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(Research Article)

Implementation of FEM analysis into additive manufacturing to increase productivity and components strength

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Abstract

Technologies of additive manufacturing present in this age a progressive way for component production from different materials using only one production device. Additive production has great potential and high growth in the market. The main applications are in sectors such as aerospace, automotive, healthcare and consumer goods. This paper describes development of new methodology with approach integrated outputs of stress analysis into the printing software. Methodology is based on some steps. The digital CAD model of the proposed component is subjected to strength analysis through the Finite Element Method (FEM). The output of the strength analysis is the division of the component into a bounded volume areas with varying levels of stress. These outputs will be integrated into developed software to design a specific model layout and technology and material print parameters to generate data for 3D printing to gain optimized print component structure, optimized technology and material print parameters to maximize component strength and minimize production times and costs.

Keywords: Additive manufacturing; Fused Deposition Modeling; Finite Element Method; Stress analysis

1. Introduction

At present, there are a number of scientific articles dealing with the properties of components or samples produced by additive manufacturing, when changing various parameters. In most cases, it is a research on tensile strength, compressive strength or bending, depending on changes in the production factors. Such manufacturing factors include for example, material, thickness of material layering, temperature, speed, and similar. Scientific papers always research on effect of changing such parameters on the strength, dimensions, or precision of the manufactured parts. These are isolated studies which state which factors have and which factors do not affect the parameter under consideration. In some cases, there is a mathematical model that is prepared based on measured data and is actually an interpolation function that is valid the interval the experiment was performed. By now, there is no tool that would be able to predict the selected properties of parts made by some of the additive technologies.

The most widespread technology is just the melting of plastic wire and the application of semi-liquid material, the fiber next to the fiber and layer by layer until the production of the entire volume of the part. The technology is called Fused Deposition Modeling (FDM) or Fused Filament Fabrication [1]. This method uses an external continous filament of the thermoplastic material. During this process the filament is fed through massive spool through a heated printer extruder head and is melted at the nozzle, passing the glass transition temperature, so extruded by making objects layer by layer. The layers of the material are then fused together in a pattern to form an object. Typically the primary deposition takes place in one horizontal plane or one layer at a time. After this the print head moves vertically by a small amount to begin

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a new layer. The FDM technology works with production grade thermoplastic to make sturdy, robust objects and to maintain dimensional stability of the parts with finest accuracy. [2]

Many scientific works [3,4,5,6,7] deals with the experimental determination of the tensile strength of additive manufactured components, especially by fused deposition modeling. The results of the experiments on production time for model creation by different additive technologies are also known [8]. On the opposite side number of scientific papers are focused on effect of printing parameters on mechanical properties of parts from various types of materials used in additive manufacturing [9,10]. Based on these research results of many scientific works it can be stated that the field of achieved mechanical properties of components produced by additive manufacturing is well known. In the present time, the topology optimization is a challenge in production. The main focus of topology optimization is material distribution within the preferred region. It takes the part of design space which is called finite element mesh and increase the strength by minimizing the material. [11] However, topological optimization changes the resulting shape of the component, but this is not suitable for all applications. In some cases it is it is necessary to leave the shape of the component unchanged. For this purpose new methodology described in this paper was developed and applied.

The subject of research activities described in this paper is the development of methodology for software tools design on the basis of which it will be possible to predict the strength properties of structured parts made by FDM technology, later expandable to other technologies of additive manufacturing. The software tool should take into account all the necessary parameters that can be and need to be set in the data preparation process and generating the production data for the additive manufacturing components and affecting the functionality and strength of the manufactured components.

These data and information have a direct link to the time required for the production of the parts. It is scientifically proved and experimentally verified that the quantity of infill material, the complexity of component structure and infill structure, the thickness of deposited layers and other factors have a direct impact on the production speed of parts. Speed is very important in industrial production and it is therefore necessary to find an optimum condition between those factors, that the product meets strength requirements and that the production is performed at the maximum speed possible given the situation.

2. Design of methodology implemented stress analysis

The aim is to generate data for 3D printing based on the FEM analysis of the parts in order to obtain an optimized printing structure of parts, optimized technology and printing material parameters with regards to maximizing the strength of components and minimizing production times and costs.

