

# Some Insights on Chemical Treatment of 3D Printed Parts

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**Abstract:** *The substantial increase in the use of the FDM (Fused Deposition Modeling) process for the production of plastic parts in ever wider fields has led to the search for methods to improve the quality of the printed parts. In the case of ABS parts (Acrylonitrile Butadiene Styrene), one of the most common and used methods to improve surface quality is the process of acetone steam treatment, but the application of this method also brings more or less negative effects on the part. The main side effects when applying this method is the low breaking strength and loss of part details on the sharp edges. This paper presents a set of contributions on the relationship between surface quality and the level of detail of parts subjected to acetone steam treatment. In order to analyze the influence of the treatment on the details of the parts, a reverse engineering method was used in which a polyarticular arm FARO Edge 7.5 was used to scan the parts and reconstruct them. The study was performed on parts with 20% infill, grid tipe.*

**Keywords:** *3D printing, reverse engineering, acetone smoothing, detail level*

## 1. Introduction

With the increasing use of the production process by 3D printing, especially FDM / FFF (fused deposition modeling / fused filament fabrication), both in the industrial and private sector (independent users both for the commercialization of printed parts or used as a hobby), began to focus on methods to improve surface quality and strength of the parts.

Acrylonitrile butadiene styrene (ABS) is a thermoplastic polymer usually used for injection molding applications made up of three monomers: acrylonitrile, butadiene and styrene. Because it has a low melting temperature and a good impact resistance, ABS meets the property requirements for processing by 3D printing by FDM processes. Also, the low price of these material recommends it for a large number of applications across a wide range of industries.

Mainly, the methods of improving the surface quality of the parts made by the FDM process are either of mechanical nature [1-4], where the roughness is improved by various mechanical processes such as milling, turning, grinding, etc., or by chemical methods, methods that has been used in several scientific articles [5-10]. The current state of the art concerning pre- and post-processing methods of ABS FDM parts was carried out by Chohan and Singh [11] and Daniel Castro-Casado [12], where the authors reviewed specific methods for improving the surface quality of printed parts. One of the most widely used chemical methods is the method of improving the quality of surfaces using acetone steam. Acetone vapor smoothing is one of the most used and known chemical smoothing technique for ABS filament 3D FDM printing. ABS is a thermoplastic copolymer that easily reacts with chemical finishing agents when it's exposed to chemicals vapor. Acetone ((CH<sub>3</sub>)<sub>2</sub>CO) is solvent that can melt at room temperature and dissolve plastic material superficial layers. This method is used when the ABS (acrylonitrile butadiene styrene) is used as the main working material because their chemical reactions with acetone vapors lead to the softening of the ABS layers (blend of macromolecular chains and specific additives), which are then welded and rebuilt by allowing the spatial rearrangement of polymeric chains [13].

Studies [14-18] had shown that acetone vapor post- treatment significantly improves surface finishing and conduct to some changes of the mechanical proprieties. Decreasing of the stiffness and tensile strength due to the melting and fusion of the ABS layers were reported.

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The authors consider that surface treatment with acetone vapor has also the ability to increase the hardness of 3D printed parts by increasing the bonding between each of the layers. The acetone solvent vapours also affect the 3D printed part plasticity acting as a plasticizer. These aspects will be referred in a future research work.

Acetone vapor treatment can be done in two different ways, namely cold steam treatment, where the evaporation of acetone is done at room temperature where process takes longer or hot steam treatment, as used by Chohan et.al [14], where the evaporation of acetone is done at high temperatures and the process duration is much shorter. However, of these two methods of applying acetone steam treatment, the most widely used is the cold steam method due to the fact that it is less harmful and dangerous than the hot steam treatment method. The following is the current state of research studying the influence of acetone treatment on 3D printed ABS parts.

There are several studies in the literature that focus on investigating the effect of acetone steam treatment on ABS parts. Garg et al. [5] investigated the influence of roughness and strength (both tensile and bending) of ABS parts treated with acetone, parts constructed using different printing directions. In conclusion, acetone treatment drastically improved the quality of the surfaces, and the strength of the parts decreased in a small percentage. In [13], the same authors, using several printing directions, studied the surface quality and dimensional accuracy of ABS parts subjected to cold acetone steam treatment. As in the previous case, the surface quality improves considerably, and the dimensional accuracy has minimal variations. Several articles [6, 10, 15-17] have highlighted the fact that regardless of the method, steam treatment or acetone bath treatment, the surface quality increases considerably and the breaking strength (stretching) decreases. Mu et al. [6] compared acetone steam treatment with ethylene acetate steam treatment. Following the studies, in addition to the results similar to those found in the literature related to roughness and strength, the authors concluded that regardless of treatment and with increasing its duration, printed parts become heavier and acetone treatment had a greater impact on this aspect. Khan and Mishra [10] studied the influence of acetone treatment on the roughness of three different surface geometries: flat surface, inclined surface and round surface. As shown in other cases, acetone treatment improved surface quality regardless of its geometry.

Gao et al. [18] investigated the impact of acetone treatment on tensile strength and elongation of ABS printed parts. Following the application of the cold acetone steam treatment, the authors concluded that the duration of the treatment (in their case 1h and 2h respectively) has a significant impact on the breaking strength but also on the elongation of the material. According to the results obtained, it is observed that after the treatment, the breaking strength decreases and the elongation of the material increases. However, the trends of the studied factors differ depending on the orientation of the printing direction of the parts. At the same time, the authors observed that the layer size has no impact on the studied factors.

