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Study on Support Structure Optimization for Additive Manufacturing

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Abstract: 3D printing also known as Additive manufacturing is a cutting-edge technology that is rapidly expanding. The decreasing cost of entry-level extrusion-based 3D printers is responsible for the continuous expansion of additive manufacturing (AM). Additional support structures are often needed, which leads to material, time, and energy waste. Research in support structures is, therefore, of great importance for the future and further improvement of additive manufacturing. This paper aims to conduct a study on the optimization of various support structures for additive manufacturing by conducting a series of trials on various widely used support structures.
Keywords: Additive Manufacturing, 3D printing, patterns, support structure, CAD design

I. INTRODUCTION

A support structure is an important part of additive manufacturing processes, which often plays a determining role in determining the time and material requirements for a certain print.

In this project, we aim to study these support structures. The study is mainly focused on the infill pattern of the supports.

In FDM printers, there are various types of patterns that are currently used. In the slicing software, we can use support types such as treelike, linear, zigzag, etc. Out of these types, the most widely used ones are simple patterns. There are a couple of complex-shaped support structures available, such as the treelike, gyroid, etc. But having a complex algorithm to generate them, and the geometrical complexity is the reason why these support patterns are not yet widely used.

This study will focus on the most commonly used and simple support patterns, used in the FDM 3D printers.

By optimizing the support structure, we can reduce the material required, can save time in the printing process, and energy that printer uses. This is the basic goal, to make this study.

II. LITERATURE SURVEY

Jingchao Jiang [1] made a review paper on the support structure in additive manufacturing. This paper aims to review varied research performed in the field of support structures. They did this review by selecting fifty-seven publications regarding support structure optimization. This paper also talks about the advantages and disadvantages of different support structures. A comprehensive review of this research paper on support structure optimization helps to understand advancements easily.

G. Strano [2] tried a new approach to the design and optimization of support structures in additive manufacturing such as SLM. In this research, they used cellular structure to optimize support structures. In the final result, they achieved a 45% reduction in the weight of support structures. This new method to optimize support structures exhibits great potential to achieve high efficiency in the SLM process and energy saving.

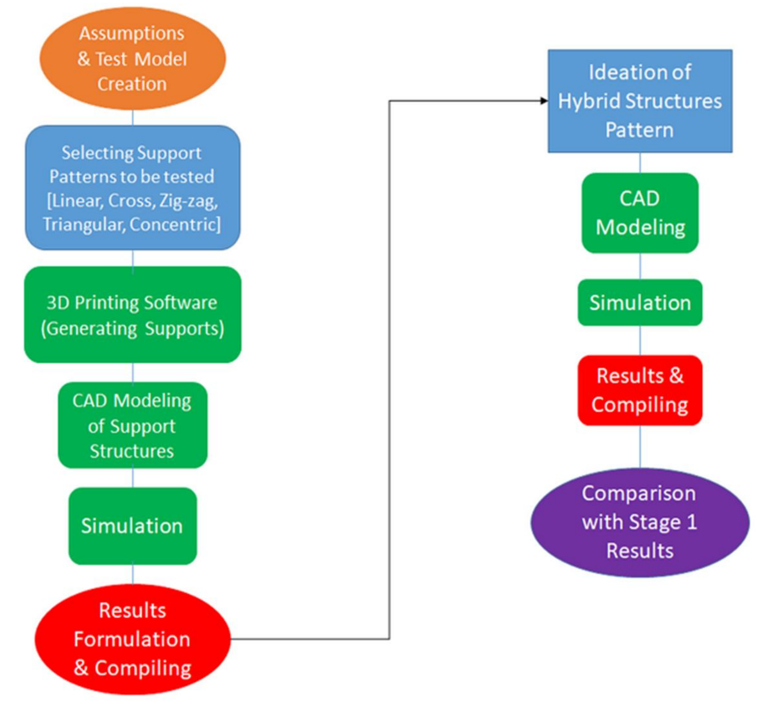
Jingchao Jiang [3] and his team created a benchmarking part for evaluating and comparing support structures of additive manufacturing. This benchmarking part has five features and all of these features are good enough to test any new support structure.

