White paper

Smoothing HP Multi Jet Fusion parts with a vibratory finish - HP MJF applications

HP MJF part surface

3D technologies based on powder sintering, like HP MJF, usually print parts that have a rough surface. This effect is caused by particle size distribution, which is visible by zooming in on the part surface where small particles are attached.

In this article, we will analyze one of the well-known mechanical methods used to reduce surface roughness of MJF printed parts: tumbling or vibratory finishing.

Executive summary

Choosing the right parameters (time and abrasion) for your surface requirements will help optimize the tumbling process by minimizing the amount of material that is removed during the process and preventing the loss of fine features. Here are two further considerations:

• **Time:** This test analyzed the tumbling process for up to 24 hours during which the efficiency of the tumbling process is not constant. Tumbling is more efficient at the beginning and loses efficiency during the process.

• **Abrasion:** Customers can choose between two main types of abrasives: ceramic and plastic. With plastic, it takes more time to achieve the same surface roughness than with ceramic, but it removes less material during the process and more of the small features are preserved.

Applications for HP MJF - printed parts

For many applications, the surface roughness of natural HP MJF parts is sufficient, but there are certain applications/ verticals that require a specific surface roughness for MJF-printed parts. Surface roughness is especially critical for cosmetic applications such as external covers or parts that require electroplating.

Vibratory polishing is also used for parts that require a low-friction coefficient, such as, parts that are used in packing machines.

Test overview/method

In this test, the following factors will be analyzed using three different types of parts: the surface roughness improvement, the amount of material that is removed during the tumbling process, and the aggressiveness of the removal process.

Poker chips

A poker chip will be used to evaluate the influence of the surface roughness through out the entire process. This part is four times: twice for the top surface (see Figure 2) and twice for the bottom surface to see if there is a difference in surface roughness between the top and bottom. These two measurements are taken perpendicularly to each other and always in the same orientation.

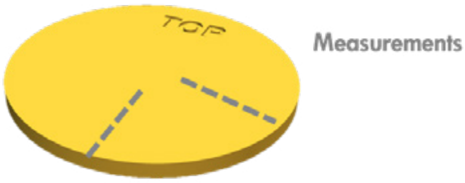

Figure 2: Measurements of poker chip surface roughness

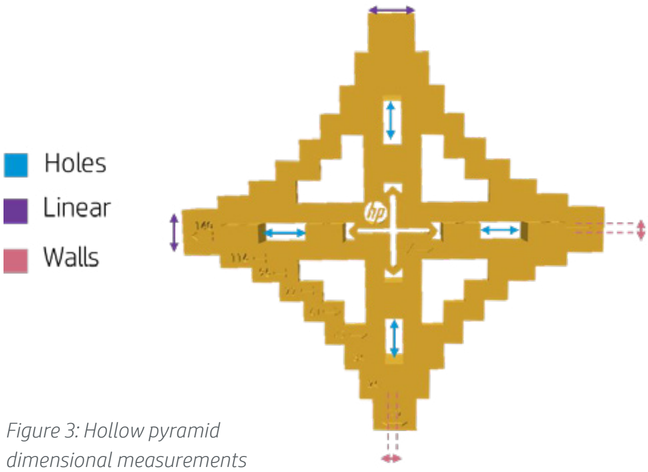

Figure 3: Hollow pyramid dimensional measurements

Hollowed pyramid

Mechanical polishing methods usually remove some material, especially in the part borders. In order to calculate how much material is removed through this process in the hollowed pyramid (see Figure 3), a 3D scanner is used to measure the part during the tumbling process.

Pins

This part (see Figure 4) will measure the number of pins that the tumbling process will break in order to test their aggressiveness with the printed part.

Figure 4: Pins part

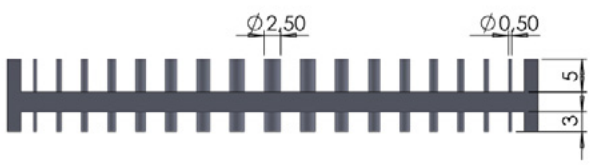

Figure 5: Pins schema (mm)

The pins will have different lengths (3 mm and 5 mm) and different diameters (from 0.5 mm to 2.5 mm). Figure 5 shows the Pins schema.

