THE IMPORTANCE OF SUPPORT OPTIMIZATION FOR ADDITIVE MANUFACTURING PROCESS

NICOLETA MIRELA POPA , LUCIANA LAURA SHAMIEH, NICHITA LARISA MILODIN

Abstract. The paper describes why support optimization is a very important step in additive manufacturing process. Additive manufacturing process gains an important place in medical industry due to the ability to obtain complex geometries, lattice structures impossible to be achieved using conventional technologies. Our paper focus on the support structures in the additive manufacturing process, required to ensure the quality of the final built part. The support structures solve many problems such as: channeling the heat flux produced by the laser beam, and thus improving the cooling down of the structure during the fabrication process, they avoid detachment of parts from the baseplate during the job due to uneven contraction, and transfer the heat to it, but also introduces new challenges such as: how to remove of support structures, the optimization. The requirement of manually removing the support from the part constrains the geometric freedom of the part as there needs to be hand/tool access. Support structures typically result in wasted feedstock material as they are not reusable and have to be discarded after removal if not recyclable. Thus the aim of this paper is to provide information on the importance of the support structures in the quality of the final parts.

Key words: Additive manufacturing, Support, Optimization, part quality.

1. INTRODUCTION

Additive manufacturing process provides significant opportunities for obtain complex geometry and internal detailed parts, thanks to their technique of add material to form a desired solid geometry, the opposite of subtractive technique as in the conventional manufacturing process.

Additive manufacturing technology, SLM (Selective Laser Melting) requires support structures to resist deformation or even collapse caused by gravity as the fabrication of the component proceeds, or to tether parts so far unconnected to the main body of the printed part during production, to mitigate against the effects caused by any generated thermal gradients during the manufacturing process and shrinkage upon solidification that are inherent within a large number of AM techniques [1].

National Institute of Research and Development in Mechatronics and Measurement Technique (INCDMTM)

Ro. J. Techn. Sci. – Appl. Mechanics, Vol. 64, N° 3, P. 219–229, Bucharest, 2019

When designing the support, material consumption and build time should be considered as a significant factor, as well as the trade-off between them and the final printed quality, [1].

First, structures can be optimized, not only for their final use but also for their behaviour during the building process, without requiring the addition of supports.

Can optimize the placement of supports to improve the building process and avoid any of the possible defects, previously mentioned, like overhang deformations or residual stresses, [2].

This helps to reduce thermal distortion that can lead to cracking, curling, sag, delamination and shrinkage.

The support can be optimized by maximizing the rigidity or in term of topology. Thermal properties of the support can also be optimized in order to facilitate the evacuation of heat produced by the additive manufacturing process. A combination of both mechanical and thermal properties can be taken into account.

Simple enough models so that support optimization is cheap and easy to implement into automatic design software.

Investigating the process of additive manufacturing, in terms of optimization of the support is still a necessity because they influence the quality of the final part. Hence, it is very important to understand the effects and the interactions that manufacturing process parameters will have on the properties of finished parts [3].

The problems which structure support introduce is how to remove the support, thus One possibility is to add geometric constraints, ensuring that any contact zone between supports and the actual shape is accessible from the outside along a straight tubular hole, allowing for the passage of some tool able to cut the supports.

The main objective of this paper is to establish and highlight the importance of optimization of the support for additive manufacturing process, by reviewing the underlying (thermo-) mechanical processes that define the necessity of a support structure for a given additive manufacturing technique. The paper will present also the differing strategies for support structure generation on EOS INT M270 and try to relate these between different additive manufacturing technologies, and the established underlying process with the aim of obtaining the properties of the final parts.

2. ADDITIVE MANUFACTURING PROCESS FOR METALLIC BIOMATERIALS

Additive manufacturing technology has captured an increasing attention thanks to the evolution of technology, which allows production of complex geometries and parts impossible to be achieved by traditional techniques.

This study started from the using SLM machine EOSINT M270 to obtain metallic parts by additive manufacturing process. The EOSINT M270 Machine, owned by INCDMTM is shown in Fig. 1 and also the process.