Amir M. Mirzendehdel [4] represented a topology optimization methodology that provides a way to minimize the requirement of the support structure. They proved the effectiveness of the proposed method through numerical experiments and demonstrated using FDM technology.

III. METHODOLOGY

The study is divided into 2 stages. In stage 1, a series of trials are conducted on the support structures that are currently used in real-world applications. Stage 2 is a study based on the conclusions from stage 1, and hybrid support structures were generated. These support structures are ideated from the results and are not being used in actual printing processes.

IV. FLOWCHART



Stage 1 Stage 2

V. STAGE I: EXISTING SUPPORT STRUCTURE STUDY

We have considered 5 existing support structure patterns for this study:

1) Linear
2) Cross
3) Triangular
4) Concentric
5) Zig-zag

Test model

We have chosen a cube structure (50mm×50mm×50mm) as the test model for this study. The support structures are generated within this cube model, for all the patterns. This model is kept constant for the study of every pattern in this research paper.

Constant parameters:

- Support density – 10%
- Layer thickness – 0.2mm
- The volume of the test model
- The geometry of the test model

Varying parameters (parameters on which the models are tested):

- Time required for print
- Material required for print
- Stress
- Strain
- Deformation

A. Support Structures Generation

For the given test model, various support patterns were generated within the model. Using 3D printing software 'Ultimaker Cura', we imported the cube CAD model and made the entire model to be printed as support.

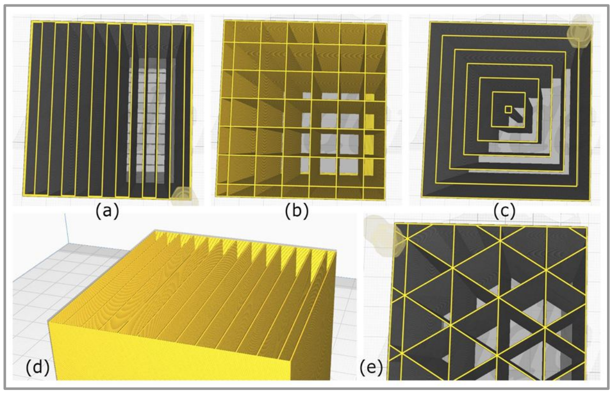


Fig. 1 Different Support Structures (Zig-zag, Cross, Concentric, Linear, and Triangular respectively)

B. CAD Modelling of the Structure

CAD models of the support patterns we got from the Cura software were generated. CAD models were made to perform simulations on it.

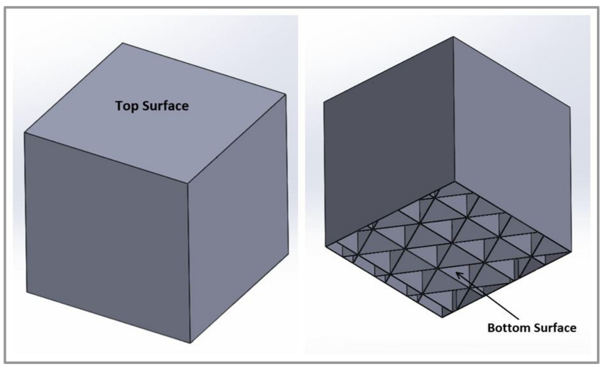


Fig.2 CAD Model of Triangular support

C. Simulation

Finite element analysis was performed on the CAD model. Static structural analysis was carried out. We checked the stress, strain, and deformation on the model when a force of 30N was applied on the top of the model.

There is always a load acting on the support structures, in real-life applications. This load is primarily due to the weight of the part, and nozzle pressure while printing. So, this simulation was performed to check the strength of the support structures.