The methodology of this solution is based on the digital CAD model of the proposed component. This 3D component model will be subjected to strength analysis using FEM (Finite Element Method). Output of the strength analysis will be the division of the volume of the component into the bounded volume areas with different levels of stress. These outputs will be integrated into developing software to design a specific model layout and technology and material printing. The individual bounded volumes in the component will be defined by a different level of stress. For each stress level, the software develops the optimum printing technology parameters with respect to component strength, production times, and cost. For areas of low stress, a lightened infill structure will be designed to save production time and material. For areas with higher stress levels, there will be proposed optimal technological or material parameters (fiber diameter, print speed, temperature, material type).

3. Tools and procedures of analysis based on Finite Element Method (FEM)

3.1. Finite Element Method

The finite element method (FEM) is a widely used method for numerically solving differential equations arising in engineering. To resolve a problem, the larger system is subdivided into smaller, easier elements that are known as finite components.

The FEM is a general numerical method for solving partial differential equations in two or three space variables (i.e., some boundary value problems). To solve a problem, the FEM subdivides a large system into smaller, simpler parts that are called finite elements. This is achieved by a particular space discretization in the space dimensions, which is implemented by the construction of a mesh of the object: the numerical domain for the solution, which has a finite number of points. The finite element method formulation of a boundary value problem finally results in a system of algebraic equations. The method approximates the unknown function over the domain. [12] The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. The FEM then approximates a solution by minimizing an associated error function via the calculus of variations. [12]

3.2. Application of FEM analysis on a simple joist manufactured by FDM technology

There are several ways to fix and load a simple joist. Two basic cases will be considered in the paper for the stress analysis by FEM – simply supported joist and cantilever joist.

3.2.1. Simply supported joist

Both free ends of the joist are fixed. The external force acts in the middle of the joist. The joist bends as shown in Fig. 1. The material on top of the neutral axis are in compression. If this component is produced by FDM technology, the fibers must be printed in a direction perpendicular to the neutral axis. In case the fibers are printed parallel to neutral axis, they would be very long for axial compression load and every fiber would be under the buckling stress and would get damaged. The fibres underneath the neutral axis are in tension, so they must be printed in an orientation parallel to the neutral axis. In case the fibres are printed opposite to the neutral axis, the fibres would be in tension and they would easily get separated from each other.

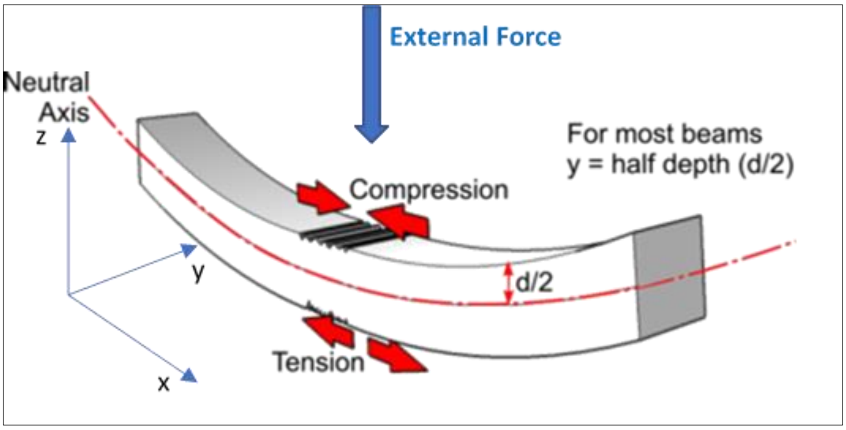

Figure 1 Simply supported joist load (Consider a neutral axis at a depth of d/2 where „d"is the depth of the joist)

3.2.2. Cantilever joist

As shown in Figure 2, one end of joist is fixed and the second end is free. The free end of the joist is subjected to the external loading and the external force acts downwards. The joist deforms according the image (Fig 2). It is evident to conclude that the deformed joist has the opposite curvature as the simply supported joist. If this component is produced by FDM technology, the fibers needs to be printed in opposite directions as in the case of simply supported joist. The fibers above the neutral axis are in tension, so they must be printed in a direction parallel to the neutral axis and the fibers below the neutral axis are in compression, so they must be printed in a direction perpendicular to the neutral axis.

