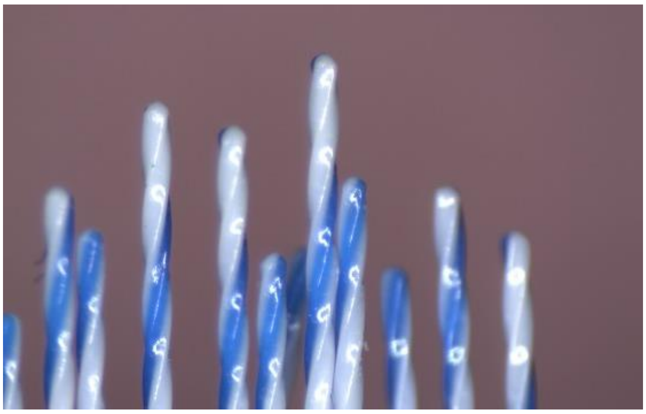

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Expert´s Report

Endrounding Quality of Toothbrush Filament Tips

by the

Machine FRM

of V-Air Machines GmbH

Machine FRM of V-Air Machines GmbH

Content

1. Introduction and Scope of Expertise

Toothbrushes have plastic filaments, normally made out of polyamid PA-6.12 or polyester PBT. The filaments are in most cases round and made out of one material and color. There are some new filaments in the market which do not have a round cross section, but have a rectangular or hexagonal cross section. These are called diamond-shaped or brilliance filaments. Also, twisted filaments are found in rare cases, where two materials of different colors are inter-twisted together, known as spiral or spiral magic filaments.

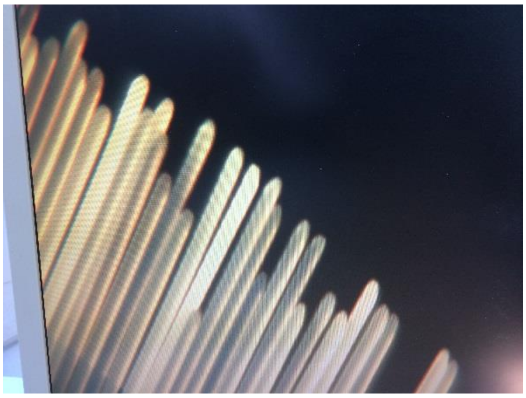

Fig. 1.1: Filament with round cross section

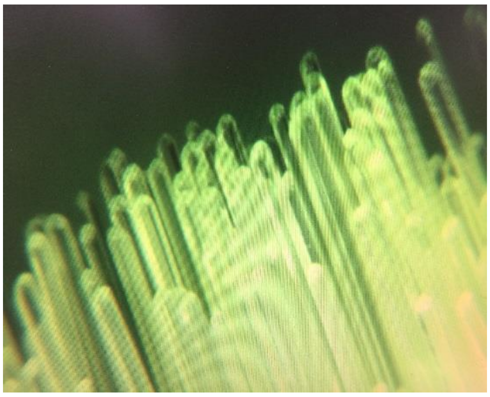

Fig. 1.2: Filament with rectangular cross section

Fig. 1.3: Twisted filament

The filament diameters vary in the market. The used unit for the diameter is mils, a US unit, used for small lengths.
1 Mils = 1/1000 Inch = 0.0254 mm.

The filament diameters vary for normal toothbrushes between 5 and 9 mils. The filament diameter and the filament length determine the stiffness of the filaments and thus the toothbrush qualities "soft", "normal" or "stiff".

Quality toothbrushes must have filaments with rounded tips. The reason is explained shortly in chapter 2 of this expertise.

In this expertise, only rounded filament tips are analyzed. The filaments are treated mechanically to achieve the rounded tips.

The sharply pointed filament tips, called **tapered filaments** –the production of these requires a chemical treatment– **are not analyzed in this investigation.**

There are basically two production techniques for the toothbrush tufting:

- The tufting by the traditional anchor technique. The folded filaments are fixed in the toothbrush handle by a metal chip, the anchor. The holes in the toothbrush handle are tufted one by one. Modern anchor toothbrush production machines yield a speed of up to 1000 tufts/min.
  The filaments are tip rounded after the tufting procedure, when using this technique, as the tufting causes non-equal filament lengths after the tufting. Previously to the rounding, the filaments are cut to an equal length. The end-rounding quality is normally not as good as with the new anchor-free technique.
  The end-rounding with the anchor-technique is not subject of this analysis.

- The tufting by the new anchor-free technique. Here, the holes can be tufted one by one, but also by a matrix tufting, where all holes of the toothbrush are tufted in one stroke. The filaments are cut to the required length and end-rounded, prior to the tufting.

Only the end-rounding quality of filaments which are used for the anchor-free tufting technique is subject of this analysis.

It is the scope of this expertise to investigate the end-rounding quality (which is made by the machine FRM) of different filament qualities in respect to material, diameter, color and texture.

2. Importance of end-rounding of toothbrush filament tips

Here, only the basics for the necessity of the filament tip end-rounding are out-lined.

The end-rounding of the toothbrush filament tips are important to avoid gum irritations. Details are documented, e.g., in the MD dissertation work:

NURAN SOYDAN:
DIE QUALITÄT DER BORSTENABRUNDUNG BEI WECHSELKÖPFEN ELEKTRISCHER ERWACHSENEN-ZAHNBÜRSTEN;
INAUGURALDISSERTATION zur Erlangung des Grades eines Doktors der Zahnheilkunde des Fachbereichs Medizin der Justus-Liebig-Universität;
VVB LAUFERSWEILER VERLAG, Gießen, 2008

For example, Nuran Soydan states in his thesis, page 7:

"Bei der konventionellen Zahnbürste stellt die Abrundung der Borstenenden ein wichtiges Qualitätsmerkmal dar. Durch unzureichende Bearbeitung der Borstenenden entstehen scharfkantige Borstenenden. Diese können zu Weichgewebsschädigungen in der Mundhöhle, insbesondere zu Verletzungen des Gingivaeptihels führen."

The translation:

„The rounding of the filament tips represents an important quality feature for the conventional toothbrush. Inefficient processing of the filament tips generate sharp edges at the filament tips. These may cause damages of the soft tissue in the mouth, particularly injuries of the gingivaeptihels.

It is clear, that this statement is not only true for electric toothbrushes, but also for conventional toothbrushes (for manual use).