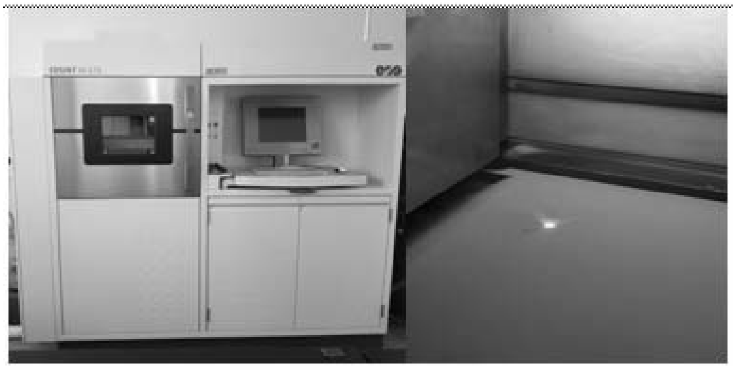


Fig. 1 – EOSINT M270 Dual Mode Machine, owned by INCDMTM and the laser beam.

The use of metal in additive manufacturing in the biomedical industry thanks to their possibility have a significant role in development of the biomedical industry [1].

The metallic materials which are used on EOSINT M270 are only biomaterials namely: titanium alloy – TI64 and cobalt-chrome alloy, intended to be used in the medical field. The biocompatible powder and SEM images are presented in the figure below.

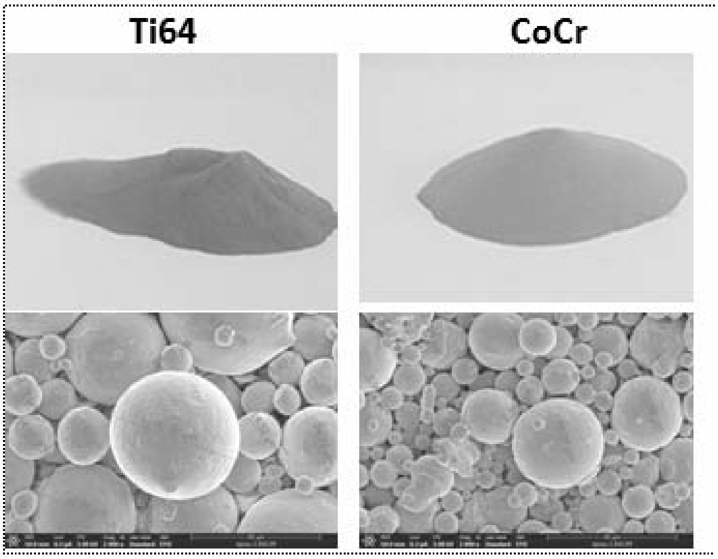
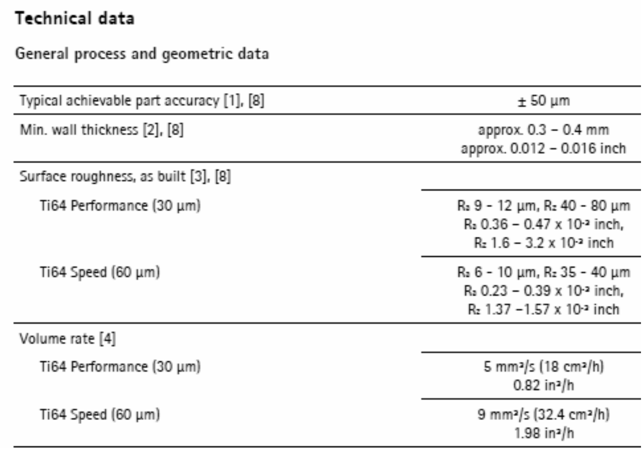


Fig. 2 – Biocompatible powder and SEM images(x2000) for Ti64 and CoCr.

Next figure, Fig. 3, the general process and geometric data for Ti64 and CoCr are presented.