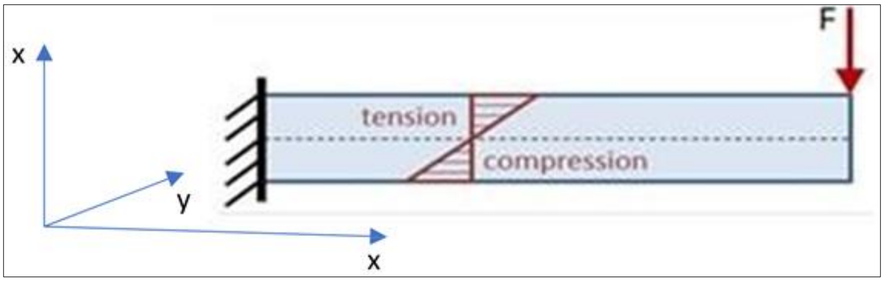

Figure 2 Cantilever joist load

Finite element method or analysis is a crucial step that can be used to develop new effective methodology for design of optimization printing software for FDM technology. It will save production time, costs by highlighting problems and finding solutions during your product design phase, before any material is ordered or even before we even contemplate the design or product.

In this paper, the application of FEM analysis on a simple joist was done on SolidWorks. Basic procedure of FEM software application in component design:

- Create basic 3D CAD model
- Define material and its properties
- Define finite element model (create mesh with FEA software)
- Define operating environment (apply forces, constraints, etc.)
- Compute structural response (stress, deflection, etc.)
- Review and interpret the results
- Apply the results and re-design as necessary and repeat until satisfied

3.3. Stress analysis

It is possible to achieve high-strength components by implementing FEM analysis into additive manufacturing – FDM technology. Output of FEM will be division of volume of component with different levels of stress and stress directional vector (compressive and tensile). The exemplary procedure is described in detail on a simple cantilever joist (this done on SolidWorks), as it is shown in Fig. 3

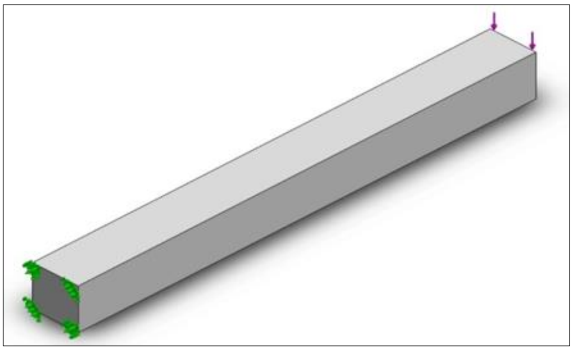

Figure 3 Loaded 3D CAD model of the cantilever joist

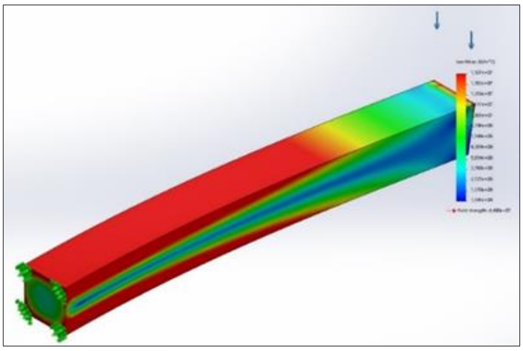

Figure 4 Stress analysis with deformation of the joist

Due to the external force load, stresses are created in the joist. After the calculations, the used FEM software draws the stress in the CAD model with a colour scale (Fig. 5). The blue volume is the volume with low stress, the red volume is the volume with high stress. This simple example (Fig. 4 and Fig. 5) shows the blue line along the joist. Blue line resp. blue horizontal plain is called "zero plain". Zero plain means that there is zero stress in this plain (thin volume). The volume above the zero plane is tensile stress because the material (fibers) are pulled. The volume under the zero plane is compressive stress because the material (fibers) are compressed

