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FMT
FUTURE MANUFACTURING TECHNOLOGIES

C3TS Report 1 – Demonstration parts and designing with DFAM

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DFAM and DFMA in general

DFAM (Design for Additive Manufacturing) means that parts are designed especially for additive manufacturing technology. In general it means that parts can be manufactured profitably with 3D AM if they are designed to the technology. Such things as the digital consolidation of many parts into one, using features that cannot be made with conventional mechanical manufacturing methods (milling, turning, casting, injection molding etc.) to improve performance, etc.

Basic DFAM process is described in Fig.1. Usually used design methods are topology optimization, design for multiscale structures (lattice structures) and part consolidation (unite multiple parts together) as well as taking into account parts orientation and support structures /1/. In designing, the first step is to inspect the functional aspects of the part and then the printing orientation.-Next step is to make the part 3D-printable (slicing and parameter settings for the machine).

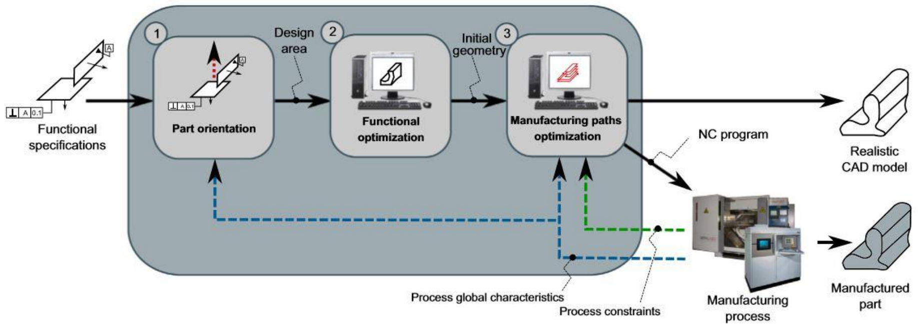

Fig.1 Principle of the DFAM process /2/

DFMA (Design of Manufacturing and Assembly) process is used normally to decrease the costs in product development phase. Fig. 2 shows the principle of DFMA process. In DFMA process, product is designed so that assembly (DFA) and manufacturing (DFM) are both taken into account. First there is a concept model that begins the iteration process. Simplifications for the part/assembly and iterations are continued until the structure is at accepted level. Next step is to optimize the material costs by selecting the best material with required properties (product behavior must be known!). When first iteration round is completed, DFA stage begins. In this step, manufacturing methods are selected and prototype is made.

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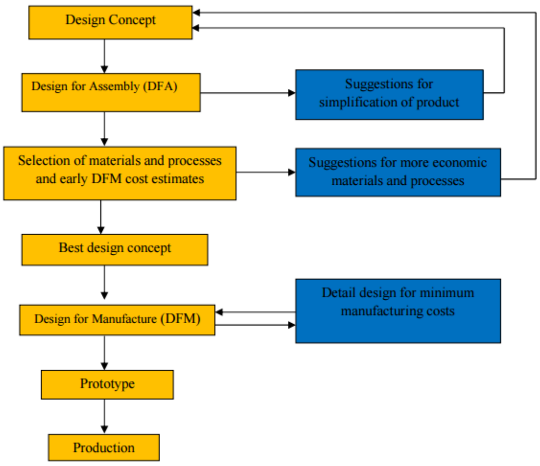

Fig.2 Principle of DFMA process /3/

Demonstration case 1; Topology optimized clamp

Version 1

DFAM has been used to design a clamp. This is a demonstration part, which is designed especially to concretize designing methods (topology optimization) by DFAM. This part was designed with some preconditions:

- The clamp is for automated line (space reservation)
- Certain forces and constraints involved has to be taken in account when designing
    - Fastening points and loading points indicated
    - First aim was to reduce weight i.e. to increase payload

Part is a demonstration to C3TS-project (Arctic Platform to Create, 3D-print, Test and Sell). Material was selected to be AlSi10Mg due to low loadings and weight reduction. As mentioned previously in technical report 6, the yield strength of AlSi10Mg is 250 MPa in printed condition and 150 MPa after annealing. (Specimens were printed in vertically).