Although the literature provides extensive information on the influence of the acetone steam treatment process on ABS parts, this topic still requires relevant studies. Considering viable the information found, it is proposed to extend the studies on the influence of acetone steam treatment on FDM-ABS parts. As the literature suggests, in most cases, acetone steam treatment drastically reduces the roughness of the parts and decreases on a small scale the resistance to stretching and bending. At the same time, although the literature suggests that the dimensional accuracy does not change substantially, some information regarding the smoothing effect of the edges of the parts has been found [6], especially of the parts with very sharp edges. However, the FDM process has expanded to other areas such as aerospace, automotive [19], medical, etc. [20, 21], areas in which the parts must have the best possible dimensional accuracy, and thus the deformations due to the acetone steam treatment must be as small as possible. In this regard, it is proposed to use a reverse engineering method to study the degree of deformation of parts subjected to acetone steam treatment. With the study of these factors, it is possible to determine the quality of the surface of the parts subjected to treatment, thus obtaining an idea relative to the optimal treatment period to obtain both a good roughness and limiting the loss of parts details. At

the same time, in order to choose the optimal method of treatment, a comparison was made between simple and ventilated treatment methods.

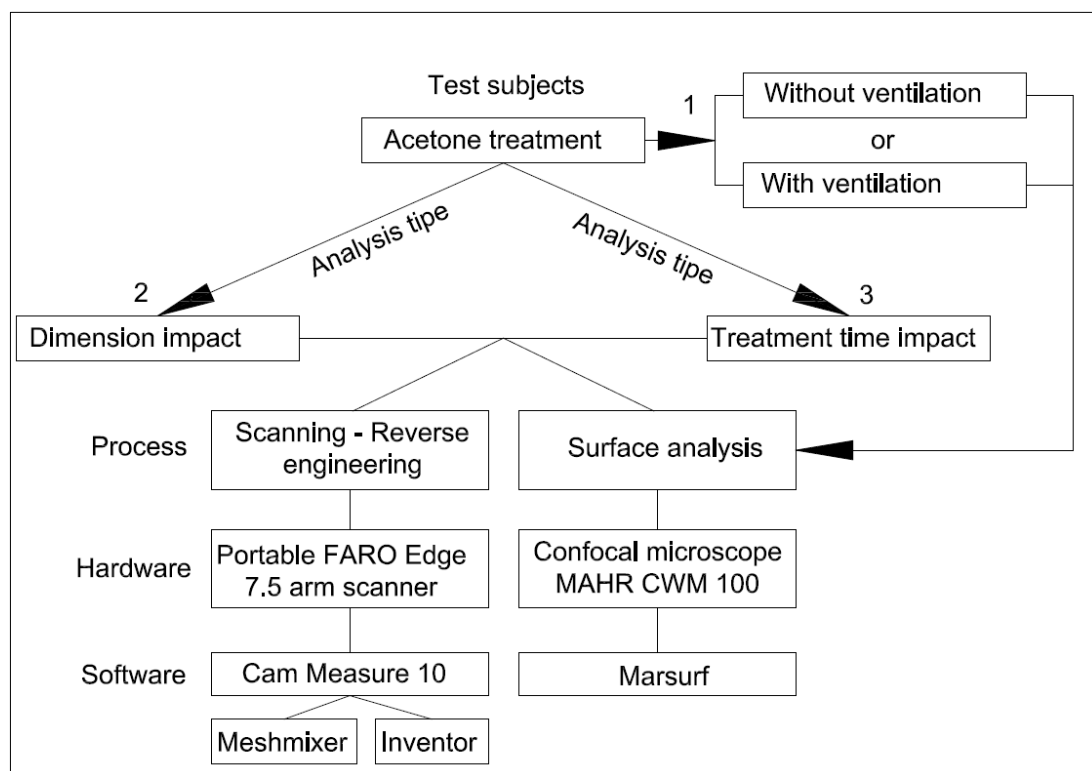
## 2. Materials and methods

In order to study the factors mentioned above, several determinations were made according to the scheme in Figure 1. The parts were processed on a desktop FDM 3D cartesian printer (build volume: 200x200x250). The working conditions used for printing the samples are presented in Table 1. The determinations were performed on specimens subjected to treatment in the order mentioned in the scheme. In the first stage, a comparison was made between the treatment with ventilated acetone and the unventilated one in order to establish the type of treatment subjected to the parts for the following stages. Once the optimal treatment variant has been established, the influences of the part size and the treatment time on the level of details as well as the quality of the surfaces can be studied.

**Table 1.** Printing conditions

Layer Height	Infill	Infill speed	Wall speed	Infill pattern	Printing temperature	Build plate temperature	Retraction	Print cooling	Nozzle
0.3mm	20%	50 mm/s	25 mm/s	Grid	235 °C	100 °C	6.5 mm	OFF	0.4 mm

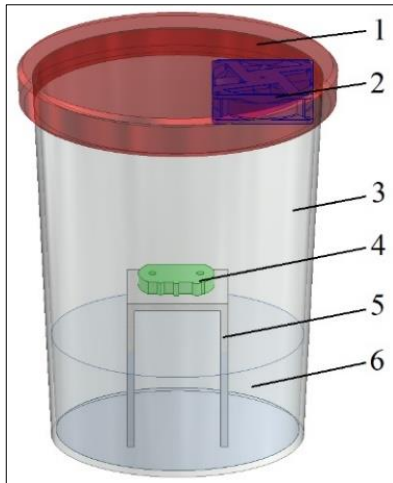
Finally, the results obtained are analyzed, interpreted and correlated so that the optimal period of application of the treatment can be concluded.



