USE OF VAN-DER-WAALS FORCES ACTUATED POLYURETHANE MICRO-GRIPPERS IN THE HANDLING OF IC MICRO-COMPONENTS.

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ABSTRACT

The handling of integrated circuit (IC) micro-parts is a great challenge in micro-assembly of electronics micro-components. The micro-parts adhere to the mechanical grippers used and in the event that they are released, precision is comprised. In some cases the micro-parts are strained or broken during the handling operations. Therefore, this paper presents a solution through the use of Van-der-Waals forces actuated polyurethane grippers. These grippers have advantages in that they do not leave residual stresses, charges and strains on the handled IC micro-components. They afford precision position of micro-parts and provide the necessary working space for soldering operations. A motoman robot coupled with polyurethane micro-grippers was used to pick, transfer and place micro-parts ranging from 10 mm down to 500 \( \mu \text{m} \) in the micro-assembly of IC micro-components.

Key words: Polyurethane micro-gripper, Van-der-Waals forces, IC micro-components

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1. INTRODUCTION

This paper seeks to demonstrate the effective handling of integrated circuit (IC) micro parts and materials. The handling of integrated circuit (IC) micro parts and materials involves challenges in the operation of picking and placing parts accurately. Currently pincers are used, which in some cases impart excessive force on the micro-parts that may strain or break the fragile micro-components. Some metallic pincers are also inaccurate when it comes to the releasing of the micro-part and they may offer very little gripping area, leading to the generation of highly concentrated stresses at the point of contact.

Polyurethane grippers offer a potential solution. Since polyurethane grippers are soft, they are able to pick and place without exerting excess strain or stress, and without leaving residual strain and stress ([1]). Furthermore, they do not leave any residual electrical charge on the handled components ([1]) making them suitable for sensitive electronic micro-parts handling. The fundamental gripping force of polyurethane gripper is Van der Waals force ([2], [3], [4], and [5]). To improve the precision in the placement of the handled micro-parts, a single polyurethane gripper with a single interactive flat surface is used for the picking and placing of the micro-materials.

2. BACKGROUND

Murphy et al [2] have found that a 1 cm x 1 cm polyurethane flat material can exert over 1 N of Van-der-Waals’ forces on smooth surfaces. The recent developments in the field of gecko-setae-like polyurethane micro- and nano-structures has enhanced the development of Van-der-Waals force actuated material handling operations ([3], [4], and [5]). These directional, hierarchical and high aspect ratio micro-structures with nano-fibres at the end, are shown in Figure 1.

![Image](Error! Reference source not found.)

Figure 1: Directional and Hierarchical polyurethane Fibres (NanoRobotics Lab, 2011)

Polyurethane materials can firmly grip both micro- and macro-workparts whose root-mean-square surface roughness values can be as high as 35µm ([2]). The advantage of these numerous nano-fibres is that they can increase the surface’s contact area by being in contact with the entire profile of a rough surface. Van-der-Waals’ forces were experimentally proven by Murphy et al [2] and Murphy et al [6] to hold (in a fixed position) micro-robot’s masses of at least 0.1 kg on vertical walls. This corresponds to shearing forces of 0.981N magnitude when gravity is taken as 9.81 N/Kg.

Furthermore, Murphy et al [7] proved that vacuum suction was not the principal source of adhesion in this scenario, but rather Van-der-Waals’ forces. They hung a mass of 0.5 kg onto the 1cm² polyurethane pad in a vacuum of less than 0.01 atmosphere, and the load was sustained for 10 minutes.

3. EXPERIMENTATION ON POLYURETHANE GRIPPER

Given the background, polyurethane material commercially produced by Smooth-On Company as Vytaflex Liquid Urethane Rubber Series was chosen for material handling purposes. Vytaflex is available in Shore Hardness of 10A, 20A, 30A, 40A, 50A and 60A. For the purpose of this experiment, polyurethane of shore hardness 30A was chosen because it was readily available locally and had the desired relatively low hardness so that it would not over strain or stress electronic micro-parts during handling.

Vytaflex polyurethane comes in 2 parts. These were mixed together in equal quantities before being poured into moulds and left to cure for 20 hours. The moulds were of a radius of 6 mm.

Attia and Alock [8], and Cao et al [9] indicate that the dimensions of a micro-part start from 1µm to a maximum 10 mm. The typical location accuracy is in the range of 0.1 to 10 microns ([10]). Therefore, an electronic micro-component of 9 mm x 9 mm encapsulated by epoxy was used. It was a 32-pin Low profile Quad Flat Pack (LQFP) integrated Circuit micro-chip whose part number was RSF21276NFP. The mass of the LQFP Micro chip was 0.2 grams ([11]).
Analysis of surface roughness was done on the Veeco NanoMan V Atomic Force Microscope with Nanoscope version 7.3 software at iThemba labs in Cape Town. The area of the scan was 10x10µm for the microchip. The resulting 3D surface roughness scan is shown in Figure 2 and a summary of the characteristics of the surface roughness is shown in Figure 3.

Figure 2: Chip Surface Roughness

Figure 3: Chip Surface Scan with Scan Details
The roughness is vital in the calculations of Van der Waals forces, and needs to be scrutinised. A lower root mean squared value allows for higher Van der Waals forces and therefore better picking capability ([12]). In this case the root mean square (rms) surface roughness value of the micro-chip was found to be 44.9 nm given by the “Image Rq” in Figure 3. This is suitable for micro-material handling using polyurethane gripper because it is far less than the rms surface roughness value of 35 µm which Murphy et al [2] postulated as the highest surface roughness value where Van-der- Waals forces may be applied for micro-material handling purposes.