Topology optimization method is described here below as a recap from previous technical report (Technical report 1):

Lightweight part design process for 3D printing:

1. Joint surfaces, geometric space reservations and technical requirements
    a. “mass model” – 3D model that have joint surfaces and geometric space reservations
2. Generating of preliminary 3D geometry using ParetoWorks
3. Design of the final geometry
    a. Main features of the geometry are due to be collected from result of the topology optimization.
    b. Manufacturing method is taken into account in final geometry design
    c. Strength requirements are taken into account using FE-analysis
4. 3D Printing

Mass model

First a mass model was built. Space reservations were included and also other technical requirements met the design. In Fig. 3, mass model with constraints is shown. Boundary conditions used were 1) fixed supports on the top, 2) 200 N load on the surface (marked as blue in Fig. 3) and 3) counterforces to the holes on the back (100 N each) of the mass model. Used topology optimization program was Paretoworks (add-in of Solidworks).

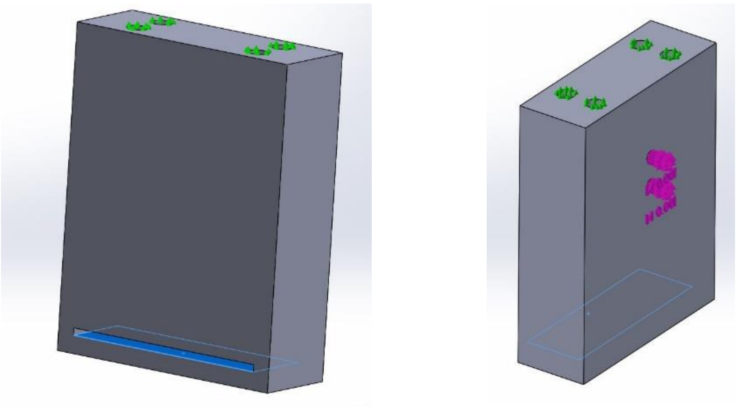

Fig.3 Mass model with boundary conditions: (a) frontside view and (b) backside view.

Topology optimizing result

The aim for the optimization was to lighten up this mass model up to 75 % with stresses below 250 MPa. The optimization was began with rough topology optimization as shown in Fig. 4. This rough topology optimization showed that how stresses are distributing to the structure and what are the main features to use in final geometry.

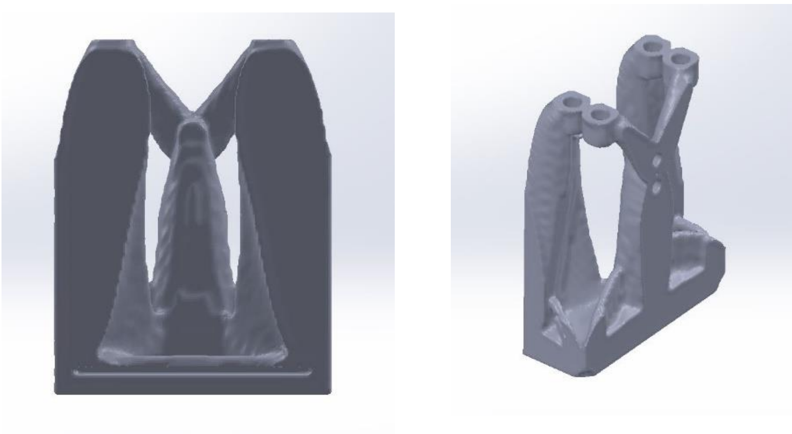

Fig.4 Results from topology optimization: (a) frontside view and (b) backside view.

