White paper

Producing molds for clear dental aligners with HP Multi Jet Fusion 3D printing

Data courtesy of nivellmedical

Executive summary

This paper investigates the application of 3D printing dental molds to produce clear dental aligners through thermoforming. There are three main stakeholders in the market of clear aligners: patients, dentists and manufacturers. Traditionally the patient visits the dentist for treatment and the dentist orders the aligners. There is a trend of new businesses offering a direct-to-customer approach, offering clear aligners at a lower cost. It is estimated that in 2017 over 80 million dental molds were printed. The market has been growing rapidly and a steady growth over the next 5 years is predicted.

HP Multi Jet Fusion (HP MJF) technology is a relatively new 3D printing technology that powers HP's Jet Fusion 3D Printers, which can offer disruptive cost,[1] speed,[2] and quality[3] benefits compared to other 3D printing technologies. The end-to-end workflow of producing dental molds with HP MJF is explained in detail here, each step being covered, from 3D-scanning to producing the final dental aligner. The main advantages of HP MJF for this application is the increased production capacity[2] compared to currently implemented 3D-printing technologies and the lowest cost[1] per part. Up to 1200 dental molds can be produced per day with a part cost of $1-2.50. The production capacity is up to 5x higher than that of currently implemented technologies and at up to a 50% lower cost.[4]

Clear dental aligners

Clear dental aligners have been available on the market for over 20 years. It is estimated that currently, the majority of clear dental aligners are produced using 3D-printed molds. Predominantly resin-based 3D-printing technologies such as Stereolithography (SLA), PolyJet (PJ) and MaterialJet (MJP) are being implemented for production. In 2017 it was estimated that over 80 million units were printed. The forecast in fig.1 predicts a steady increase in production over the next 5 years.[1]

Data courtesy of nivellmedical

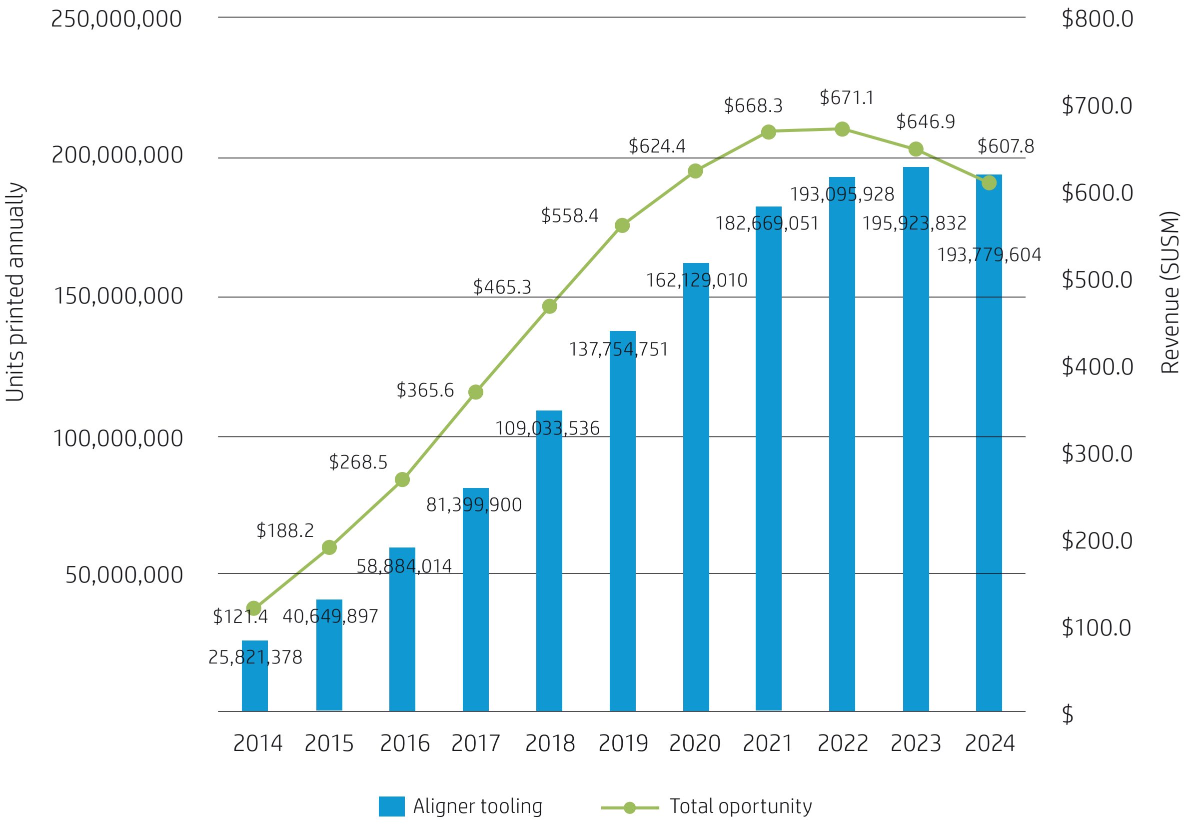
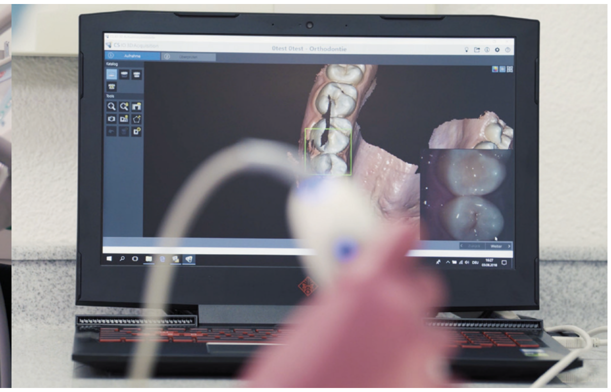


