RESEARCH ARTICLE | MAY 23 2023

Design of nozzles for surface mount technologies produced by additive manufacturing

Álvaro M. Sampaio ✉; Ana C. Miranda; António J. Pontes

AIP Conf. Proc. 2607, 120004 (2023)
https://doi.org/10.1063/5.0136200

Design of Nozzles for Surface Mount Technologies Produced by Additive Manufacturing

Álvaro M. Sampaio[1,2,3 a)], Ana C. Miranda [1,2 b)] and António J. Pontes [1,2 c)]

[1] *DONE Lab – Advanced manufacturing of Products and Tools, Guimarães, Portugal*
[2] *Institute of Polymers and Composites, University of Minho, Guimarães, Portugal*
[3]*Lab2PT, University of Minho, Guimarães, Portugal*

[a)] Corresponding author: amsampaio@eaad.uminho.pt
[b)] acmiranda@dep.uminho.pt
[c)] pontes@dep.uminho.pt

Abstract. The increasing use and production of electronic systems, equipped with multiple PCBs, leads to constant development in manufacturing technologies. A predominant choice in PCB production is Surface Mount Technology (SMT). The most important phase of the SMT process is the pickup and placement step, where nozzles, specific to the electronic component, are responsible to pick components and place them on the PCB. The interaction between the nozzles and the components imposes issues that lead to losses of process productivity. Currently, the development of a nozzle for an electrical component is time-consuming and, sometimes, the final solution is not tailored enough to take full advantage of the SMT machine efficiency. This research aims to fill this gap, through a new nozzle production method using additive manufacturing (AM), which makes it possible to respond to requirements such as, real-time, customized, and high dimensional accuracy nozzle design and production. Despite these advantages, the materials and manufacturing technologies available need improvements to meet the SMT requirements for nozzles production. Therefore, the research focused on the development of an electrostatic discharge (ESD) solution for AM, and the study of geometries that allow vacuum picking of electronic components with zero or low leakage. To show the viability of this method, electrical characterization tests were performed on the materials used, showing that ESD properties could be achieved. Moreover, a set of experimental tests were also performed to prove that the vacuum values were in the same range as the traditional nozzles. In sum, this research presents an alternative solution that allows for quick and flexible nozzle production.

INTRODUCTION

The production of electronic equipment has presented a great impact on the industry. This equipment, when produced in large quantities, resort to automatic assembly processes, as is the case of surface mount technology (SMT). This is an automated circuit assembly process that ensures the assembly of electronic circuits using surface-mount devices (SMD), this process consists of different phases such as: adhesive application for surface mount components; placing the surface mount components; wave soldering and cleaning [1].

In particular, the pickup and placement system is responsible for placing the components in the PCB through a vacuum system with the following assembly sequence: (i) vacuum is activated, (ii) the component is picked by a nozzle, (iii) vacuum is checked, if vacuum levels are below a programmed limit, the equipment rejects the electronic component, if vacuum values are within the permissible values, (iv) it allows to go to the transport phase, that is followed by (v) the blow responsible for placing the component in the PCB [2]. With respect to the nozzles for pickup and placement these are very small parts with internal channels that are responsible for handling the components.

However, the handling of the components is not always efficient, mainly because the dimensions of the components and their variability creates the necessity for a huge range of nozzles and, therefore, in many cases, nozzles are not custom-made for the component but rather "the best adaptation" that was possible. This is due mainly because of the long development and production times that a nozzle needs, that are not aligned with companies lead times. In this context, current solutions are not tailored enough which leads to losses of components during pickup and placement process the rejection of final parts and, therefore, lack of productivity.

Proceedings of the 36th Conference of the Polymer Processing Society – PPS36
AIP Conf. Proc. 2607, 120004-1–120004-6; https://doi.org/10.1063/5.0136200
Published by AIP Publishing. 978-0-7354-4506-2/$30.00

This research aims to develop a production method to mitigate the problems associated with the current nozzles by resorting to Additive Manufacturing (AM) technologies to produce these parts. These technologies allow the development of new nozzles, that can be customized, present high dimensional accuracy and can be produced in shorter lead times. In this perspective, to meet the Electrostatic Discharge (ESD) requirements of nozzles for SMT process (i.e., resistance between 10^4 and 10^9 Ω), the research focus on developments to define the best application conditions for a coating process on an AM material available on the market, since none of the materials available present such characteristic. Therefore, the present work reports the design of experiments implemented to define the best application conditions for the coating according to the electrical characterization, flowed by the evaluation of vacuum flow rate in specific nozzles for the best materials studied and then the production of different nozzle geometries and their application on a SMT process.