**Figure 1.** Testing stages

### 2.1. Choosing the treatment method

For smoothing using acetone steam treatment, the cold steam method was used because it is less dangerous than other methods and can be used by anyone. In this sense, the principle of operation of the method is presented in Figure 2. In the container, 3, was poured 100mL of acetone, 6, which was completed at each treatment. The treated specimen, 4, is positioned on a metal support, 5, that has a flat

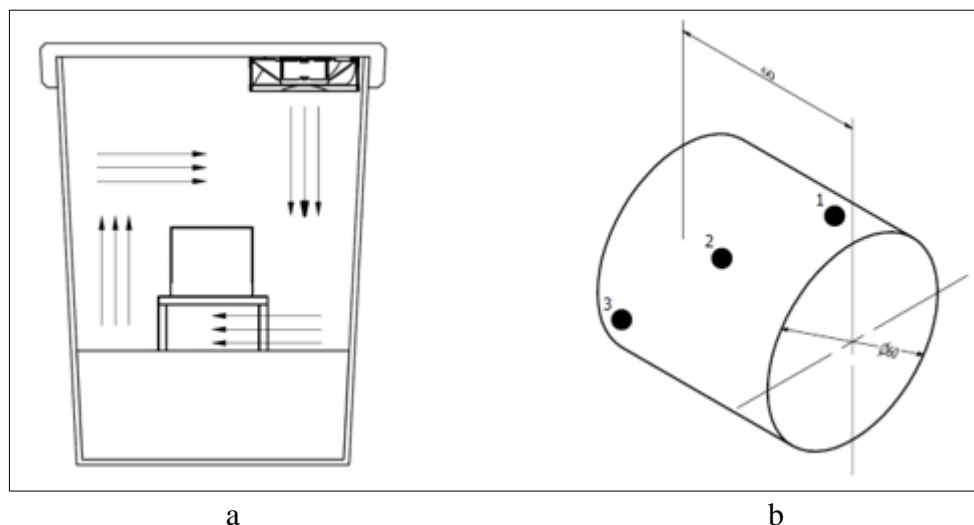


**Figure 2.** Methodology for applying acetone treatment

positioning surface. The lid of the container, 1, is placed on the container to ensure the tightness of the assembly. A fan, 2, was placed on the inner surface of the lid to ensure the even distribution of steam over all test tube surfaces.

To be noted that all components of the chamber are made of materials that do not interact with acetone. The reason for choosing plastics at the expense of glass is to eliminate the possibility of explosion of the container due to the increased pressure inside it. A total of 8 treatments were performed. The time of acetone steam treatment for the specimens was: 10, 20, 30, 40, 50, 60, 70 and 80 min. The treatment was performed in an ambient environment at a temperature of 25°C. After applying the acetone treatment, the pieces were left to dry outside the chamber in the same ambient environment to evaporate all the acetone on their surface.

To justify this method of applying acetone treatment, the unventilated treatment was compared with the ventilated one, in which the fan is switched on and the acetone steam circulates inside the container, thus reaching all surfaces of the part (Figure 3a). For this purpose, two pieces with the same dimensions were used, subjected to treatment for 40 min, in the container previously presented, in the version with the fan turned on and in the version with the fan turned off. Finally, three points randomly placed on the surfaces of the parts were chosen (Figure 3b), their analysis was performed using the Mahr CWM 100 confocal microscope and the Mahr perthometer, and their comparison was performed in order to choose the optimal method.

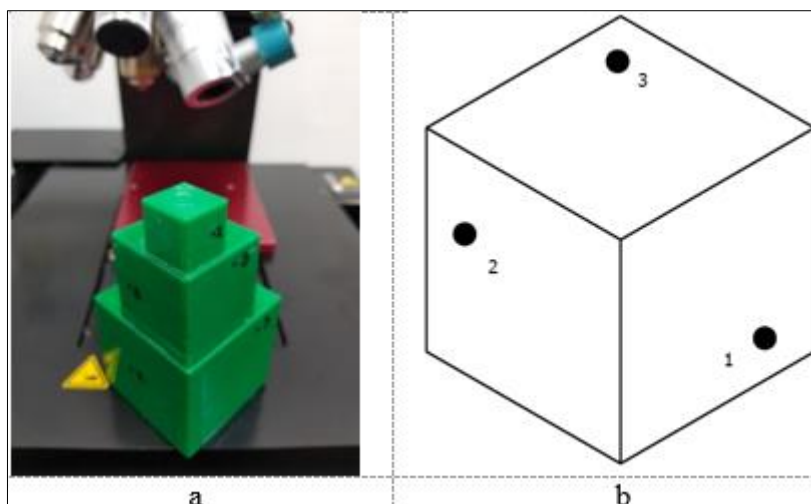


**Figure 3.** Acetone treatment a. the circulation of air in the container and b. the areas studied

Given the results obtained, it was not necessary to apply the reverse engineering method to choose the type of treatment.

