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A SELF-PEELING VAT FOR IMPROVED RELEASE CAPABILITIES DURING DLP MATERIALS PROCESSING

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ABSTRACT: This paper describes research to increase the competitiveness of vat polymerisation by increasing the manufacturing rate while lowering the normal forces that induce part stress during the lift procedure of vat based systems. This is achieved through introducing a polymerisation vat that allows for an eased release of the manufactured part from the vat by means of a flexible membrane system. A membrane of fluorinated ethylene polymer will through elastic deformation automatically peel off the part as the part is lifted during layer changes. Peeling has been qualified by means of a truncated inverted cone as test geometry. As the cross-sectional diameter of the cone increases throughout the build-job, the geometry will release from the glass based build platform at the point where the peeling force exceed the adhesion force between platform and part. At failure point the lateral surface area of the top and bottom of the truncated cone is used as a measure of the performance of the vat with respect to release-capability. This has been tested at increasing manufacturing rates. The new self-peeling vat outperformed industrial state-of-the-art vats by 814% percent.

INTRODUCTION
Vat based polymerisation has become one of the most industrially adopted and competitive polymer based Additive Manufacturing methods for production quality parts. This is at large driven through mass-customisation within the hearing aid industry. It is estimated that more than 10 million hearing aid shells have been produced by vat polymerisation and thus the method has become the most ubiquitous production means for the world’s plastic shells for custom in-the-ear hearing aids. Today, 90% of all new shells are manufactured by either bottom-up style vat based DLP or SLA machine tools. [Wohlers (2015), p. 185]

![Figure 1. Hearing aid shell showing the region that adheres to the build plate (dark red) and the region that adheres to the vat one third through the manufacture (light red)](image-url)
Large-scale manufacture of hearing aid shells by Additive is still a labour costly manufacturing method, as all vat polymerisation technologies are limited to support structures that cannot be created in a secondary material. This leaves the use of the base material for the formation of supports, which subsequently must be removed mechanically from the hearing aid shells. Whereas the main purpose of support structures is often related to overhanging features, the support structure that is added when hearing aid shells are produced by vat polymerisation, often serve the purpose of ensuring that the shells are not pulled off the build plate during the lift sequence between each layer [Pedersen (2012), table 2.7]. It cannot be assumed that every hearing aid shell has a large surface that will allow good adhesion to the build plate, as each shell is customised to the consumer which governs the shape of the shell. The hearing aids often barely adhere to the build plate, and currently support structure is the only reliable fashion by which adhesion can be improved. Figure 1 shows a hearing aid shell that during manufacture will have an increased surface area in contact with the vat (67.9 mm²), compared to the build plate (55.7 mm²). In such cases it is imperative to ensure improved adhesion to the build plate when using traditional vats and vat coatings. The research that is presented in this paper aim to solve this issue by introducing a new vat design that has a release capability manifold better than what is currently industrially used.

VAT CONSTRUCTION

The fundamental difference between traditional industrial vats and the new vat construction presented in this paper is by the introduction of a membrane to replace the anti-stick coating that is normally found on the vat. This coating on traditional vats serves to reduce interface adhesion of the manufactured object to the bottom of the window but experiments has shown that the reduction of adhesion of the object to the vat from capillary adhesion is not altered [Jørgensen (2015), p.56, p.64]. This leave one of the two primary stiction forces unaffected by traditional coatings with the denouement that manufactured objects with increasing cross-sectional area has a tendency to detach from the build plate and remain stuck on the coated window in the vat. The new vat design abolishes this phenomena by introducing a self-peeling mechanism to the anti-stick surface by detaching the coating from the window through self-contained membrane that is stretched over the window. The membrane on the prototype vat has been made from Fluorinated Ethylene Propylene (FEP) film, that is stretched over the exposure window in the bottom of the vat. The construction principle of the vat can be seen in figure 2.

![Figure 2. Flexible membrane vat principle. (a) Resting position prior to lifting sequence. (b) Peeling effect during lift.](image)
Upon mask exposure, the object lay flat, flush against the membrane as seen in (a). On a traditional vat, high normal force is needed to break the capillary adhesion. During lift (b), the membrane deforms elastically and a peeling of the membrane off from the object drastically reduces the force needed to break the adhesion. One last but important design feature of the flexible membrane vat is that the vat as a component in a DLP system gets elevated from being a consumable that needs replacement when the coating wears. The vat has been manufactured in a fashion where the membrane and the separate exposure window each can be replaced in a matter of minutes, hereby elevating the vat to become a permanent subsystem with interchangeable membrane and window as consumables.