Ti64

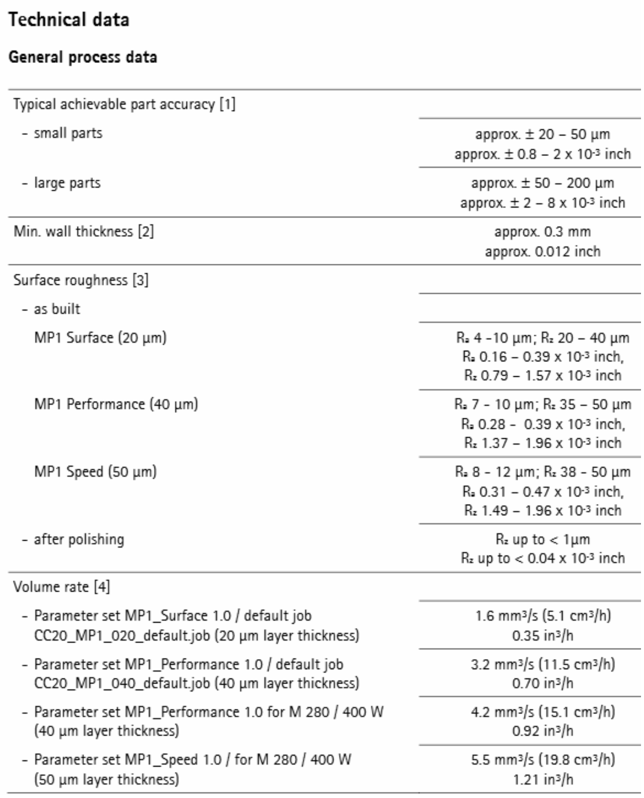


Technical data

General process and geometric data

Typical achievable part accuracy [1], [8]	± 50 µm
Min. wall thickness [2], [8]	approx. 0.3 – 0.4 mm approx. 0.012 – 0.016 inch
Surface roughness, as built [3], [8]	
Ti64 Performance (30 µm)	R_a 9 - 12 µm, R_z 40 - 80 µm R_a 0.36 – 0.47 x 10^{-3} inch, R_z 1.6 – 3.2 x 10^{-3} inch
Ti64 Speed (60 µm)	R_a 6 - 10 µm, R_z 35 - 40 µm R_a 0.23 – 0.39 x 10^{-3} inch, R_z 1.37 –1.57 x 10^{-3} inch
Volume rate [4]	
Ti64 Performance (30 µm)	5 mm³/s (18 cm³/h) 0.82 in³/h
Ti64 Speed (60 µm)	9 mm³/s (32.4 cm³/h) 1.98 in³/h

CoCr



Technical data

General process data

Typical achievable part accuracy [1]	
– small parts	approx. ± 20 – 50 µm approx. ± 0.8 – 2 x 10^{-3} inch
– large parts	approx. ± 50 – 200 µm approx. ± 2 – 8 x 10^{-3} inch
Min. wall thickness [2]	approx. 0.3 mm approx. 0.012 inch
Surface roughness [3]	
– as built	
MP1 Surface (20 µm)	R_a 4 -10 µm; R_z 20 – 40 µm R_a 0.16 – 0.39 x 10^{-3} inch, R_z 0.79 – 1.57 x 10^{-3} inch
MP1 Performance (40 µm)	R_a 7 - 10 µm; R_z 35 – 50 µm R_a 0.28 - 0.39 x 10^{-3} inch, R_z 1.37 – 1.96 x 10^{-3} inch
MP1 Speed (50 µm)	R_a 8 - 12 µm; R_z 38 - 50 µm R_a 0.31 – 0.47 x 10^{-3} inch, R_z 1.49 – 1.96 x 10^{-3} inch
– after polishing	R_z up to < 1µm R_z up to < 0.04 x 10^{-3} inch
Volume rate [4]	
– Parameter set MP1_Surface 1.0 / default job CC20_MP1_020_default.job (20 µm layer thickness)	1.6 mm³/s (5.1 cm³/h) 0.35 in³/h
– Parameter set MP1_Performance 1.0 / default job CC20_MP1_040_default.job (40 µm layer thickness)	3.2 mm³/s (11.5 cm³/h) 0.70 in³/h
– Parameter set MP1_Performance 1.0 for M 280 / 400 W (40 µm layer thickness)	4.2 mm³/s (15.1 cm³/h) 0.92 in³/h
– Parameter set MP1_Speed 1.0 / for M 280 / 400 W (50 µm layer thickness)	5.5 mm³/s (19.8 cm³/h) 1.21 in³/h

Fig. 3 – General process data for Ti64 and CoCr [2].

