# Polyurethane Grippers as a Substitute for Vacuum Grippers: A Case Study in an Electronics Environment

George Cronje[1] and Stephen Matope[2]

***Abstract***— In competitive electronics manufacturing industry, effective material handling of printed circuit boards is of utmost importance. This paper attempts to demonstrate that polyurethane grippers can be a viable substitute to current vacuum grippers used in the electronics industry. Polyurethane grippers are actuated by naturally existing van der Waals forces and do not require electric energy to operate as in the case of vacuum actuated grippers. The polyurethane grippers were applied in a manufacturing environment, in a company in KwaZulu Natal, and were found to be a viable solution in the handling of printed circuit boards beside the current vacuum grippers. Polyurethane is an inexpensive material and incorporating it in the design of grippers could lead to economic benefits since no external energy is required for actuation as in the case of vacuum grippers.

***Keywords***— polyurethane grippers, vacuum grippers, van der Waals force

## I. Introduction

THIS paper attempts to demonstrate that polyurethane grippers can be a viable substitute to current vacuum grippers used in the electronics industry. Currently vacuum grippers are used to pick and place printed circuit boards (PCBs) in assembly processes in a manufacturing company in KwaZulu Natal, where the case study was done. These grippers are experiencing insufficient pick-up reliability due to their inability to pick up a panel once a gripper is placed over a PCB's mounting hole (since no vacuum can be created over a through-hole). In the electronic manufacturing industry many different sizes of panels have to be picked and thus gripper positioning has to constantly be altered. There is no standard as to where grippers should be positioned on panels of different sizes, resulting in long setup times, consequently delaying the downstream production steps.

Polyurethane grippers could provide a solution to these problems since the grippers merely utilise their naturally occurring van der Waals forces for actuation, eliminating the need for a pneumatic system as in the case of vacuum grippers. Furthermore, they are less affected by through holes during operation as compared to vacuum grippers.

George Cronje[1], is with the University of Stellenbosch.
Stephen Matope[2], is with the University of Stellenbosch.

## II. Background

The usage of polyurethane for gripping purposes has origins in the research of gecko inspired adhesion. Billions of hairs cover the bottom of gecko's feet and give them the ability to scale flat surfaces, rapidly adhering and releasing from the surface without leaving any residue ([1] and [2]). The exact mechanisms of attachment of the gecko's feet when climbing had been unclear, but Autumn et al [3] provided evidence that van der Waals forces were the primary source of attachment strength. Tests ran by Murphy et al [4] state that a 1cm x 1cm cross-sectioned polyurethane flat material can exert over 1N of van der Waals forces on smooth and flat surfaces. Murphy et al [5] proved the effective use of polyurethane as an adhesive material by implementing fibrillar adhesive footpads on a tetherless wall climbing robot called Waalbot. The robot used polyurethane adhesive material and moved vertically on a wall consisting of rough and smooth surfaces whilst supporting the mass of the robot of 0.1kg. Polyurethane materials can firmly grip both micro and macroparts whose root-mean-square surface roughness values can be as high as 35μm [4].

## III. Polyurethane Gripper

The polyurethane material chosen to produce the gripper is part of the VytaFlex Series Liquid Urethane Rubber Series, supplied by AMT Composites in Cape Town, a distributor of Smooth-On Company (USA) [6]. Vytaflex polyurethane was selected because it was shown to be viable for large scale use in the application of van der Waals force based adhesion ([5], [7], [8]) and has been implemented in wall climbing robots as mentioned earlier. Vytaflex variants are available in shore hardness ranges of 10, 20, 30, 40, 50 and 60. For the purposes of this paper, Vytaflex 10, 20, 30, 40 and 50 were chosen. The Vytaflex variants are supplied in two parts. These liquid parts were mixed together in equal quantities (1:1 ratio) as per manufacturer's recommendations and thoroughly stirred for 3 minutes before being poured into moulds. Vytaflex 10 was left to cure for 24hours whereas Vytaflex 20 – 50 were left to cure for 16hours so as to meet the manufacturer's specifications.

