The effect of finite element analysis programs on the quality of infill design of the 3D printed model

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Introduction

3D printing known as Additive Manufacturing (AM), it has continued to experience significant market and technological growth with many forecasting and a tripling in market value over the next decade. One of the primary drivers for this growth is the increased freedom afforded to the design of both the external form and internal structure of fabricated parts. This freedom presents greater opportunities in optimizing a part of a mechanical property, (such as strength and stiffness).

Defining the basic standards elements in the design such as (supports, bridging, infill and wall thickness) is an important tool for the successful design of the 3D printed model, and these elements lie in durability, ergonomics, dynamic stability and longevity, even storage conditions. All these elements affect the quality of the 3D printed model.

In a 3d model design, if a hollow pattern is printed from the inside and has a cover from the outside only, it will be less expensive and faster in printing time but has low quality under any pressure in normal use so the presence of the infill of the printed form is important to raise the quality of the final model.

In FDM technique, the INFILL is handled as a separate design to take advantage of the resolution and color adjustment, but it is weak in mechanical performance; Therefore, the design of the internal structure (INFILL) of the model is affected by using FEA component analysis software to achieve the highest quality of the digitally designed model before printing.

Research problem

How can better quality and durability of the 3D printed pattern be achieved with an internal filler design? What are the standard design criteria for inner filler to raise the quality of the 3D printed model?

Research aims

The research aims to raise the quality of the 3D printed model by applying specific standards to the design of the infill of the FDM printed models without changing the design of the external structure of the model...

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Research hypotheses:

The researcher assumes that:
Applying the infill design criteria for the printed 3D model and using simulation through FEA finite element analysis software to prepare the design files in 3D printing leads to an increase in the quality and durability of the printed model.

Research Methodology: Research is based on methodology

1. Descriptive approach: Through a survey study of the international standards for the design of the INFILL for the printed 3D model.
2. Experimental Approach: Using one of FEA finite element analysis programs to influence the INFILL design of the model designed for 3D printing without changing the design of the external structure of the model.

The research steps are divided into two axes:

The first axis is the Theoretical Study: which includes;
1- Definition of internal filling.
2- Design criteria for the infill of 3d printing by using CURA 3D.

The second axis: Practical Study:
Includes the use of FEA (Autodesk Fusion 360) to influence of the INFILL pattern for the 3D print model (bottle opener design).

Theoretical Framework

The theoretical framework for the research is based to improve the quality of the 3d model, the density of the infill of the model is increased which is meaning the increase of using the raw material, but the problem will still be standing because when it is exposed to Pressure it is crashing easily, the model's infill design criteria are studied as it gives the models a larger structure and stability which grants it a higher durability against pressure and reduces the chances of crashing and does not make it weak. The model is simulated using FEA limited component analysis programs to identify weaker parts that are under pressure and affect the quality and the durability of the model, and through this the intensity of the infill is increased in these parts, which leads to a better quality of the printed pattern, especially if it performing a functional task.

First: Definition of INFILL:

The internal structure of the 3D printed model to occupy the empty interior spaces during printing. In other words, its repetitive structure used to take up space inside an empty 3D print. This pattern is not seen after the printing is completed in most prints, although there are designs for the interior pattern with an aesthetic appearance.

Second Standard for infill design

1/Infill designs:

Infill comes in many shapes, sizes, and patterns. Each style has its own strengths and weaknesses, and each has its own use. Though infill can take countless forms, there are several fairly standard patterns.

Since infill takes up the space inside a print, it makes sense that infill designed for structure works better than infill designed for aesthetics. In this case, patterns incorporating grids, lines, honeycombs as well as rectilinear or concentric patterns work best.

2/Infill density

The infill density defines the amount of plastic used on the inside of the print. A higher infill density means that there is more plastic on the inside of your print, leading to a stronger object. An infill density around 20% is used for models with a visual purpose, higher densities can be used for end-use parts**.**

After deciding on a style, the next step is to set the density of your 3D printing infill, measured in percent. 0% is generally equivalent to no infill and 100% is equivalent to a solid print. Of course, there are many levels in between, and adjusting this value is incredibly useful in accommodating a variety of functions.

One very obvious use is to vary the mass of the print. A higher infill density makes for a heavier, more solid print. In contrast, a lower infill density would provide a simpler, more lightweight result. Infill density can also affect a print’s strength, buoyancy, and the used material.

Common infill densities are between 20% and 25%. This offers a nice balance between durability and material consumption. If structure isn’t a concern but cost is, the best infill range is between 10% and 15%.

None of these ranges give much support, so don’t use them if your object needs to be strong, or needs structure during printing. Finally, if structure is a concern, and filament usage isn’t, the best range is somewhere between 30% and 50%.

Lastly, with a functional part, feel free to go right up to 100%.