The German norm
„DIN-Norm 13917" (of the norm Committee Dental; 1988)
emphasizes also the necessity of rounded filament tips.

3. Examples of end-rounding qualities of premium toothbrushes which are found in the market

Premium toothbrushes in the market are used as benchmark – they serve as a comparison for this analysis. Both, manual and electric toothbrushes are documented. The purchased toothbrushes (bought in Oct. 2018 from an EDEKA supermarket) are from the brands P&G, GSK, Philips, ORAL B, Dr. Best and Colgate. The magnified end-rounding quality is shown in the following, but in an anonymized way.

Toothbrush 1:

This example is an electric toothbrush - a sonic toothbrush. The blue filaments at the top and the end of the brush are longer as the middle filament with white and light blue color (Fig. 3.1).

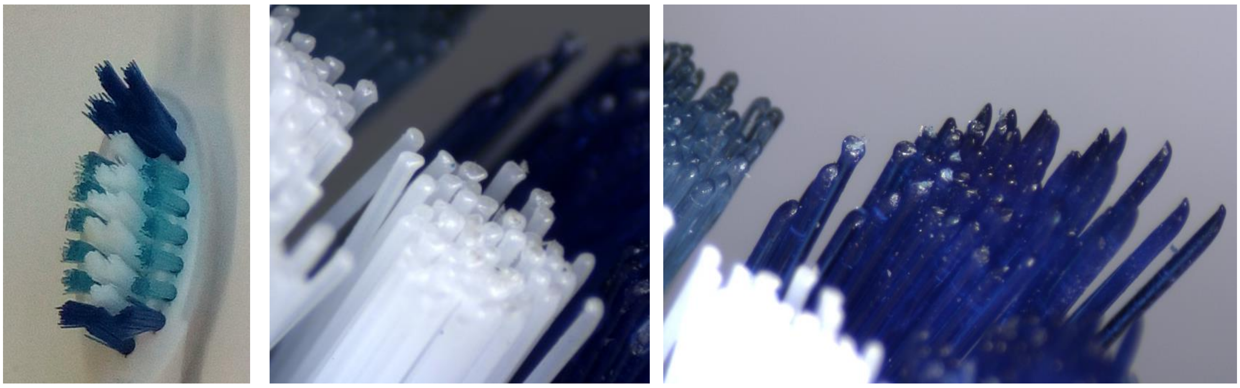

Fig. 3.1: Toothbrush 1, tufted with anchor

The white filaments have mainly a flat end-rounding form. Some filaments are hardly rounded and show cutting residues. The longer blue filaments and the light blue filaments have non-symmetric tip rounding, whereas the outer and longer filaments are spiky.

Toothbrush 2:

Toothbrush 2 is a well-known brand

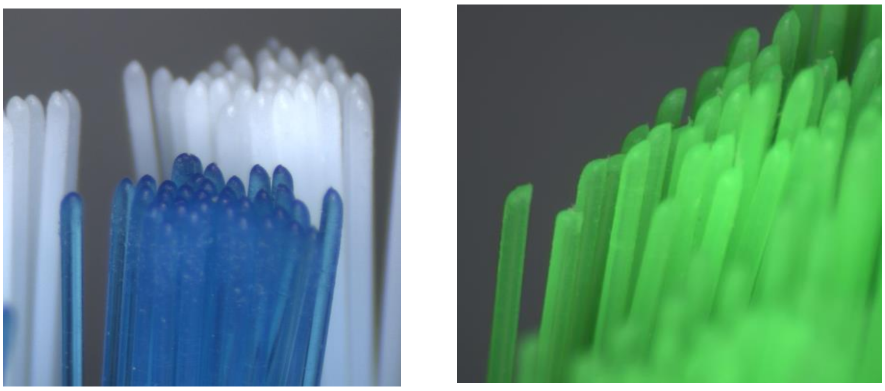

Fig. 3.2: Toothbrush 2, tufted with anchor

The Toothbrush 2 is a manual toothbrush with oblique tuft topography. The blue and white filaments are reasonably rounded. Only the longer green filaments show a non-symmetric tip and some fibers on the left side of the picture are not rounded.

Toothbrush 3:

This is the brush from an electric toothbrush. The outer tuft rows are a bit longer than the middle ones. A lot of these blue and white filaments are not rounded. The inner green filaments have a diamond-shaped cross-section. The edges are rounded, but show a flat end tip.

Toothbrush 3 is a well-known brand

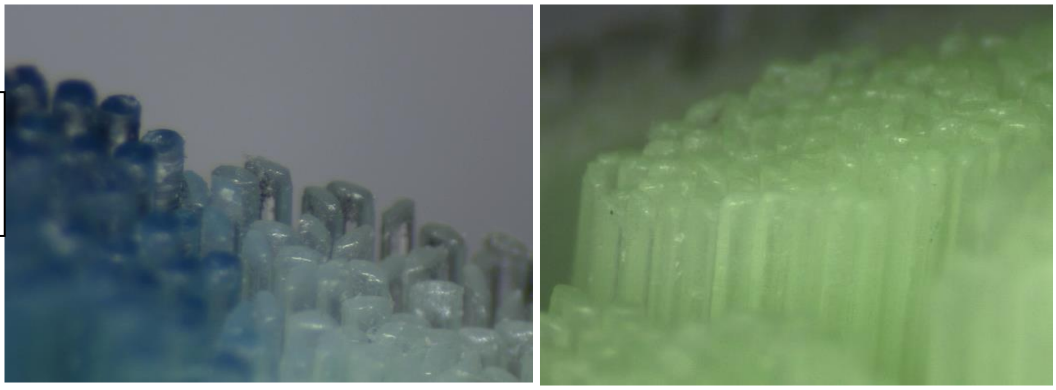

Fig. 3.3: Toothbrush 3, anchor-free tufting (over-molded)

Toothbrush 4:

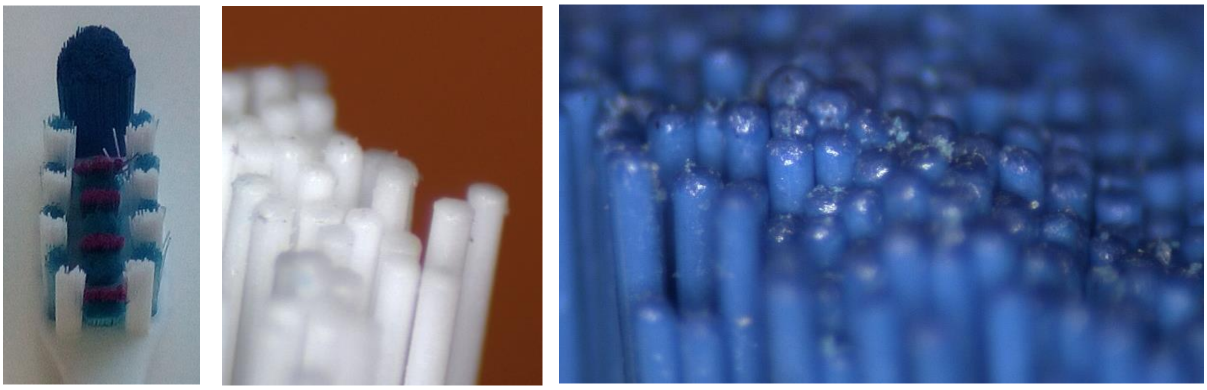

Fig. 3.4: Toothbrush 4, anchor-free tufting (over-molded)

This is a manual toothbrush. The blue filaments are all acceptably rounded with a half dome end tip. The whole bristles are covered by a white dust, probably residues from the rounding process. The white bristles are not acceptably rounded, only half of the filaments show a reasonably flat end tip.

Toothbrush 5:

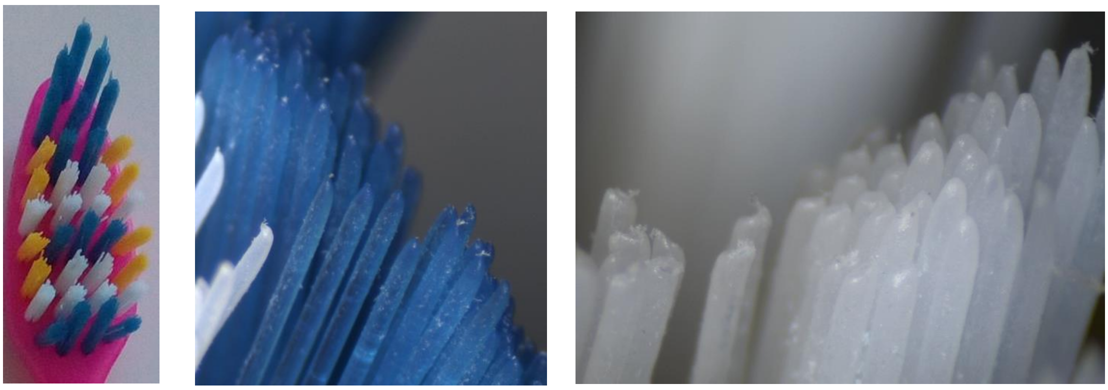

Fig. 3.5: Toothbrush 5, with anchor tufting

The surface of the toothbrush 5 is wave-like. The blue (longer) filaments are rounded, but the tip is pointed. The white filaments in the wave troughs (in the valleys) are irregularly rounded with cutting residues. All filaments are covered with dust.

4. Technique of rounding of filament tips by the machine FRM

The manufacturer V-Air Machines GmbH describes the machine FRM and the essential features as follows:

- The FRM is a production machine to make filament pucks (see Fig. 4.1) out of filament hanks (see Fig. 4.2) of typically 1200 mm length and 48 to 52 mm diameter. Filament hanks are cut into pieces of required length, i.e. filament pucks are made. The filament tips within the individual pucks are at the same time rounded on one side.
- The filament hanks must be wrapped in a plastic hose
(paper wrapped hanks cannot be processed).
- The precision of each filament puck lengths is controlled by a high precision measurement system.
- The precision in the length variation of the pucks is guaranteed by V-Air Machines GmbH to be within ± 0.15 mm.
- The filament length of the pucks is for the AVT-S12, AVT-S12E or AVT-S6 of V-Air Machines GmbH (which produce anchor-free toothbrush heads) is normally between 11 and 17 mm.
- This machine FRM is delivered with a change-over kit to allow additionally puck lengths between 28 and 35 mm.
- The FRM can process filament diameters between 0.12 mm (= 5 mils) to 0.30 mm (= 12 mils) with good end-rounding qualities.
- Polyamid (Nylon) 6.12, PBT and all known other filament materials for toothbrushes can be processed on the FRM.
- The filament grinding dust is extracted which guarantees that practically no dust remains on the rounded filaments.
This is a major requirement for the further hygienic production process of toothbrushes.
- The grinding program can be adjusted to every filament diameter and filament material.
- Cycle times depend on the filament material and diameters: The production time for one puck is approx. 20 to 30 sec. Thus, the output is 2 to 3 pucks per minute.
- The production of the FRM machine serves the filament consumption of two to three toothbrush production machines AVT-S12, AVT-S12E or AVT-S6.
- The cut and rounded pucks are automatically stored in a hygienic plastic tray.
- The diameters of the filament hanks may vary between diameters of 48 to 52 mm (standard filament hanks for toothbrushes).
- The machine is equipped with a newly developed rotating grinder for an excellent end-rounding of the filaments.
- Gentle treating of the filament hank: No twisting of filaments.

- Even suitable for filaments with non-spherical cross sections, e.g. diamond shaped or twisted filaments.
- Short filament waste piece due to a special gripper.
- The filament hanks of 1200 mm length is conveniently and quickly inserted in the machine FRM.

Fig. 4.1: Cut filament puck (out of the filament hank)

Fig. 4.2: Filament hank, prior to be cut into "pucks"

The end-rounding of the filament tips should look like Fig. 4.3.

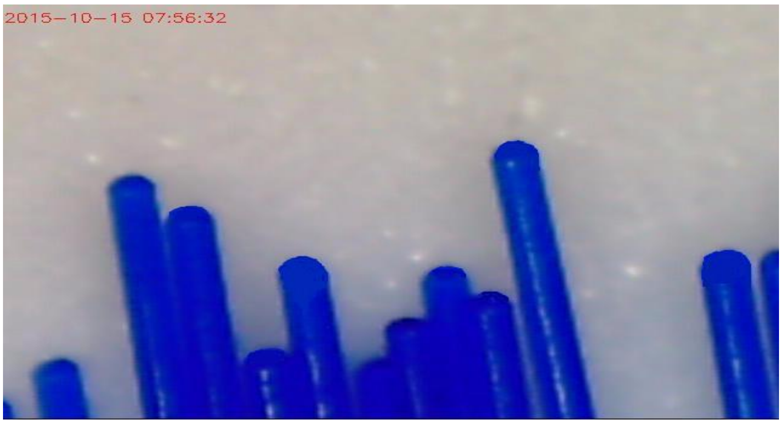

Fig. 4.3: End-rounded filament tips (magnified)

The filament hanks to be cut and rounded are put onto the guide rails of the machine FRM, Fig. 4.4.