The polyurethane grippers were designed such that they were compatible with the holding mechanism used for the current vacuum grippers at the company of the case study. The disassembly of one of the vacuum gripper holding mechanism can be seen in Figure 1. A machine screw was screwed into the

http://dx.doi.org/10.15242/IIE.E1115034

bottom of the gripper leg and rubber caps were placed around it. The assembly of the vacuum gripper during an industrial operation is shown in Figure 5.

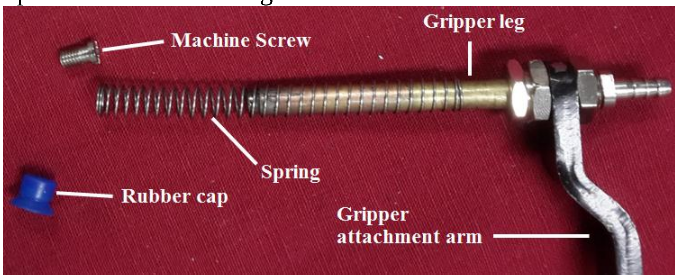


Fig. 1 Disassembly of a vacuum gripper mechanism

The compatible polyurethane grippers were designed and produced having aluminum bases of diameter (Ø) of 50mm as in Figure 2. Their final mounting during the case study is as shown in Figure 6.

Fig. 2 Vytaflex 20 polyurethane grippers

## IV. Force measurement of van der Waals forces

For a considerable amount of Van der Waals forces to be exerted between interacting surfaces, a preload has to be exerted first. A Motoman SDA10 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 gripper on a given surface. An ATI multi-axis force/torque feedback sensor was used in this case. The polyurethane gripper was mounted to the industrial gripper leg and was used for experimentation, replicating picking operations in industry. The spring of the gripper leg ensured that preload forces exerted by the Motoman robot were dampened and that uniform loading of the gripper was achieved. To eliminate electrostatic force from the equipment; the gripper and the PCB were connected to an anti-static mat. Figure 3 shows the experimental setup.