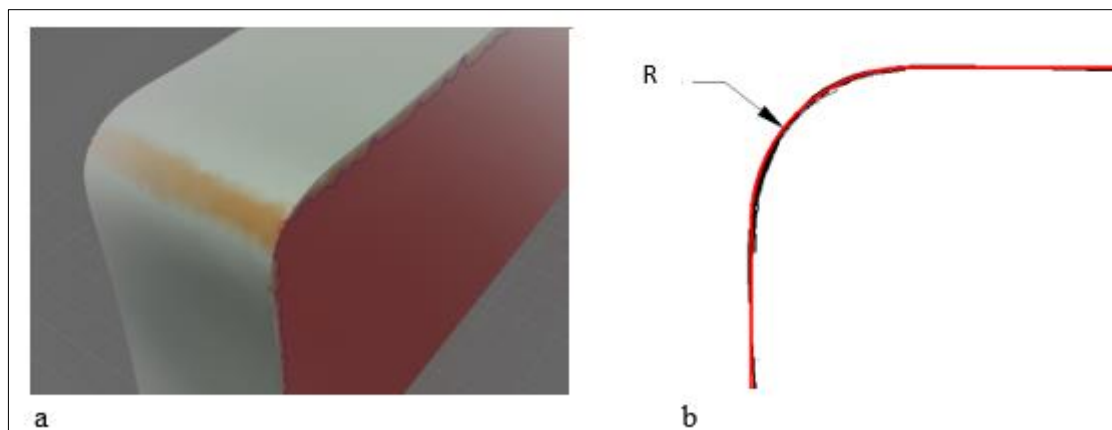
## 2.2. Part dimensions

In order to study the influence of the size of the part subjected to acetone steam treatment, cubic parts of different sizes were used (Figure 4a). Each piece was treated with acetone for 40 min, and these were studied using the same method as in the choice of treatment method (Figure 4b), where 3 points were randomly selected from the surfaces of the cubes, and their analysis was performed using the Mahr CWM 100 confocal microscope. At the same time, the surfaces were measured with the Mahr perthometer.



**Figure 4.** Cube dimensions (a) and randomly selected points (b)

Using the reverse engineering method, it was possible to study the degree of deformation of the parts subjected to treatment. The parts were scanned using the FARO Edge 7.5 polyarticulated arm. The point cloud resulting from the scan was processed and transformed into mesh using the Faro CAM 10 program related to the polyarticulated arm. The study on the degree of deformation was done in the Meshmixer and Autodesk Inventor Student Version programs, both of them being free programs, accessible to anyone. Using Meshmixer, the approximate maximum deviation of the surfaces of the treated parts from the surfaces of the parts in CAD format was studied (Figure 5a), and in Autodesk Inventor the radii of the edges of the treated parts were reproduced (Figure 5b), by sectioning the part and approximate reconstruction of the edges, therefore validating the results obtained in Meshmixer.



**Figure 5.** Deformation analysis using Meshmixer (a) and Autodesk Inventor Student Version (b)

### 2.3. Level of detail

Given the volume of determinations required for this study, specially designed specimens (Figure 6) were used to study both surface quality and level of detail. The test piece contains three primitive geometric shapes, circle, square and triangle, respectively, shapes that will be used later to study the level of detail resulting from acetone treatment.

To study the level of detail of the specimens subjected to acetone steam treatment, the same reverse engineering method was used as in the previous case. Following the generation of STL files, both the total dimensions of the specimens and their edges, especially the edges of the primitive geometries (Figure 7) were analyzed. At the same time, the surface quality of the specimens was analyzed using the same method as in the previous sections, thus achieving a correlation between the level of deformation and the quality of the surfaces obtained.

