Improvement of Machining Thin-Walled Parts Generated by Hybrid Manufacturing

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Abstract

This paper is intended to show the problem in the production of thin-walled parts using hybrid manufacturing. It is necessary to machined the parts generated by 3D printing at certain stages of the production process. The problem can arise during machining of thin-walled parts. This paper shows the way in which the critical depth of cut can by changed by adding support structures, instead of changing cutting parameters.

Key words: Hybrid Manufacturing, Additive Manufacturing, Lattice Structure.

1. Introduction

The hybrid manufacturing has been on the rise for the past decade, because it combines the benefits of machining process a additive manufacturing. The machines for hybrid manufacturing are mostly five-axis rotary milling machines with additional laser welding head either as a new axis or with a holder for clamping to spindle.

Figure 1. *Deposition of a nozzle for a rocket engine made of stainless steel (X5CrNiMo17-12-2): ø 450 × 470 mm, approx. 10 h machining time incl. 6-sided turn & mill complete machining. [1]*

The parts created by additive manufacturing are layered layer by layer from additional material. These parts must be machined at certain stages of production, due to its use as a commercial product. Parts ranging from prototypes to difficult-to-cut materials in aerospace and energetic industry can by created by this technology.

The advantage of the additive manufacturing is lesser material removal of the part than there is with the cutting technology. The parts, which are being cut, have material removal of fifty percent or even higher. With the same parts produced by hybrid manufacturing, the material removal can be reduced to zero and thus it saves the material. The disadvantages of the additive manufacturing are higher roughness of surface and higher geometric inaccuracy. Therefore, it is necessary to machine the functional surfaces of printed parts. Another disadvantage is relatively long printing time in additive manufacturing. (This time can range from one hundred grams per hour up to ten kilos per hour. It depends on the accuracy of printing and choice of technology.)

The machine for hybrid manufacturing have no issue with roughness of surfaces and geometrical accuracy because the parts are machined during 3D printing. An issue may arise with machining high thin-walled parts, which may have resonance frequency during machining, which complicates machining. The resonance frequency seldom occurs in thick-walled workpieces.

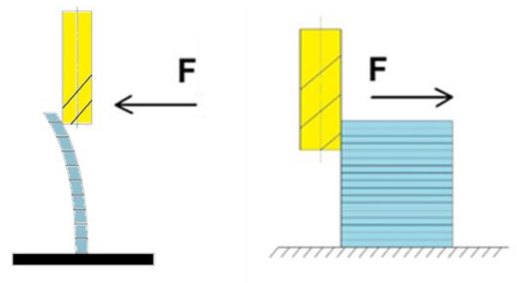

Figure 2. *Machining of the thick-walled parts in comparison with machining the thin-walled parts*

Therefore, an appropriate solution seems to be reinforcing the parts by support structure or various ribs. These can either remain attached to the part or can by easily removed. The printing time must be taken into consideration when designing support structures.

2. The critical depth of cut of thin-walled plate

To be able imagine what support structures will be needed for machining of thin-walled parts, parametric model of thin-walled plate about dimensions was created see

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Figure 3. This plate was loaded by modal force in software ANSYS. The loading took place vertically to the plate, on its the upper surface. Frequency Response Function (FRF) data for different dimensions of the plate was generated in software ANSYS. Also, FRF data was generated for different loading places on the upper surface of the plate. This step helped to determine how the critical depth of cut varies depending on the loading place of the plate or on the machining track.

