of the objects made from any type of material or possessing any kind of shape. However, it should be addressed that the up-to-date level of the tangential force of electroadhesive devices is far below the capability of human fingertips.

Concurrently, electroadhesion is electrically controllable adhesion technology and electroadhesive force is caused within two interfacial surfaces, i.e., the polarized electroadhesive device and the substrate. It has been pointed out that the electroadhesion mechanism has several advantages, such as reduced complexity, silent operation, low energy consumption, and smooth contact, but the areal adhesion force is so low in comparison with human fingertips (ca. 8.9 kPa) that the practical application is still limited. For example, the shear stress (areal adhesion force) of an electroadhesive device on the paper objects has been reported as 2.4 kPa (4.0 kV of the applied voltage) and 0.8 kPa (0.6 kV of the applied voltage) utilized for the application of climbing robots. In the most recent study, the shear stress of a wall-climbing robot was 2.3 kPa (6.0 kV of the applied voltage), which is still far lower than the human fingertip capability. In addition, the combination of a triboelectric generator with the electrostatic system allows us to move microfluids with electrostatic force and generate 1.5 kPa of adhesion force (2.0 kV of the applied

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