Plan overview

These three parts will be measured individually for their attributes every four hours. The study will start with aggressive media (ceramic or plastic) followed by a finishing tumbling. The practice of starting with harder media and finishing with a softer one is commonly used in the metal industry (especially for gears).

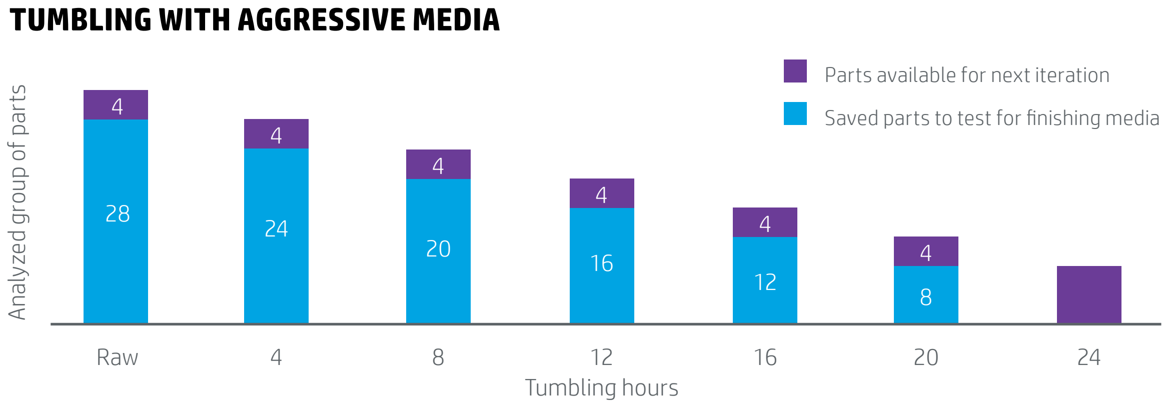

Figure 6: Tumbling planning

The study starts by measuring each of the 32 groups (a total of 96 parts). After every four-hour interval, four parts are set aside for finishing testing (see Figure 6 and Table 1).

Number of parts tested	Raw	4 hr	8 hr	12 hr	16 hr	20 hr	24 hr
Poker chip	32	28	24	20	16	12	8
Hollowed pyramid	32	28	24	20	16	12	8
Pins	32	28	24	20	16	12	8

Table 1: Number of parts tested by type

This test will be performed twice: once with ceramic media and once with plastic media.

Material used

Vibratory grinding:

The vibratory grinding experiments were performed using Rösler MINI 120 rotary vibrator with fixed revolutions at 1450 rpm.

Ceramic media:

Ceramic media recommended by Rösler: RSF/2 10/10 ZS.

Plastic media:

Plastic media recommended by Rösler: RKB/W B2 12K.

Roughness analysis:

Surface roughness measurements were taken using the Mitutoyo Surftest SJ-201P following the ISO 4288 standards. The measuring distance was 12.5 mm; the measurement was reproduced five times for each sample and the media value was calculated.

Optical analysis:

The optical analysis was performed using ATOS Capsule.

HP MJF parts:

HP MJF parts were printed in balanced print mode with natural cooling using a recyclable ratio of 20/80 of HP 3D High Reusability PA 12.

Test results

Surface roughness improvement

The surface roughness measurements obtained from the poker chip part and tested for the two types of abrasives are summarized in Figure 7.