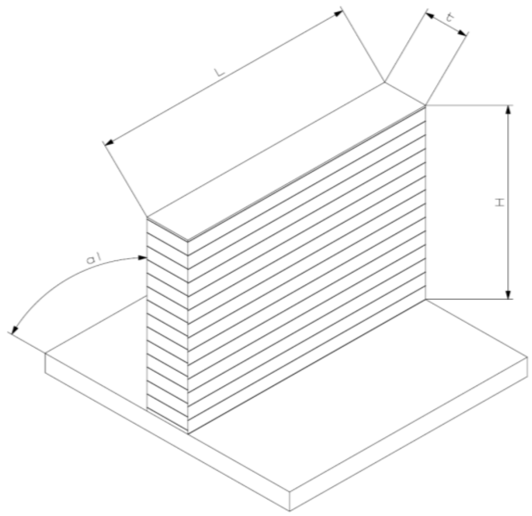

Figure 3. *The parametric model of plate with dimension*

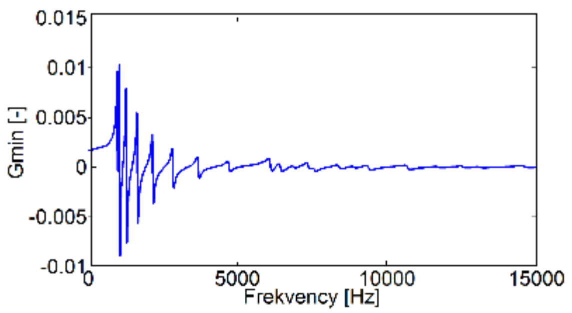

Figure 4. *Example of the FRF diagram*

On the Figure 4, FRF diagram is shown where the minimum value of the real part of the dynamic compliance can taken. The critical depth of cut is calculated according to the equation 1.

$$B_{lim} = -\frac{1}{2KcGmin} \qquad (1)$$

From thus calculated value, it is necessary to take the smallest B_{lim} for the each dimension , they are called B_{limmin}. The minimum depth of cut of the examined thin-walled plates was found mostly on the edges of the plates, as can be seen in Figure 5. On the basis calculated minimal critical depth of cut, a graph was created in relation to the critical depth of cut and the height and thickness of the machined material (see on Figure 6).

If we set the limit value of productive machining as one millimetre, a number of dimensions of thin-walled plates do not meet the criteria, and thus it will be necessary to adjust the cutting conditions. When we use a support structure, we do not need to take resonant frequency of the plate in the first stage, but we need to raise the value of critical depth of cut over the desired value depth of the cut.

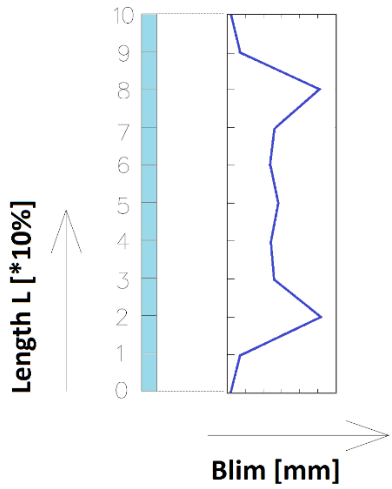

Figure 5. *Dependence the critical depth of cut on cutting place*

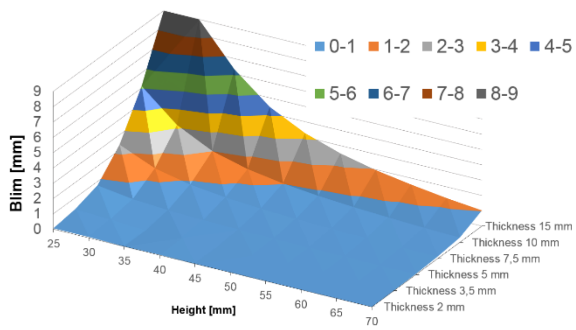

Figure 6 *The critical depth of cut for different dimensions of plate*

3. The critical depth of cut of parts with support structures

In the second phase a plate lying in area with the low critical depth of cut is selected. The dimensions of the plate are: High = 70 mm, length = 160 mm and thickness 5 mm. This plate is supported by more kinds of support structures, see Figure 7.

The support structure was designed so that the props form comprehensive lattice along the entire length of plate (see the Figure 8). The base of cell this lattice structure is designed as a cubic cell with these dimensions: diameter of cell edge = 5,5 mm and length of this edge = 21 mm. The dimensions of the cell are given on the basis of technology tests on prototype of metal 3D printer.