Figure 1 - Total 3D-printed clear dental aligner tooling, 2014-2024

Data courtesy of nivellmedical



Data courtesy of nivellmedical

Benefits of 3D printing for the:

- Patients: Clear aligners offer increased comfort and a better customer experience
- Dentists: The ability to offer cosmetic treatments to their regular customer bases
- Orthodontists: Allows them to offer a product that can be sold to adult patients
- Dental labs / Manufacturers: Reductions in production costs and increased capacity

There are two types of clear aligner treatments:

Full dental: For a full dental treatment, the patient visits a dentist to receive treatment with clear aligners. The dentist then orders the aligners from the manufacturer. The patient continues visiting the dentist during treatment to check his or her progress.

Front teeth: There is a new trend of direct-to-customer treatments correcting only the front teeth that are visible when smiling. Companies are offering this to customers at a lower cost without the need for them to visit a dentist.

Data courtesy of nivellmedical

HP Multi Jet Fusion benefits

Cost and productivity

For the application of clear dental aligners, the key benefits of HP MJF are productivity and cost. This productivity combined with the lower production cost positions HP MJF as the ideal technology for this application.

Hazardous materials and waste disposal

Two more important points are environmental impact and operator safety. Currently, the vast majority of dental molds are produced using resin-based 3D printing technologies. These resins are hazardous for both humans and the environment. They require further investments in specialized ventilation and monitoring systems to remove any harmful vapors. In addition to these safety concerns, these materials also require special waste disposal.

HP 3D High Reusability PA 12 is not hazardous and it is safe for operators to handle. The high reusability of HP 3D HR PA 12 reduces waste to an absolute minimum, with a high refresh ratio of 80% used and 20% fresh powder.

Accuracy

Several studies comparing plaster models with digital models [3D-printed] showed that a measurement difference of less than 0.20 mm is clinically acceptable because it is almost identical to the reliability determined for manual measurements. Another study researched the accuracy of digital models [3D printed] and concluded that it is unlikely that a mean difference of 0.27 mm would have a significant clinical impact.[2]

Under the correct conditions it is possible to deliver even better results than the stated accuracy for this specific part. Optimizing the build job and the printer's calibrations can improve these conditions.

End-to-end workflow

Scan the patient/customer

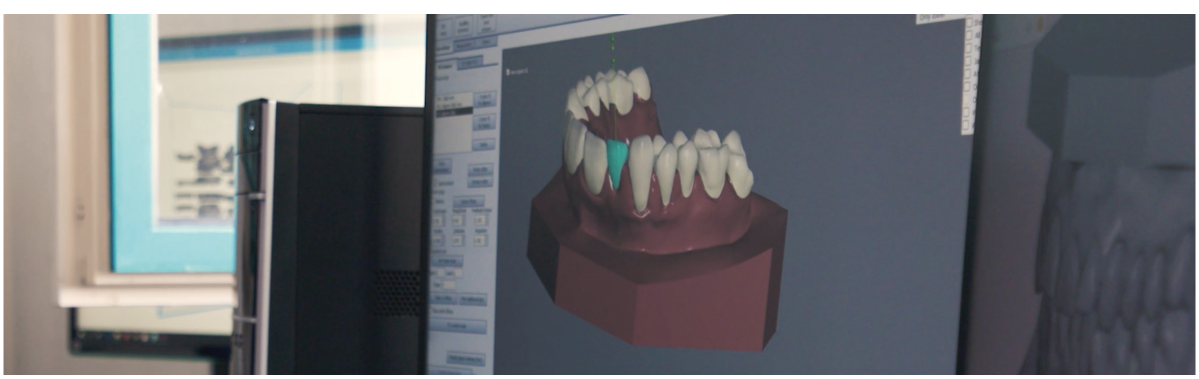
There are two methods of obtaining a digital file of a patient's teeth:

- Direct intra-oral 3D scans: The teeth of the patient can be scanned directly using a handheld 3D scanner by a dentist, orthodontist or by visiting a store that offers a 3D-scanning service.
- Scans of an impression: In this case, an impression of the patient's teeth is made. The impression can be done by the patient or it can be performed by a local dentist orthodontist. The impression is then sent to a lab to be 3D scanned and further processed.

Data courtesy of 3Shape

Remodel his teeth to an ideal position

After scanning the patient's teeth, the desired position of the teeth is modeled. Once the final position is determined, different stages are modeled with incremental movements of the teeth. The number of increments is determined by how extreme the change in position of the individual teeth is. A 3D model is created to produce a dental aligner for each of these increments.
Depending on the treatment, the number of incremental models can range from 5-30 (on average, 6-10). The duration of the treatment is from 6 to 24 months.



Recommended build job preparations

• Orientate teeth facing down:

To achieve the best part quality it is recommended to place the teeth face down.

• Hollow the parts with 1-1.5 mm wall thicknesses:

  – This reduces the packing density of the build by nearly 50%. And as a result, there is less heat in the build, which improves printer performance.

  – By hollowing the parts, the amount of fused areas is significantly reduced. This has several benefits in cost and part quality. By reducing the amount fused areas, agent consumption is reduced by up to 40%. The hollowing of parts also leads to better part quality, as there is less thermal energy stored in the part and the parts can be nested closer together.

• Automatic nesting of parts using Materialise Magics with Materialise Build Processor for HP Multi Jet Fusion or Autodesk® Netfabb® Engine for HP:

  – A spacing of 3 mm between parts is recommended.

  – It is important to maintain the parts' orientations during nesting. This can be done by restricting part rotation to the Z-axis only.

  – TIP: Triangle reduction of the files can significantly reduce nesting time, as less processor capacity is required (smallest detail = 0.04 mm, max. angle = 1°). Using 3MF instead of STL can also reduce the file size.

• Print 400-600 parts at a time (depending on dental model dimensions):

  – Manufacturers may use different model dimensions, and the size of the patient's jaw is an additional factor. Trimming the models to reduce the amount of unnecessary gum "tissue" that needs to be printed can increase the number of parts per build job. Models can be trimmed to within 2 mm of the lowest gum line, keeping the Z-height as low as possible. Results have shown that in a full build job, the number of dental molds placed can range from 400 to 600 parts.

Print the dental molds

• Fast print mode = approximately 12 hours: Printing in Fast mode maximizes productivity, allowing for up to 2 full builds per day. With an 80 micron layer thickness, high accuracy of the parts is ensured.

• Fast Cooling = approximately 12 hours: Fast cooling allows a 1:1 ratio of printing time vs. cooling time. The use of Fast Cooling combined with the Fast print mode enables a turnaround time of 24 hours for up to 600 parts.

• 2 builds/day possible → 800-1200 parts/day production speed: By using this printing and cooling configuration, it is possible to run 2 full build jobs per day. With one machine it would be possible to produce up to 1200 parts per day.

Post-process the printed parts

• Automatic bead blaster:

  – An automated cleaning process is highly recommended. Automatic bead blasting can clean the parts down to a smooth finish. Use ceramic or metal abrasives.

• Ceramic or metal abrasive media (200-400 microns):

  – Ceramic media does not contaminate parts (it does not become embedded in them).

  – Metallic media separates from the powder more easily.

  – These media clean and smoothen the parts to produce transparent dental aligners.

• 45 min bead blasting + 15 min air blasting (in the automatic bead blaster):

  – 4-5 bars of pressure is recommended for the bead blasting cabin. Further details can be found in the separate bead blasting whitepaper.

  – To clean and smoothen the surface of dental molds, a blasting time of approx. 45 minutes is recommended. An additional air blasting of 15 minutes removes any particles that may be attached to the parts (**TIP**: Blasting cabins with air ionizers prevent particles from sticking to the parts due to static charges).

• 10 min water rinse:

  – As an additional process to ensure the parts are completely clean, a 10-minute water rinse of the parts is recommended.

With this automated post-processing solution, up to 600 parts can be processed per hour. Results vary with the types of bead blasting and tumbling methods that are used.