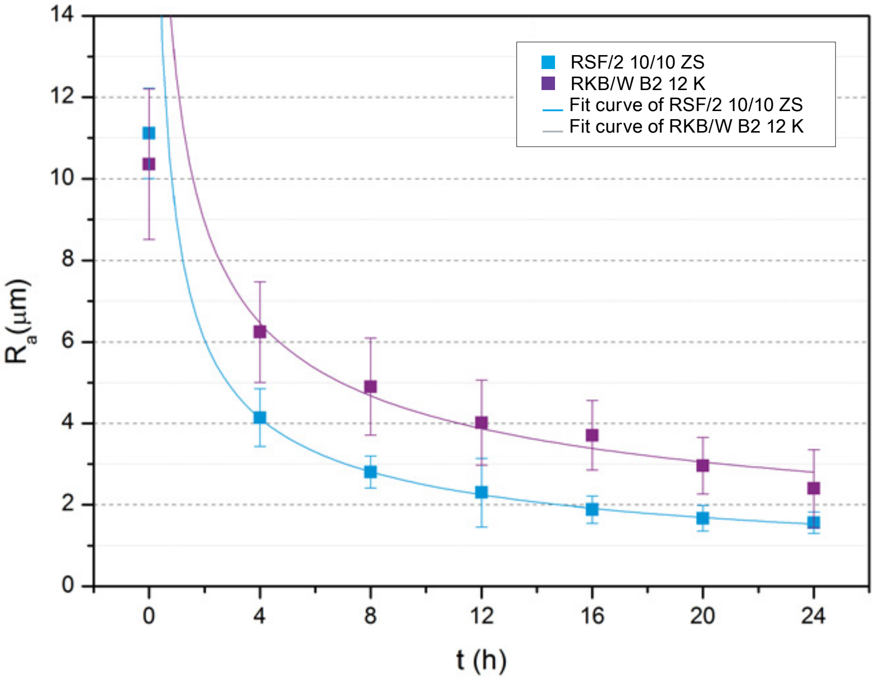

Figure 7: Surface roughness during the tumbling process with RSF/2 10/10 ZS and RKB/W B2 12 K (ceramic and plastic media, respectively)

The measured surface parameter R_a (arithmetic average of absolute values) is in inverse proportion to the part surface smoothness.

It is evident that the effectiveness of the tumbling process is not constant during the process. There are diminishing returns on how much improvement is achieved based on the length of the process.

If raw part R_a is analyzed, it can be observed that this value (10.74 ± 2.95 µm) has an important variability. This variability between parts is minimized during the tumbling process (see Figure 8) up to 0.26 (not italicized) µm, and with the ceramic media we can achieve a lower R_a of up to 0.8 µm.

The influence of the roughness throughout tumbling exposure can be extrapolated by the exponential interpolation of the experiental data. For more information see Annex 1, where an estimation of the intermediates time has been described.

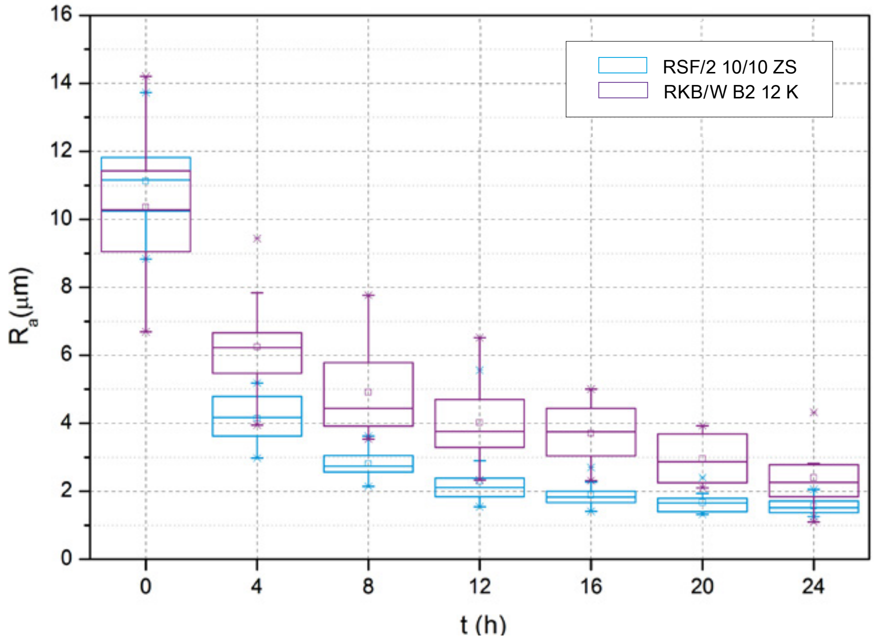

Figure 8: Bottom surface roughness box plot throughout the tumbling process with RSF/2 10/10 ZS and RKB/W B2 12 K (ceramic and plastic media, respectively)

As shown in Figure 8, ceramic media are more effective compared with plastic media, as the abrasive manufacture indicates in the instructions. In the next chapter, we will test whether this is effective as this type of media removes more material.

