Polyurethane Micro-Gripper Utilizing Van-Der-Waals' Forces in Micro-Assembly

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Abstract
Handling of micro-parts with dimensions of 10 mm x 10 mm and below is a common issue for electronics and sensor or actuator manufacturing. Particularly if the parts are very thin compared to the lateral dimensions, for example less than 0.3 mm for a 10 mm x 10 mm part, care has to be taken handling those parts. In case of piezoceramics, as used for sensors and actuators, common mechanical and vacuum grippers apply high local contact pressures inducing the risk of micro-fractures. Given this background, this paper provides a new approach for handling piezoceramic micro parts with one handling system and one gripper. This gripper is a polyurethane micro-gripper which is soft and only actuated by van-der-Waals’ forces. Unlike conventional micro-grippers, polyurethane micro-grippers do neither require power supply nor pressurized air.

Keywords
Polyurethane Gripper, Van-Der-Waals’ Force, Micro-Assembly.

1 INTRODUCTION
Mechanical and vacuum grippers are widely used in the handling of micro parts during assembly operations. However, these grippers have limitations when fragile micro parts are to be assembled because they cause highly localised forces which develop high concentrated stresses. This may eventually lead to fracture. Piezoceramic micro parts which are vital micro-components in the assembly of piezo-metal sensor modules are extremely brittle given their slender ratio of about 1:10 [1]. Therefore, mechanical and vacuum grippers would be unsuitable. Fortunately, polyurethane van-der-Waals’ force actuated micro-grippers prove to provide a better option.

2 VAN-DER-WAALS’ FORCES EXERTED BY POLYURETHANE MATERIAL
Van-der-Waals’ forces occur when objects are sufficiently close together. They are caused by a naturally fluctuating electromagnetic field between surfaces of interacting objects. This electromagnetic field is caused by the spontaneous electrical and magnetic polarisations occurring on the molecular level [2]. The use of polyurethane as a material handling force has origins in the research of gecko inspired adhesion. The unique feature of these creatures is that they can move rapidly over smooth surfaces, with the pads on their feet rapidly adhering to and releasing from the surface, leaving no residue [3-5]. The synthetic development of this type of adhesive is now possible and shows similar capabilities to its gecko counterpart [6-8].

The adhesive strength and versatility of polyurethane has been demonstrated in the creation of a wall climbing robot that uses polyurethane pads. These pads allow quick adhesion and removal with only the inherent Van-der-Waals’ forces being used [9, 10]. These Van-der-Waals’ forces were proven by Murphy et al [11] to be able to hold a 0.1 kg robot attached to a vertical wall. It was experimentally shown that the forces are no suction forces. A 0.5 kg mass was successfully hung onto a 1 cm² polyurethane pad in a 0.01 atmosphere vacuum chamber for 10 minutes [11]. Van-der-Waals’ forces exerted by given surfaces depend on several parameters which include material type, geometrical configuration and surface roughness of the interacting surfaces [12, 13]. A plane or flat geometrical configuration generally exerts more van-der-Waals’ forces than others [14]. VytaFlex polyurethane (commercially available from Smooth On) was shown to be viable for large scale use in the application of Van-der-Waals’ force based adhesion [9] and has been implemented in the wall climbing robots. The VytaFlex adhesive uses the desired “preload” technique which enhances the contact area and ultimately results in the exertion of optimal Van-der-Waals’ forces. Varying the preload force causes a variance in the adhesive force up to a point. Beyond this point an increase in preload force does not yield an increase in adhesive force [9, 15]. Using an optimal preload, Murphy et al. 2011’s polyurethane wall climbing micro-robot could scale vertical surfaces whose root-mean-square surface roughness values were as high as 35 µm. This indicates that an optimal preload overcomes (to some degree) the negative effects of high surface roughness. The micro-robot could scale any type of
surfaces (including wood, glass and metallic surfaces) which were inclined at any angle (including inverted walls). It shows that the combined effect of the preload, contact area and Hamaker coefficient of the polyurethane material led to the exertion of high van-der-Waals’ force on any given surface.

Mechanical grippers such as stainless steel pincers are very hard with a Brinell hardness number as high as 150 [16]. For example, when a pair of pincers which affords a contact area of 250 µm x 1 mm (considering the width of each side of the pincers to be 500µm) applies a preload of 20 N when gripping a piezoceramic element, a localised stress of 80 MPa develops on the element, given that the stress is equal to force divided by contact area [16]. This stress is far above the depolarisation pressure (stress) of 30 MPa, and equal to the tensile strength of 80 MPa recommended by the manufacturer for piezoceramic material [17]. A stress of 80 MPa induces a shear stress which is s 70% of the tensile strength (the maximum shear stress recommended by Groover [16]).