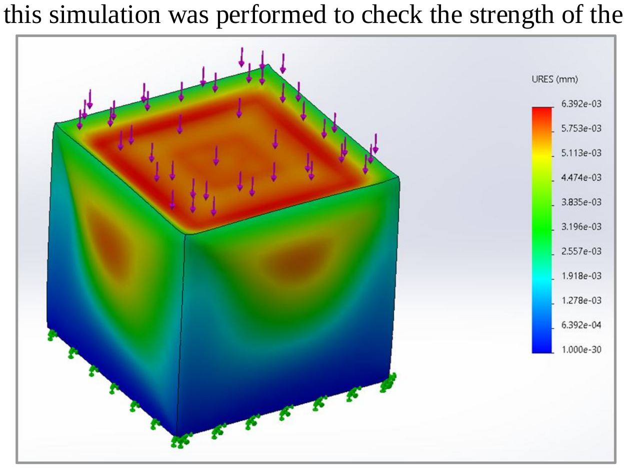


Fig. 3 Deformation plot for concentric support

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D. Findings

We compiled all the results for every support pattern that we generated. By plotting graphs, we were able to conclude some findings.

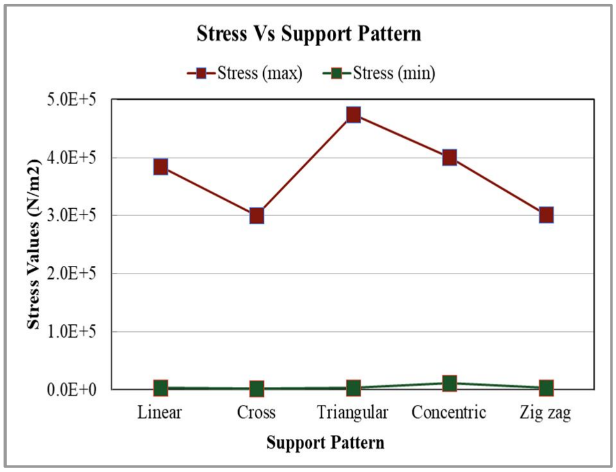

Fig. 4 Stress Vs Support Patterns

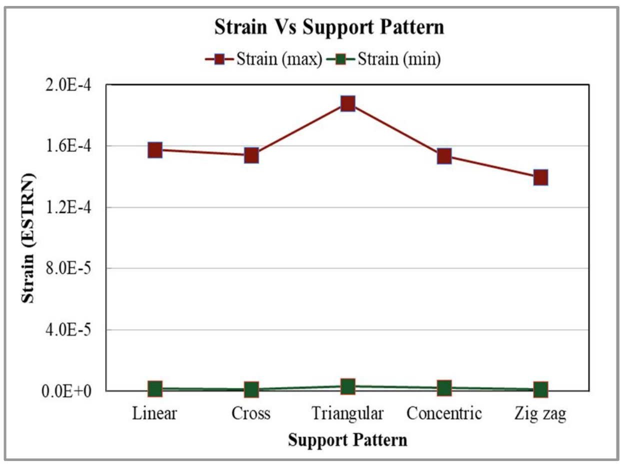

Fig. 5 Strain Vs Support Patterns

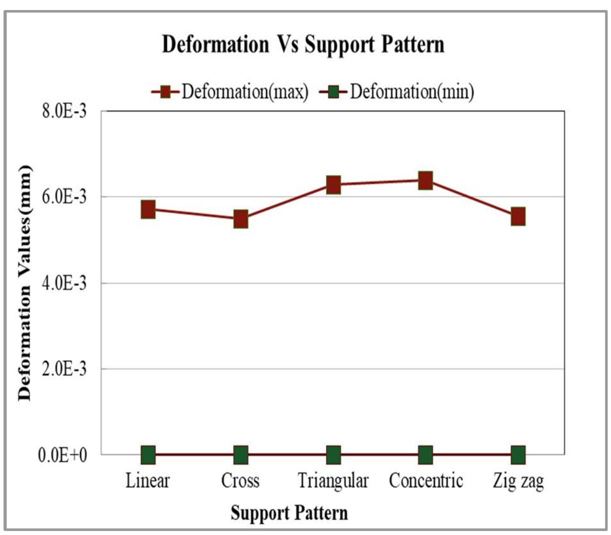

Fig. 6 Deformation Vs Support Patterns

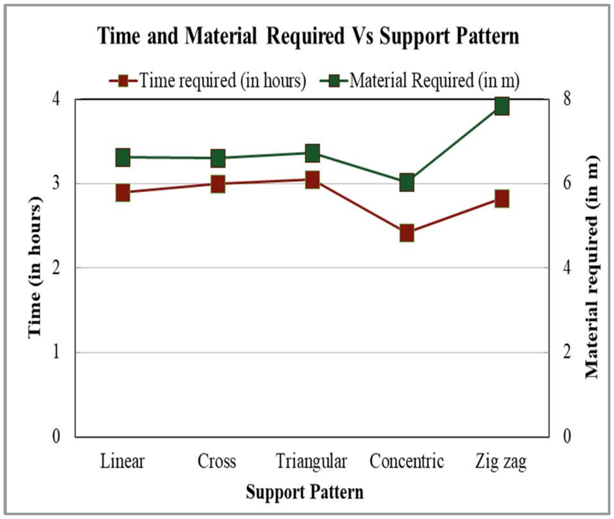

Fig. 7 Time and Material required Vs Support Patterns

With these graphs, we can conclude that:

1) Cross and zig-zag supports showed the least stress, strain, and deformation
2) Concentric supports showed the least time and material requirements

VI. STAGE II: HYBRID SUPPORT STRUCTURE GENERRATION

In this stage, based on the results from stage 1, we have come up with 4 hybrid support structure types by brainstorming. These hybrid structures are ideated, in order to possibly be most efficient in all the parameters that we are testing them for. Being efficient in all of these test parameters will make these structures the most suitable for 3d printing.

