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Topology Optimization of Press Tools for Additive Manufacturing: Reducing Manufacturing Time

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Abstract

This research paper presents a topology optimization study of a press tool consisting of a punch and a die, with the aim of optimizing the press tool topology to reduce material usage, and manufacturing time while maintaining necessary strength. The tools will be manufactured using additive manufacturing technology with Polylactic Acid (PLA) material. The Additive Manufacturing method can be used to make prototypes of press tools in the development stages. This method also allows us to make low-cost press tools for short production runs. The loads acting on the punch and die were calculated and a Finite Element Analysis was performed to simulate the tool's behaviour under loading. The results from this analysis were used to conduct topology optimisation of the press tools. Another finite element analysis was then used to validate the optimized design and to ensure that it met the necessary strength and factor of safety. The final optimized design was selected based on its ability to meet the minimum factor of safety of 4 while also achieving a significant reduction in material usage and weight. A manufacturability analysis was performed using Cura slicing software to ensure that the design could be fabricated using the additive manufacturing process. The results. showed that the optimized design could be manufactured with the additive manufacturing process. This confirmed the feasibility and effectiveness of the proposed optimization approach. This study demonstrates the potential of using topology optimization and additive manufacturing in the design and manufacture of press tools.

Keywords: Topology optimization, additive manufacturing, Press tools, Factor of Safety

INTRODUCTION

Press tools, consisting of punch and die, are widely used in manufacturing processes to shape various materials into desired shapes. The design of press tools has a direct impact on the quality of the finished products, and thus, the optimization of press tool design is of great significance in modern manufacturing processes [1]. The topology optimization technique has been widely applied in press tool design to improve its performance by optimizing its shape and size while meeting the required mechanical specifications [1].

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One of the most common types of press tools is the V-die and punch, which is used to form materials such as sheet metal into various shapes. The V-die and punch consist of two parts, the punch, which is the upper part that applies the force, and the die, which is the lower part that provides support. The V-die and punch are widely used in various industries, including automotive, aerospace, and electronics.

[2] Additive manufacturing, also known as 3D printing, has revolutionized the manufacturing industry by enabling the production of complex

geometries with high precision and accuracy [2]. Among the various additive manufacturing techniques, fused deposition modelling (FDM) is widely used to produce plastic components. FDM involves the deposition of molten plastic material layer by layer onto a build platform based on a 3D CAD model.

In this research, we aim to determine loads acting on the punch and die and optimize a basic V-Die press tool based on the determined load and constraints input parameters. The optimized V-Die press tool will be lighter and have less material while ensuring that it has a minimum safety factor of 4.

This reduction in weight and material usage will result in reduced manufacturing time and hence increase productivity in prototyping work scenarios.

METHODOLOGY

Press Tools

Press tools are specialized equipment used in sheet metal forming, which is a manufacturing process that involves shaping metal sheets into different shapes and sizes. For the purposes of this research paper, the press tool is designed to be used with a press brake and consists of a die and a punch (Figure 1) that is used to apply pressure to the metal sheet and shape it into the desired form. Press tools are commonly used in a variety of industries such as automotive, aerospace, and construction, where precision and high output quality are essential. The use of press tools in sheet metal forming allows for the efficient and precise production of a variety of products, from simple brackets and housings to complex parts and assemblies. A V-die, also known as a V-block die, consists of a groove or channel that is shaped like a V, with an angle typically ranging from 60 to 90 degrees. The punch is used to apply pressure to the metal sheet, causing it to bend or form the shape of the V-die.

Estimation of maximum bending force, F

$$F_{max} = k\{(UTS)Lt^2/W\} \quad (1)$$

Where,

UTS = Ultimate Tensile strength of work

L = Length of bend

T = Thickness of the work

W = Width of the die opening

k = The factor includes various factors, including friction

= 1.2 to 1.33 for V-die

= 0.3 to 0.34 for wiping die

For the purposes of this research paper, we will be making a basic, unoptimized V-Die press tool to bend a 1.5mm thick Mild Steel blank. The Length of the bend is taken to be 20mm. The die opening is taken to be 19.172mm.

UTS Mild Steel = 400MPa

L = 20mm = 20×10^{-3}m

t = 1.5mm = 1.5×10^{-3}m

W = 19.172mm = 19.172×10^{-3}m

Now putting the values in (1), we get,

Fmax = k{(UTS)Lt2/W}

Fmax = (1.3) {[(400) (20) (1.5) (1.5)]/ (19.172)}

= 1220.52N

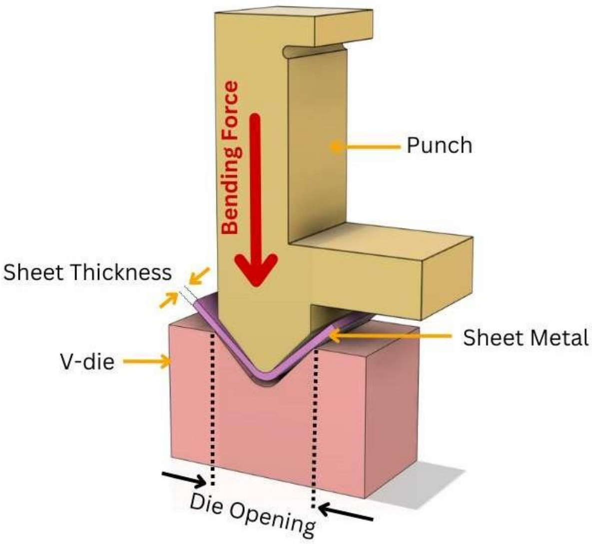

Figure 1. Diagram of V-Die Press Tool

Input Geometry, Constraints and Load for Finite Element Analysis of Unoptimized Punch and Die

Separate analysis for Punch and Die was conducted. Input parameters for both are listed below:

PUNCH

The punch serves as the upper component of the V-die press tool. It is responsible for applying force to the metal sheet. The tip of the punch is usually designed with a specific shape or contour that matches the intended form or cut you wish to achieve in the material. When in operation, the punch descends into the V-shaped cavity of the die, resulting in the deformation or cutting of the metal sheet as needed.