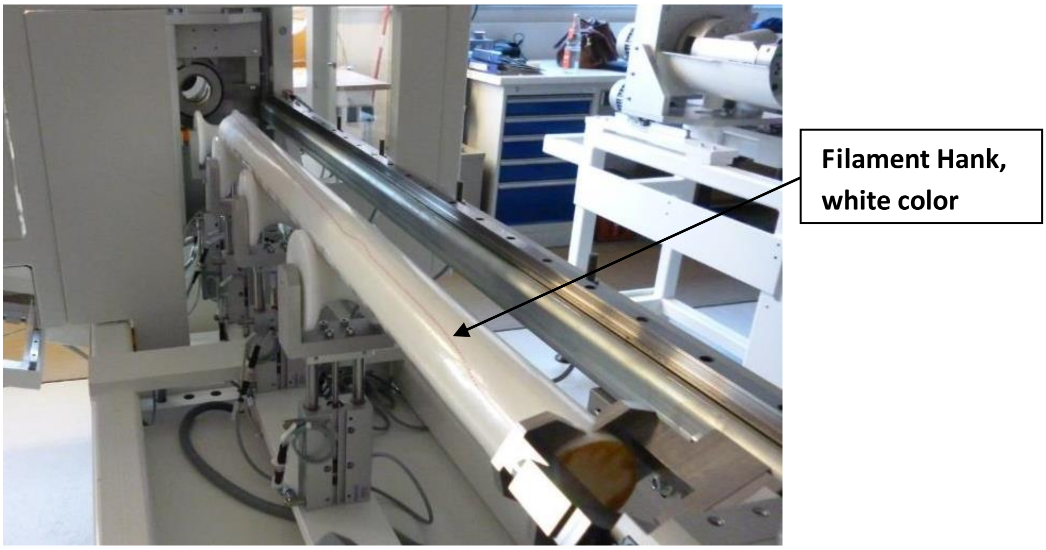

Fig. 4.4: Partial view of the machine FRM

The filament hank is pushed below the knife unit, Fig. 4.5.

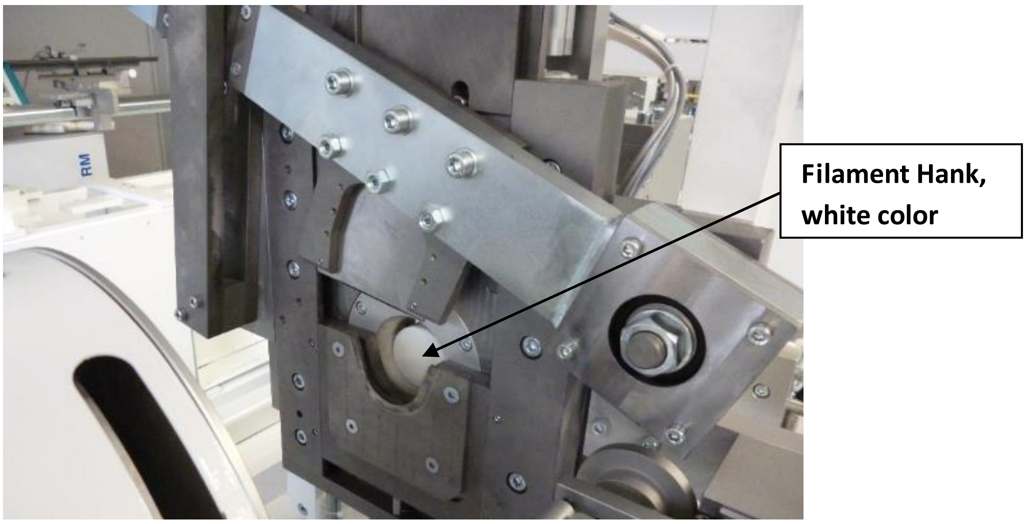

Fig. 4.5: Knife unit and partial view of the grinding unit

Once the filament hank is placed in the machine, the hank is pushed through the knife unit (knife in Fig. 4.5 is in its open position). Then, the plastic wrapping is pushed back by a special gripping device, so that approx. 50 mm of the filaments are loose; Fig. 4.6.

Fig. 4.6: Loosened filaments out of the hank during grinding procedure.

The loosened filaments are then pressed against the grinding surface (grinding belt is rotating in two dimensions) and are thus mechanically rounded. The rounding quality is pre-programmed to yield the required result according the filament thickness, filament material, filament texture,..... There are several recipes in the PLC pre-programmed, but the operator can make own recipes. Once the filaments are rounded, the plastic wrapping is reinstalled and the “puck” can be cut from the hank in PLC-programmed length.

Finally, the puck (cut filament hank) is stored in a tray, Fig. 4.7.

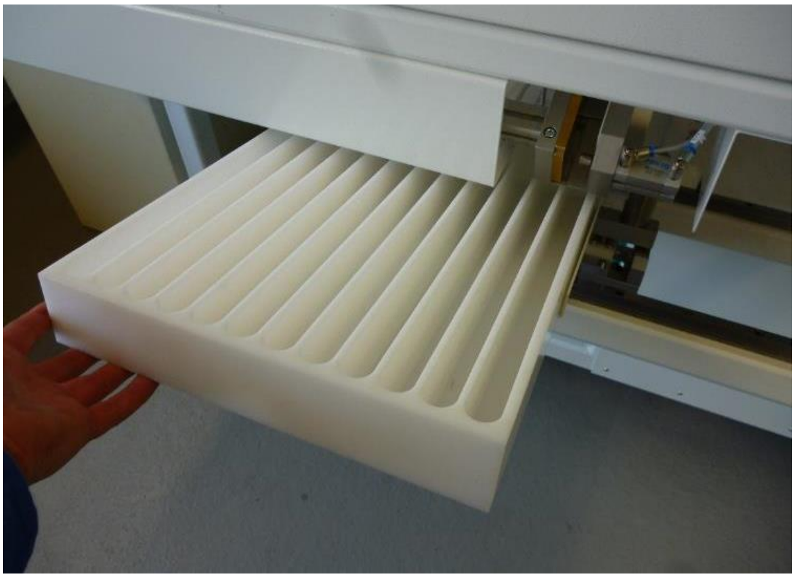

Fig. 4.7: Tray, where pucks will be stored.