4. FORCE MEASUREMENT OF THE VAN DER WAALS FORCES

A Motoman SDA10D, with a 15-axis capability and with a haptic force feedback system was used to measure the exerted Van der Waals forces exerted by the polyurethane material. An ATI multi-axis force/torque feedback sensor was used in this case.

An electrostatic mat was placed on the workstation to negate the effects of static electricity in the working environment. A grounding clip was attached to the force sensor to ground the robot. A copper coated circuit board was securely attached to the workstation, while the polyurethane gripper was attached to the force sensor.

The gripper was placed in position over the workstation. The gripper moved to within 5mm above the copper circuit board workstation. The final movement was performed via computer control employing haptic feedback. The 30A gripper was tested 6 times with an average preload of 0.369281 N (Table 1) bringing the polyurethane gripper in contact with a flat copper circuit board. Later the computer controller retracted the gripper in the vertical direction in 0.5mm increments until the gripper reached the 5mm original starting position.

During this lifting process the gripper exerted Van der Waals forces on the copper coated circuit board and these forces were recorded by the haptic force feedback sensor. The maximum positive force was then noted, which was the maximum Van der Waals force’s value.

5. ANALYSIS OF RESULTS

Table 1 shows the results for 6 tests of the polyurethane 30A grippers, of 6 mm radius. The 30A polyurethane mean maximum release force was 0.92005N. The results indicate that the process is indeed repeatable with a standard deviation of 0.04569 N as indicated in Table 1.

Table1: Van-der-Waals forces of polyurethane gripper acting on a flat copper circuit board

<table>
<thead>
<tr>
<th>Test 30A</th>
<th>Preload (Newtons)</th>
<th>Max Van-der-Waals forces upon release (Newtons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.363744</td>
<td>0.968435</td>
</tr>
<tr>
<td>2</td>
<td>0.394447</td>
<td>0.972948</td>
</tr>
<tr>
<td>3</td>
<td>0.356173</td>
<td>0.91884</td>
</tr>
<tr>
<td>4</td>
<td>0.389720</td>
<td>0.850674</td>
</tr>
<tr>
<td>5</td>
<td>0.335856</td>
<td>0.907136</td>
</tr>
<tr>
<td>6</td>
<td>0.375807</td>
<td>0.902294</td>
</tr>
<tr>
<td>Mean</td>
<td>0.36929</td>
<td>0.92005</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.02197</td>
<td>0.04569</td>
</tr>
</tbody>
</table>

Figure 4 shows a time plot of a specimen with almost average values of the preload and the exerted maximum Van-der-Waals force.
Figure 4: Van der Waals forces of 30A polyurethane gripper

Figure 5 shows a Van der Waals forces actuated polyurethane gripper applied in the assembling of the electronic micro-components onto an electronic circuit board. These masses and weights are far less that those Murphy et al [2] manipulated (0.1 Kg and 0.981 N) using Van der Waals forces as indicated earlier.

1. 9mm x 9 mm IC micro-component gripped by the polyurethane gripper
2. 9 mm x 9 mm IC micro-component transferred to the IC circuit board
3. 9 mm x 9 mm IC component being placed on the IC circuit board
4. 9 mm x 9 mm IC micro-component released on the IC circuit board after soldering

Figure 5 The picking, transfer and assembly of a 9 mm x 9 mm x 1.7 mm IC micro-component
Figure 5 shows the stages in the assembly of a 9 mm x 9 mm x 1.7 mm micro-component onto a circuit board using the “Van-der-Waals force actuated polyurethane gripper”. The polyurethane gripper affords a large contact area which prevents development of concentrated stress or high localised stresses. The gripper also affords a relatively improved placement of the micro-part because the polyurethane gripper does not interfere with the placement position since it grips one surface leaving the other for placement purposes. Furthermore, the Van der Waals forces exerted by the polyurethane gripper on the electronic micro-component are surface forces which do not strain or damage the work part.

To improve efficiency in the release of the micro-component from the gripper onto circuit board, soldering may be performed. The soldering temperature of approximately 183°C for the normally used eutectic alloy of 63% tin and 37% lead does not affect the polyurethane gripper because the IC component’s epoxy covering provides a shield from the heat emitted. Epoxy is a high heat resistant material and has a low thermal conductivity of less than 0.24 W/m°C ([13]). Furthermore, the polyurethane has a very low thermal conductivity of about 0.042 W/m°C. The authors successfully released their micro-component this way. In cases where more soldering space is required, a smaller polyurethane gripper may be used which does not overlap the dimensions of the electronic micro-component to be assembled.

6. CONCLUSION

In this paper Van-der-Waals forces actuated polyurethane micro-grippers have been explored and found to provide an alternative solution in the handling of electronic micro-components in assembly operations. They avail a large gripping interface on the micro-part. Since polyurethane grippers are soft, they do not leave residual stresses and strain on the handled micro-chip. Furthermore, the polyurethane micro-grippers interact with one surface of the handled micro-part leaving the other for placement purposes in a micro-assembly operation. In addition they do not interfere with the assembly base, creating room for soldering operations to take place on the handled micro-component.

6. REFERENCES