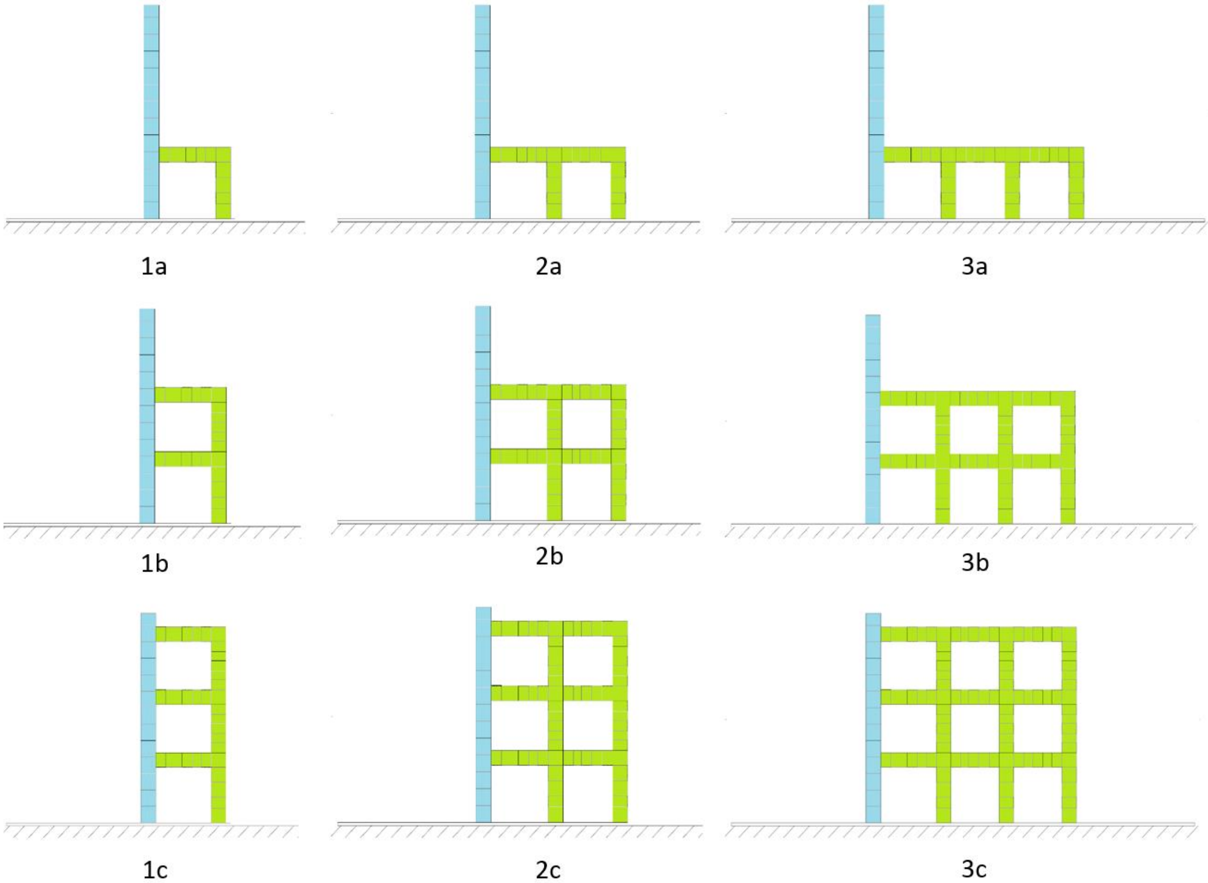

Figure 7. *Various types of support structures*

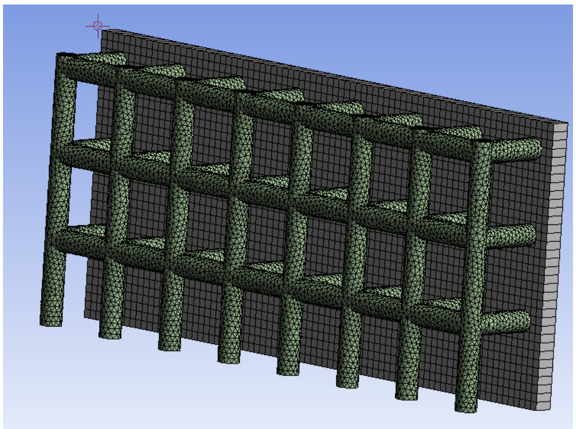

Figure 8. *The model of plate with support structures in software ANSYS.*

This plate was also loaded of modal force on the upper surface of the plate and FRF data was generated in software ANSYS on eleven places of the plate. The minimum value of the real part of the dynamic compliance was read from FRF data.