Applying design criteria for infill of the printed pattern using the Cura software:

Infill line directions

The infill lines are usually printed at a 45° angle. At this angle, both the X- and Y-motor work together to obtain maximum acceleration and jerk on the layer without losing quality. If the lines need to be printed in a different direction, you can set it here at 0° for vertical and 90° for horizontal. For example: [0,90] results in a horizontal-vertical top/bottom pattern.

Infill XY offset

Infill patterns are centered for each loaded model. To move the pattern to the left, right, top, or bottom a X or Y offset can be used. A positive value moves it UP and RIGHT, while a negative value moves it DOWN or LEFT. This does not work for the concentric infill types.

Infill overlap percentage

can control the amount of overlap between the infill and walls. It can be set as a percentage or a true value. A higher value usually results in better bonding between the infill and walls. However, it might also reduce the visual quality of the print, as a value that is too high could lead to over extrusion. The default value in Ultimaker Cura will be insufficient in most cases.

Infill layer thickness

Since the layer height of the infill is not important for visual quality, we can use thicker layers on the infill to reduce the print time. When adjusting this setting, always make sure that there is multiple layer height, otherwise Ultimaker Cura will round it up to a multiple of the layer height. This means that you can, for example, print with an infill thickness of 0.2 mm while the layer height is 0.1 mm. The printer will first print the walls for two layers, and then it will print one thicker infill layer.

Gradual infill steps

Gradual infill reduces the amount of infill used by decreasing the infill percentage in the lower layers. Every gradual infill step divides the infill percentage by a factor two. The result is a dense infill near the top layers, which is essential, and grants a reduced print time.

The second axis: practical study

Use FEA Finite Element Program (Autodesk Fusion360) to influence the INFILL inner pattern of a 3D printing model

The aim of this experiment is to prove that a three-and-a-half-fold increase in strength can be achieved when stress values within the model structure (infill) can be achieved by affecting the design of the infill of FDM printed models. This is to identify the weaker parts that are under pressure and affect the quality and durability of the model and through this increase the density of infill in these parts, resulting in better quality of the printed model.

1. Steps of the experiment:

The study of the model and its simulations is made in which the weaker parts are known as the field of finite element analysis and the FEA program affects the internal filling in what is known as Smart Infill when applied to FDM technology while ensuring that the external structure of the model is not affected.

The experiment consists of 5 stages:

1 / Design the form on the CAD program.

2 / Entering the form in Autodesk Fusion 360.

3 / Design the Smart Infill Padding with FEA on Autodesk Fusion 360.

4 / G-code production on Cura.

1 / Model design (bottle opener):

It is a model design on the CAD program by creating a STL file for the model that demonstrates the geometry of the part using the aforementioned international standards and specifications.

2 / Entering the form in Autodesk Fusion 360:

After designing the model, the model is inserted into one of the FEA finite element analysis programs. Autodesk Fusion 360 has been used.

3/ Design the Smart Infill Padding with FEA on Autodesk Fusion 360

First Simulation:

Through Autodesk Fusion 360 Infill Filler interior design is simulated to study the weakest part of the procedure to improve the internal structure of the model.

choosing the MODEL →Simulation →Shape optimization setting

Second: Preparing pressures on the structure of the model:

The stress pathways in the model are defined on areas where it is desirable to obtain a higher density than the internal filling to withstand pressure, paths that are not subjected to pressure are the ones in which the density can be reduced.

By adjusting the Structural constraints→Fix → structural load setting and adjust the settings in the x, y, and z axes to define the anchor points subjected to pressure.

Third: Create a mesh design scale for the infill design

The grid scale is established for the internal structure where the program calculates the coefficient in the x, y directions for the grid and determines the lengths of the model's sides to ensure that the network does not overlap with the outside perimeter of the model when printing.

4 / Inclusion of the model on the Meshmixer program

5 / G-code production on Cura.

2. Results of experiment

Then, the unmodified models were tested on the Universal Testing Machine, and the following results were achieved:

1_ The first model with an infill density of 20% tolerated pressure up to 15 kg while failing under 30 kg pressure.

2_ The second model with an infill density of 50% tolerated a pressure of 30 kg while failing at 60 kg.

3_ When printing the modified form in what is known as (Smart Infill) with an infill density of 100% for the hard places subjected to pressure and 20% for the rest of the model parts, it was found carrying a pressure strength of up to 85 kg.

Results:

1- The quality of the 3d printed model is affected by applying the standard criteria when designing the model according to the technology used and selecting the raw material as well as the file format.

2- The infill patterns affected by FEA are more solid and can withstand up to 80 kg than the triangular design.

3- The modified infill pattern design on the FEA program is less affected by the extension than the design before modification when using the triangle shape with a density of 20%.

Recommendations:

1_Recommended to apply the standards for 3D printing through the design process to improve the quality of the 3D printed product.

2_ It is recommended to simulate the model on one of the FEA programs to identify weaker parts subjected to pressure in order to increase the quality of the printed model and save raw materials.

3_ It is recommended to apply the infill design criteria as it has an effect on the strength and quality of the 3D printed model.

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