EXPLORING THE 3D PRINTING OF METAL VACUUM SEALS

AUTHORS' NOTE

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3D printing has been on the rise for some time now. Anything from plastic jewellery and car bodywork to biomaterial tissue and organs can now be printed, with industry experts continually learning about how to optimise materials, machinery, processes and procedures. The 3D printing of metal products for high-tech industrial applications remains quite the challenge however, with very demanding specifications in terms of accuracy, tolerances, surface finish, strength, etc. KMWE 3DP joined forces with Settels Savenije to build up experience in the 3D printing of metal vacuum seals.

ARNO GRAMSMA AND DORINE LAHEIJ

Research scope

The KMWE 3DP business unit is researching the additive manufacturing, popularly known as 3D printing, of metals (titanium and stainless steel) in collaboration with eight partners in the AddLab consortium. AddLab is the first 3D printing pilot factory for the production of industrial metal parts in Eindhoven, and it is here that KMWE works on manufacturing-for-design, parameter optimisation, support strategy, material research and integration with existing technologies to make world-class additively manufactured parts.

The Research & Feasibility team of Settels Savenije's development department took part in AddLab's Design Challenge 2015 with a self-sealing vacuum seal designed for reducing construction space in high-tech vacuum systems for semicon-related and process industries.

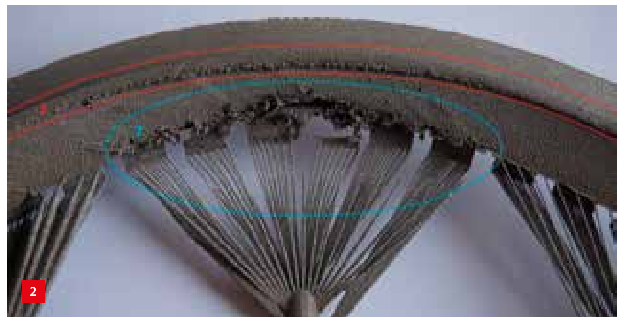
After meeting during the Design Challenge finals, KMWE 3DP and Settels started working together to bring this design to market. KMWE is eager to learn about printing industrial products in stainless steel and titanium, while Settels is exploring the opportunities to issue a new standard for vacuum seals.

To kick off the research, a print job was built using the original seal design, printed in an upright position and supported by a so-called tree structure. This position was chosen to minimise the total amount of supports and material required. Reducing the machining effort for removing the structures is an added benefit. Figure 1 shows the single seal on the printer after the 3D printing process has finished and most of the printing powder has been removed.

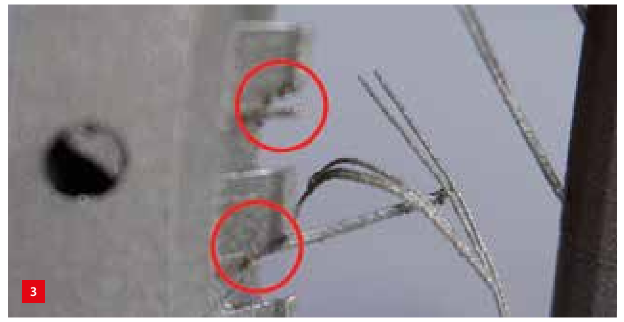
1 *Single seal printed in an upright position supported by the so-called tree structures. In the back, the same seal can be seen printed with full supports. For this last type of support, note the undesirable amount of printing powder that remains after cleaning.*

The prototypes made during this first print job demonstrate the difficulty of printing this design and the bad manufacturing because of the choice of support structures (see Figure 1). The following observations can be made.
A full structure support leads to:
1) Printing powder remaining in the structure.
2) A lot of post-processing time needed to remove structures and clean up the part.

A tree structure leads to:
1) A rough surface finish because of the absence of support structures (see area marked 1 in Figure 2) or support structures that are too fragile (see area marked 2 in Figure 2). A low thermal conductivity in these areas causes the surfaces to erode.
2) Fragile branches in the tree structure which have unfortunately snapped (see Figure 3).