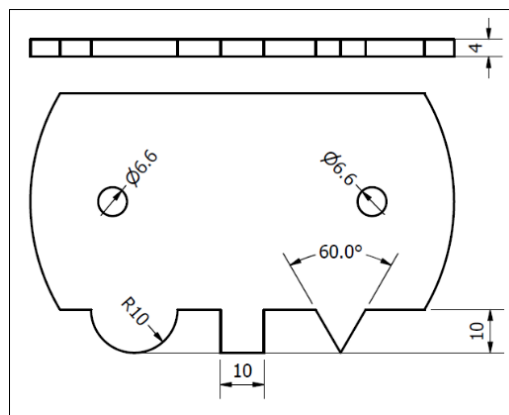


Figure 6. Test specimen

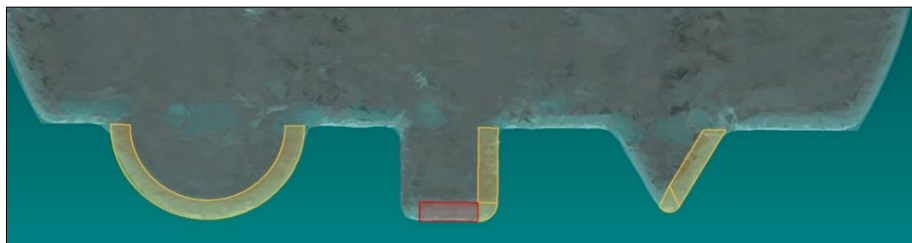


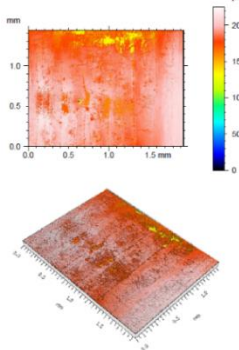
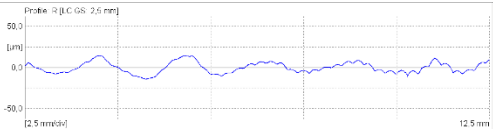
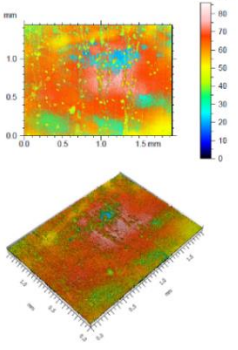
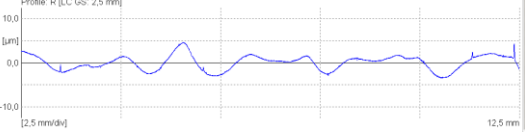
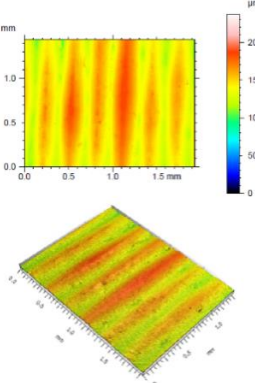
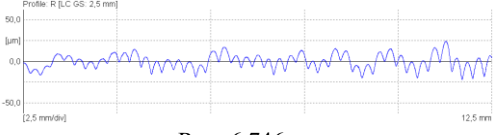
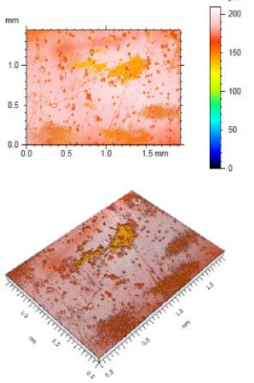
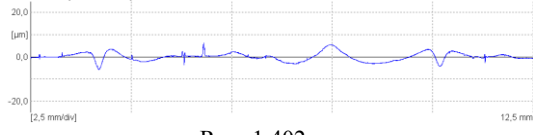
Figure 7. Approximation of test tube shapes