*Please note that Punch (in green) and Mount for Press Brake (in orange) are in contact (Figure 2)

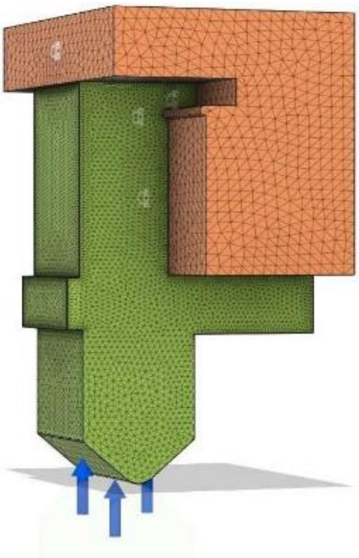

Figure 2. Geometry of unoptimized Punch

Constraints

Constraints were applied to the mount of the press brake (Figure 3). The Punch is set in contact with the mount in the study. The faces coming in contact with the punch were constrained along all axes, to restrict any relative motion between the punch and the press brake mount.

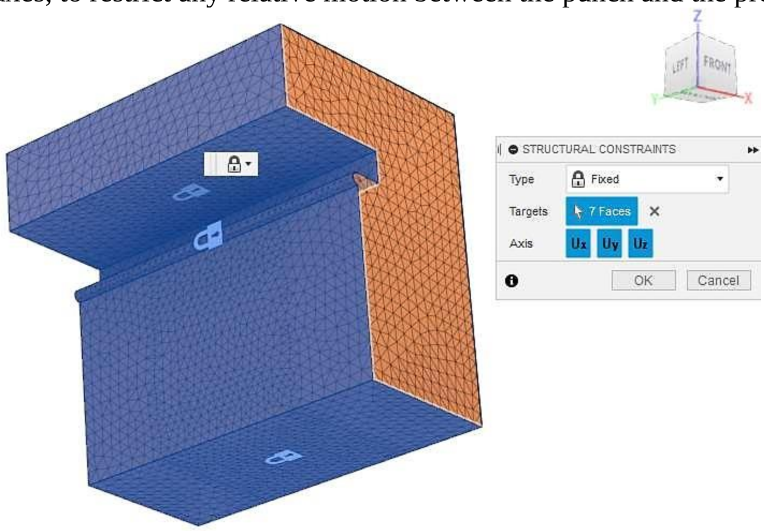

Figure 3. Constraints on Punch

Load

A force of 1220.52N along the Z-axis was applied to the faces coming in contact with the blank (Figure 4).

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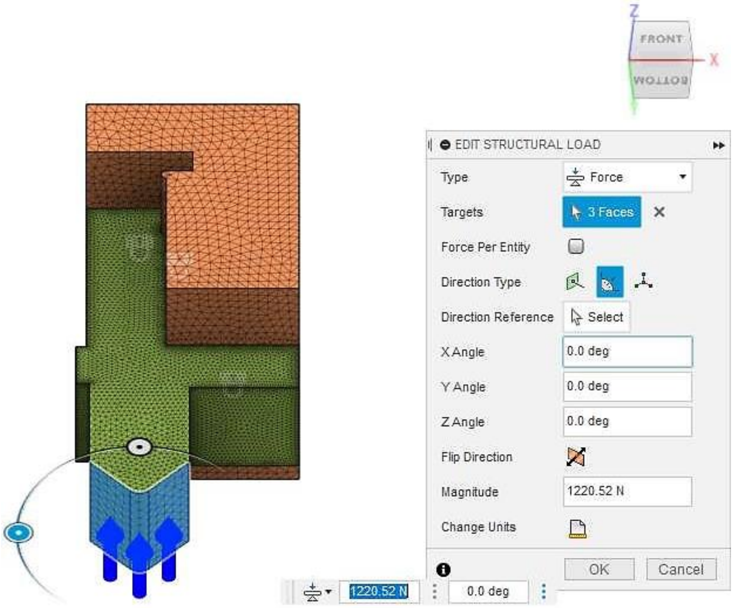


Figure 4. Represents the load applied on the Punch

DIE

The die functions as the lower component of the V-die press tool. It is characterized by a V-shaped cavity or channel. The configuration and dimensions of the V-die align with the intended bend or shape of the metal sheet (Figure 5) . As the punch exerts pressure on the metal sheet, guiding it into the V-die, the metal sheet conforms to the shape of the die's cavity. This particular process is employed for the purpose of bending the sheet into the desired angle or shaping it into a specific form.

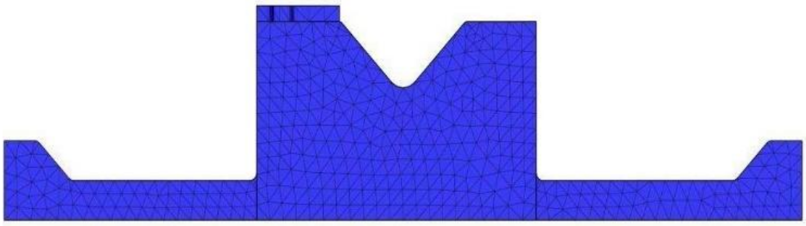


Figure 5. Geometry of unoptimized Die

Constraints on unoptimized design of Die

Constraints were applied to the bottom face of the die (Figure 6). Constraints were applied to restrict any relative motion between the punch and press brake mount [4].

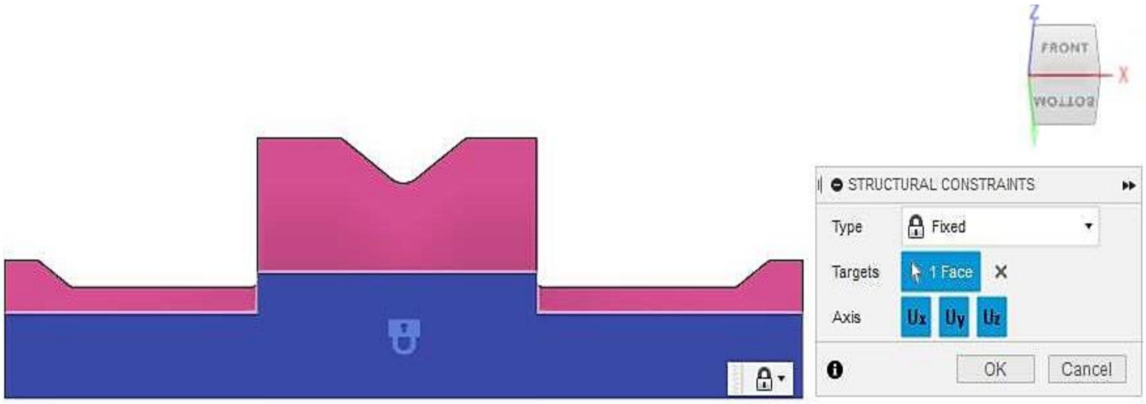


Figure 6. Constraints on Die

Load

A force of 1220.52N along the (-) Z-axis was applied on the highlighted faces (Figure 7).