The minimum depth of cut was calculated according to equation 1 for different loading places on the plate after finding the minimum value of the real part of the dynamic compliance. The minimum depth of cut was mostly on the edges of the plates with support structure as well as on the plates without the support structures.

Table 1*. Compared the critical depth of cut for different plates with support structures*

The type of support	B_{lim} [mm]	1. resonance frequency[Hz]
Without support	0,029	861,74
1a	0,04	1126
1b	0,085	1667,8
1c	0,138	1680
2a	0,043	1180,4
2b	0,122	1972,5
2c	0,282	1916,5
3a	0,044	1218,4
3b	0,147	2146,2
3c	0,475	2024,6

The critical depth of cut and resonance frequency are changed for different types of support structures of the plate, as you can see from Table 1. The critical depth of cut was increased about sixteen times when support structures type 3c were used instead of plate without the use of support structures. The resonance frequency was increased to a higher frequency.

4. Potential replacement of support structure with solid body

The support systems can significantly affect the mechanical properties of the whole system (thin-walled plate – support structure). Therefore, it seems convenient to use them. The support structure can be composed of the base cell with different dimensions (i.e. diameter of edge and length). These changes in size can significantly affect the mechanical properties of support structure.

Generating 3D models of these structures is time consuming, and the same applies for the FEM calculation. Therefore, it would be useful to build on studies of many foreign scientists, in which the support structures are replaced by solid material. The density of the solid material is reduced to the so called relative density. When we use this density to calculate yong´s module, which is called the initial stiffness. Poisson's ratio remains unchanged.

Hereby, when a support structure is replaced with solid body with defined relative density and the initial stiffness, time otherwise spent on designing the support structure can be saved.

The relative density is the ratio between volume of the support structure and volume of the solid body.

$$\rho^* = \frac{V_{cell}}{V_C} \qquad (2)$$

The initial stiffness for closed cubic cells was defined by Ashby at al. in university textbook [2], as:

$$E_{ef} = E_s * [0{,}5(\rho^*)^2 + 0{,}3\rho^*] \qquad (3)$$

As can be seen from the relation, the initial stiffness is dependent on relative density of the new solid body.

5. Conclusion

The parametric model of thin-walled plate was being loaded with modal force in order to determine the critical depth of cut. The critical depth of cut was being calculated for different cutting (loading) height, even for different thickness of the plate.

One plate was chosen from the tested plates. This plate was reinforced in several ways using support structures. The support structures were composed of individual basic cubic cells. The value of critical depth of cut is significantly higher in the same loading conditions. The value of critical depth of cut is sixteen times higher with support structures (three rows and three columns of basic cells) than in case of a plate without support structures.

This increase of the critical depth of cut changes in relation to density of support structure. It means changes of the dimensions of basic cell. It is therefore crucial to come up with ways of speeding up the design process of support structures. One of possible solutions is to replace the support structure with a solid body with changed initial stiffness corresponding to the original support structure. This step would accelerate the first design of the support structure, because FEM model of any support structure is computationally very demanding. Therefore, its replacement with solid body will decrease the computational demands. However, the question remains what the degree of accuracy would be or whether is it at all possible?

Acknowledgements

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The list of symbols

B_{lim}	The critical depth of cut (mm)
B_{limmin}	The minimum critical depth of cut (mm)
E_{ef}	The initial stiffness (MPa)
E_S	Young's modulus (MPa)
F	Cutting (Loading) force (N)
FRF	Frequency response function
FEM	Finite element method
GMIN	Min. real part of the dynamic compliance (-)
H	Height of plate (mm)
Kc	Tangential metal cutting force coefficient (MPa)
L	Length of plate (mm)
t	Thickness of plate (mm)
VC	The value of solid body (mm3)
Vcell	The value of support structure (mm3)
α1	Rotation angle of plate (°)
ρ*	The relative density (-)

References

[1] DMG MORI, „NEW: LASERTEC 4300 3D and LASERTEC 65 3D – Additive production of 3D components to finished parts quality.," [Online]. Available: http://www.dmgmori.com/webspecial/journal_2015_2/en/wp-lasertec.htm. [Přístup získán 20 March 2017].

[2] M. Ashby, Metal Foams: a Design Guide, Woburn: Butterworth-Heinemann, 2000.