Design of the final geometry

In the next stage, a sketch of a new model has to be done due to practical file conversion and printing aspects. The file (.stl) of Paretoworks add-in is printable in theory, but in practice the part has to be modified. Fig. 5 shows the topology optimized part after the modification. Geometry of the final part is same kind as in rough model. This model also includes some reliefs comparing to rough model.

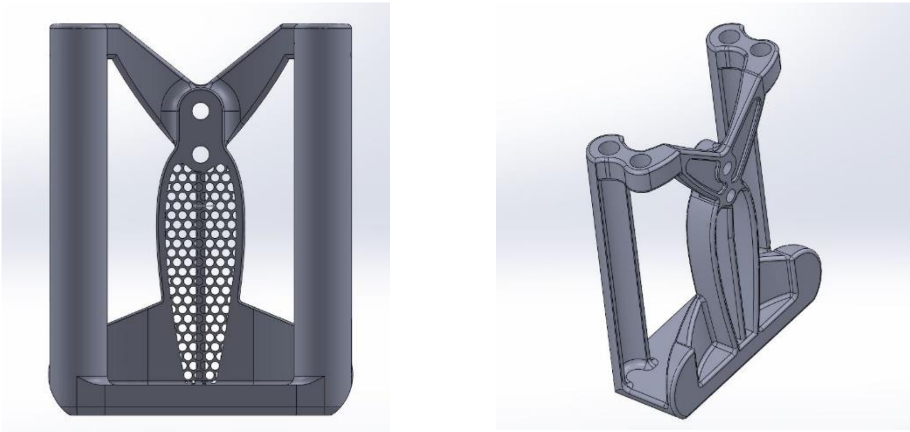

Fig.5 Topology optimized part after modifications: (a) frontside view and (b) backside view.

After the modifications, the final FEM-model was created and stresses and displacements were calculated and analyzed. FEM model was made in Solidworks. (Fig.6). FEM-inspection showed that part will withstand the loads. Maximum stress and displacement was 81 MPa and 0.1 mm, respectively. Results indicate that there are no strong local stresses, i.e. stress is evenly distributed to the part.

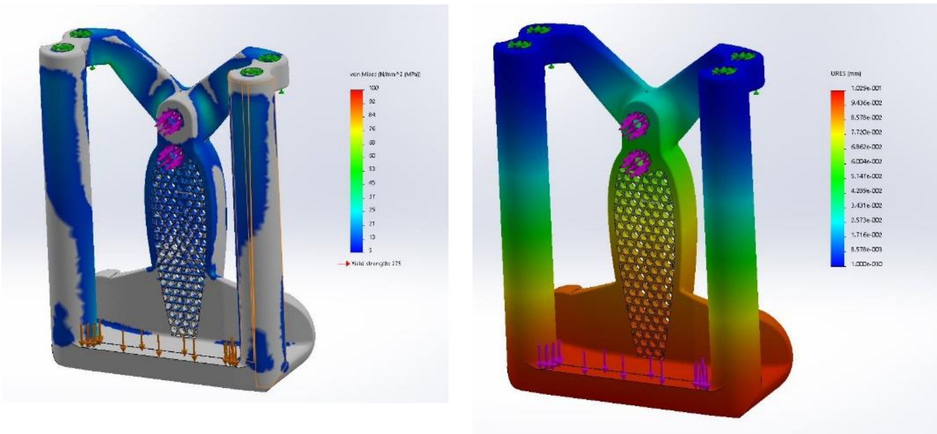

Fig.6 FEM results showing (a) stress and (b) displacement distribution in the optimized part.

3D-printing

The overall volume of the part was 0.033 dm^3 and the volume of the supports was 0.005 dm^3. Fig. 7 shows the printing angle and support structures of the part. To reach the geometrical tolerances (fastening points and loading surface) and to fulfill the requirements for surface roughness, printing angle of 30 ° and layer thickness of 30 µm were selected. Supports were placed on surfaces where they can be easily removed. Some failures were observed due to the incomplete support structure. In practice, some areas were not supported and the printing failed due to the lack of supports. Also teeth of the support structure were too weak to keep the face straight causing bending effect and collapsing. Printing time was 8 hours and 30 minutes for 1 piece and 16 hours and 30 minutes for 4 pieces meaning that the costs are about 680 € (80 €/h * 8.5h) and 1320 € (80 €/h * 16.5 h) respectively. The costs of a single piece were reduced from 680€ to 330€ by printing 4 pieces simultaneously.

