Support Structure Generation and Topology Optimization in Metal 3D Printing: A Review

Navneet Singh*[1]

Assistant Professor, Mechanical Engineering Department,

Faculty of Engineering and Technology, Rama University,

Kanpur, Uttar Pradesh, INDIA.

Abstract –

Alongside the expanded utilization of added substance fabricating (Additive Manufacturing – 3D Printing) in the aviation, automobile and bio-medical industry, a superior comprehension of various angles for the system has turned out to be important to satisfy the levels of popularity of unwavering quality and vigor. The capacity to present perplexing, even inner, highlights into part design with AM claims many structure specialists to this new gathering of innovations. In this regard, new design rules for AM are being examined, created and refreshed every day. In spite of the fact that, it is usually expressed that AM offers boundless geometrical intricacy, there are a few points of confinement of the innovation. There is noteworthy intrigue today in incorporating additive manufacturing (AM) and topology enhancement (TO). In any case, topology optimization regularly prompts structures that are not AM well disposed. For example, topologically optimized design may require significant amount of support structures before they can be additively made, bringing about expanded manufacture and clean up expenses.

Design of the support structures which are easy to apply and evacuate in AM. The trade off in the design of support structures roots from the way that the support structures must be sufficiently able to associate the part to give protection from twisting up and they are wanted to be free enough to be effectively expelled. Furthermore, redundant utilization of support structures expands the measure of material spent, manufacturing time just as post preparing endeavors. This paper shows the review of various support structure designs.

Keywords: Rapid Prototyping, Additive Manufacturing, Direct Metal Laser Sintering, Support Structure, Topology Optimization.

---

1. Introduction

As per ASTM F2792.429494-1 standard, additive manufacturing is the procedure of joining materials to make objects from 3D model information for the most part layer upon layer, instead of subtractive manufacturing methodologies, example: conventional machining. Laser Beam Melting (LBM), additionally alluded to as immediate metal laser sintering/softening (DMLS/DMLM), Laser Cusing or Selective Laser Melting (SLM) by various machine sellers or clients, is a powder-based combination process whereby a 3D part is manufactured, layer by layer, using a high-vitality centered laser shaft to specifically dissolve powdered material and wire the powder particles during solidification [1-4].

Starting examination for single material supports has started over twenty years prior, for the most part concentrating on computational support generation procedures relevant to Stereolithography (SLA) and Fused Deposition Modeling (FDM). One of the regular objectives of these studies were to decide best form direction, which requires least number of support structures for a given shade edge between 30-45 degrees[5-7]. Different objectives included mechanization, speed of support generation and convenience, which added to the advancement of CAD (Computer Aided Design) and data preparation for additive manufacturing. In current scenario, there are several software available for CAD modeling and data preparation of models and support generation for additive manufacturing. And they are given both as independent bundles or installed modules running inside universally useful CAD programming [8-10].

Current research investigate about support structures are directed in various fields yet the principle objective to decrease the measure of association of support structures to the part stays comparable with previous studies [6]. In this unique situation, a portion of the current research topics cover support generation algorithms and its calculations, practical investigation on the support structures of fundamental geometric components, displaying of support structures by methods for finite element analysis and design of cellular porous support structures. The exploration on demonstrating and modeling the procedure and support structures has been performed so as to anticipate the impacts of thermo-mechanical loads on the plastic disfigurement or deformation [8]. However, there are different impacts to be considered on the performance of support structures, for example, breakdown and detachment of overhanging geometries during the process [11].

2. Literature Review

For reasons expressed before, support structure minimization is of noteworthy enthusiasm inside the additive manufacturing people group, and a few strategies have been proposed. These are ordered into the accompanying classes.

A. To Find the Optimal Building Direction

AM manufacturing building direction can significantly affect support structures. Consequently, a prominent technique is to discover a building direction that limits or minimize support structure volume (and alternatively optimizes other AM metrics). For example, Jibin [14] built up a multi-target capacity to locate an ideal form course to limit volumetric error, support structure, and build time. Along similar study Pandey et.al. proposed a multi-criteria hereditary algorithm to minimize support structure and build time, while improving surface quality. In the both occurrences, weighted averaging was utilized to solve of multi-objective problems. Nezhad et.al. proposed following the Pareto front to locate the optimal part direction; the Pareto front included two objective functions, in particular support structure and manufacture time. Paul and Anand utilized a voxel portrayal (as opposed to the STL portrayal) to minimize support structure while fulfilling requirements on cylindricity and levelness or flatness error [15]. More recently, Das et al. distinguished optimal building direction as for tolerance errors and support structure volume by removing product manufacturing data. Interchange approaches for choosing building direction includes optimizing post-fabricate quality and observation, and expanded (cross-sectional) mechanical quality [17].