From stage 1 findings, cross and zig-zag showed the best performance in stress, strain, and deformation conditions, as compared to the rest of the patterns. Also, the concentric pattern showed the characteristics of the least material and time required to print.

We aimed towards creating the most optimized support structure, from these test patterns. So, we made design combinations of

1) Cross and concentric
2) Zig-zag and concentric

These combinations were done, as per our hypothesis. The hypothesis was, that if we make a hybrid structure of 2 patterns showing good results in separate domains, the combination of these patterns would give us a more efficient design, incorporating good performances in both domains.

In our case, concentric was the best performer in the time and material domain, and the cross and zig-zag were the best performers in the structural strength domain.

A. Sketch Ideation

Sketches for the support pattern were ideated. From many sketches, 4 final sketches were finalized as the combinations for Cross and Concentric, and Zig zag and Concentric.

Hybrid support structures:

- Cross L1
- Cross L2
- Zig-zag L1
- Zig-zag L2

L1 and L2 here, are the levels of the concentric shape. L1 represents one level of a concentric layer inside the wall of the cube. Similarly, L2 represents the presence of two concentric layers in the design.

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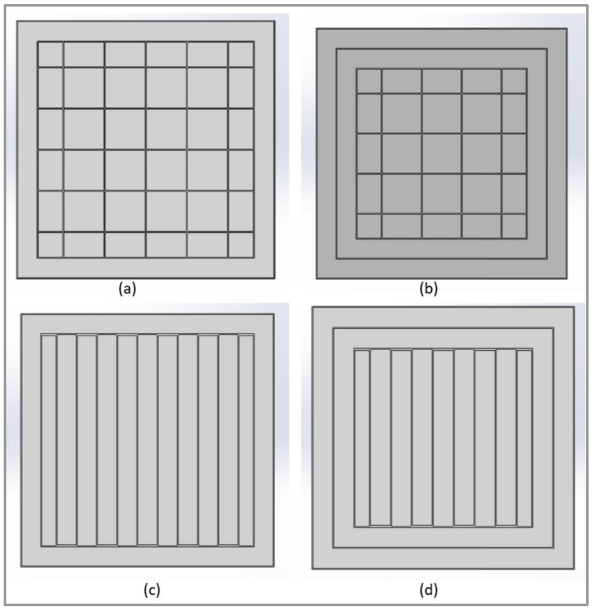