Data courtesy of nivellmedical

Thermoform the dental aligner

- Process: vacuum or pressure molding (>3 bars):
  - Vacuum forming:
    This process uses atmospheric pressure to force a heated sheet against a mold's surface as it cools. The maximum force that can be applied with this process is limited to atmospheric pressure (1 atm or 15 PSI). When using vacuum thermoforming, small features and details may be lost in the final part.
  - Pressure forming:
    A similar process to vacuum forming, but adds positive pressure. Pressures of up to 10 bars can reached with this equipment. The advantage of pressure forming is that small features and details are transferred to the final part. This results in dental aligners with better accuracies that fit better.
- Material: PET-G, PVC, PU:
  - Different polymers are used for producing dental aligners. It depends on supplier, but the most widely used polymers are polyesters (PET-Gs), polyvinylchlorides (PVCs) and polyurethanes (PUs).
- Temperature:
  - The molding material is pre-heated to soften it for thermoforming. The samples are exposed to 200-220° C temperatures and the exposure time is modified depending on material type. This information is provided by the material supplier. This is the process for pressure forming. One of the most widely used pieces of equipment is Biostar by Scheu Dental.
  - Pre-heating times for vacuum forming are less controlled. There is a general recommendation of pre-heating the material until there is a 0.5 inch (13 mm) sag in the material. This is very operator dependent and less repeatable than for pressure forming.
- Wall thickness: 0.7-1.0 mm:
  - The wall thickness of the material can vary in the range of 0.7-1.0 mm.

Post-process/trim the aligner

There are two options for trimming thermoformed aligners: robotic or manual trimming. It is feasible to implement robotic trimming for large scale production. In many cases, aligners are trimmed manually using a variety of power tools or scissors:

- Manual trimming:
  The aligner is trimmed to its rough outline while it is still attached to the model. Then it is finely trimmed to the desired shape to ensure functionality and patient comfort while wearing. As a final step, the trimmed edges are polished to remove any sharp edges.
- Robotic trimming:
  A robotic arm or CNC machine trims the aligner along a predefined line to attain its final shape. As each model is individual, specialized software is necessary to define the cutting lines based off the 3D model. As a final step, the edges require polishing, which can be automated using a vibratory finisher.

1. Based on internal testing and public data for solutions on market as of April, 2016. Cost analysis based on: standard solution configuration price, supplies price, and maintenance costs recommended by manufacturer. Common cost criteria: using HP 3D High Reusability PA 12 material, and the powder reusability ratio recommended by manufacturer. HP Jet Fusion 3D 4200 Printing Solution average printing cost per part is half the average cost of comparable fused deposition modeling (FDM) and selective laser sintering (SLS) printer solutions from \$100,000 to \$300,000 USD. Cost criteria: printing 1 build chamber per day/5 days per week over 1 year of 30 cm^3 parts at 10% packing density. HP Jet Fusion 3D 4210 Printing Solution average printing cost per part is 65% lower versus the average cost of comparable FDM and SLS printer solutions from \$100,000 to \$300,000 USD and is 50% lower versus the average cost of comparable SLS printer solutions for \$300,000 to \$450,000 USD. Cost criteria: printing 1.4 full build chambers of parts per day/5 days per week over 1 year of 30 cm^3 parts at 10% packing density on fast print mode.
2. Based on internal testing and simulation, HP Jet Fusion 3D average printing time is up to 10 times faster than average printing time of comparable fused deposition modeling (FDM) and selective laser sintering (SLS) printer solutions from \$100,000 USD to \$300,000 USD on market as of April, 2016. Testing variables for the HP Jet Fusion 4210/4200 Printing Solutions: Part quantity: 1 full build chamber of parts from HP Jet Fusion 3D at 20% of packing density versus same number of parts on above-mentioned competitive devices; Part size: 30 cm^3; Layer thickness: 0.08 mm/0.003 inches.
3. Based on HP's unique multi-agent printing process. Excellent dimensional accuracy and fine detail within allowable margin of error. Based on dimensional accuracy of ±0.2 mm/0.008 inches on XY for hollow parts below 100 mm/3.94 inches and ±0.2% for hollow parts over 100 mm/3.94 inches, using HP 3D High Reusability PA 12 material, measured after sandblasting. See hp.com/go/3Dmaterials for more information on materials specifications.
4. The productivity and cost estimation are based on this application specific requirements and printing settings.

References:
[1] S. Dunham, "3D Printing In Dentistry 2015," SmarTech Markets Publishing, Charlottesville, 2015.
[2] J. J. R. H. S. a. Y. R. Aletta Hazeveld, "Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques," American Journal of Orthodontics and Dentofacial Orthopedics, vol. 145, no. 1, pp. 108-115, 2014.

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