The 3D virtual models of the parts designed in SolidWorks were saved in a Standard Tessellation Language (STL) file and then imported into Magics RP software from Materialise company [2]. This software is used to multiply, orient and position the parts on the print surface, add the supports, and prepare the job to be exported to the machine. In the next step, the parts with the supports saved in the STL file are pre-processed using the EOS RP Tools program, and converted into a SLI 2D file type (Fig. 2). This conversion is necessary because sintering occurs only through melting layer by layer.

The virtual 3D model and the supports are divided into layers with a thickness of 0.02 or 0.03 mm depending on the material used.

After "slicing" the part, an error checking must be carried out to correct any errors in the file. The operation is necessary as parts made in 3D design software may have some errors, often undetectable by the user that can lead to problems in the printing operation.

The set-up of STL (or equivalent data file) models ready for printing requires the specification of the print orientation and the subsequent generation and placement of support structures.

This generally requires manual intervention based on the expertise of the operator.

The orientation and emplacement are two very important parameters in the quality of the final part. Due to their advantages of low solid volume fraction, this has tended to lead to cellular support structures, which also provide opportunities to reduce the time needed for removal of support structures as well as build time. After design the part and save it as STL. file, Magic and RP tools (PSW) software help us to prepare parts for job.

3. MANUFACTURABILITY CONDITIONS - OPTIMIZATION SUPPORT

Starting from the fact that the additive manufacturing process joins the material layer-by-layer, this can lead to issues when a new layer has a footprint different to the previous layer, as is likely to be encountered in the complex geometries that additive manufacturing is best suited for. In the additive manufacturing process in the fabrication of complex parts, a support structure of some type is necessary, which needs to be removed from the part to obtain the final component, wasting materials and cost.

Manufacturability conditions could be taken into account, most notably removal of supports. Our work is just a first step, proposing a general framework for support optimization.

In a first approach, only the shape and topology of the supports are optimized, for a given and fixed structure. In a second and more elaborated strategy, both the supports and the structure are optimized, which amounts to a specific multiphase optimization problem.

Starting for the fact that the supports are required to be strong enough to avoid detachment of parts from the baseplate during the job due to uneven contraction, and transfer the heat to it.

When designing the support, material consumption and build time should be considered as a significant factor, as well as the trade-off between them and the final printed quality. Their results revealed that, with only 2.2% overhang–support contact area, uniformly spaced vertical struts can manufacture relatively level thin plates.

Some require such a structure to resist deformation or even collapse caused by gravity as the fabrication of the component proceeds, or to tether parts so far unconnected to the main body of the printed part during production. Support structures can also be used to mitigate against the effects caused by any generated thermal gradients during the manufacturing process and shrinkage upon solidification that are inherent within a large number of AM techniques.

This helps to reduce thermal distortion that can lead to cracking, curling, sag, delamination and shrinkage. Support may also be used to balance a printed object so that it is securely tethered to the build platform during manufacture.

Different support methods will also lead to different finish surface roughness, thus, influencing the post-processing.

The requirement of manually removing the support from the part constrains the geometric freedom of the part as there needs to be hand/tool access. Support structures typically result in wasted feedstock material as they are not reusable and have to be discarded after removal if not recyclable. When adding a support structure to a part, the print time will be longer as the support structure also needs to be printed. As additive manufacturing processes typically have energy costs that scale with the volume of material used, this leads to increased energy usage.

A support structure may be detrimental to the surface finish when the structure is removed.

Extra time is required to design the part to accommodate the support structure and the design of the support structure itself. This implies a larger data file for the part. As printing speed increases and the complexity of a single voxel increases by incorporation of information such as color and material, the speed of data transfer may become a limitation.

The set-up of STL (or equivalent data file) models ready for printing requires the specification of the print orientation and the subsequent generation and placement of support structures.

This generally requires manual intervention based on the expertise of the operator.