Due to the printing process, the surface roughness is not constant along all part surfaces. Through the tumbling process, the roughness of the part surface is homogenized. A good indicator of this variability is to observe the difference between the maximum R_a and minimum R_a in a given batch of samples. The variance of this difference decreases with the length of the tumbling process. This homogenization is more effective if the ceramic abrasive is applied during the process. To illustrate the effect in the homogeneity of the tumbling process, the variance of the maximum differences of roughness per batch part is shown in the following graph.

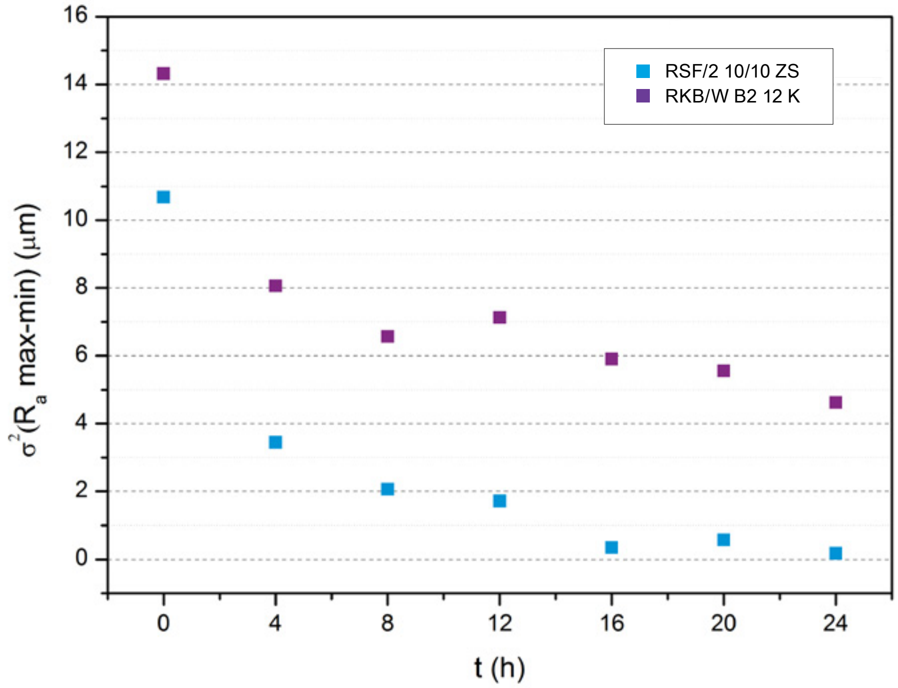

Figure 9: Evolution of the variance of difference between part surface rough

The following table shows the R_a prediction for the two distinct types of abrasives:

R_a value (μm)					
Hours	RSF/2 10/10 ZS	RKB/W B2 12K	Hours	RSF/2 10/10 ZS	RKB/W B2 12K
1	8.8 ± 2	*	13	2.1 ± 1.4	5.6 ± 1.9
2	6 ± 1.8	12.2 ± 3	14	2 ± 2.1	5.5 ± 2.2
3	4.8 ± 1.6	10.3 ± 2.7	15	1.9 ± 1.9	5.3 ± 2.1
4	4.1 ± 1.4	9.1 ± 2.4	16	1.9 ± 0.6	5.2 ± 1.7
5	3.6 ± 1.2	8.3 ± 2.4	17	1.8 ± 0.6	5 ± 1.6
6	3.3 ± 2	7.7 ± 2.5	18	1.8 ± 0.6	4.9 ± 1.8
7	3 ± 2	7.3 ± 2.5	19	1.7 ± 0.6	4.8 ± 1.7
8	2.8 ± 0.7	6.9 ± 2.3	20	1.7 ± 0.6	4.7 ± 1.3
9	2.6 ± 1	6.5 ± 2.3	21	1.6 ± 0.5	4.6 ± 1.5
10	2.4 ± 0.3	6.3 ± 2.5	22	1.6 ± 0.6	4.5 ± 1.1
11	2.3 ± 0.5	6 ± 2.4	23	1.5 ± 0.6	4.4 ± 1.2
12	2.2 ± 1.6	5.8 ± 2	24	1.5 ± 0.5	4.4 ± 1.9

Table 2: R_a summary for different abrasives

Dimensional variation

Quantitative analysis

The dimensional changes evaluated were the holes and the small wall figures because it was easier to identify the small changes that occur during the tumbling process. To evaluate the influence of the tumbling process with in the parts that have a higher mass, the small distance was selected because it was considered the worst case.