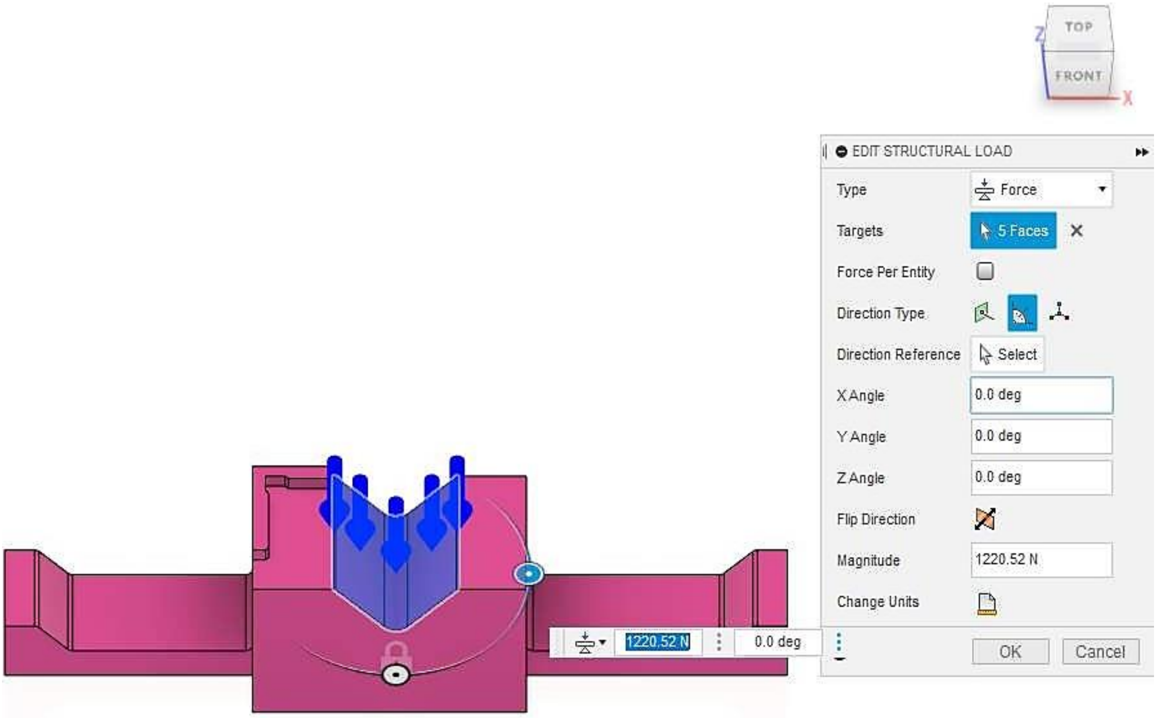
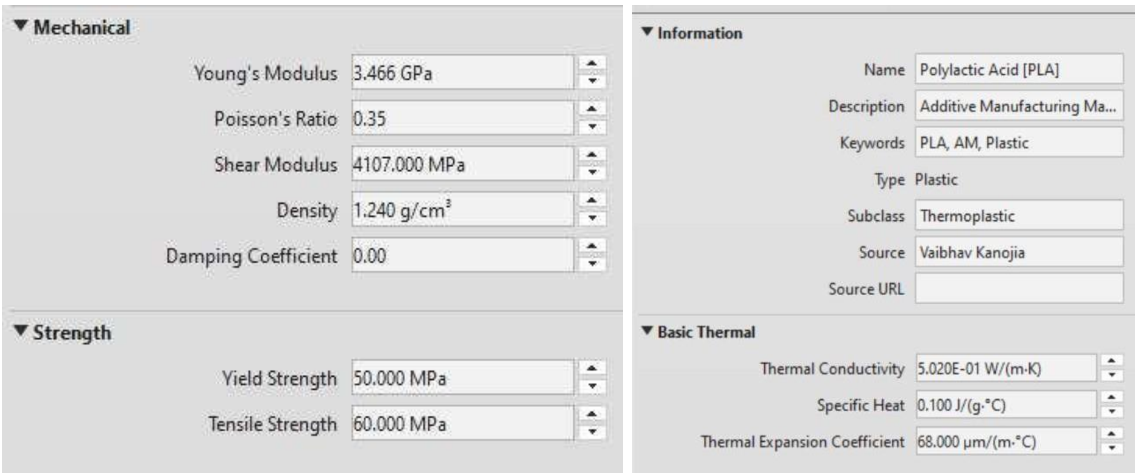


Figure 7. Represents the load applied on the Die

Material Properties

Polylactic Acid (PLA) was chosen as the study material (Figure 8 (a) and (b)). PLA is a biodegradable and compostable thermoplastic polymer that is derived from renewable resources such as cornstarch, sugarcane, or tapioca roots [5]. PLA is a popular material used in 3D printing due to its ease of use, low toxicity, and low emission of greenhouse gases.



(a) **(b)**

Figure 8 (a) and (b): Properties of PLA

SIMULATION OUTPUTS OF PUNCH AND DIE

As per the simulation result, the unoptimized Punch has a minimum safety factor of 1.686 (Figure 9). This is relatively low for the intended application. The part may permanently deform under sudden loading, which is possible in the use-case of a press tool.