EXPERIMENTAL PROCEDURES

Materials and equipment

The technologies used to produce the nozzles was a Stereolithography (SLA) equipment with a resolution of 25 µm, and a Material Jetting (MJ) with an accuracy of 20-85 microns [3] [4]. The corresponding materials were an engineering resin (Flexible 80A), from Formlabs, for SLA Technology, and a rubber-like photopolymer (Agilus30) and a rigid and opaque material (VeroBlack) from Stratasys for the MJ technology. The coating applied in the nozzles was a thermoplastic binder with pure, fine electrically conductive graphite powder (GRAPHIT 33) from Kontakt Chemie. The materials were chosen according to the suitability of the properties to the product under development.

Methods

Nozzle assembly

The nozzles are comprised by three components (Fig. 1): a) a pipette, that is responsible for picking up the component, and the focus of this research; b) a mirror, where pipettes are fixed, c) a pin with an internal channel that mounts to the machine head and clamps the mirror and pipette.

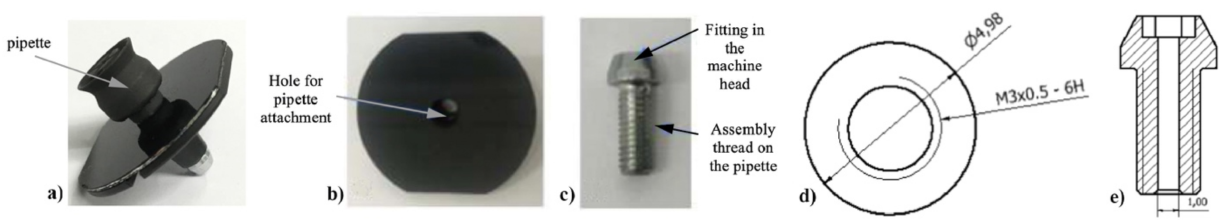

FIGURE 1. Constitution of a nozzle: a) mirror; b) pin; c) assemble nozzle; d) sketch of the cylindrical area section of the pipette tip for mirror attachment; e) sectional view of the machine connection pin.

In order to be able to mount pipettes to the mirror they must have a 4.98 mm of outer diameter and a M3x0.5 mm in the inner circle (Fig. 1d), that is then screw up to the pin. The pin for this assembly is a 1 mm diameter through hole (Fig. 1e). that is responsible for connecting the entire vacuum system of the pipette with the vacuum circuit of the machine.

Coating application

The coating was applied by pulverization, in this procedure the coating material is forced through a nozzle to produce a fine aerosol [5]. The application conditions were studied trough a design of experiments (DOE), according to the indications provided by the technical sheet. The application parameters that influence the performance of the coating are: i) application distance; ii) surface polishing; iii) number of layers. The fixed parameters were an application time of ± 5 seconds and a drying time of 4 hours.

TABLE 1. Parameters studied and respective values of the design experiment.

Levels	Application distance	Surface polishing	Number of layers
0	20 cm	No	1
1	30 cm	Yes	2

A regular experimental design of 2 levels, 3 factors and 8 experiments (L8 matrix) were performed (Table 1). For each experiment, 3 samples were collected and analyzed. The materials used in this study were Agilus30, VeroBlack and Flexible 80A. The DOE response variable is electrical resistance.

Electrical characterization

The electrical resistance measurement was performed with a multimeter. The nozzle was placed between two stainless steel surfaces, each of these surfaces is connected to the multimeter, thus allowing the measurement of the electrical resistance between the two ends of the nozzle.

Vacuum flow rate check for leakage determination

The flow rate measurement is performed in order to check the existence of leaks in the developed nozzles which make it impossible to transport and insert the electronic components. This measurement is carried out with the nozzle open and closed (by placing a component at the end). The results are analyzed by comparing the values obtained on the developed nozzles with those obtained on the original nozzle.

Rejection rate

The developed nozzles were put into production in the SMT process, throughout production the following is recorded in the statistical report: the number of insertions made by each nozzle; the number of errors and the number of defects. With this data collected during the operation of the nozzle it is possible to estimate the rejection rate. Results were compared with the original nozzle.

Wear resistance

The wear resistance of the coating is measured as a function of how many insertions the nozzle achieves until it moves out of the ESD range. The electrical resistance is therefore measured before the nozzle is put into the SMD machine and then periodically after insertion until the nozzle is out of the ESD range or loses its functionality.

RESULTS AND DISCUSSION

Electrical characterization of the coated samples

The results of the electrical resistance of each of the 8 application conditions is presented in fig. 2, for the three materials studied.

The ESD concept is based on the transfer of charge between bodies at different electrostatic potentials caused by direct or induced contact with an electrostatic field [6]. In the results presented in fig. 2 all the experiments show results within the range required for this functionality. Nevertheless, the coating application parameters used in Experiment 7 was the one considered for the application on nozzles developed (application distance: 20 cm; number of layers: 2; with surface polishing).