5. Applied tools and procedure to analyze the end-rounding quality of filament tips

The produced filament pucks are analyzed in the following ways:

- The length of the pucks is measured mechanically with an accuracy of approx. 0.05 mm, Fig. 5.1.
- These lengths are compared to the set value of the PLC recipe.
- 12 pucks are cut from a blue polyester filament of 0.127 mm diameter to gain information about the repeatability and length variation.
- Each puck is measured 4 times at different places of the puck surface.
- The tips of individual filaments within the pucks are visualized by a microscope (Fig. 5.2), and documented. For this purpose, the puck is put in a mechanical holder (Fig. 5.3), that pushes out a row of filaments stretching over the diameter of the puck. The holder allows the observation of the pushed-out filaments at a 45 degree angle under the microscope. To achieve a good contrast, a colored plastic foil is placed behind the pushed-out row of filaments.
- Filaments from practical each position of the cross section of the puck are analyzed.
- It was particularly compared, how the rounding quality varies over the cross section, i.e. it was investigated, if there are differences of the tip rounding, whether the filament is in the center of the puck or at the outer rim near the wrapping, or in between.
- Finally, it was visually checked, if the filaments are aligned straightly in the puck (this is desired), or if filaments are twisted or are in an oblique position (which would not be acceptable). See Fig. 5.4.
- All results are documented for each investigated puck.

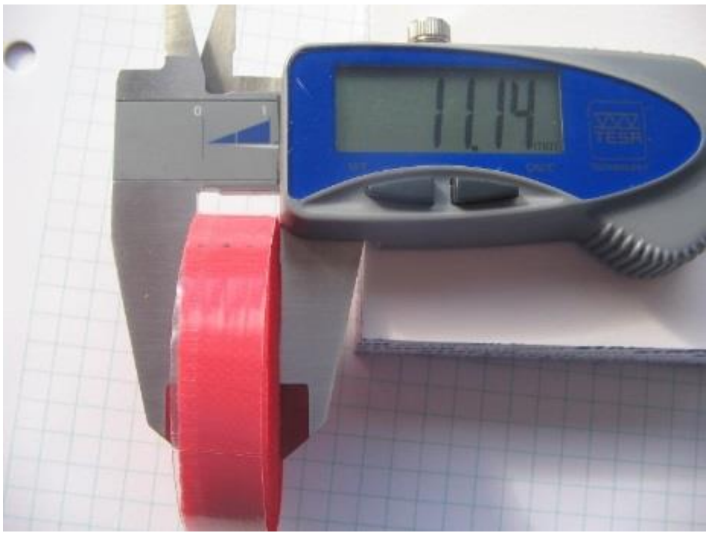

Fig. 5.1: Measurement device for the length of the pucks

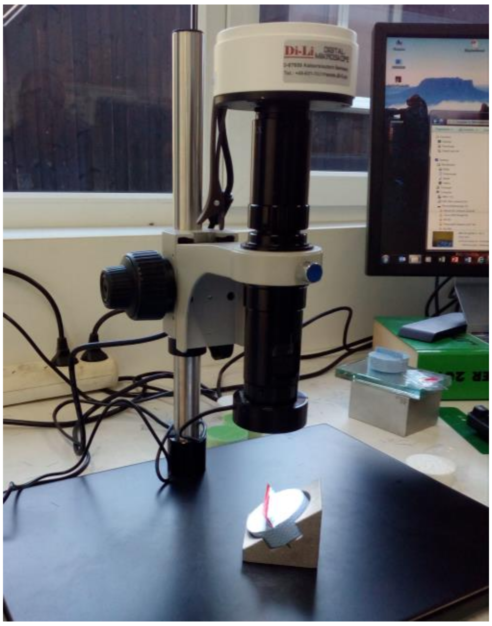

Fig. 5.2: Microscope, which is used

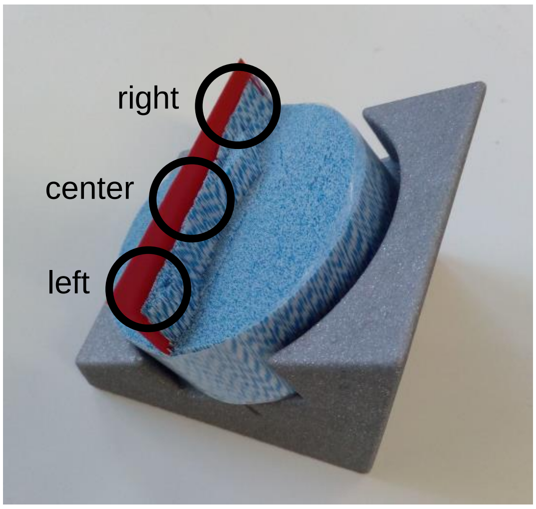

Fig. 5.3: Positions, where the filaments are taken out for the analysis

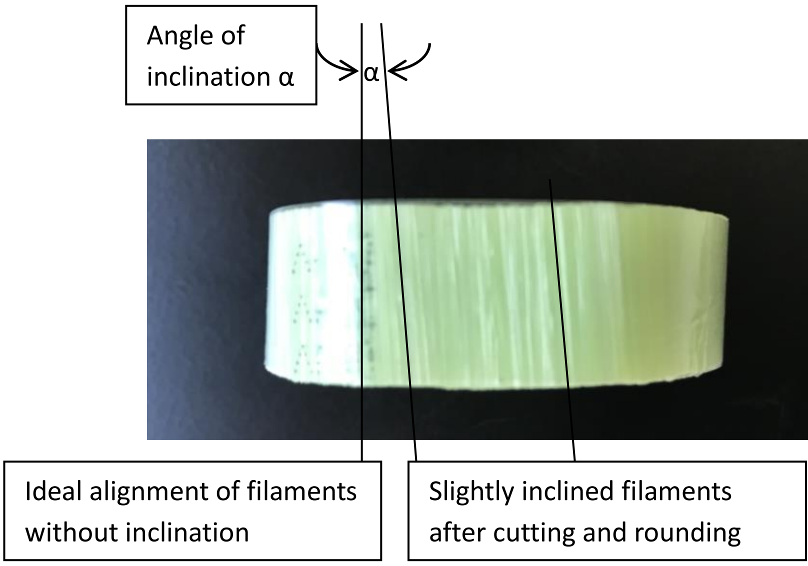

Fig. 5.4: Visualization of alignment of filaments with the filament puck (after cutting and rounding)

6. Results

6.1. Accuracy and reproducibility of the cutting length

The set-point of the filament length (thickness of the puck) is set to 16 mm. 12 pucks are cut from a polyester (PBT) hank with 0.127 mm diameter filaments. The thickness of the puck was measured at four points with the caliper (Fig. 5.1). The results are shown in Table 6.1.