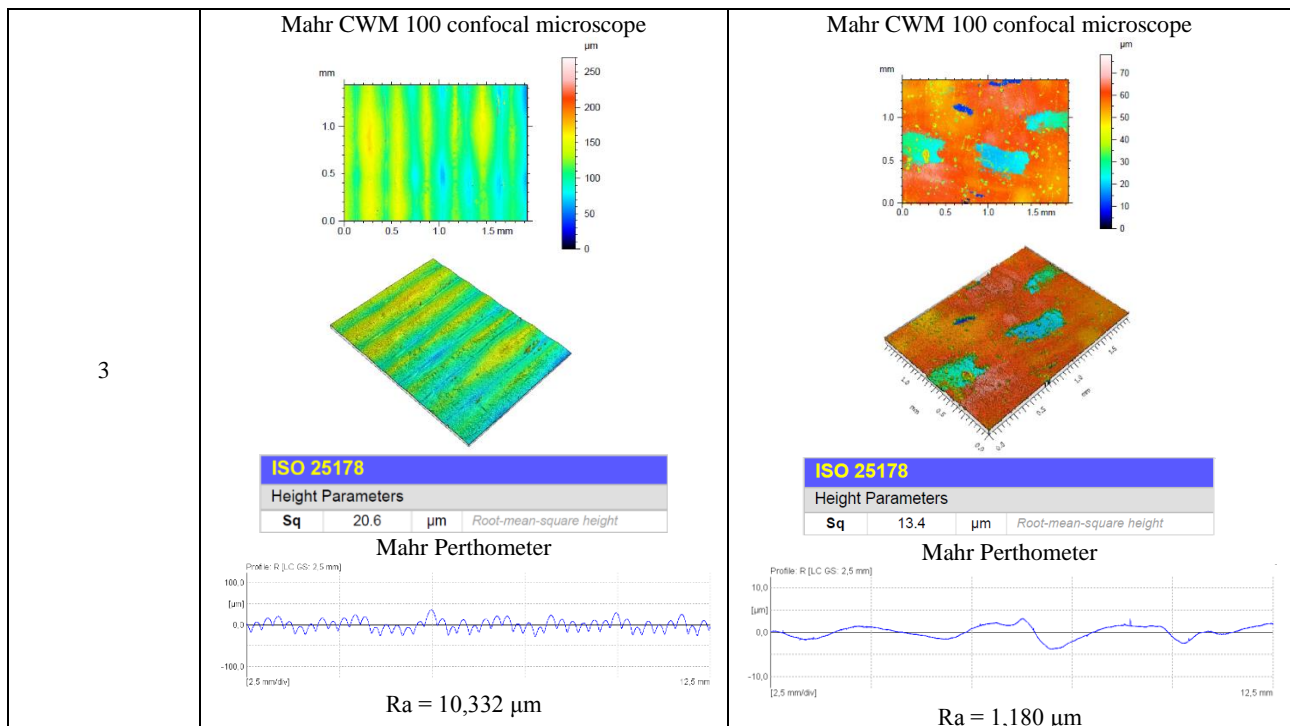
## 3. Results and discussions

### 3.1. Choosing the treatment method

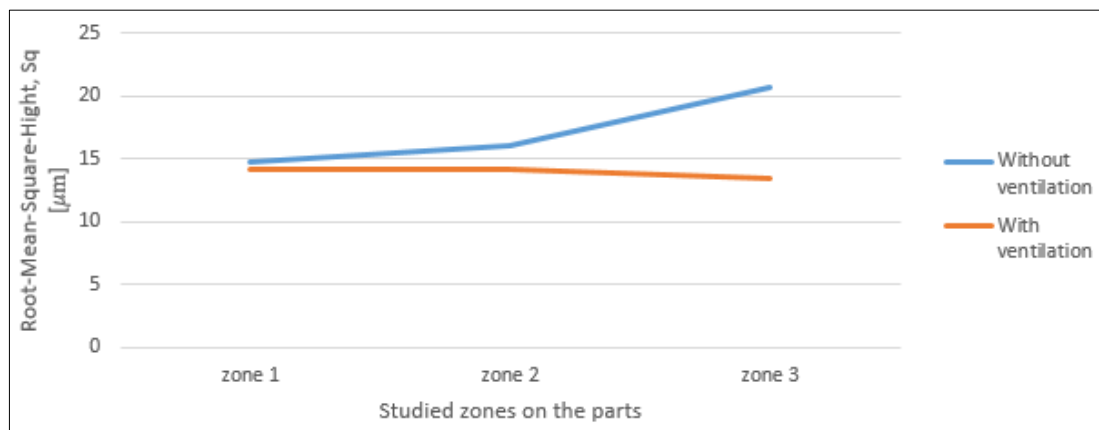
To establish the method of treatment (with or without ventilation), 3 points randomly placed on the surfaces of the part were analyzed, starting from the base of the part (closer to acetone), increasing towards the top of it (further from acetone). Using the Mahr CWM 100 confocal microscope, it was possible to obtain the average roughness of the studied area ( $S_q$ ) according to ISO 25178, as well as a graphical representation of the studied areas. The roughness of the surfaces was also taken with a Mahr perthometer. The results obtained are presented in Table 2.

**Table 2.** Treatment method results

Point on part	Part without ventilation	Part with ventilation								
1	<p>Mahr CWM 100 confocal microscope</p>  <p><b>ISO 25178</b> Height Parameters</p> <table border="1" data-bbox="406 683 853 772"> <tr> <td><b>Sq</b></td> <td>14.7</td> <td><math>\mu\text{m}</math></td> <td>Root-mean-square height</td> </tr> </table> <p>Mahr Perthometer</p>  <p><b>Ra = 5,614</b></p>	<b>Sq</b>	14.7	$\mu\text{m}$	Root-mean-square height	<p>Mahr CWM 100 confocal microscope</p>  <p><b>ISO 25178</b> Height Parameters</p> <table border="1" data-bbox="949 683 1396 772"> <tr> <td><b>Sq</b></td> <td>14.2</td> <td><math>\mu\text{m}</math></td> <td>Root-mean-square height</td> </tr> </table> <p>Mahr Perthometer</p>  <p><b>Ra = 1,366 <math>\mu\text{m}</math></b></p>	<b>Sq</b>	14.2	$\mu\text{m}$	Root-mean-square height
<b>Sq</b>	14.7	$\mu\text{m}$	Root-mean-square height							
<b>Sq</b>	14.2	$\mu\text{m}$	Root-mean-square height							
2	<p>Mahr CWM 100 confocal microscope</p>  <p><b>ISO 25178</b> Height Parameters</p> <table border="1" data-bbox="430 1422 829 1512"> <tr> <td><b>Sq</b></td> <td>16.0</td> <td><math>\mu\text{m}</math></td> <td>Root-mean-square height</td> </tr> </table> <p>Mahr Perthometer</p>  <p><b>Ra = 6,746 <math>\mu\text{m}</math></b></p>	<b>Sq</b>	16.0	$\mu\text{m}$	Root-mean-square height	<p>Mahr CWM 100 confocal microscope</p>  <p><b>ISO 25178</b> Height Parameters</p> <table border="1" data-bbox="957 1422 1388 1512"> <tr> <td><b>Sq</b></td> <td>14.2</td> <td><math>\mu\text{m}</math></td> <td>Root-mean-square height</td> </tr> </table> <p>Mahr Perthometer</p>  <p><b>Ra = 1,402 <math>\mu\text{m}</math></b></p>	<b>Sq</b>	14.2	$\mu\text{m}$	Root-mean-square height
<b>Sq</b>	16.0	$\mu\text{m}$	Root-mean-square height							
<b>Sq</b>	14.2	$\mu\text{m}$	Root-mean-square height							



As can be seen, both in the case of results obtained using the CWM 100 confocal microscope and in the case of the perthometer, the surface quality of the part subjected to treatment without ventilation decreases from the base to the top, presenting a difference of 5.9  $\mu\text{m}$ , and in the case of the piece subjected to the treatment with ventilation, it is observed that the roughness is kept relatively constant, being a small difference between points of 0.8  $\mu\text{m}$ . Comparing the obtained results (Figure 8), it can be concluded that the optimal method of applying the acetone treatment is the ventilated method, the roughness having very small deviations on all the surfaces of the part.



**Figure 8.** Comparison of surface roughness results for different types of treatment

An explanation for this phenomenon could be the fact that acetone vapors deposit faster on the surface close to acetone, and the distance between acetone and the part has a major impact. By applying the ventilated method, due to the uniform distribution of steam on the surfaces of the part, the factor of the distance between the part and the acetone is eliminated. Analyzing the results, for the next studies, the method of steam treatment by ventilation was chosen.



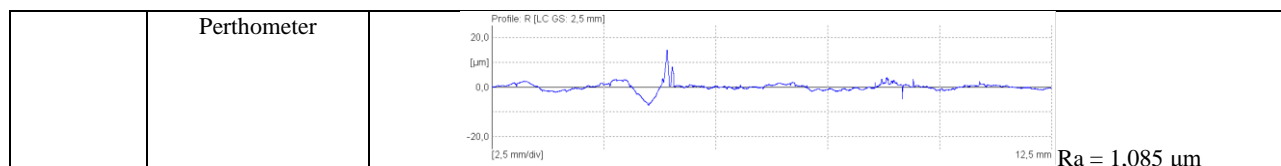
### 3.2. Parts dimensions

As in the previous case, the surface quality was studied using both the confocal microscope and the perthometer. The results obtained are shown in Table 3.