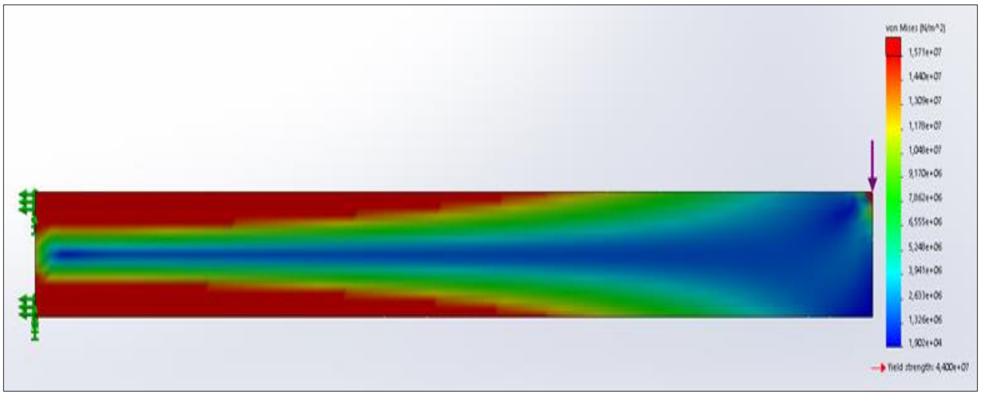

Figure 5 Stress analysis of the joist without deformation

3.4. Identification of stress levels

Identification of stress levels in investigated component volume is very important step of developed methodology. In practice, this means that the optimum printing technology parameters with respect to component strength, production times, and costs can be set for each volume of components with different stress levels. For areas of low stress levels, a simplified infill structure will be designed to save production time and material. For areas with higher stress levels, there will be proposed optimal technological or material parameters to achieve high-strength component.

Using tools of FEM allows to investigate the optional stress levels. The developed methodology for optimization software is based on separating component volumes based on stress analyses and generate optimal printing parameters for the most effective production. For this purpose it is needed to find the volume with the stress level higher than determined value and separate it. FEM tools allow to set specific Iso value and investigate the stress changes in volume. This is way to find and see only component volume with the stress value over or under specific level. The following examples can be given in a simple joist. Figure 6 shows the joist volume with highest stress level – over 90% of maximum stress. This volume must be printed as solid. This analysis also define the ratio of this element volume to whole component volume. In this case (for the specified load), this would mean that about 44% of the component volume would be printed as solid. Also the printing parameters should be set according the material properties and external load to achieve maximum strength

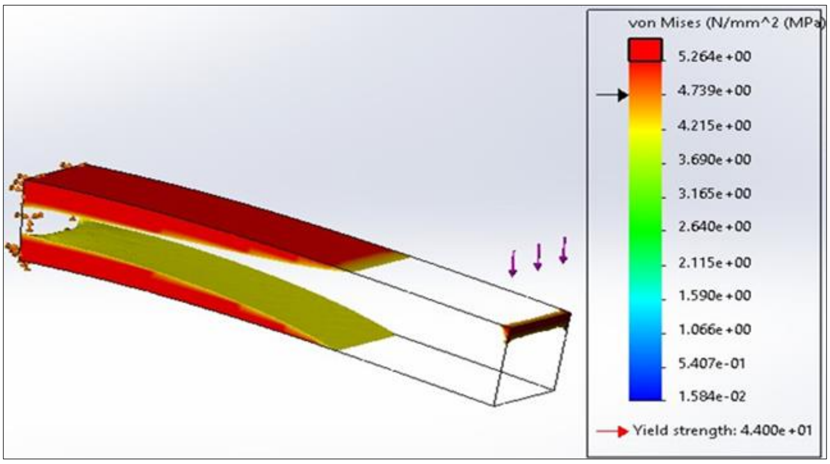

Figure 6 Volume with stress level higher than 90% of maximum stress

The component volume with stress level from 50% to 90% of maximum stress is presented in Fig. 7. The methodology may decide that this volume will be printed as solid, but with optimized setting of printing parameters with respect to the maximum speed and required strength. The setting of optimal printing parameters is based on mechanical properties of material, external load and it is outcoming from experimental results