In order to obtain quantitative data to study the effect of tumbling in the dimensions of the parts, some representative distances were selected: the holes, small walls, and one dimension of the stairs. The experiments were performed with both abrasive media (plastic and ceramic), and the results are shown below.

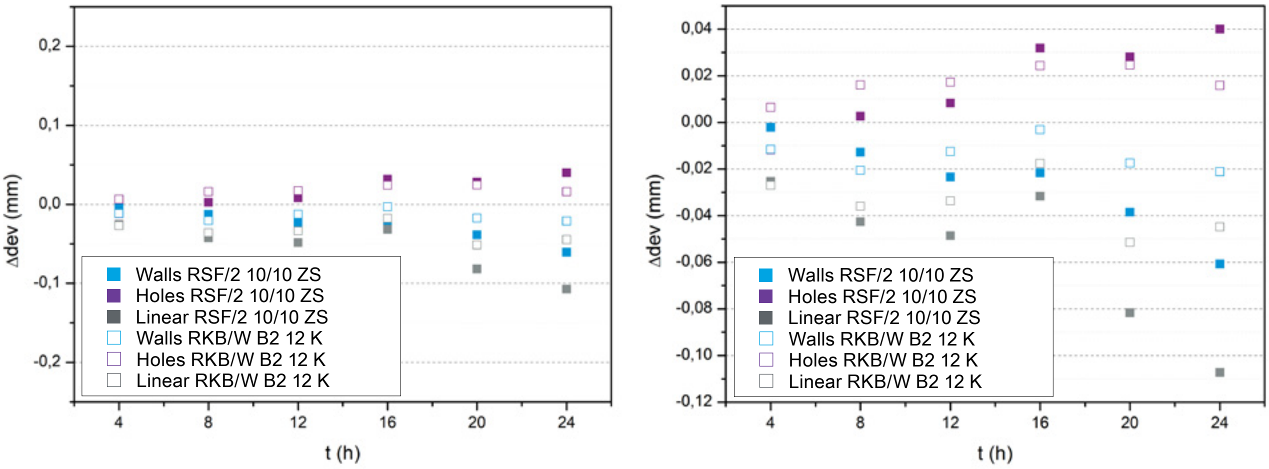

Figure 10: Dimensional variation of the tumbling process with the scale of dimensional specification of FDM parts (a) and (b) shows a zoom of the measurement.

The dimensional results confirm that the tumbling should affect the dimensional variation in fewer than 60 µm (with the most aggressive media in the case of walls and holes). If the part was solid with more mass, it would have been possible to observe dimensional changes of up to 100 µm in the case of the ceramic abrasive and 50 µm for the plastic abrasive. This result only conveys the dimensional changes that occur during the tumbling process. The final part should have more dimensional changes attributable to other processes.

Qualitative analysis

Figure 11 shows the evolution of the pyramid through the tumbling process with the ceramic media. The raw part only shows a slight deviation from the nominal value, but as the tumbling time increases it is evident that a loss of material begins, especially on the borders, as indicated by the blue areas in Figure 11.