**Table 3.** Influence of part dimensions on surface quality

	Points on part	Results
Big cube	1  Sq = 14.34 $\mu\text{m}$	
	2  Sq = 14.30 $\mu\text{m}$	
	3  Sq = 14.30 $\mu\text{m}$	
	Perthometer	
Medium cube	1  Sq = 13.45 $\mu\text{m}$	

	<p>2</p> <p>Sq = 15.03 <math>\mu\text{m}</math></p>	
	<p>3</p> <p>Sq = 15.20 <math>\mu\text{m}</math></p>	
<p>Perthometer</p>	<p>Perthometer</p>	
<p>Small cube</p>	<p>1</p> <p>Sq = 12.91 <math>\mu\text{m}</math></p>	
	<p>2</p> <p>Sq = 13.48 <math>\mu\text{m}</math></p>	
	<p>3</p> <p>Sq = 14.75 <math>\mu\text{m}</math></p>	



According to the results obtained, it can be seen that the value of Sq, for all parts is between 13 and 15  $\mu\text{m}$ , and the value of Ra is between 1,085  $\mu\text{m}$  and 1,182  $\mu\text{m}$ . The differences are very small, so it can be considered that, in this particular case, the size of the parts does not have a major impact on the quality of the surfaces treated with acetone steam. As in the previous case, the justification for these results is that the method of uniform distribution of steam over all surfaces of the parts was used by recirculating the steam from the container.

Regarding the level of detail, as in the case of surface quality, the maximum deviations are between 0.6 mm and 0.7 mm. Due to the fact that the deviations are close, it can be concluded that the size of the parts subjected to the treatment does not have a major impact on the level of deformation of the ABS material.

### 3.3. Detail level

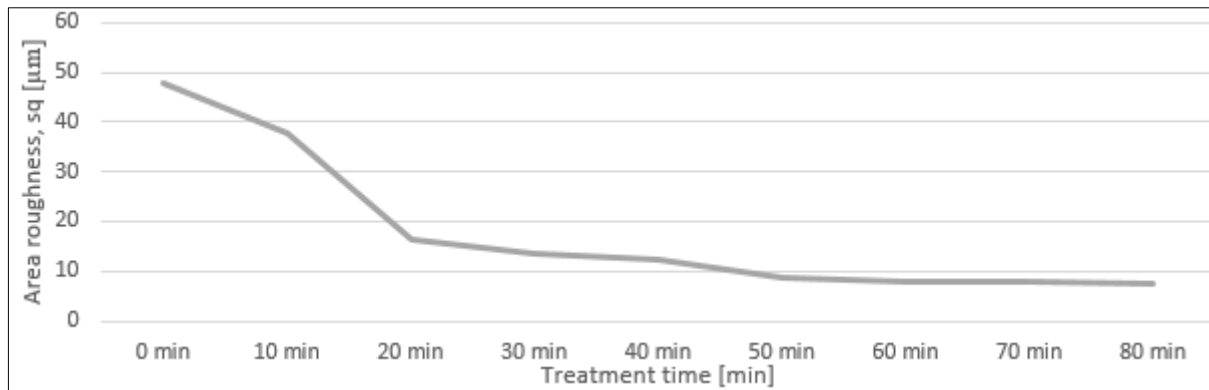
As stated in the previous sections, the specimens were subjected to treatment for 10, 20, 30, 40, 50, 60, 70 and 80 min. A non-treated specimen was also analyzed in order to observe the degree of improvement of the surfaces of the other parts. The surface inspection can be found in Table 4.

**Table 4.** Influence of treatment time on surface quality

Time	Surface and roughness	Sq [ $\mu\text{m}$ ]
0 min		<b>ISO 25178 - Primary surface</b> Sq 47.97 $\mu\text{m}$ <i>Root-mean-square height</i>
10 min		<b>ISO 25178 - Primary surface</b> Sq 37.70 $\mu\text{m}$ <i>Root-mean-square height</i>
20 min		<b>ISO 25178 - Primary surface</b> Sq 16.49 $\mu\text{m}$ <i>Root-mean-square height</i>

30 min		<p><b>ISO 25178 - Primary surface</b></p> <p>Sq 13.53 <math>\mu\text{m}</math> <i>Root-mean-square height</i></p>
40 min		<p><b>ISO 25178 - Primary surface</b></p> <p>Sq 12.24 <math>\mu\text{m}</math> <i>Root-mean-square height</i></p>
50 min		<p><b>ISO 25178 - Primary surface</b></p> <p>Sq 8.528 <math>\mu\text{m}</math> <i>Root-mean-square height</i></p>
60 min		<p><b>ISO 25178 - Primary surface</b></p> <p>Sq 7.891 <math>\mu\text{m}</math> <i>Root-mean-square height</i></p>
70 min		<p><b>ISO 25178 - Primary surface</b></p> <p>Sq 7.989 <math>\mu\text{m}</math> <i>Root-mean-square height</i></p>
80 min		<p><b>ISO 25178 - Primary surface</b></p> <p>Sq 7.644 <math>\mu\text{m}</math> <i>Root-mean-square height</i></p>

The obtained results show a direct correspondence with the results found in the literature and it can be confirmed that with the increase of the treatment duration, the quality of the surfaces improves. However, analyzing the graph of surface smoothing trends (Figure 9), it is observed that the effect of acetone steam treatment has a drastic influence on surface quality between 10 and 20 min, the surface roughness improving by about 65.62%, followed by an average improvement of 16.6% between 20 and 50 min. In the interval of 50-80 min, the roughness is kept relatively constant, the difference between the roughness values being very small.