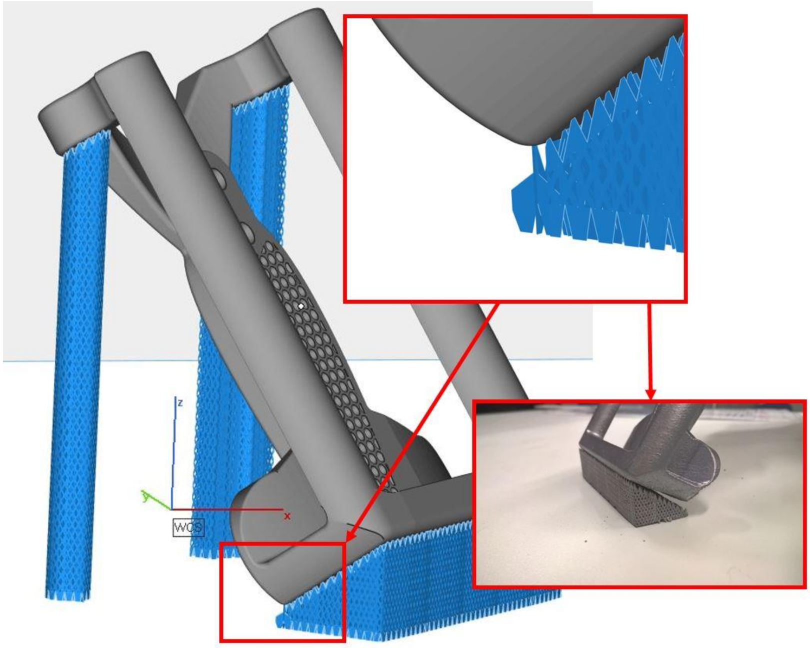

Fig.7 Support structures (insert showing the reason for failure)

Post-processing and final part

Post-processing treatments included:

- machining bottom surface (fastening and machining)
    - time about 5 min
- unfasten the part from platform, smooth the upper surface with file and glass ball blasting
    - 20 min

In fig.8 is shown a picture of printed part after post processing. In the fig.8 can be seen deviations on the features which is due to partial collapsing during the scanning. Front side view is the same as in final design geometry.

Fig.8 Printed clamp after post-processing; (a) frontside view and (b) backside view.

Results for demonstration case 1 version 1

- Structure will withstand the loads
- Topology optimized part is about 80 % lighter than mass model Weight of the final part of version 1 is measured for mass model and topology optimized with solidworks and weight of the 3D-printed part is measured with Kern FFN scale. Results are summarized in the table 1.

Table 1. Weight of different models

Model	weight [kg]	Measuring tool
Mass model	0.416	Solidworks
Topology optimized	0.077	Solidworks
3D printed part	0.072	Kern FFN scale

- Support structures have to improved
- Overall volume of the part is 0.033 dm^3 where supports share is 0.005 dm^3 → material costs are for one part 100€ /kg * (0.033 dm^3*2.7 kg/dm^3) = 9 € /piece
- Design time was approximately 8 h
- Printing time was for one piece 8 hours and 33 minutes and for four pieces 16 hours and 30 minutes → costs are 660 € and 1320 €, respectively
  - 4 pieces batch the cost for one part is 330 €
- Post-processing time was 25 min/piece

Version 2

Version 1 had an issue with the support structure. In the version 2, support structures has been improved so that teeth synchronization is deleted. This means that support structure is more solid in the interface of part and support structure. This support worked well for this part. There was no bending and the interface of support structure and part were tightly closed. In the fig. 9 is shown supports of the version 2.