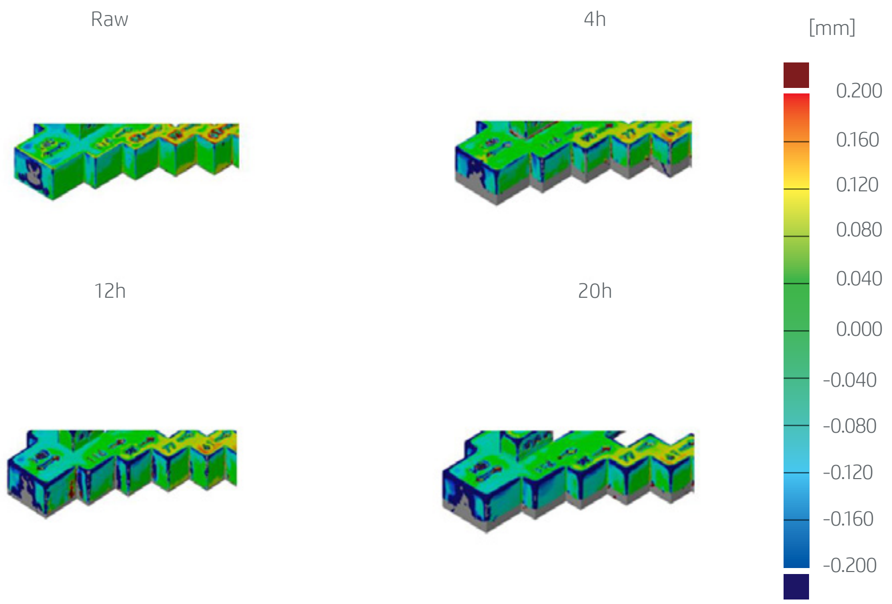

Figure 11: 3D scan results for RSF/2 10/10 ZS abrasive

This loss of material on the border is more visible in the case of ceramic media (see Figure 12). This should be taken into consideration when selecting which media to use.

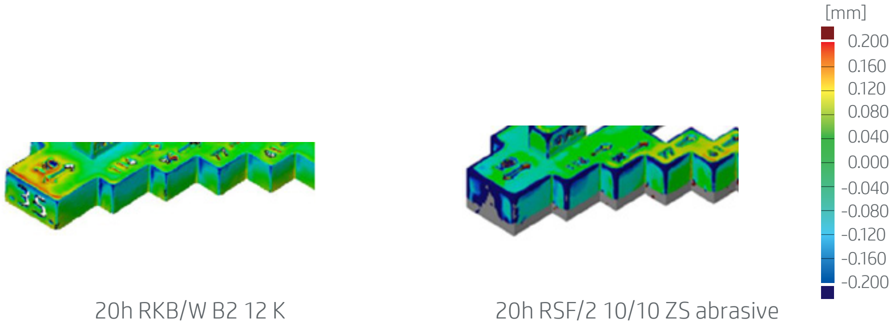

Figure 12: Comparison of abrasives

Determining process hardness through broken pins

Figure 14 sums up the percentage of pins (see Figure 13) that are not broken during the tumbling process with the ceramic and plastic media. Notice that pins with a diameter of less than 1.5 mm are not shown as they broke within the first four hours of tumbling.