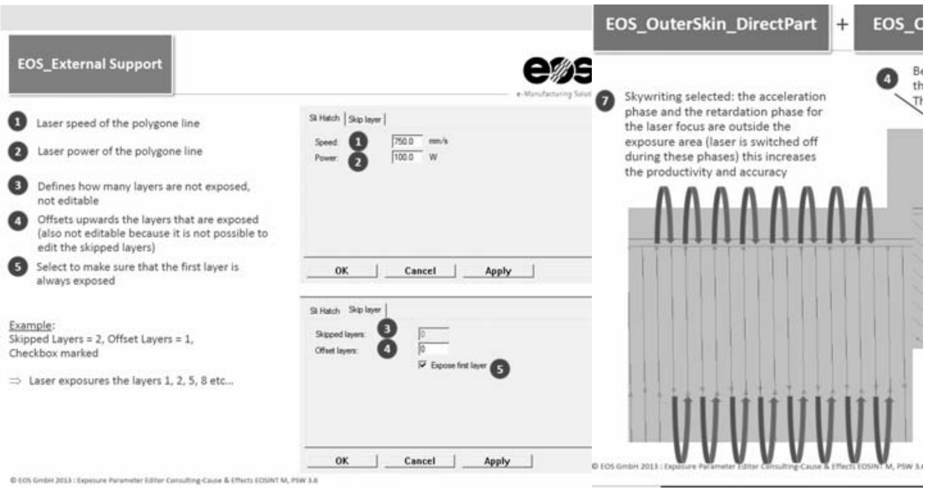
In general support structures are usually optimized in terms of material to be minimal and also in terms of build time and cost of the fabricated part.

Due to their advantages of low solid volume fraction, this has tended to lead to cellular support structures, which also provide opportunities to reduce the time needed for removal of support structures as well as build time.

After design the part and save it as STL. file, Magic and RP tools (PSW) software help us to prepare parts for job.

To obtain parts from TI64 and CoCr, using EOSINT M270 we have built support, that should be able to prevent parts from collapse/warping, especially the outer contour area which needs support; using Magic software allow us to modify the structure of support, size.

In next figure are presented general characteristics of external supports and outer skin for direct part and also the exposure strategy in the EOS.



EOS_External Support

① Laser speed of the polygone line

② Laser power of the polygone line

③ Defines how many layers are not exposed, not editable

④ Offsets upwards the layers that are exposed (also not editable because it is not possible to edit the skipped layers)

⑤ Select to make sure that the first layer is always exposed

Example:
Skipped Layers = 2, Offset Layers = 1, Checkbox marked

⇒ Laser exposures the layers 1, 2, 5, 8 etc...

Speed: ① 750.0 mm/s
Power: ② 100.0 W

Skipped layers: ③ 0
Offset layers: ④ 0
☑ Expose first layer ⑤

EOS_OuterSkin_DirectPart

⑦ Skywriting selected: the acceleration phase and the retardation phase for the laser focus are outside the exposure area (laser is switched off during these phases) this increases the productivity and accuracy

© EOS GmbH 2013 : Exposure Parameter Editor Consulting-Cause & Effects EOSINT M, PSW 3.6

Fig. 4 – General characteristics of external supports [2].

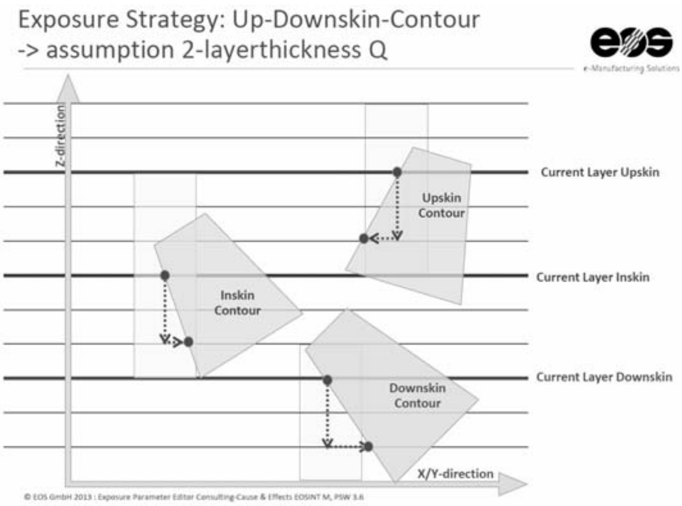


Fig. 5 – Exposure Strategy [2].