Fig. 8 Hybrid pattern sketches (Cross L1, Cross L2, Zigzag L1, Zigzag L2 respectively)

B. CAD Modeling of Structures

CAD modeling was performed for the 4 hybrid models.

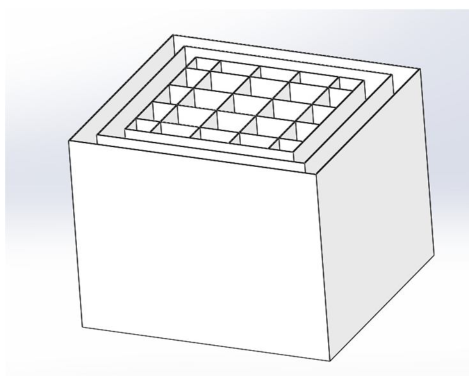

Fig. 9 CAD Model of Cross L2 support

C. Simulation

The simulation was carried out, on the same factors that were used in stage 1.

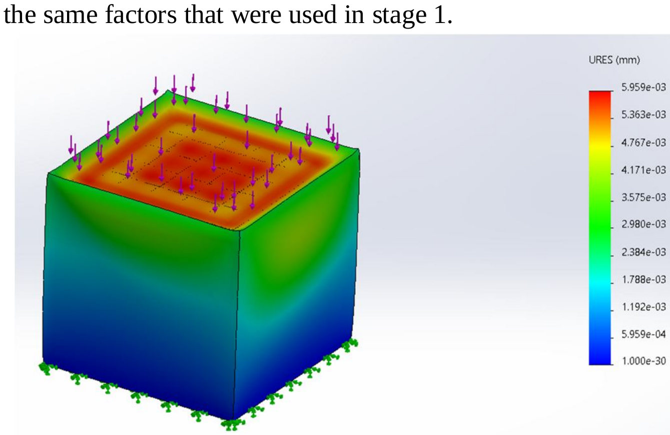

Fig. 10 Deformation plot of Cross L2

D. Findings

Graphs were plotted, for comparison between these 4 hybrid structures, based on the same parameters which were used initially.