**VERIFICATION**

The peeling capability of the flexible membrane vat has been assessed on a purpose built vat polymerisation system and numerical engine. This Additive machine-tool has been designed and constructed at the Technical University of Denmark in order to serve as a Next-Gen technology platform. The platform combines vat polymerisation with light modulation done by Digital Light Processing (DLP) based on a Texas Instruments’ DLP4500 chipset with a WXGA resolution (1280x800), as also found in state-of-the-art industrial equipment. The assessment has been done by manufacturing a series of truncated cones with a top diameter of Ø2.5mm and a bottom diameter of Ø28.5mm. The bottom diameter corresponds to the largest possible exposure mask that can be generated on the vat based DLP system on which experiments has been conducted. A short stem on the top of the cone has been added in order to allow for the process to stabilise prior to expanding the cross-sectional diameter. The geometry can be seen in figure 3.

![Figure 3. Test geometry for verification of the peeling capabilities of the flexible vat.](image)

As the truncated cone is being manufactured, the cross-sectional area is constantly increasing. As this happens, the release-force from the vat is proportionally increasing. The failure point has been defined as the point at where the cone fails to release from the vat but either detaches from the build plate or the stem breaks. The flexible membrane vat has been benchmarked against a 2mm ET.06.01.1009.M066 M-Type vat from EnvisionTEC. [EnvisionTEC (2016)] Benchmarking has been done in two modes of operation. A straight lift mode, which is the simplest motion pattern that can be implemented, and a tilt-lift motion pattern which is the method by which EnvisionTEC Perfactory DLP systems operate. It is speculated that the tilt-lift is an attempt by EnvisionTEC to reduce the adhesion force of the object to the coated vat. In both modes, lift was done at a rate of
100 mm/min, at 35μm layer height. The photopolymer used is composed of a blend of Acrylate Monomers, and Glycol Diacrylate Monomers and with a Phosphine Oxide based Photo Initiator as crosslinking agent.

RESULTS
A series of cones has been manufactured, in each mode of operation. Most noticeable from the experimental series was, that whereas the control-experiments with the EnvisionTEC M-Type vat failed consequently upon reaching a surface area of ~82-87 mm², no failure could be introduced with the flexible membrane vat design. The limit of the build envelope of the DLP system was reached before failure occurred.

Figure 3 shows one of the manufactured cones, made using the flexible membrane vat. A liquid droplet of photopolymer resin has been captured near the stem, at the top of the cone, rendering it difficult to make out the true start diameter of the cone. Yet, it is obvious, that the peeling forces occurring while using the membrane vat is minimal. Table 1 clearly show that the peeling effect from the membrane allows for much larger ratio between the top bottom diameter of the truncated cone. It can be seen from the results that the flexible vat performs over 700% better than the EnvisionTEC M-Type vat in straight lift mode, and over 800% better than the EnvisionTEC vat in tilt mode. It is remarkable that the cones manufactured with tilt failed before the ones without tilt.
The reason for this is believed that the tilt of the vat introduce a bending momentum around the top of the cone, that will contribute to breaking the object off of the build plate

Table 1 Performance of vats. Top diameter is the initial diameter. Bottom diameter is at the failure point (marked red) or bottom diameter upon job completion.

<table>
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<tr>
<th>VAT</th>
<th>Top Diameter [mm]</th>
<th>Area [mm²]</th>
<th>Bottom Diameter [mm]</th>
<th>Area [mm²]</th>
<th>Bottom area [mm²]</th>
<th>Top area [mm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flex Vat (No failure)</td>
<td>2,45</td>
<td>4,71</td>
<td>28,66</td>
<td>645,12</td>
<td>136,84</td>
<td></td>
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<tr>
<td>EnvisionTEC, with tilt</td>
<td>2,49</td>
<td>4,87</td>
<td>10,21</td>
<td>81,87</td>
<td>16,81</td>
<td></td>
</tr>
<tr>
<td>EnvisionTEC, no tilt</td>
<td>2,39</td>
<td>4,49</td>
<td>10,52</td>
<td>86,92</td>
<td>19,37</td>
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Performance of flexible vat relative to EnvisionTEC with tilt: 814%
without tilt: 706%

CONCLUSIONS
This research aims to raise concern about vat coating strategies for vat polymerisation in Additive Manufacturing. A new generation of flexible vats has been developed and tested to prove how that there is much to be perfected before issues with unwanted bonding forces to the vat has been eliminated. By adding a flexible membrane above the window of a vat for a DLP system, a performance gain of least 814% has been achieved over an industrial vat from EnvisionTEC Gmbh. Lesser release force may yield not only a more stable process, that can allow for the use of less support structure, but also yield a process speed increase, as layer changes can be carried out more rapid than what currently is the norm. Further research into vat designs seem to be one of the focus areas from which the most obvious performance gains of DLP technologies can be achieved.

REFERENCES


EnvisionTEC GmbH (2016) Datasheet; Perfactory® 3 Mini Multi Lens with ERM, EnvisionTEC GmbH; Brüsseler Straße 51 • D-45968 Gladbeck • Germany