Table 6.1: Reproducibility of cutting length, all dimensions in millimeter (mm)

Puck Nr.	Measurement 1 mm	Measurement 2 mm	Measurement 3 mm	Measurement 4 mm	Average mm	Tolerance mm
1	16.02	16.02	15.99	16.02	16.01	+0.01/-0.02
2	16.08	16.05	16.01	16.04	16.05	+0.03/-0.04
3	16.00	16.01	16.02	16.00	16.01	-0.01/-0.01
4	16.02	15.99	16.01	16.01	16.01	+0.01/-0.02
5	16.02	15.98	15.99	15.96	15.99	+0.03/-0.03
6	16.07	16.05	16.03	16.07	16.06	+0.01/-0.03
7	16.02	16.02	16.04	16.04	16.03	+0.01/-0.01
8	15.98	16.04	16.04	16.04	16.03	+0.01/-0.05
9	16.01	15.99	15.99	15.97	15.99	+0.02/-0.02
10	16.02	15.97	16.00	16,05	16.01	+0.04/-0.04
11	16.06	16.05	16.05	16.02	16.05	+0.01/-0.03
12	16.00	16.08	16.06	16.06	16.05	+0.03/-0.05

The mean value of all 48 measurements is 16.02 +0.06/-0.05 mm. In comparison with the setpoint, the filament length of 16 mm is achieved with a tolerance of +0.08/-0.03 mm. This is far below the tolerance of +/- 0.15 mm guaranteed by V-Air Machines GmbH.

6.2 Tip rounding

Several filament qualities, filament diameters and filament colors have been investigated. The table below shows the matrix of the analyzed filaments. Besides filaments with fully round cross sections, the end-rounding of some diamond shaped and twisted filaments are also tested.

Samples are taken out of the puck from its center and the outer rim on the right and left side: See figure 5.3.

Table 6.2: Results of tip-rounding quality.

Figure Nr.	Filament Material	Diameter mils/mm	Color, Texture, cross section	Remarks
6.1	PBT	5 / 0.127	light blue fully round	End tips after the cutting, i.e. prior to the tip-rounding
6.2	PA 6.12	5 / 0.127	light green diamond shape	100 % of the end tips are rounded, no fluff, no dust
6.3	PA	8 / 0.2	blue/white twisted filament	100 % of the end tips are rounded, no fluff, no dust
6.4	PBT	5 / 0.127	blue fully round	100 % of the end tips are rounded, a few dust particles
6.5	PA	6 / 0.152	clear fully round	100 % of the end tips are rounded, no fluff, no dust

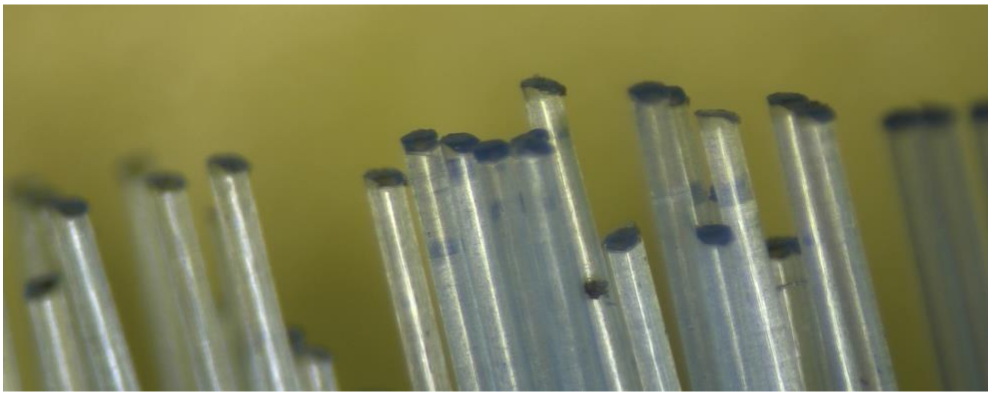

Fig. 6.1: Magnified tips after cutting, without end-rounding (prior to the tip-rounding)
Filament diameter: 5 mils; material: PBT color: light blue

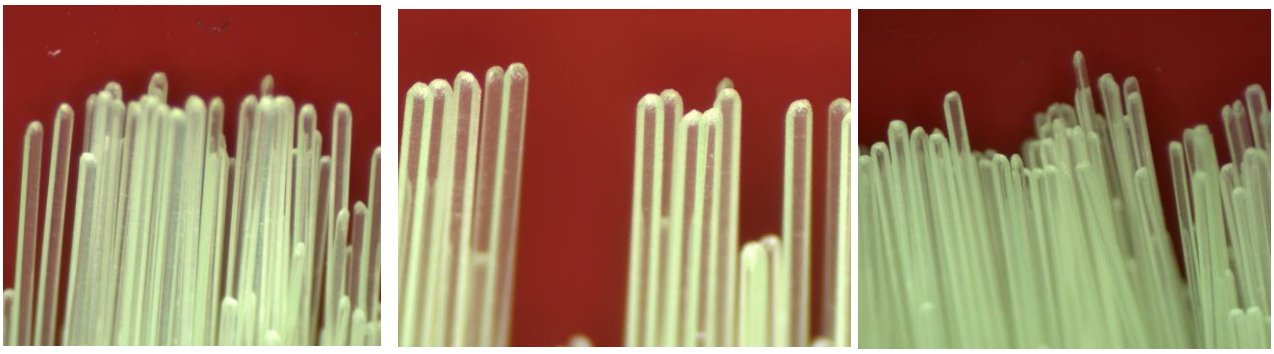

Fig. 6.2: Magnified tips (end-rounding quality)
Filament diameter: 5 mils; material: PA 12; color: light green; texture: diamond
Left photo: From center of puck. Middle photo: From outer rim. Right photo: From outer rim
Samples taken: See Fig. 5.3