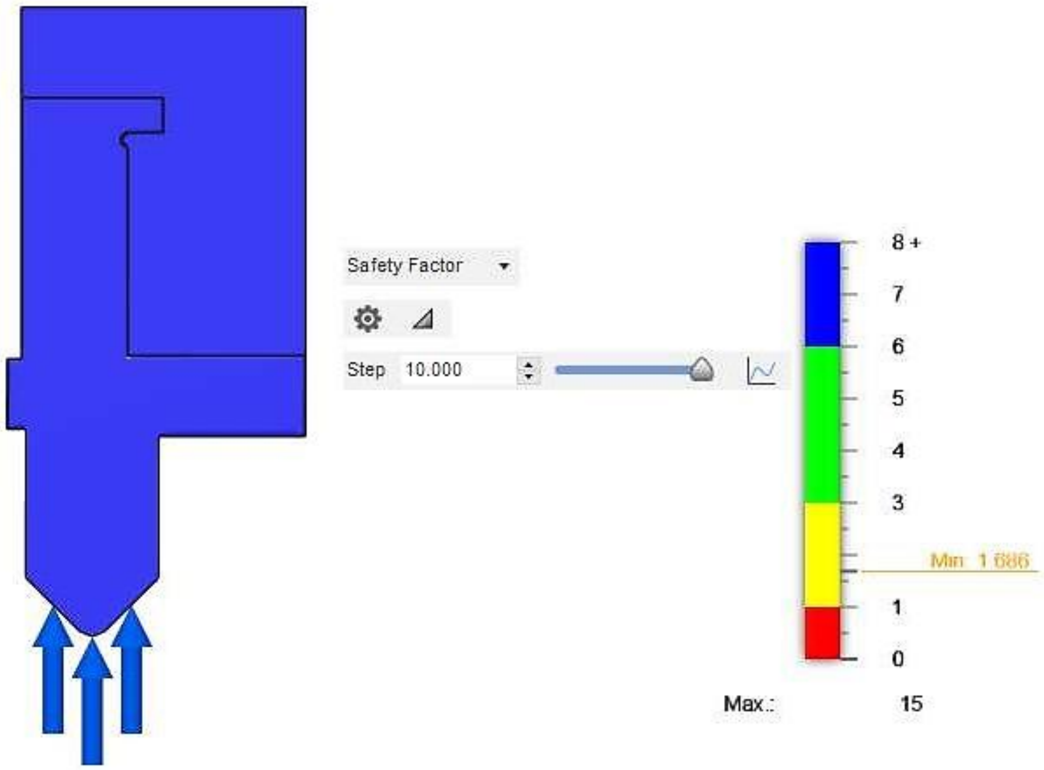


Figure 9. Factor of Safety of Punch

Stress Applied on Unoptimized Design of Punch

As per the simulation result, the unoptimized Punch will experience maximum stress of 11.86 MPa (Figure 10). This is less than the yield strength of the material. But, as per the result, we can see that there are a lot of areas where stress concentration is very low. This presents us with an opportunity to optimize the design and save on unnecessary material usage.

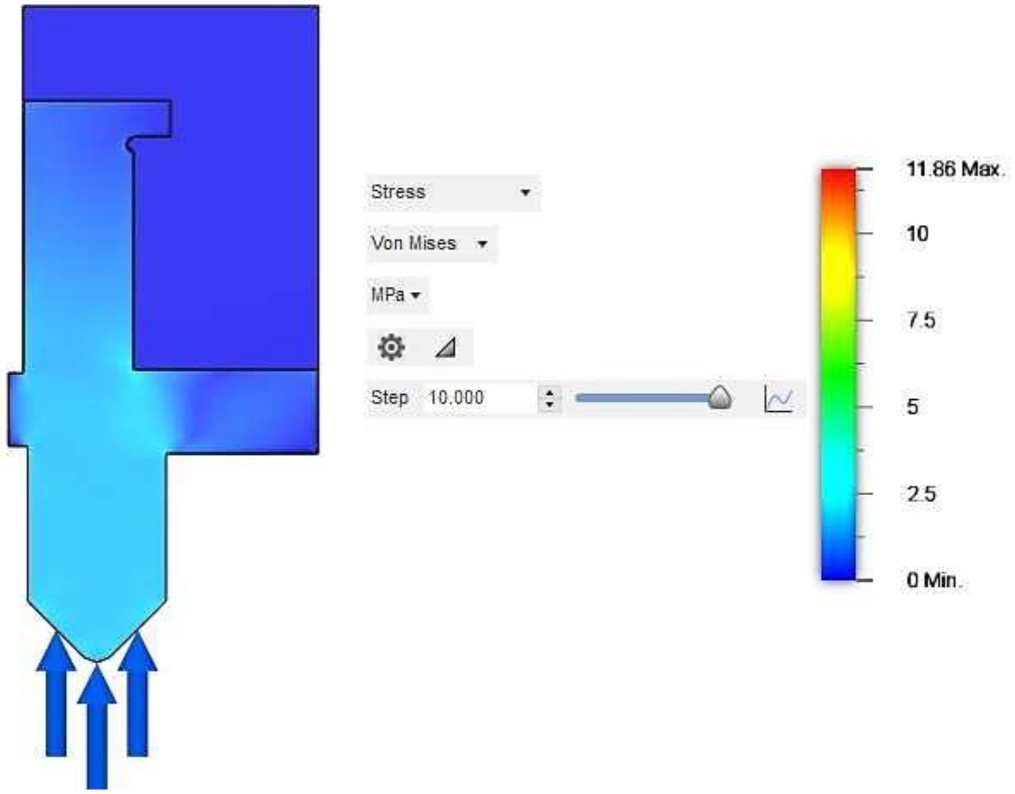


Figure 10. Stress acting on the Punch

Deformation of Unoptimized Design of Punch

From the above results, we can see that there will be a maximum displacement of 0.058 mm under loading (Figure 11).