Starting from the up-down skin hatch, we can highlight, as is shown in the next figure, that if an overhang tilts at an angle less than 45 degrees from the vertical, support structures are not necessary.

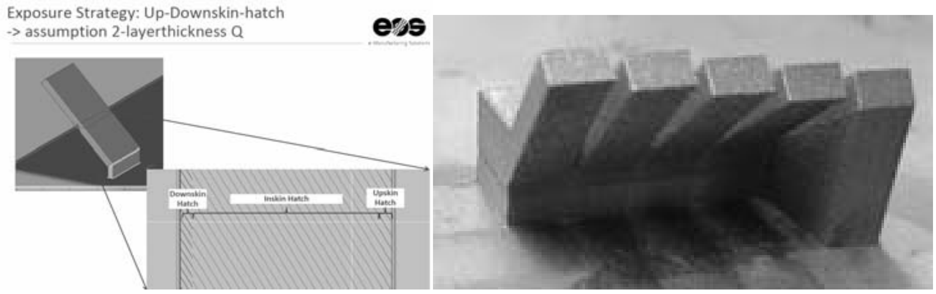


Fig. 6 – Part obtained by EOSINT M270 angle less than 45 no supports.

4. EXPERIMENTAL DETAILS-FAILURES PARTS

Next the paper will presents examples of the parts, manufactured by additive manufacturing technology, using EOSINT M270 Dual Mode, which give us conclusion regarding the support structure.

The support structure can help solve many problems, but also we observe that it introduces some new challenges.

We can notice that the main disadvantages of a support structure are how to remove of support structures after printing requiring a significant work support structures need extra time to be cut, ground or milled off after printing which consequently, labor and time to manufacture the part increases.

In the first example the part was manufactured by additive manufacturing with 40 µm layer thickness.

Starting from the fact that the support should be able to prevent the collapse or deformation of the parts, especially the outer contour area that needs support, we can conclude that in this case, the type of supports were not suitable and did not help but created problems. Thus, a poor quality piece resulted, and the circularity was not obtained. The job was completed due to the layer thickness, even if the supports were detached and led to deformation of the part.

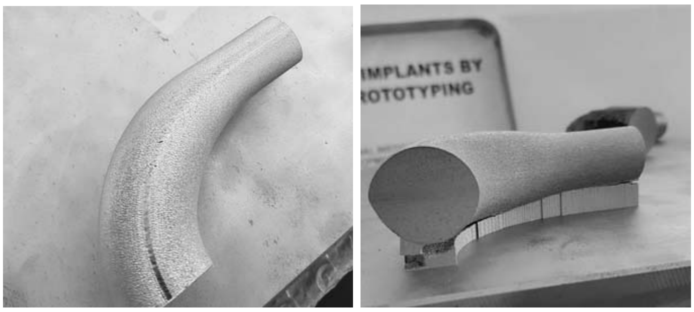


Fig. 7. – The baseplate with the printed part in job1.

In the same job, a failure part is presented below, because of the layer thickness.

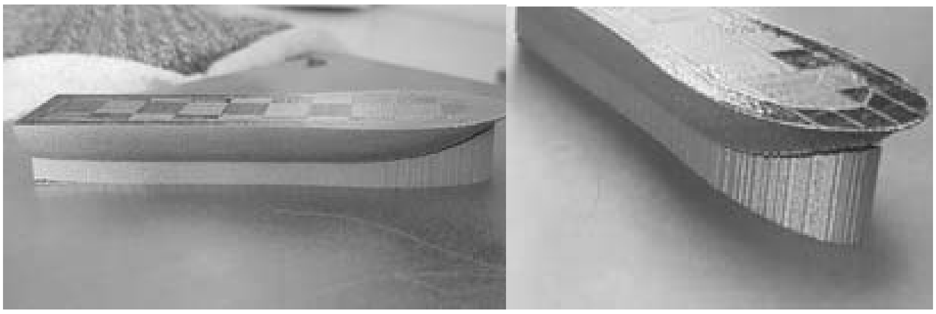


Fig. 8 – The baseplate with the printed part in job 2.