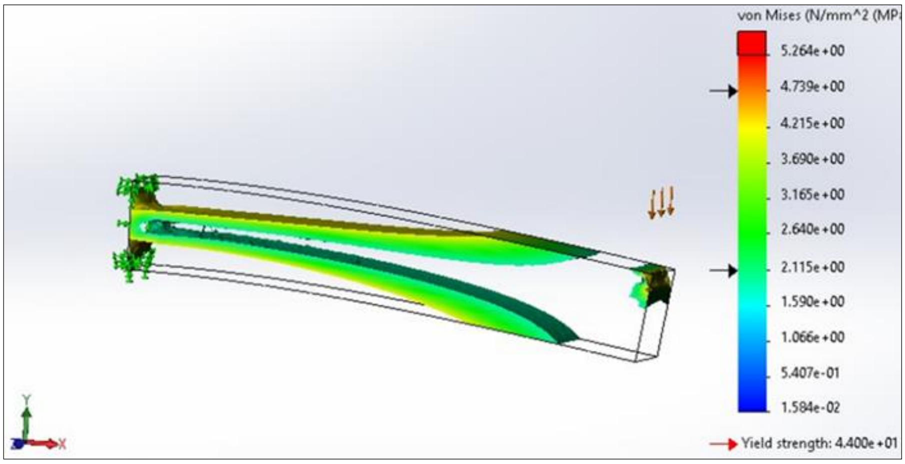

Figure 7 Volume with stress level from 50% to 90% of maximum stress

Based on FEM results the methodology may decide that e.g. the component volume with stress level lower than 25% (Fig. 8) can be printed like lightened infill. By isolating regions of very low stress it can be seen where material can be eliminated (the volume is printed as lightened) without affecting the structural integrity of the part. This approach significantly saves material, costs and shortens production time.

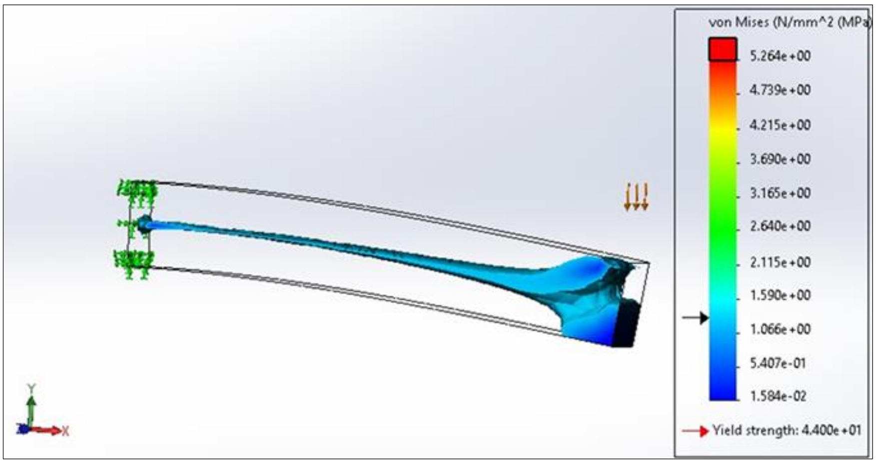

Figure 8 Lightened volume with stress level lower than 25% of maximum stress

4. Conclusion

Integration of this developed methodology results into printing software for 3D printers based on FDM technology will help significantly to make production more efficient. Once the volumes of different stress are separated, these outputs will be integrated into developing software to design a specific model layout and technology and material printing parameters. For component volumes of low stress a lightened infill structure will be designed to save production time and material. For component volumes of higher stress levels the software will propose optimal technology or material parameters (fibre diameter, print speed, temperature, material type etc.). This approach allow to generate data for 3D printing based on the FEM analysis of the parts in order to obtain an optimized printing structure of parts, optimized technology and printing material parameters with regards to maximizing the strength of components and minimizing production times and costs.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest.

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