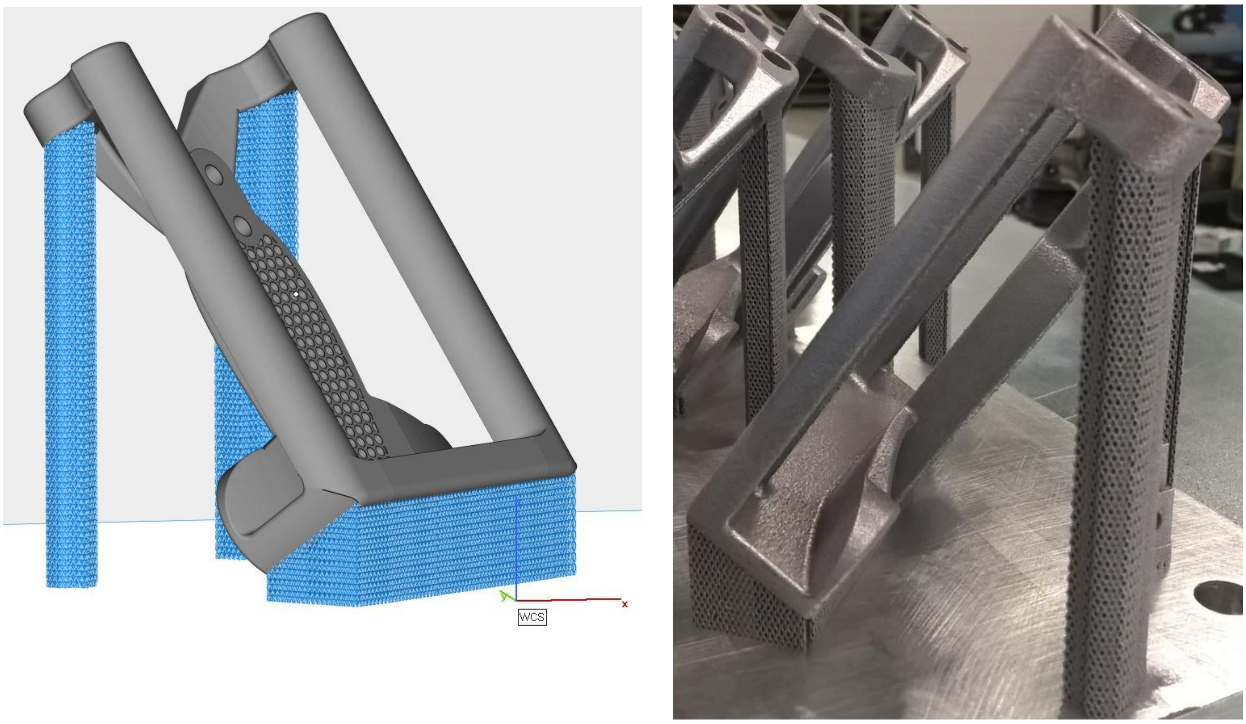

Fig.9 Improved support structure

Demonstration case 2; Part consolidation complex channels and nozzle

This demonstration case is designed to describe DFAM method part consolidation meaning in practice combining many parts in to one part. In this demonstration, hollow features and complex channels are demonstrated. Part is also sectioned so that hollow structures can be seen.

Design

This demo case had also some assumptions:

- part is a nozzle for some kind of material mixer
    - part has cooling/heating channel going spirally around part
    - Three input channels united to one output nozzle
- Material is selected to be aluminum (AlSi10Mg) because it have good heat conduction
- Eight parts have been combined into one
    - 4 legs
    - inside nozzle
    - middle shell
    - outer shell
    - spiral channel structure

This part was a demonstration case for C3TS-project.

Part was designed so that supports are only needed on the bottom of the part. New layer supports the next and so on. Design time was about 12 h for this part. In fig.10 is shown a picture of the sectioned part with support structures. In fig.10 can be seen three channels combining into one nozzle structure (output). Cooling/heating channel goes spirally around the part. Support structures are marked in blue which are only on the bottom of the part.