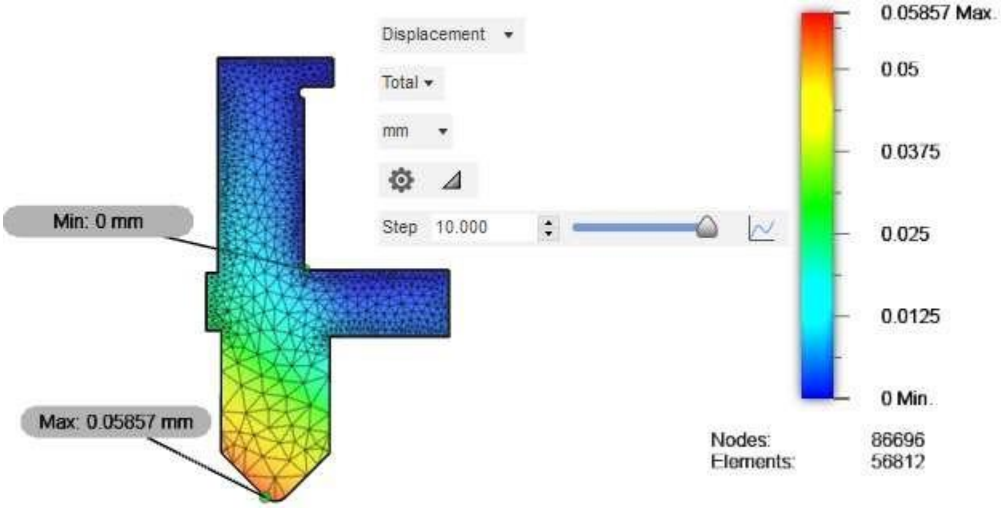


Figure 11. Deformation of Punch

As per the simulation result, the unoptimized die has a minimum safety factor of 9.47 (Figure 12). This is relatively high for the intended application. This indicates that the part might be over-engineered. There is a possibility that the design has excess material.

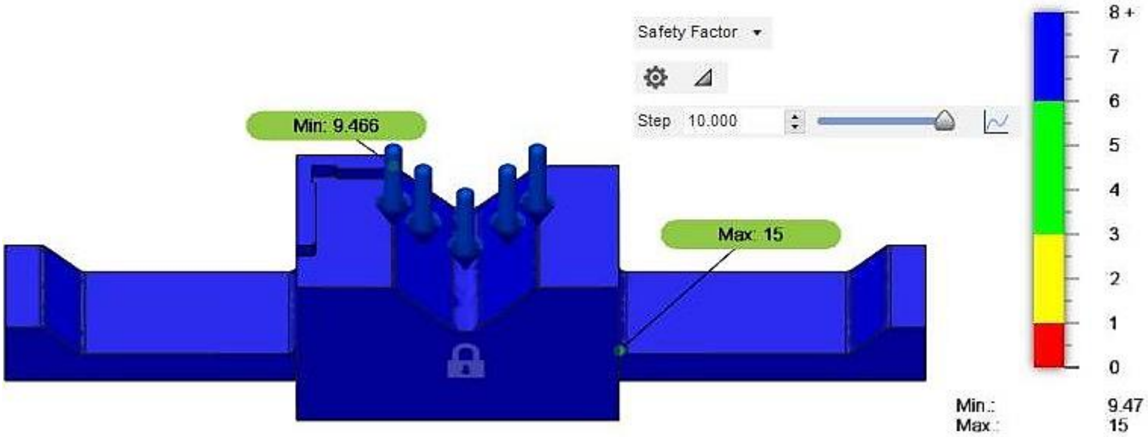


Figure 12. Factor of Safety of Die

STRESS ANALYSIS ON UNOPTIMISED DESIGN OF DIE

As per the simulation result, the unoptimized Punch will experience maximum stress of 5.282 MPa (Figure 13). This is less than the yield strength of the material. But, as per the result, we can see that there are a lot of areas where stress concentration is very low. This presents us with an opportunity to optimize the design and save on unnecessary material usage.

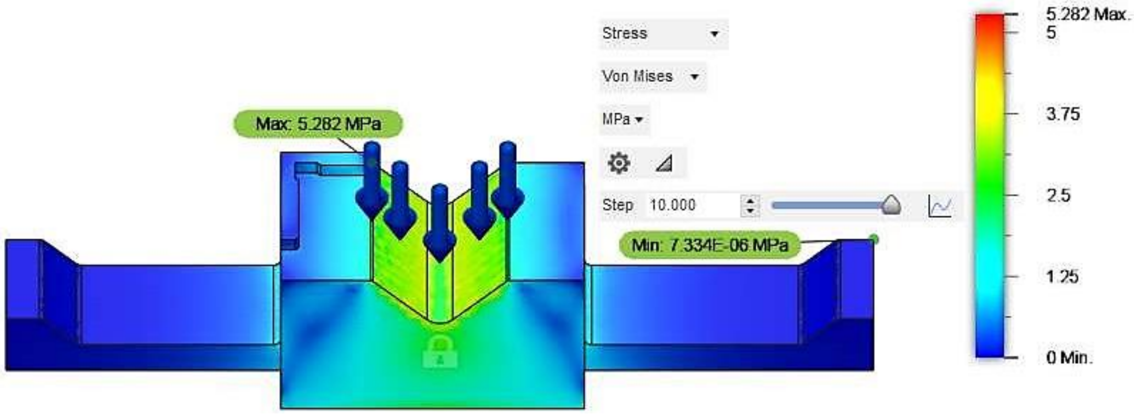


Figure 13. Stress acting on the Die

DEFORMATION ON UNOPTIMIZED DESIGN OF DIE

From the above results, we can see that there will be a maximum displacement of 0.014 mm under loading (Figure 14).