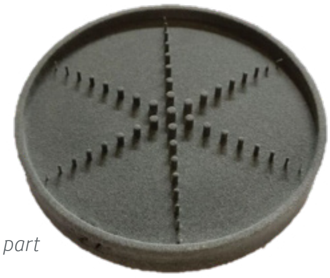

Figure 13: Pins part

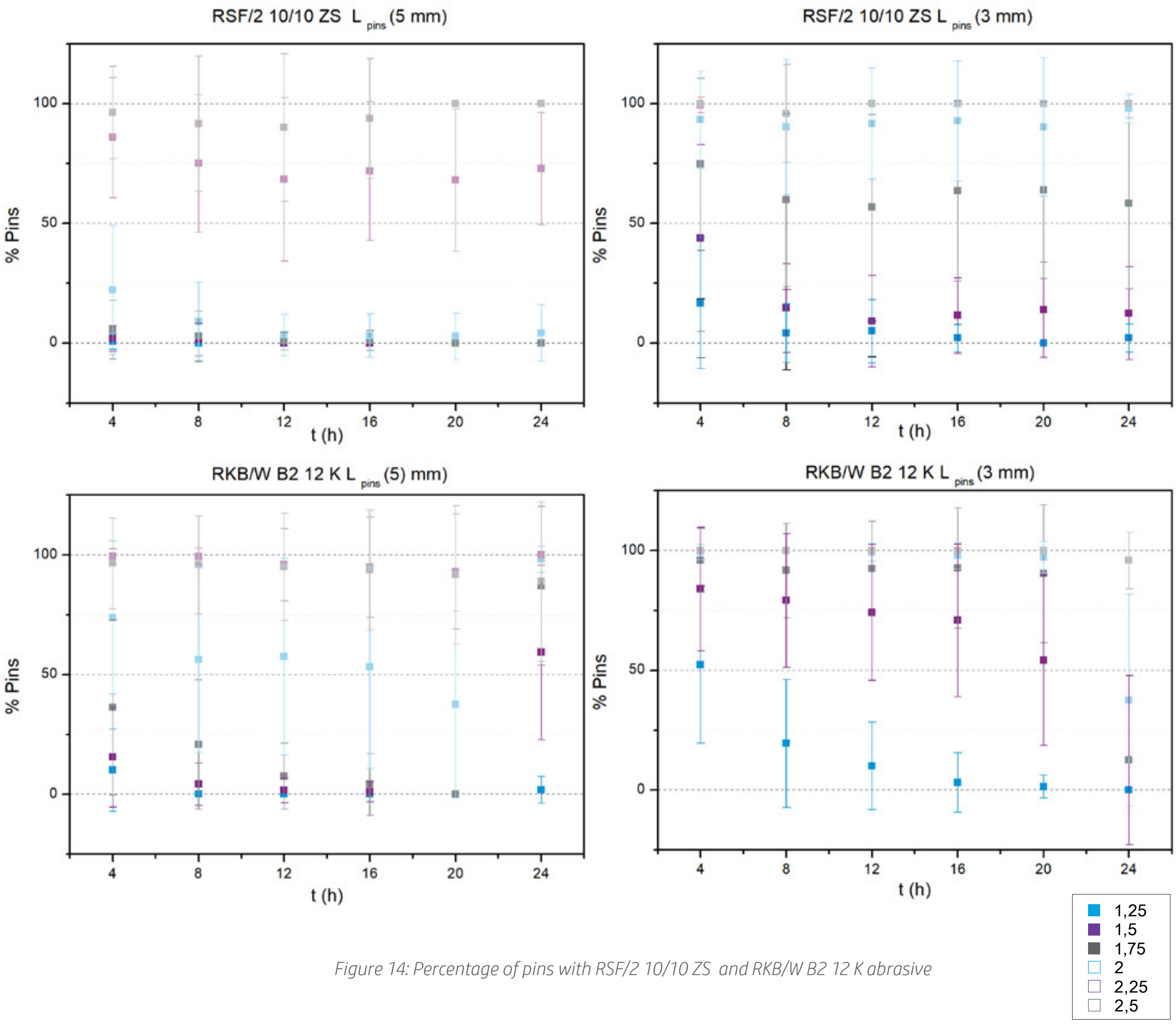

Figure 14: Percentage of pins with RSF/2 10/10 ZS and RKB/W B2 12 K abrasive

The number of pins that broke during the process is directly related to the slenderness of the pin, but not to the tumbling time. Figure 14 it shows that if a pin has not broken in the first four hours, it won't break if more tumbling time is applied.

For small figures, follow the recommendations below, balanced with the necessary roughness.

Abrasive	Minimum diameter (mm) for 3 mm height	Minimum diameter (mm) for 5 mm height
RSF/2 10/10 ZS	2	2.5
RKB/W B2 12 K	1.75	2.25

Table 3: Minimum pins recommendation for abrasive

Annex 1. Interpolating R_a with exponential equation

The tables below show the surface estimation from the exponential fit of the experimental data. These data are only an orientation to fix the time of the process.

Model Allometric for RSF/2 10/10 ZS			
Equation	y = a*x^b		
Reduced Chi-Square		0.00916	
Adj. R-Square		0.99737	
		Value	**Standard Error**
R_a	a	8.8597	0.61411
R_a	b	-0.55243	0.02754

Model Allometric for RSF/2 10/10 ZS			
Equation	y = a*x^b		
Reduced Chi-Square		0.12156	
Adj. R-Square		0.96378	
		Value	**Standard Error**
R_a	a	16.23749	1.28097
R_a	b	-0.41611	0.03522

Table 4: Predicted evolution of surface roughness in the tumbling process with different media

4AA7-1407EEW, November 2018