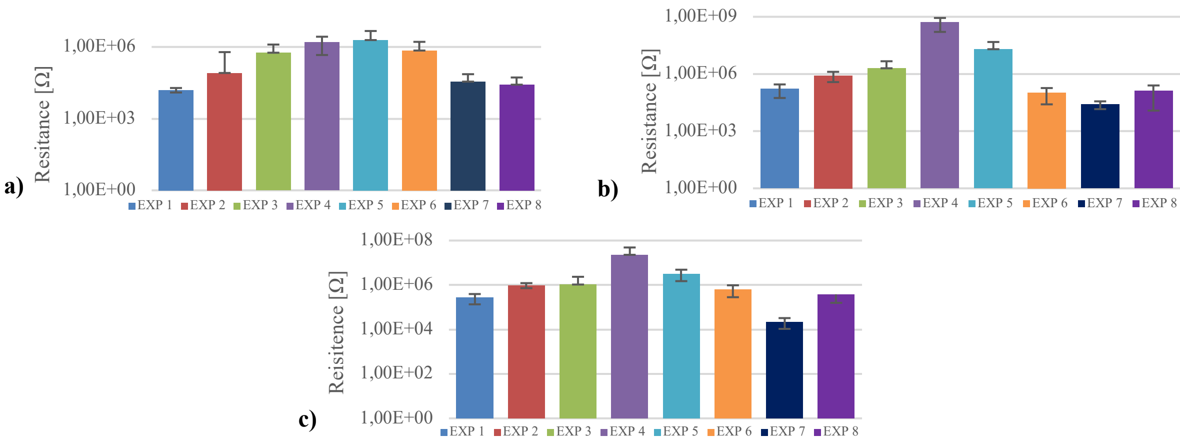

FIGURE 2. Electrical resistance of the material with coating application: a) Agilus30; b) VeroBlack; c) Flexible 80A.

Selection of additive manufacturing materials to produce the nozzles

The pipettes for the 1003 nozzle were produced in the different materials: Flexible 80A; VeroBlack and Agilus30; Agilus30; VeroBlack, these are presented in fig. 3a). The pipettes produced in the different materials were assembled on the mirror with the aim of test their functioning in the vacuum system. The fig. 3b), shows some examples of the nozzles 1003 assembled.

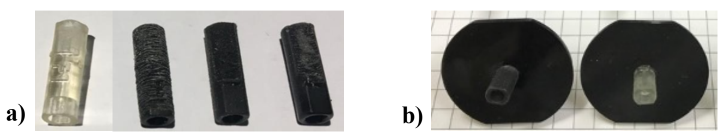

FIGURE 3. Prototypes of the 1003 nozzle: a) pipettes in the various materials; b) examples of the nozzles 1003 assembled.

The functionality of the nozzles and consequent definition of the most suitable materials for nozzle production was performed through the vacuum flow rate check.

TABLE 2. Results of vacuum flow rate check for the nozzles with the reference 1003.

Nozzle Geometry	Material	Sample	Open nozzle	Closed nozzle
1003	Metal	Original	-80	-7
	Agilus30 and VeroBlack	AV1	-70	-8
	Flexible 80A	F1	-75	-3
	VeroBlack	V1	-78	-13
	Agilus30	A1	-71	-50

The manufacture of the nozzle 1003 in the different materials/combination of materials followed by the vacuum flow rate test allowed to understand which of these materials presented the best results for this functionality, the values obtained and shown in table 2, indicate the following materials as viable to use in vacuum system: Flexible 80A and the combination between Agilus30 and VeroBlack. The nozzles excluded presented high values for the experiments with the nozzle closed, the existence of high leakages would lead to difficulties in the transport and placement of the electronic component.

Development and production of other geometries of nozzles

Considering the defined material selection, geometries 1005 and 2442 were developed only with the materials that showed positive results for geometry 1003.

Figure 4 shows the prototypes developed for the nozzle with reference 1005 (a to e) and with the reference 2442 (f to i). The rigid and flexible zones are assigned according to the materials used in the original nozzles, to obtain a nozzle as close as possible to the original. For both references, the original part is a combination of a rigid and a flexible material. In the development of nozzle 1005, the first approach developed that combines rigidity and flexibility was produced by combining the materials Agilus30 and VeroBlack. The result of this combination was not satisfactory as the flexible part of the nozzle did not have the structural integrity required for proper operation in a vacuum system, this led to the development of a nozzle combining Flexible 80A and VeroBlack materials, Fig. 4 c).