In the second experiment, the manufacture of the same part, with the same parameters, less the layer thickness (layer thickness 20 μm), gives us interesting information.

We can conclude that, in this case, by modifying the support structure in the boarded term, and by changing the thickness of the layer (decreasing the layer 20 μm), the problem of detachment appears again. In this situation, the job cannot be completed due to the thickness of the 0.02 mm layer. Thus, the supports were detached and led to the deformation of the piece, that which had the consequence of stopping the job. We can notice that although the part quality is better than in the first job, but due to supports detached the job couldn't be finished.

Starting from the EOS exposure time and skin can be notice on our part the core and the skin, as in Fig. 9.

Fig. 9 – The core and the skin exposure strategy.

5. SUCCESSFUL PARTS OBTAINED BY EOSINT M270

We can present also successful parts obtained by additive manufacturing using EOSINT M270 Dual Mode.

For specific application, complex shape and geometry as anatomical shape as well as lattice structure, the additive manufacturing technology has proven perfect.

Thus the additive manufacturing is best suited for complex and detailed parts as we can notice from resulted printed parts.

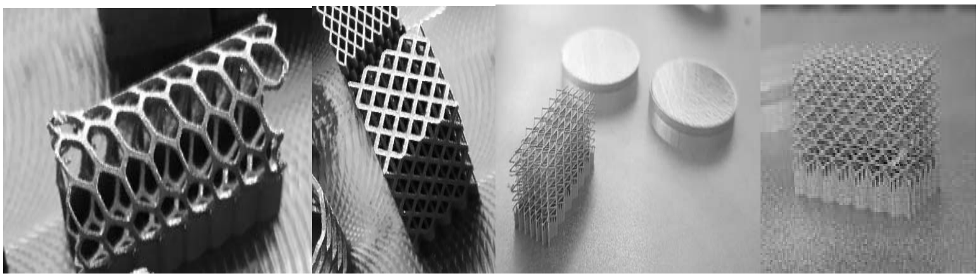


Fig. 10 – The successful parts manufactured by EOSINT M270.

6. CONCLUSIONS

In this paper, the importance of optimizing supports structures in additive manufacturing process is exposed. On the basis of the analysis carried out in this paper, it was found that:

The successful and failures part manufactured by additive manufacturing process were presented.

Our case studies have been highlighted to demonstrate the importance of the support structures, because material and build time can be significant reduced while fulfilling the structural demands.

From our experiments, we can observe that the designing of support are very important and depend on the design part and also the final part, considering the final parts quality but also material consumption and build time as a significant factors.

We should give an special attention of the attachment between the part and support, to not be detached but also the contact area between the support and final parts in the same time should be as small as possible to reduce surface deterioration after support removal, but also should be of minimal strength to perform the support function, with the aim of easily removing support.

So that the supports are required to be strong enough to avoid detachment of parts from the baseplate during the job due to uneven contraction, and transfer the heat to it.

We can conclude that the support can be optimized the by maximizing the rigidity of the supported structure with a fixed structure, or in term of topology.

We can conclude that especially graded structures providing less support where it is not needed and more robust support elsewhere.

Acknowledgements. This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI – UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0224/ctr. number 77PCCDI/2018 – DigiTech, within PNCDI III

Received on November 26, 2019

REFERENCES

1. JINGCHAO JIANG, XUN XU AND JONATHAN STRINGER, *Support Structures for Additive Manufacturing:* A Review, Department of Mechanical Engineering, University of Auckland, Auckland 1142, New Zealand; Published: 20 September 2018.
2. *** Exposure Parameter Editor Consulting-Cause & Effects EOSINT M, PSW 3.6,
3. www.eos.info.
4. ALLAIRE, G., BOGOSEL, B., *Optimizing supports for additive manufacturing*, Structural and Multidisciplinary Optimization, **58**, *6*, pp. 2493–2515, 2018.
5. HARUN,W.S.W., KAMARIAH, M.S.I.N., MUHAMAD, N., GHANI, S.A.C., AHMAD, F., MOHAMED, Z., *A review of powder additive manufacturing processes for metallic biomaterials*, **327**, pp. 128–151, March 2018.