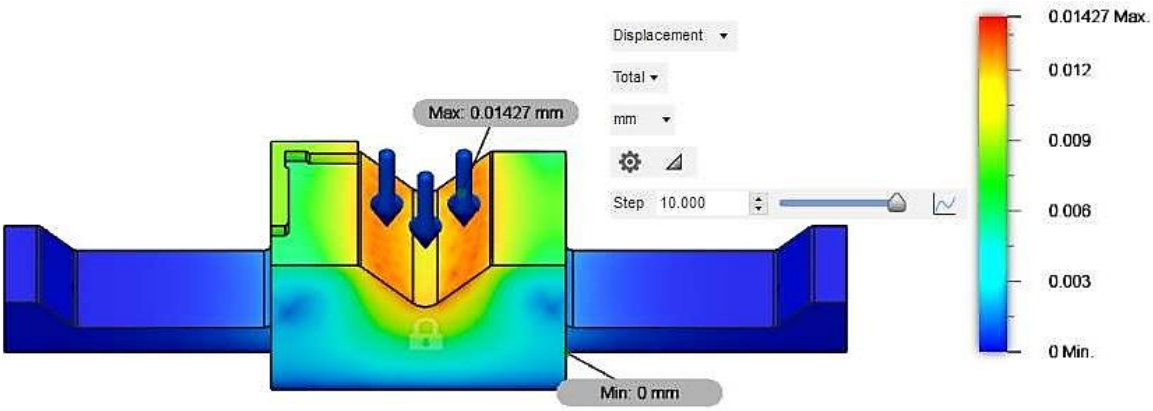
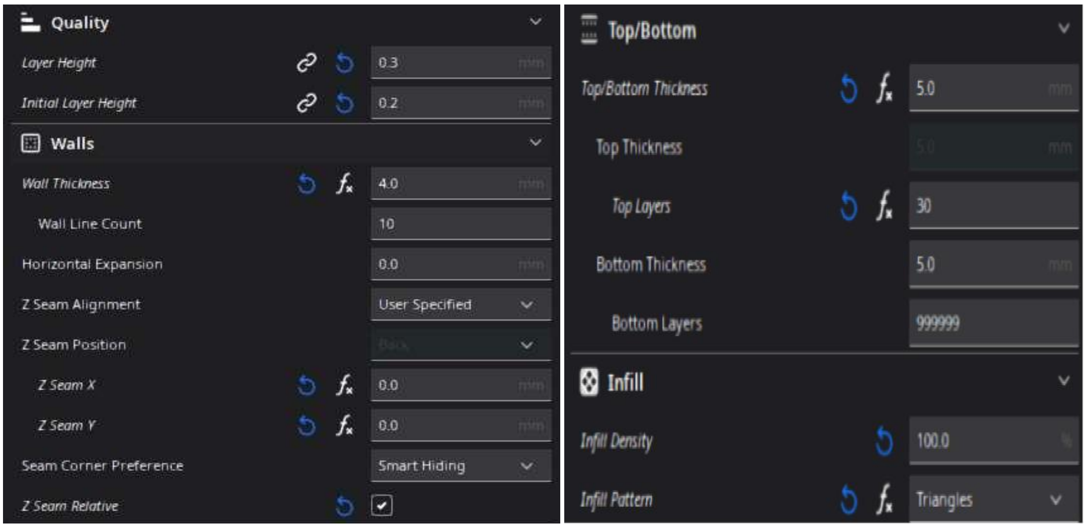


Figure 14. Deformation of Die

Manufacturing Feasibility and Manufacturing Time Calculation

Unoptimized punch and die CAD models were exported in .3MF format. These .3MF format files were used as input for Slicing software (CURA) [6]. Slicing software is used to convert .STL, .3MF or other compatible files into G-Code. This G-Code is used as an input for the 3D Printer. A slicer also helps us to visualize the 3D Printed part and provide manufacturing times [6]. The following parameters were set for slicing the .3MF files in the CURA slicer (Figure 15 (a) and (b)).



(a) (b)

Figure 15 (a) and (b). Input parameters for Slicer

The predicted Manufacturing time for an unoptimized Punch: are 3 hours 28 minutes (Figure 16).

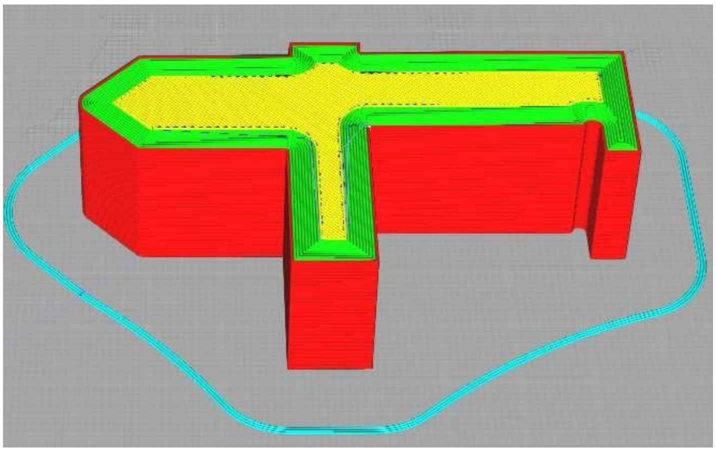


Figure 16. Preview of a sliced unoptimized Punch at the start

Image showing a preview of sliced 49 unoptimized Punch (Figure 17).

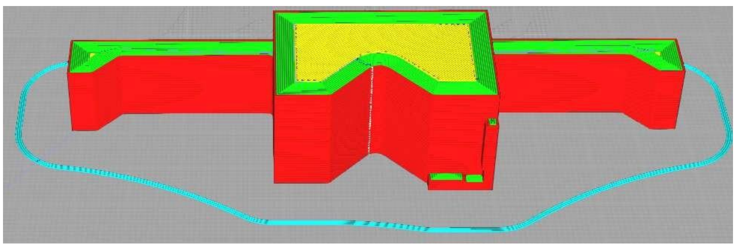


Figure 17. Preview of a sliced unoptimized Die at the end

Weight Estimation of Unoptimized Punch and Die

Weight of the punch and die can be estimated using the density of PLA and volume of the punch and die respectively. Autodesk Fusion 360 was used as the 3D Modelling software for the purposes of this research project. This software enables us to view the properties of individual parts, including the weight of the selected part.

Following are the values for weights of the unoptimized Punch and Die. The weight of the unoptimized Punch came out to be 39.37 g.

- The weight of the unoptimized Die came out to be 36.58 g.

Topology Optimization of Punch and Die

Once simulation results of punch and die are obtained, they can then be used to optimize the respective 3D Models. We will be focusing on obtaining a minimum safety factor of 4 and removing material from areas of low-stress concentrations.

Topology Optimization of Punch

After examining the results of the Simulation of an unoptimized punch, we focused on removing material from regions of lower stress concentrations. After removing the material, the following geometry was obtained.