B. Generating the Efficient Support Structure

While the above techniques accept vertical support sections, increasingly productive support structures have been proposed for a provided fabricate guidance. For instance, the business programming Meshmixer produces tree-like support structures. While this conceivably lessens the support volume, manual changes are required to guarantee printability. Vanek et al. [18] conquered this lack by showing an effective technique for naturally making tree-like support structures that are printable. Particular techniques have additionally been proposed for explicit AM forms. For example, Barnett and Gosselin [19] created shell and film methods to make bolster structures for procedures with feeble support materials, for example, three dimensional froth printers. Dumas et al. exploited scaffold structures to create proficient backings for Fused Deposition Modeling (FDM). Considering the strength of the article all through the construct procedure, the strategy initially recognizes support points and afterward makes even bars between vertical columns to decrease the support volume. A contour based support generation design was proposed in dependent on layer-wise investigation. The strategy initially investigates the majority of the layers and after that produces support stays utilizing counterbalance or offset and boolean tasks to guarantee printability of the part [20].

C. Design Rules for Additive Manufacturing

It includes support volume constraints during the manual design process. This is often based on the design rules, as – (1) avoid surfaces with large overhanging angle (more than 45 degree angle), (2) avoid large size holes (more than 5mm) which are perpendicular to building direction, (3) avoid trapped surfaces where support structures are hard to remove and (4) use of explicit fillets and chamfers to avoid support structures [21-23].

D. Optimizing the Topology for AM

The last methodology is to incorporate AM imperatives inside TO. As expressed before, the upside of this methodology lies in the (potential) joining of these two innovations

Bracket et.al. [24] recommended on integrating the topology optimization and additive manufacturing to minimize the support structure. Author suggested the overhang constraint but not explained it.

Wang et.al. [25] proposed the unique method to reduce the material cost by extracting the frame structure of the design model. In the Wang proposed method, the solution of the multi-objective optimization, which minimizes the number of struts with considering stability and printability.

On the basis of method proposed by Bracket, it employed a smooth approximation to penalize overhanging surfaces, on the basis of topology optimization.

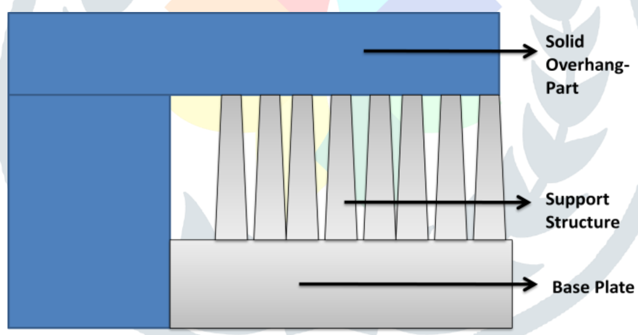

Fig1: Overhang Solid Part with its support structure

3. Results and Discussion

In the present study, author investigated about the overhang part's support structure for DMLS manufacturing technique. And the main objective of this paper is to propose a topology optimization, which is used to reduce the support structures. Author described the unique topological sensitivity method for the constraining the support structure volume during design shape optimization.

Support structure were determined to be the vertical for simplicity, but author believe that this approach to be extended to handle non-vertical support structures.]

At long last, the work introduced is viewed as an initial move towards a progressively far reaching structure for coordinating topology enhancement or the optimization and added manufacturing. Extra research is expected to incorporate other AM-connected limitations, for example, surface roughnesses, volumetric error, inter layer combination, etc. At long last, the proposed strategy must be combined with techniques for finding the ideal form optimum building direction to further reduce support volume.

References –

1) ASTM F2792 – 12a Standard Terminology for Additive Manufacturing Technologies, DOI: 10.1520/F2792-12A.

2) VDI 3404 Additive Manufacturing: Basics, Definitions, Processes, May 2014.

3) Yasa, E., Demir, F., Akbulut, G., Cızıoğlu, N., & Pilatin, S. (2014) Benchmarking of Different Powder-Bed Metal Fusion Processes For Machine Selection In Additive Manufacturing. In Proceedings of Solid Freeform Fabrication Symposium, Austin, Texas.

4) Hague, R. (2006). Unlocking the design potential of rapid manufacturing. Rapid manufacturing: an industrial revolution for the digital age, John Wiley & Sons, Ltd.