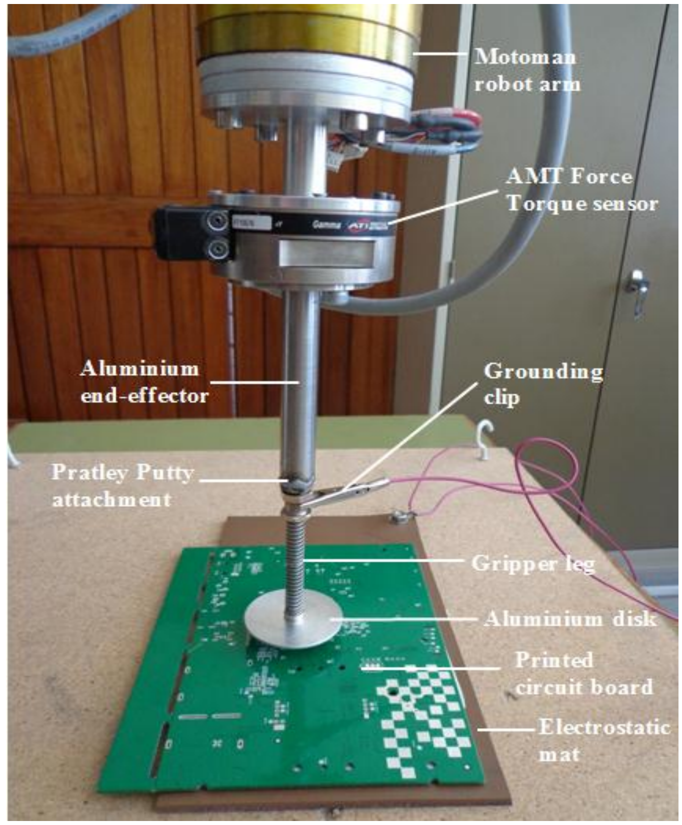


Fig. 3 Experimental setup for the Van der Waals force measurement test

The Motoman SDA10D was programmed through a lead-through method for it to exert the required preloads in gradual increments. The gripper was aligned 10 mm vertically above the PCB. The robot arm was moved vertically downwards until the gripper barely made contact with the PCB surface. From there the robot arm was vertically retracted to its initial position. This was performed at a constant 3% speed of the robot's full speed (0.045m/s). This vertical downward and retracting movement of the robot arm was repeated 19 times; however, each downward movement was slightly longer than the previous movement which created an increased preload between the gripper and targeted PCB surface when in contact. The longest downward movement of the robot arm was the same as that executed in industry, the case study was conducted. During a retraction movement the gripper exerted van der Waals forces on the PCB and these forces were recorded by the ATI multi-axis force/torque feedback sensor. The maximum positive force of the movement was noted, which was taken as the maximum van der Waals force's value. The ATI sensor recorded 50 readings per second.

The above testing process was repeated 20 times for Vytaflex 10, 20, 30, 40 and 50 grippers in order to make a comparison between the van der Waals forces exerted by the different Vytaflex variants.

### A. Force measurement interpretation

The van der Waals forces for the Vytaflex 30 gripper of diameter 50 mm can be seen in Figure 4. The vertical axis indicates the force applied, negative force indicating preload and positive force indicating retraction (and therefore adhesion due to van der Waals forces). The horizontal axis represents time in seconds.

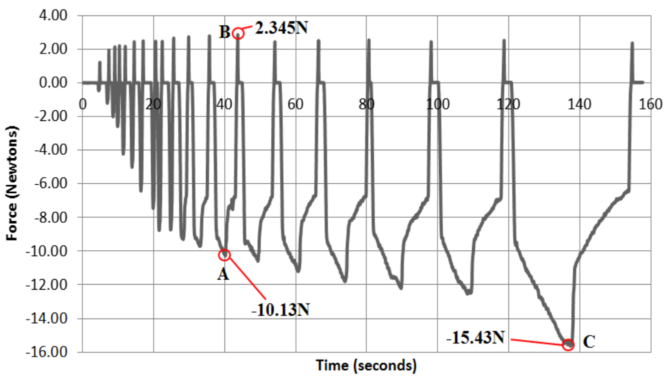


Fig. 4 Preloads and Van der Waals forces against time for Vytaflex 30

It can be seen on the graph that the van der Waals forces increased as the preload increased up to a certain point (point B in this case). Once this point was past an increase in preload force could not bring about an increase in adhesive force as was seen in the work of Murphy et al [5]. This plateau of adhesive force was reached at a preload of -10.13 N (at a point A) and offered a maximum release force of 2.345 N (at a point B) as indicated on the graph. Each variant of polyurethane reached its own different plateau of adhesive force (at a point B) at a different preload (at a point A).

Point C (in Figure 4) indicates the preload that is currently being applied in industry (-15.43 N) on vacuum grippers, which in the case of a polyurethane gripper does not increase the resulting van der Waals force exerted. Table 1 demonstrates the comparison between spring compressions (directly related to the preload exerted) for the points B and C. Using the spring constants and their respective displacements; the corresponding energy equations, as indicated in (1) and (2) are derived.

$$W_1 = 0.5kx_1^2 \quad (1)$$

$$W_2 = 0.5kx_2^2 \quad (2)$$

Where:

- $W_1$ = Work done by the least preload (corresponding to point A) which gives the maximum Van der Waals force (Joules)
- $W_2$ = Work done by the preload in industry (corresponding to point C) (Joules)
- k = Spring constant (N/m)
- $x_1$ = spring compression due to the preload corresponding to point A (m).
- $x_2$ = spring compression due to the industrial preload corresponding to point C (m)

Dividing Equation (1) by Equation (2) we get:

$$W_1 / W_2 = x_1^2/x_2^2$$

The energy calculations in Table I revealed that in industry more than 160% preload energy ($W_2$) is expended than that for the least preload to achieve the maximum van der Waals forces ($W_1$).