2 *The marked surfaces illustrate the effect of printing small surfaces without support.*



3 *Clamp fingers with defects due to a (3D-printing-specific) mismatch of length-to-width ratio.*

Partners: KMWE and Settels Savenije

KMWE / DutchAero is a Dutch company based in Eindhoven, operating as both a supplier to and partner for the high-tech equipment industry and aerospace sector. The company specialises in high-mix, low-volume, high-complexity machining. It develops and delivers a wide range of complex, function-critical components and high-quality (cleanroom) assembled mechatronic modules and systems to meet the demands of customers in the medical, semiconductor, aerospace and industrial automation sectors.

Settels Savenije is a group of companies that combines high-level technology with a passion for people. The group invents, designs, manufactures, assembles and tests high-tech products, modules, tools and equipment. Their international customers serve the display, semiconductor, medical, aerospace and sensor markets.

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Redesign of support structures

The vacuum seal design was optimised for 3D printing using the lessons learned from the first print job. The following principles were applied for this new design:
1. The product is placed at an angle of 5° off the normal (upright) orientation with respect to the baseplate to avoid having to use vertical supports.
2. Perforations are incorporated into the support structures, so the structures can be removed easily.
3. The support strategy changed from tree supports to reinforced supports, as these can be removed more easily (post-processing). Changing from a closed to an open support structure means less material is needed.

4 *Result of the second print job, with optimised support structures and adjusted seal design.*

During a discussion with the seal's designers, it was decided to also optimise the seal design itself for printing. When a hole is required, most mechanical engineers will almost subconsciously choose a circular shape, as this can be easily made by machining on a lathe or a milling machine. Different rules apply for 3D printing however. A vertical printed circular hole requires a support structure, while a cat eye hole does not. As such, a cat eye hole is cheaper and quicker to create using 3D printing than conventional machining. Other concessions were made by reducing the amount of features, while still applying the learnings, e.g.

reducing the number of 'clamp fingers' (see Figure 3). This new support strategy combined with an adjusted seal design provided the basis for optimising the vacuum seal. The result of this print job can be seen in Figure 4.

This second print job provided additional lessons on 3D printing practice. Despite the new support structures, there were still some areas with a rough surface (see the marked areas in Figure 4). The reinforced support could be easily removed with the help of the perforations. There were a sufficient number of perforations and no further optimisation was required.

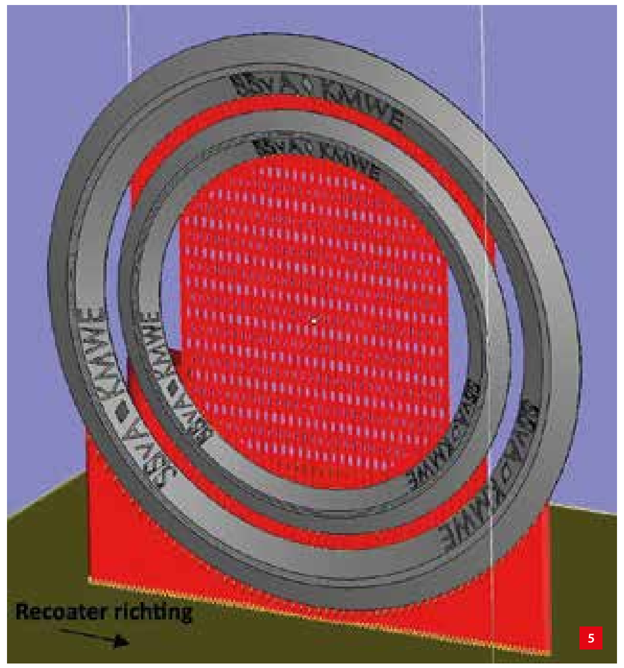
Another point that needed addressing was the discolouring of the material. At certain heights, the material seemed corroded. After investigating the complete print job, it became clear that the printing speed and breaks in the printing process were what caused this. Finally, it should be noted that supporting structures were still found in the cat eye holes, so the height-to-width ratio had to be optimised.

Redesign phase 2

To prevent the rough surface on the top of the seal, the outer radius was thickened. To further reduce the amount of support structure, a suggestion was made to nest seals with different sizes in one print job. The structure needed in the inner diameter was optimised to further reduce the amount of material required for the support structure (see Figure 5).