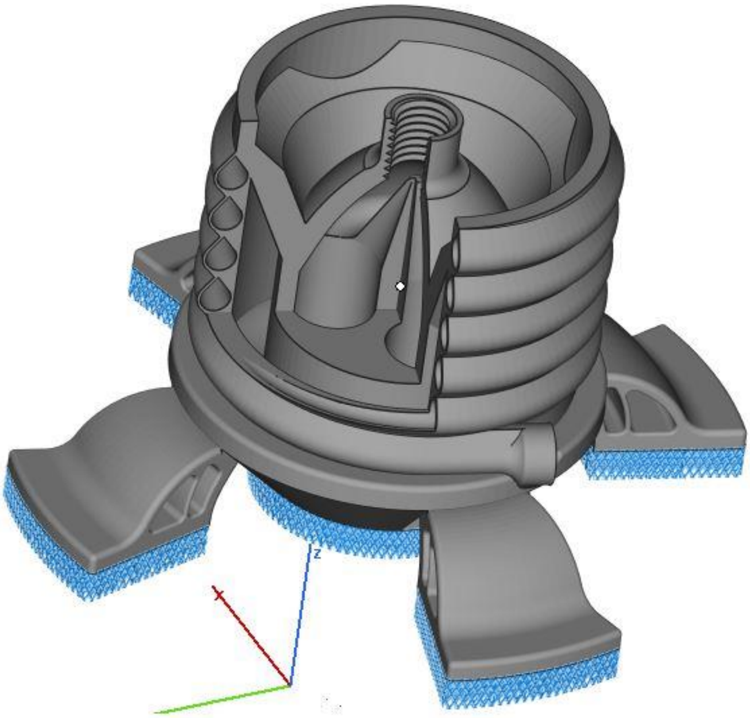

Fig.10 Sectioned channel structure with supports

3D-printing

This part was printed with 30 µm layer thickness, because the quality of the channels had to be at accepted level. This part was printed so that support structures are only bottom of the part. All supports are at flat surfaces so they are easy to machine off. Supports are fastened to the part and no teeth synchronization in the interface of the part and support structure is needed. The overall volume of the part is 0.09 dm^3 and share of the support is 0.002 dm^3. That means that material costs are 24.3 € /piece (0.09 dm^3*2.7 kg/dm^3*100 €/kg). Printing time for one part is 11 hours and for four pieces 29 hours so this means that costs are about 880 € (80 €/hour * 11 hours) and 2320 € (80 €/hour * 29 hours). In four parts batch the cost of one part is 2320€/4 = 580 €. Printed part is showed in fig.11.

Fig.11 Printed part: (a) AM part and (b) support structure of the AM part

Post-processing

Post-processing treatments include:

- unfasten the part from platform
    - time/piece 5 min
- machining
    - Time/piece 20 min
- glass-ball blasting
    - Time/piece 5 min
- Total time in post-processing per piece is 30 min.

Results for demonstration case 2

- Structure was successfully printed at the first time
- Eight parts were combined into one
- Support structures were optimized so that 2.2 % of the total amount of volume is support structure
- Printing time for 1 piece batch is 11 hours and the cost is 880 €
- Printing time for 4 pieces batch is 29 hours and cost of the one piece is 580 €
- Post-processing time is about 30 minutes

- Design time was about 12 hours

References

/1/ https://en.wikipedia.org/wiki/Design_for_additive_manufacturing, [18.10.2017]

/2/ Ponche R. et al. A novel methology of design for additive manufacturing applied to additive laser manufacturing process, Robotics and Computer-Integrated Manufacturing, 30 (2014) 389-398

/3/ Swain A.K National Pragramme on Technology Enhanced Learning, Introduction to DFMA. http://nptel.ac.in/courses/107103012/module1/lec1.pdf [18.10.2017]