5) Hussein, A., Hao, L., Yan, C., Everson, R., & Young, P. (2013). Advanced lattice support structures for metal additive manufacturing. Journal of Materials Processing Technology, 213(7), 1019-1026.

6) Mercelis, P. (2007) Control of Selective Laser Sintering and Selective Laser Melting Processes, Ph.D. Thesis, K.U.Leuven, Leuven, Belgium.

7) Chalasani, K., Jones, L., & Roscoe, L. (1995, August). Support generation for fused deposition modeling. In Proceedings of Solid Freeform Fabrication Symposium,Austin, Texas.

8) software.materialise.com/magics-sg-module

9) Allen, S., & Dutta, D. (1994, September). On the computation of part orientation using support structures in layered manufacturing. In Proceedings of Solid Freeform Fabrication Symposium, University of Texas at Austin, Austin, TX, June (pp. 259-269).

10) Majhi, J., Janardan, R., Schwerdt, J., Smid, M., & Gupta, P. (1999). Minimizing support structures and trapped area in two-dimensional layered manufacturing. Computational Geometry, 12(3), 241-267.

11) Krol, T. A., Zah, O.F., Schlip, J., & Seidel, C. (2011) Computational Efficient Design Structures and Material Modeling for Metal Based Additive Manufacturing. ANSYS Conference & 29th CADFEM Users' Meeting, Stuttgart.

12) Krol, T. A., Zah, M. F., & Seidel, C. (2012). Optimization of supports in metal-based additive manufacturing by means of finite element models. In Solid Freeform Fabrication Symposium.

13) Bo, Q., Lichao, Z., Yusheng, S., & Guocheng, L. (2012). Support fast generation algorithm Based on discrete-marking in rapid prototyping. In Affective Computing and Intelligent Interaction (pp. 683-695). Springer Berlin Heidelberg.

14) Strano, G., Hao, L., Everson, R. M., & Evans, K. E. (2013). A new approach to the design and optimisation of support structures in additive manufacturing. The International Journal of Advanced Manufacturing Technology, 66(9-12), 1247-1254.

15) Calignano, F. (2014). Design optimization of supports for overhanging structures in aluminum and titanium alloys by selective laser melting. Materials & Design, 64, 203-213.

16) EOS material datasheet for Nickel Alloy IN625.

17) Yasa, E. (2011). Manufacturing by Combining Selective Laser Melting and Selective Laser Erosion / Laser Re-Melting, Ph.D. Thesis, K.U.Leuven, Leuven, Belgium.

18) Amato, K.N., Hernandez, J., Murr, L.E., Martinez, E., Gaytan, S.M., Shindo, P.W. (2012), Comparison of Microstructures and Properties for a Ni-Base superalloy (Alloy 625) fabricated by electron and laser beam melting. Journal of Materials Science Research, Vol. 1, No 2, pp.3-41.

19) Kruth, J.-P., Badrossamay, M., Yasa, E., Deckers, J., Thijs, L., Van Humbeeck, J. (2010). Part and material properties in selective laser melting of metals. In Proc. of the 16th International Symposium on Electromachining (ISEM XVI) edition:16, Shanghai, China, 19-23 April 2010.

20) Thijs, L. (2009). Invloed van het selectief laser smelten op de microstructuur van titaanlegeringen, Master Thesis, K.U.Leuven, Leuven, Belgium.

21) Manfredi, D.,Calignano, F., Krishnan, M., Canali,R.,Ambrosio, E.P., Atzeni, E. (2013), Materials, 6, 856-869; doi:10.3390/ma6030856.

22) Murr, L.E., Martinez, E., Amato, K.N., Gaytan, S.M., Hernandez, J., Ramirez, D.A., Shindo, P.W., Medina, F., Wicker, R.B. (2012). Fabrication of Metal and Alloy Components by Additive Manufacturing: Examples of 3D Materials Science, Journal of Materials and Research Technology, pp.42-54.

23) Wang, D., Yang, Y., Yi, Z., & Su, X. (2013). Research on the fabricating quality optimization of the overhanging surface in SLM process. The International Journal of Advanced Manufacturing Technology, 65(9-12), 1471-1484.

24) P. M. Pandey, K. Thrimurthulu, and N. Venkata Reddy, “Optimal part deposition orientation in FDM by using a multicriteria genetic algorithm,” International Journal of Production Research, vol. 42, no. 19, pp. 4069–4089, Oct. 2004.

25) Z. Jibin, “Determination of optimal build orientation based on satisfactory degree theory for RPT,” in Ninth International Conference on Computer Aided Design and Computer Graphics, 2005, 2005, p. 6 pp.-pp.