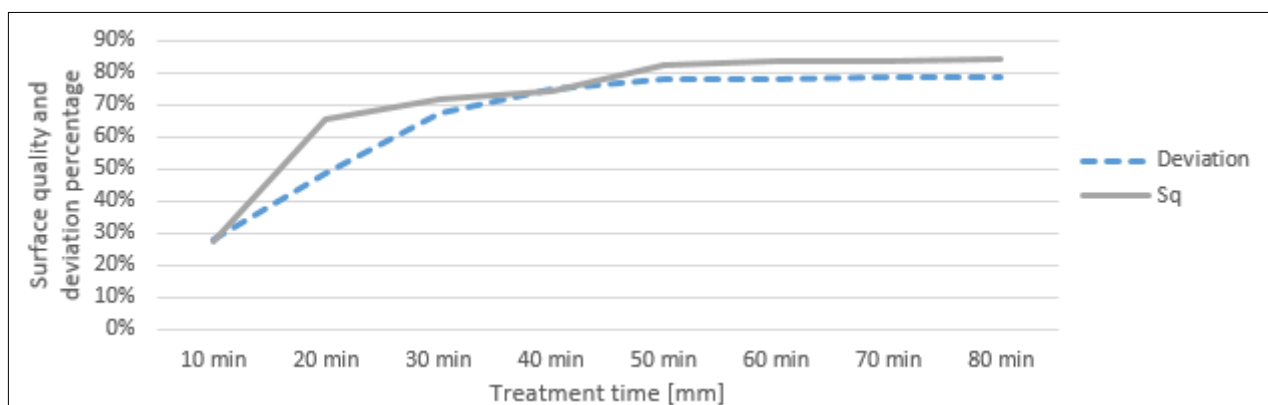


**Figure 9.** Variation of the roughness of the studied areas with the duration of the treatment

Following the analysis of the deviations, it was observed that the geometric shape has no impact on the level of deformations, the edges deforming uniformly along the entire length of the specimens. The results of the deviations and the comparison and correlation between surface quality and deviations, starting from the initial value of the untreated part can be found in Table 5 and Figure 10.

**Table 5.** Correlation between surface quality and deviations with treatment time

Duration of treatment	Sq (µm)		Deviations (mm)	
	Sq (µm)	% Change	Deviations (mm)	% Change
0 min	47.97 µm	---	≈ 0.18 mm	---
10 min	37.70 µm	↓ 27.24 %	≈ 0.25 mm	↑ 28.00 %
20 min	16.49 µm	↓ 65.62 %	≈ 0.35 mm	↑ 48.57 %
30 min	13.53 µm	↓ 71.79 %	≈ 0.55 mm	↑ 67.27 %
40 min	12.24 µm	↓ 74.48 %	≈ 0.72 mm	↑ 75.00 %
50 min	8.520 µm	↓ 82.24 %	≈ 0.81 mm	↑ 77.78 %
60 min	7.891 µm	↓ 83.55 %	≈ 0.83 mm	↑ 78.31 %
70 min	7.989 µm	↓ 83.35 %	≈ 0.84 mm	↑ 78.57 %
80 min	7.644 µm	↓ 84.07 %	≈ 0.85 mm	↑ 78.82 %



**Figure 10.** Comparison of deviations and surface quality depending on the duration of treatment

Comparing the results from Table 5 and Figure 10, it can be seen that the trends are similar for both values studied. It is observed that with the increase of the treatment duration, the maximum deviation from the initial quotas also increases. In the studied interval, the level of deformation behaves similarly to the surface roughness, thus compared to the piece without treatment a deviation of 77.78% can be observed between 10-50 min, followed by a very small decrease of 1.04% between 50 and 80 min. As in the case of surface quality, after 50 min, the deformation is so small that it can be considered to remain constant.



As the duration of acetone steam treatment increases, the quality of the surface improves and the level of detail decreases. It is observed that acetone steam treatment has a greater impact in the interval of 10-40 min. According to the authors, a 20 min treatment is enough to improve the quality and limit the level of loss of detail of the pieces. According to the results obtained in this study, depending on the need, the optimal duration of treatment can be chosen.

At the same time, in the images taken with the Mahr CWM 100 confocal microscope, on the surfaces subjected to the treatment after 20 min, areas appear in the form of cavities in the material. This phenomenon can be explained by the fact that the specimens were left to dry in a normal environment, and thus, due to the evaporation rate of acetone, in those areas acetone acted more on the material. This will be the subject of further studies.

#### 4. Conclusions

An experimental study was performed which showed that:

- the duration of acetone treatment directly influences both the quality of the surface and the degree of deformation of the edges;
- the size of the part has almost no impact on the quality of the surfaces or the degree of deformation;
- the optimal method of applying acetone treatment, in this case, is the method involving the recirculation of steam in the container. More studies involving treatment and drying methods will be the subject of further future research.
- depending on the need, an acetone treatment can be applied between 10 and 40 min, a longer duration not being necessary.

However, these conclusions are made upon using the same treatment chamber with a volume of 4 liters. The influence of the dimensions of the treatment chamber can have a major impact on the results.

**Acknowledgments.** This work was supported by Romania National Council for Higher Education Funding, CNFIS, project number CNFIS-FDI-2021-0357.

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Manuscript received: 27.10.2021