FIGURE 4. Prototypes of the nozzles 1005 and 2442: a) original 1005; b) Flexible 80A 1005; c) VeroBlack and Flexible 80A 1005; d) Agilus30 and VeroBlack 1005; e) appearance of nozzles 1005 with coating; f) Original 2442; g) Flexible 80A 2442; h) VeroBlack and Agilus30 2442; i) appearance of nozzles 2442 with coating.

Vacuum flow rate check for leakage determination

Each of the nozzles was submitted to this verification.

TABLE 3. Results of vacuum flow rate check for the developed nozzles (reference 1005 and 2442).

Nozzle Geometry	Material	Sample	Open nozzle	Closed nozzle
1005	Metal and Rubber	Original	-85	-3
	Flexible 80A	F2	-85	-4
	Flexible and VeroBlack	FV1	-85	-4
	Agilus30 and VeroBlack	AV2	-84	Without pickup
2442	Metal and Rubber	Original	-86	-3
	Flexible 80A	F3	-85	-3
	Agilus30 and VeroBlack	AV3	-84	-24

In the case of geometry 1005, three prototypes were developed with distinct materials, nominated in the Table 3. The results of the flow rate check test have approved the nozzles F2 and FV1. For the case of the nozzle AV2 when the flow rate was checked in the nozzle open the result similar to the original nozzle is achieved, however when checking the flow rate with the nozzle closed with a component the leaks were so high that the nozzle was unable to pick up the component. With respect to the 2442 geometry and the materials used, two approaches were adopted, the F3 nozzle produced in a single material and the AV3 nozzle, produced with a combination of materials. In this case only the nozzle F3 was approved in the flow rate check test.

Rejection rate

The approved nozzles, 1005 Flexible and VeroBlack, and 2442 Flexible were placed into operation in a SMT process. During the pickup and placement progression the number of insertions, errors and defects, shown in the Table 4, were recorded. The errors, refer to problems detected before placing the electronic component on the PCB, in this case only the component is discarded. The defects, refer to problems identified when assembling the components in the PCB, in this case the entire PCB is discarded.

The results of the statistical report (Table 4), show low error and defect values, the rejection rate for each of the nozzles was calculated. The nozzle AV1 had a rejection rate of 0,01%, value lower than that of the original nozzle. The nozzle FV1 present a rejection rate of 0,04%, similar to the original nozzle, and the nozzle F3 showed exceptional behavior, as no errors or defects were recorded.

TABLE 4. Statistical report of the prototypes applied to the SMT process.

Sample	Material	Number of insertions	Errors	Defects	Rejection rate original nozzle	Rejection rate new nozzle
AV1	Agilus30 and VeroBlack	123 354	11	2	1,04%	0,01%
FV1	Flexible and VeroBlack	13 240	6	0	0,04%	0,04%
F3	Flexible 80A	42 295	0	0	0,28%	0%

Wear resistance

During the testing of the nozzles in production, the evolution of the electrical resistance throughout the process was recorded. Table 5 shows the initial resistance value of the nozzle before being placed in production and after the indicated number of insertions.

TABLE 5. Electrical resistance of the nozzles during de pickup and place process.

Sample	Initial electrical resistance (Ω)	Number of insertions	Final electrical resistance (Ω)
AV1	$1,30x10^4$	123 354	$2,20x10^4$
FV1	$3,90x10^4$	13 240	$4,1x10^4$
F3	$7x10^4$	42 295	$7,3x10^4$

The results show that, in all nozzles tested the electrical resistance values remain within the required range after the insertions recorded for each of the cases.

CONCLUSIONS

Although conventional nozzles are typically more applied in the SMT process, in this paper it was presented a new strategy for producing nozzles, which is faster and more tailored, allowing real-time production and meeting the requirements of nozzles development.

The results show that some AM materials are perfectly applicable to nozzle productions, where they present similar, and in some cases better behavior than the conventional nozzles on the industry. Depending on the case, but especially when time-to-market of a new PCB, or a customized production line providing a wide range of SMD components are important factors, the production of nozzles using AM technologies adds value to the process. In addition to this advantage, it was presented an ESD solution that combining with AM materials presents good performance in vacuum systems, which can be used in another products when such requirement is necessary.

REFERENCES

1. J.E. Traister, *Design guidelines for surface mount technology* (San Diego: Academic Press, 1990).
2. Panasonic, “basic training manual.”
3. Stratasys, “Object350 and Object500 Connex 3.” Stratasys, 2016.
4. “Form 3: Industrial-Quality Desktop SLA 3D Printer.” https://formlabs.com/3d-printers/form-3/ (accessed Aug. 06, 2021).
5. V. Goodship, B. Middleton, and R. Cherringtin, *Design and Manufacture of Plastic Components for Multifunctionality: Structural composites, injection molding, and 3D printing* (William Andrew - Elsevier, 2015).
6. IEC, “Protection of electronic devices from electrostatic phenomena – General requirements,” 1998.