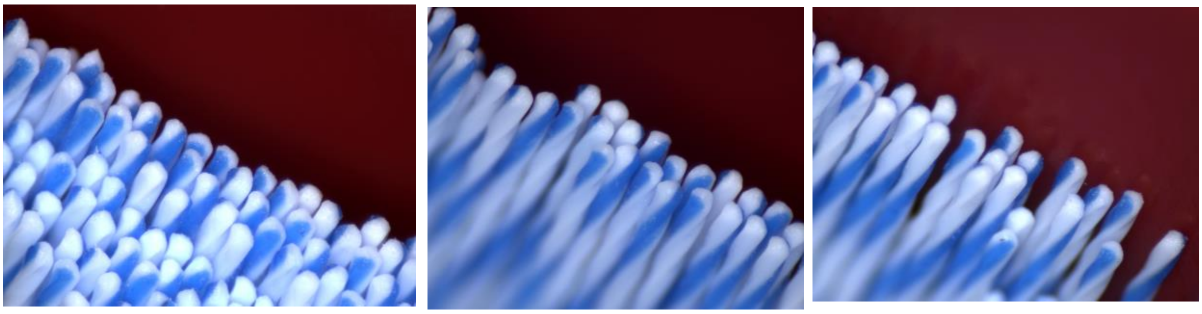

Fig. 6.3: Magnified tips (end-rounding quality)
Filament diameter: 8 mils; material: PA; color: blue/white; texture: twisted
Left photo: From center of puck. Middle photo: From outer rim. Right photo: From outer rim

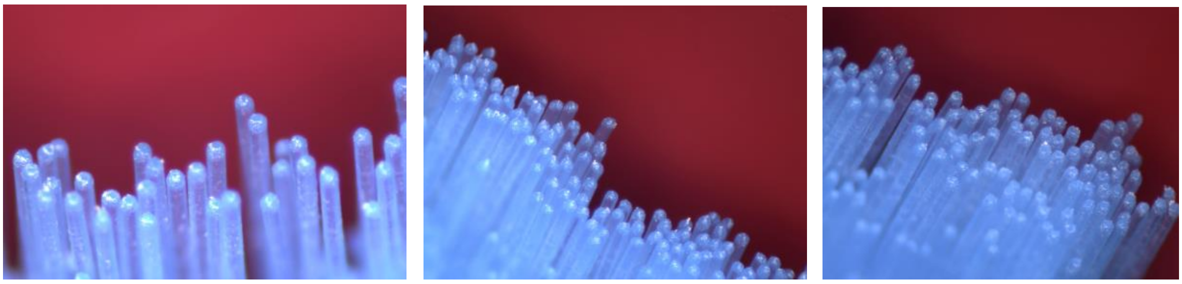

Fig. 6.4: Magnified tips (end-rounding quality)
Filament diameter: 6 mils; material: PBT; color: blue; texture: fully round
Left photo: From center of puck. Middle photo: From outer rim. Right photo: From outer rim

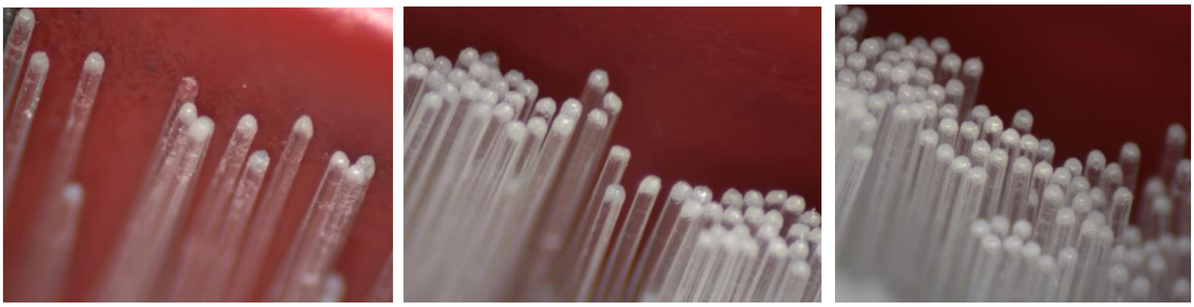

Fig. 6.5: Magnified tips (end-rounding quality)
Filament diameter: 6 mils; material: PA; color: clear; texture: fully round
Left photo: From center of puck. Middle photo: From outer rim. Right photo: From outer rim

7. Judgement – expert´s opinion

7.1 End-rounding quality

The classification of the thesis of Nuran Soydan (see page 5 of this paper) of the year 2008 was used to judge the end-rounding quality of the filament tips. Particularly, the classification of that thesis on page 52, Abb. 9 was applied. This classification is in line with previous publications on this subject, like

- Silverstone L.M, Featherstone M.J.: A scanning electron microscope study of the end rounding of bristles in eight toothbrush types.
  Quintessence International 1988; 19, 87-107
- Reiter C, Wetzel W E: Bearbeitung der Borstenenden bei Interdentalbürsten.
  Schweizer Monatsschrift für Zahnmedizin 1991; 101: 431-437

The end-rounding form of correct or acceptable filament tips varies from flat end, Fig. 7.1 to pointed end, Fig. 7.2. Most toothbrush manufacturers prefer a half-dome tip, Fig. 7.3. There are also tips which are non-symmetric, Fig. 7.4.