On the other hand, electrostatic gripping would be an alternative. However, in some cases, it leaves residual charges on the handled components [18] which may compromise the sensitivity of the piezoceramic sensors.

Given this background, van-der-Waals’ force actuated polyurethane grippers provide a better option because they are soft with shore hardness values generally between 10 A and 60 A [19]. They also afford a larger gripping surface which avoids development of high localised stresses, and do not require an external source of power to operate [7].

3 EXPERIMENTS

3.1 Machining of the piezoceramic elements and aluminium cavities

A micro-milling machine (Minitech model) was used to machine the piezoceramic elements and the aluminium cavities. The 250 µm x 260 µm x 10 mm piezoceramic elements were machined from a piezoceramic blank of 50 mm x 10 mm x 260 µm using a 254 µm diameter milling tool made of carbide material.

![Figure 1 - Dimensions of the micro-cavities in aluminium alloy carrier](image1.png)

Aluminium cavities of dimensions 300 µm wide x 220 µm deep x 10 mm, shown in Figure 1, were machined using the same tool. The adjacent cavities were 300 µm apart.

3.2 Preparation of polyurethane gripper

Polyurethane 20A (polyurethane with a shore hardness of 20 A, trade name – VytaFlex 20) was used to make the gripper. This product was chosen due to its proven viability [8, 10]. The material, supplied by AMT Composites – Smooth-On Company in Cape Town, was supplied in two parts, A and B (liquid ingredients), which were mixed in equal parts as per the manufacturer’s formula. Thorough mixing took place for at least 3 minutes as recommended by the manufacturer. A steel needle (any other suitable rigidity material may be used) was dipped into the polyurethane mix and then suspended vertically in air to allow the mix to form a spherical polyurethane tipped gripper as shown in Figure 2. The gripper was allowed to cure under ambient conditions for 24 hours.

![Figure 2 - Polyurethane spherical micro-gripper of approximately 1mm](image2.png)

3.3 Picking and placing experiments

To ensure high precision in the assembly of piezoceramic elements into the aluminium cavities a fine robotic positioning system mounted on a coarse positioning system was used [20]. The Motoman SDA 10D was used as the coarse positioning system, while the fine positioning system was from the Feinmess robot (shown in Figure 3).

![Figure 3 - Feinmess fine-positioning system](image3.png)

The polyurethane micro-gripper was used as the end effector of the Feinmess robot as shown in Figure 4A. A gripping force of approximately 0.2 N was applied by the polyurethane micro-gripper to pick the piezoceramic element. This force was found in preliminary experiments to provide an optimum van-der-Waals’ force on materials being picked. The haptic-force-feedback system incorporated on a Gamma F/T Mux transducer supplied by ATI Industrial Automation was used to measure this preloading force.
Finally, the polyurethane 20A gripper is retracted at 0.1 mm/s until the preload is zero and a horizontal displacement of the gripper away from the piezoceramic micro-assembly detaches it, leaving the assembly intact as shown in Figure 4C. This process is repeated in assembling the rest of the piezoceramic elements into the aluminium cavities as required in the design of a given sensor.

The spherical polyurethane gripper used in this case affords an improved view of the handled part, enhancing accuracy in the placement of the piezoceramic element. Another interesting feature which was observed about this polyurethane micro-gripper was its ability to pick up the piezoceramic element, removing it from a cavity. This might be a necessary operation, especially when the piezoceramic has been misplaced or misaligned. In this operation, a preload of 0.2 N is applied on the piezoceramic element by the polyurethane micro-gripper and retracted upwards, away from the cavity. In so doing the piezoceramic element is removed from the cavity.

4 CONCLUSION

This paper presents van-der-Waals’ force actuated polyurethane grippers as a viable option for micro-handling of brittle piezoceramic elements during micro-assembly. In this case, a spherical polyurethane micro-gripper of approximately 1 mm diameter was used to pick a 250 µm x 260 µm x 10 mm piezoceramic element and place it into 300 µm x 220 µm x 10 mm cavities. The Feinmess fine positioning system, with 3 µm accuracy, with the polyurethane micro-gripper as the end effector was used to achieve a precise pick and place operation. A preload of approximately 0.2 N was applied on the piezoceramic elements to ensure an optimal application of the van-der-Waals picking force. The picked piezoceramic elements were transferred and placed into the aluminium cavities. The polyurethane micro-gripper was retracted until the preload was reduced to zero and then displaced horizontally leaving the piezoceramic element in a specific cavity. This operation is repeated in assembling the rest of the piezoceramic elements into the aluminium cavities of a given micro-product. Future work would focus on how a polyurethane micro-gripper may be used to assemble simultaneously all the required piezoceramic elements into aluminium cavities in one operation.

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6 REFERENCES


7 BIOGRAPHY

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