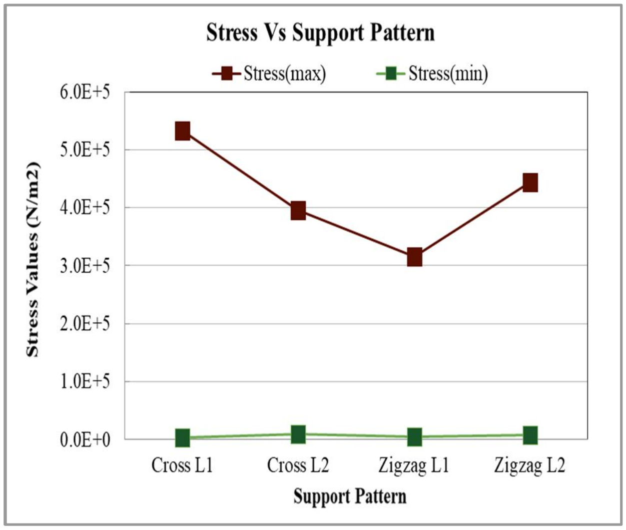

Fig. 11 Stress Vs Support Patterns

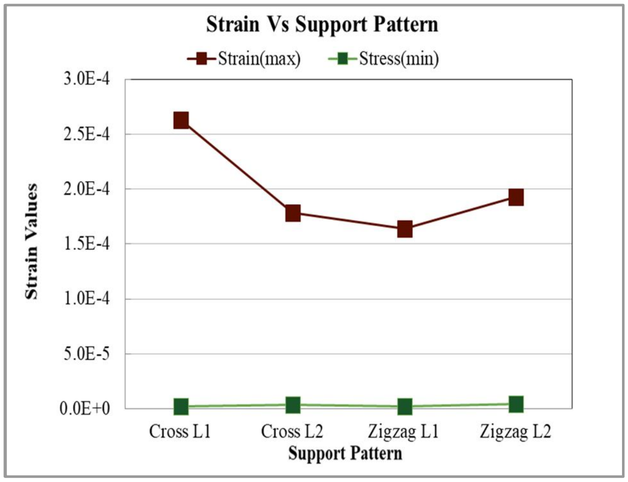

Fig. 12 Strain Vs Support Patterns

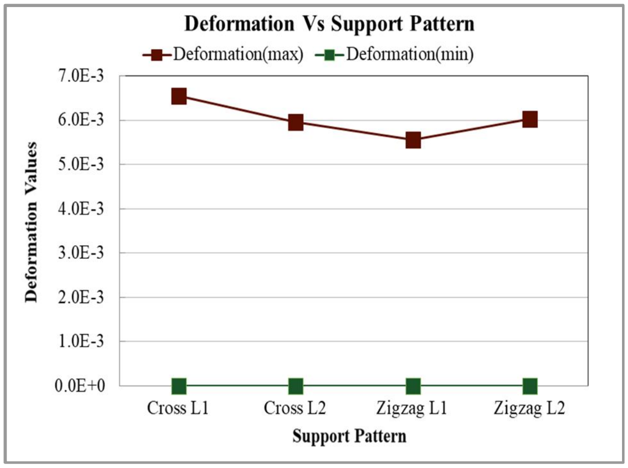

Fig. 13 Deformation Vs Support Patterns

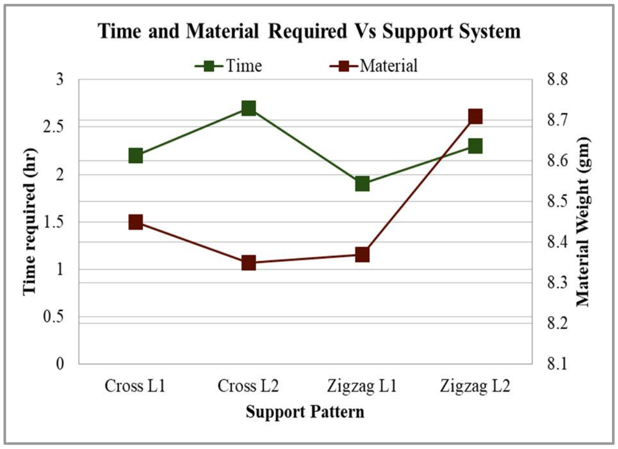

Fig. 14 Time and Material Required Vs Support Patterns

From this study of the 4 hybrid support structures, we found some concluding points:

1) Zigzag L1 was the best performing in the stress, strain, and deformation plot

2) Zigzag L1 was also having the least time and material requirements

The pattern Zigzag L1 was observed to have similar strength characteristics as compared to Cross, and Zigzag, and it is taking significantly lower time and material usage than the regular support structures.

VII. CONCLUSION

After conducting and meticulously evaluating the results of our trials, we were able to generate and compile our results in a graphical form for a better understanding. To a certain extent, we have been able to generate newer and improved hybrid support structures which are more efficient in terms of the material being used and the time required to 3D print them.

Zigzag with one layer of concentric support structure type can be speculated to be one of the most improved hybrid structures that this study has been able to generate, which shows improved results than the conventional support structures too.

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