TABLE I
COMPARISON OF SPRING COMPRESSION FOR POINT A VERSUS THAT FOR C

| Polyurethane gripper | $x_1$ (m) | $x_2$ (m) | Energy difference as a percentage = (W2 - W1) /W1 |
|---|---|---|---|
| 10 | 0.021 | 0.034 | 162.13 % |
| 20 | 0.021 | 0.034 | 162.13 % |
| 30 | 0.0084 | 0.034 | 1538.32 % |
| 40 | 0.018 | 0.034 | 256.79 % |
| 50 | 0.021 | 0.034 | 162.13 % |
| 10 | 0.021 | 0.034 | 162.13 % |

## V. PANEL PICK-UP TESTING

Figure 5 shows the four vacuum grippers that were used to pick up panels (PCBs). The grippers were moved down unto the panel through the use of a pneumatic piston. Once the rubber caps had made full contact with panel the vacuum system was switched on and the panel was gripped. The panel was picked and then released on to a conveyor belt for onward processing as in Figure 5.

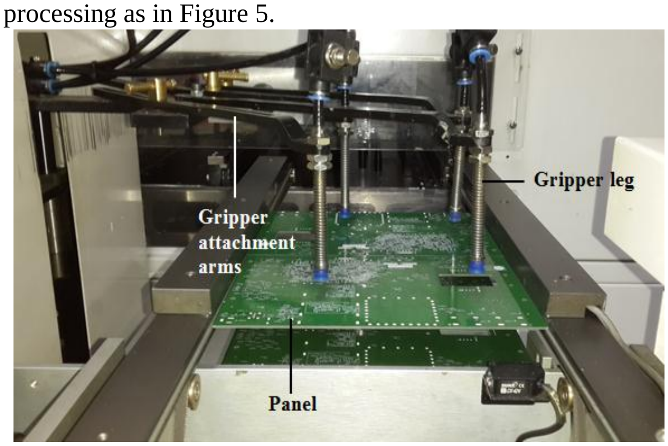


Fig. 5 Vacuum grippers picking a panel in industry

In the electronic manufacturing company, where the case study was done, many different sizes of PCBs had to be picked and thus gripper positioning had to be altered constantly. This resulted in long setup times which were relatively costly to the company.

As an alternative, a polyurethane gripper was installed on the same industrial machine as shown in Figure 6. This gripper did not require long setup times and did not necessarily require setting it up each time when a different size of panel was to be handled, since the polyurethane gripper was positioned such that it gripped the panels on their centres. The other advantage of this installation was that one polyurethane gripper replaced the four vacuum grippers. Unlike vacuum grippers, the polyurethane gripper was not easily affected by small through-holes in PCBs (also referred to as mounting holes).

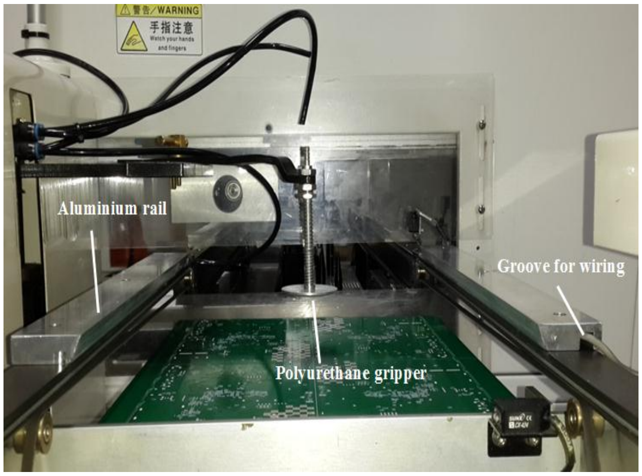


Fig. 6 Polyurethane gripper picking a panel in industry

The challenge faced by the polyurethane gripper was the release of the picked panels, since in this case no pneumatic system was being used for release. To afford a reliable release, chamfered aluminum rails were used as shown in Figure 6, which knocked off the picked PCB panel on to the conveyer belt.