OPTIMIZED GEOMETRY

In order to validate the optimized geometry (Figure 18), Finite Element Analysis was performed on the punch using the following constraints and loads:

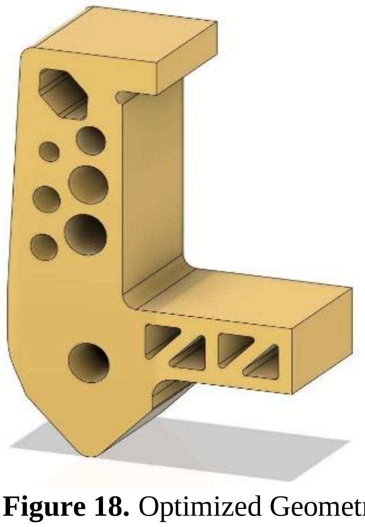


Figure 18. Optimized Geometry of Punch

CONSTRAINTS

Constraints were applied to the mount of the press brake (Figure 19). The Punch is set in contact with the mount in the study. The faces coming in contact with the punch were constrained along all axes, to restrict any relative motion between the punch and the press brake mount.

LOADS

A force of 1220.52N along the Z-axis was applied to the faces coming in contact with the blank (Figure 20).

Following were the results obtained after performing the simulation:

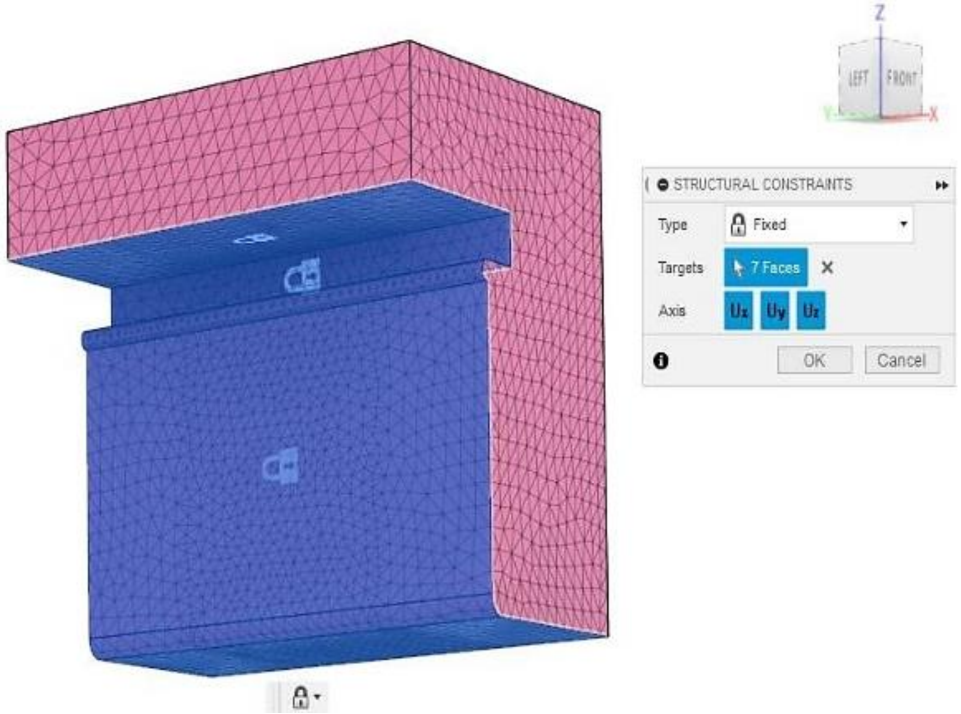


Figure 19. Constraints on Punch

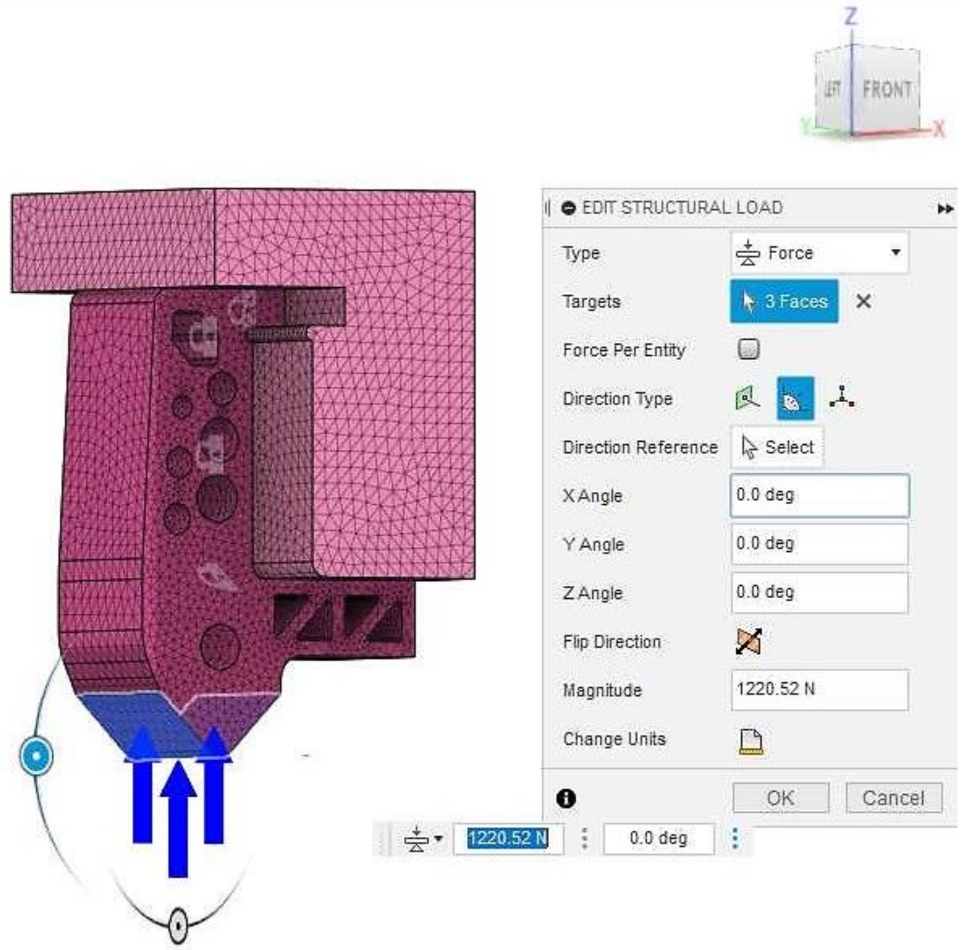


Figure 20. Load applied on the optimized design of Punch

FACTOR OF SAFETY FOR OPTIMISED DESIGN OF PUNCH:

From the above results, we can see that with [7] the optimized geometry a minimum safety factor of 4 is achieved **(**Figure 21). Also, regions of lower stress concentrations have been removed (Figure 22). This, collectively, enables us to produce parts that can provide the same performance while being able to be produced relatively quickly.