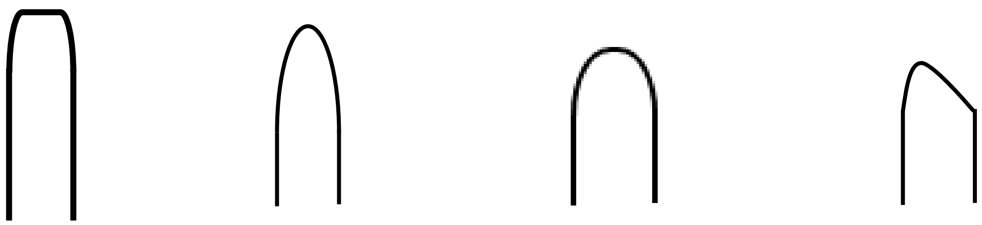

Fig. 7.1: Flat end tip **Fig. 7.2:** Pointed end tip **Fig. 7.3:** Half dome end tip **Fig. 7.4:** Non-symmetric tip

After the cutting from the filament hank, the individual filament end tips are sharp, see Fig. 6.1. The ends may also look like sketched in Fig. 7.5 (sketched in an exaggerated way to visualize it). The filament end has a sharp rim (Fig. 6.1) and sometimes, a pointed residue (which is also sharp) is left by the cutting, particularly, if the knife is not sharp enough. The sharp rim must be rounded and the sharp residue must be removed by the grinding as these would cause gum irritation if the teeth are brushed.

It does not matter, whether the rounded filament tips are flat, pointed, non-symmetric or a half dome. All these rounded tips avoid gum irritations. Thus, all these tips are considered to be correctly end-rounded in this analysis. This is also stated by the thesis (see chapter 2) of NURAN SOYDAN of the year 2008 on page 52, Abb. 9, Abb. 18 on page 60 and Abb. 19 on page 61. There are also non-acceptable filament tips listed, as e.g. Fig. 7.5.

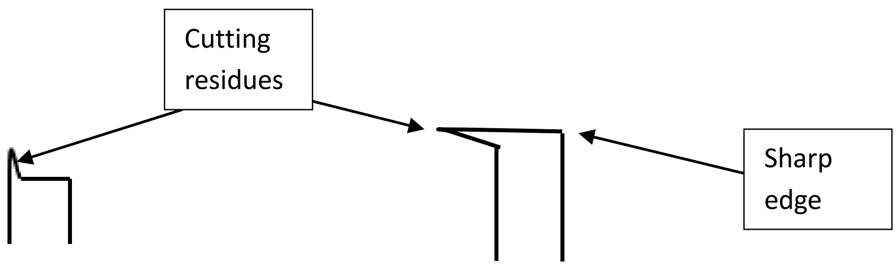

Fig. 7.5: Possible tip shapes after cutting from filament hank (prior to rounding process)

The figures in Chapter 6 demonstrate, that all the filaments are correctly end-rounded. It is seldom and unusual, that an expert must state, that the investigated issue is 100 % correct.
But the machine FRM yield a 100 % end-rounding effect for all processed filaments. Not a single filament tip could be found which is not acceptable according the thesis of Nuran Soydan.

Moreover, the machine FRM achieves practically a uniform end-rounding quality of all filaments in the puck, no matter if the filament is positioned in the puck´s center or at the rim. The differences are small and there have been no sharp edges detected.

The investigation shows that all filament tips are rounded in the perfect way according this classification. Hardly any filament could be observed which shows a shape of the type of Fig. 7.4 (which is still acceptable). All filaments are rounded in a fully acceptable way. Thus, it must be stated that this machine FRM provides a 100 % end-rounding.

The machine FRM allows to shape the filament tips flat (Fig. 7.1), pointed (Fig. 7.2) or with half domes (Fig. 7.3) – the PLC recipes can be programmed accordingly.

The visual inspection of magnified pictures does not show any dust residues nor roughness on the filament stems (like documented in Abb. 20, page 61 of the thesis of Nuran Soydan). This qualifies the processed filament by the machine FRM in an ideal way for the further production steps of the toothbrushes.

7.2 Filament length

The PLC of the machine FRM allows to program the puck length.

It was measured (Fig. 5.1), how the length varies from puck to puck. 12 pucks have been measured in total. Each puck is measured 4 times at different positions of the puck. The mean value of all 48 measurements is 16.02 +0.06/-0.05 mm. In comparison with the set-point, the filament length of 16 mm is achieved with a tolerance of +0.08/-0.03 mm. This is far below the tolerance of +/- 0.15 mm guaranteed by V-Air Machines GmbH.

Details are listed in table 6.1.

7.3 Filament alignment

It is of importance for the further production steps of toothbrushes, how the filaments are aligned within the brush. It is mandatory that the filaments are still aligned parallelly in the puck and straight –perpendicular to the cut plane– after the cutting and tip grinding.

The visual inspection of the pucks could hardly detect any oblique filaments. All the pucks had perfectly aligned filaments or inclinations which vary by very few degrees. The figure 5.4 shows an example of a slight filament inclination, i.e. deviation to the direction perpendicular to the cut plane. No further inclination could be observed.

It can be stated, that also the filament alignment is close to perfect within the puck after the cutting and rounding process by the machine FRM.

It has to be stated that the filament alignment is perfectly parallel in the puck center and deteriorates to the outer position where the wrapping is. Thus, the filament inclination shown in Fig. 5.4 is the worst case, but is still highly acceptable for the further filament processing to make toothbrushes.

8. SUMMARY

It is the scope of this expertise to investigate the end-rounding quality of different filament qualities (in respect to material, diameter, color and texture), which are made by the machine FRM of the Company V-Air Machines GmbH. Only the end-rounding quality of filaments which are used for the anchor-free tufting technique is subject of this analysis.

The classification of the thesis of Nuran Soydan of the year 2008 (see page 5 of this paper) was used to judge the end-rounding quality of the filament tips. Particularly, the classification of that thesis on page 52, Fig. 9 was applied. This classification is in line with previous publications on this subject.

The observations of the rounded filament tips have shown that the machine FRM yields a 100 % end-rounding quality for all known filament qualities for toothbrushes in respect to materials, diameters, textures and colors. The rounding efficiency is independent on the cross-section form (round, diamond shaped and twisted) and materials.

Only marginal –if any at all– differences of the filament tip quality could be observed in the position of the filaments within the puck.

The rounded filament pucks leave the machine without dust, without fluff or cutting residues on the filament surface due to the effective combination of cooling air and exhaust air system.

The length of the filament pucks is programmable. The length variation was measured to be below +/- 0.1 mm, thus well below +/- 0.15 mm, which is guaranteed by V-Air Machines GmbH.

All the filaments after cutting and end-rounding are still aligned closest to parallelism and perpendicular to the cut plane within the puck, i.e. practically no torsion of the filaments was observed.

The comparison to toothbrushes of brand names in the market shows that the filament tip quality (and the residues) processed by the FRM machine exceeds all of these toothbrushes under consideration.

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