As for the other Vytaflex variants, they were also mounted to the industrial machine as in Figure 6 and successfully picked up 100 panels each consecutively. The Vytaflex 30 gripper was chosen for further picking reliability tests, because its shore hardness falls in the middle of the Vytaflex variants' hardness. On continuous experimentation on pick and releasing cycles, failures were observed on the $130^{th}$ and $280^{th}$ cycles. After the first failure the gripper was rinsed under a running water tap and then blown by compressed air to blow moisture off the gripper's surface. After the second failure more preload was applied and the polyurethane gripper picked 800 panels in succession. This infers that more preload reduces any unevenness on the gripper face such that full contact is made with the target.

## VI. CONCLUSION

In conclusion, the polyurethane gripper proved to be a viable substitute for vacuum grippers in the handling of PCBs. The main advantage of using polyurethane grippers is that they do not rely on an external source of energy of actuation as in the case of vacuum grippers. They are simply actuated by the naturally occurring Van der Waals forces. In this case study, one polyurethane gripper was found capable of replacing four vacuum grippers in handling one PCB. Furthermore, the preload required to effectively actuate the polyurethane grippers was found to be less than that being used in the actuation of vacuum grippers, leading to some energy saving when a polyurethane gripper in used .

## REFERENCES

[1] F. Acker, "Synthetic Gecko", 2007, *Ingenia*, 30, pp. 39-42.

[2] Y. Mengüç and M. Sitti, "Gecko-Inspired Polymer Adhesives", *Polym. Adhes. Frict. Lubr.*, 2013, pp. 351–389 http://dx.doi.org/10.1002/9781118505175.ch9.

[3] K. Autumn, M. Sitti, Y. a Liang, A. M. Peattie, W. R. Hansen, S. Sponberg, T. W. Kenny, R. Fearing, J. N. Israelachvili, and R. J. Full, "Evidence for van der Waals adhesion in gecko setae.," *Proc. Natl. Acad. Sci. U. S. A.*, Vol. 99, No. 19, 2002, pp. 12252–12256. http://dx.doi.org/10.1073/pnas.192252799

[4] M. P. Murphy, C. Kute, and M. Sitti, "Waalbot II : Adhesion Recovery and Improved Performance of a Climbing Robot using Fibrillar Adhesives," *The International Journal of Robotics Research* 30(1), 2011, pp.118-13. http://dx.doi.org/10.1177/0278364910382862

[5] M. P. Murphy and M. Sitti, "Waalbot: An Agile Small-Scale Wall-Climbing Robot Utilizing Dry Elastomer Adhesives," *IEEEASME Trans. Mechatronics*, 2007, Vol. 12, No. 3, pp. 330–338. http://dx.doi.org/10.1109/TMECH.2007.897277

[6] "Smooth On." [Online]. http://www.smooth-on.com/Urethane-Rubber-an/c6_1117_1142/index.html, Accessed on 5 November 2015

[7] M. Arderne, S. Matope, A. F. Van Der Merwe, and L. Nyanga, "Use of van-der-Waals forces actuated polyurethane micro-grippers in the handling of IC micro-components", *CIE42 Proceedings*, 16-18 July 2012, pp. 189-1 to 189-7.

[8] G. B. Lennox, S. Matope, T. Dirkse van Schalkwyk, A.F. Van Der Merwe, "Application of polyurethane materials in the assembly of micro-components," *SAIIE25 Proceedings*, 9th – 11th of July 2013, pp. 560-1to 560-12

**George F. Cronje** is a final year B. Eng (Hons) student at the University of Stellenbosch.

**Stephen Matope** is a Senior Lecturer in the Department of Industrial Engineering at Stellenbosch University since 2012. He holds an MSc (Manufacturing Systems and Operations Management) UZ and a PhD (Industrial Engineering) obtained at Stellenbosch University. His research interests are in manufacturing engineering and learning factories.