Evaluation of the results

The initial appearance of the seal was very satisfying, as the surface looked smooth and clean. On closer inspection, however, it was clear that other issues would need addressing:



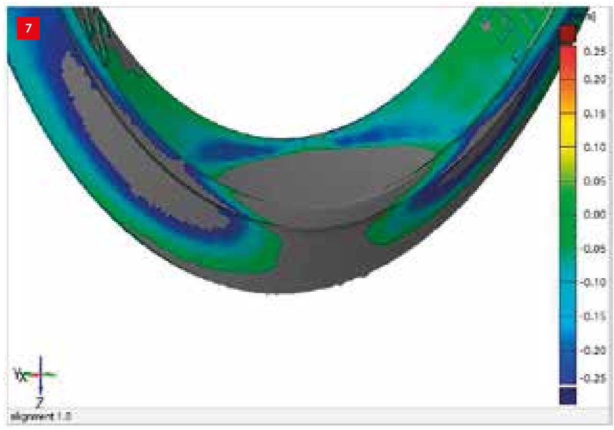
5 CAD design of the third print job.

6 Result of the third print job.

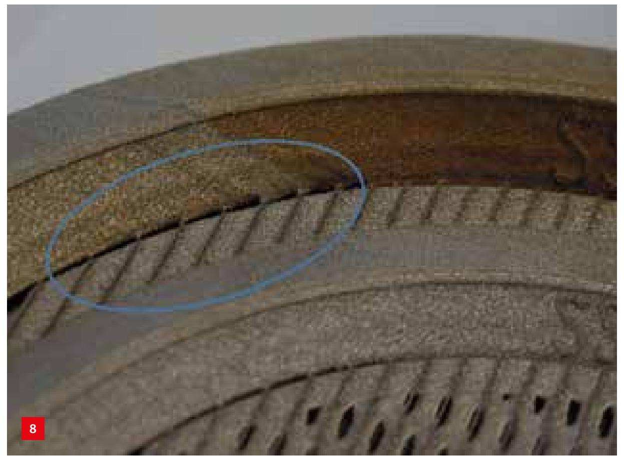
1. There was some deformation on the bottom of both seals (see the area marked in blue in Figure 6 and 7). A cause could not be determined immediately, although shrinkage of the material was suspected. After analysing the print job, the new slicer and its new parameters were found to be the cause. Slicer software is normally used to partition the product in thin layers that are printed sequentially.
2. Discolouring (see the areas marked in green in Figure 6) occurred in two places for two different reasons. The discolouring at the bottom appears at the level where all other parts in the print job were finished. We suspect that the heat supply increased on the seal at this level. The discolouring at the top was probably caused by a break during the printing process.
3. The support has separated from the seal due to thermal stress (see Figure 8). As such, the support should be optimised and reinforced (see marked area).

Final results

After 3D printing most parts require post-processing. The types of support used for this seal can be easily removed and polished with a handheld tool. Figure 9 shows some final results.



7 Measurement data (using the CAD model as a reference) showing the deformation of the lower side of the seal.



8 Detail of the third print job: supports (at the bottom) loosened from the seal (shown in the marked areas) due to thermal stress, which in turn further hampers optimal thermal conditioning.

9 Final results of the research carried out on the seal.

Settels Savenije is very happy with the progress made. The surface quality and overall finishing of the final products is currently at a level that the products can be tested on mechanical performance. A company that will apply a vacuum-compatible elastomer layer on the seal has been contacted and preparations are being made for vacuum testing. Further research has to be done on the internal stiffness of a seal made from this printed material. The tensile strength and other material properties of printed materials differ from those of traditional machined material, so tests and calculations have to be done.

KMWE learned that design and manufacturing have to work more closely together to create world-class additively manufactured parts. The orientation of the parts, parameter selection and support strategy have to be reviewed by the designers and engineers together to achieve the required quality of the product. Traditional manufacturing does not require such intense cooperation, since conventional technologies are common knowledge and have been further developed.

Settels and KMWE continue to work together on improving the 3D printing of metal vacuum seals.