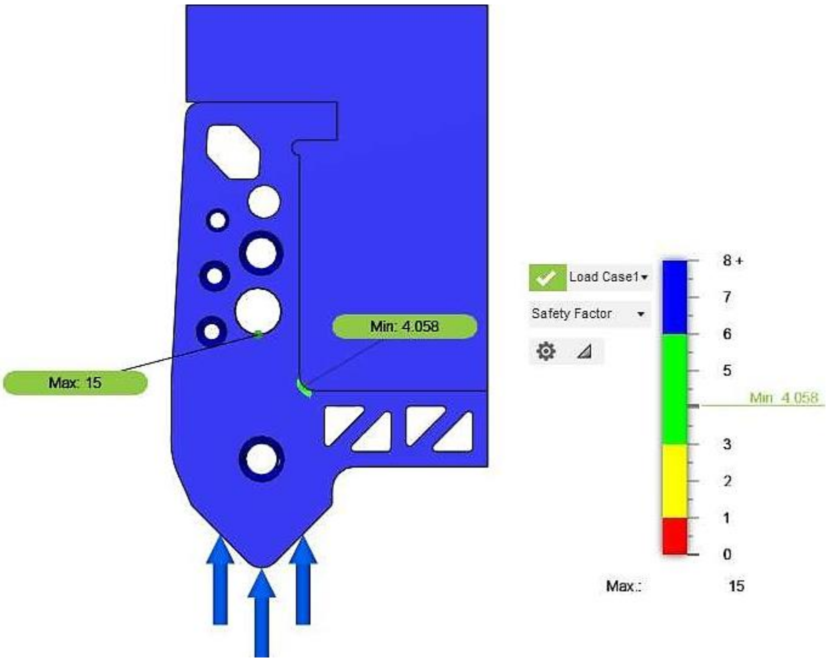


Figure 21. Factor of Safety for optimised design of Punch

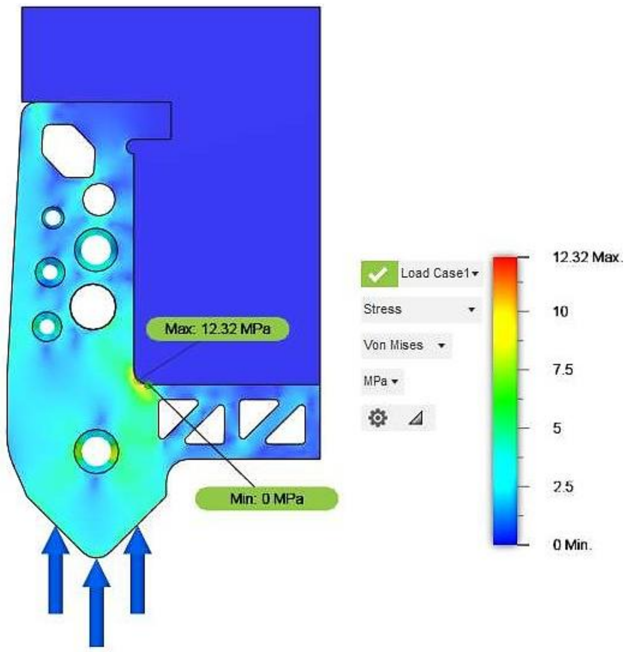


Figure 22. Stress acting on the Punch

DEFORMATION ON OPTIMISED DESIGN OF PUNCH:

From the above results, we can see that there will be a maximum displacement of 0.048 mm under loading (Figure 23).

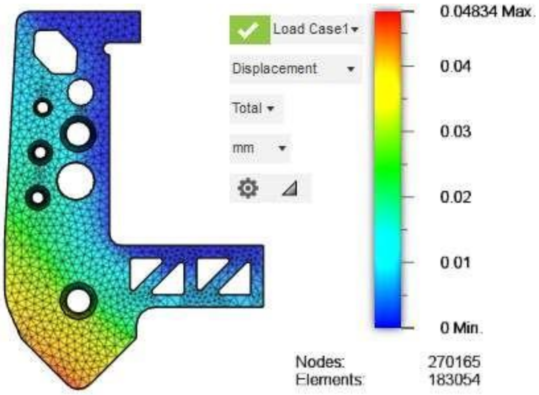


Figure 23. Deformation of optimized design of Punch

Topology Optimisation of Die

After examining the results of the Simulation of an unoptimised die, we focused on removing material from regions of lower stress concentrations. After removing the material, the following geometry was obtained.

OPTIMISED GEOMETRY:

In order to validate the optimised geometry (Figure 24), Finite Element Analysis was performed on the die using the following constraints and loads:

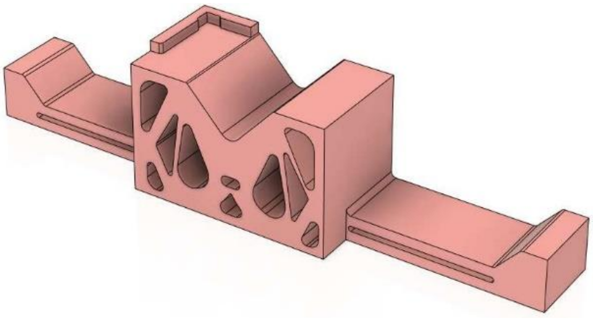


Figure 24. Optimised Geometry of Die

CONSTRAINTS ON DIE:

Constraints were applied to the base of the die. The bottom faces of the die were constrained along all axes, to restrict any relative motion between the punch and the die (Figure 25).

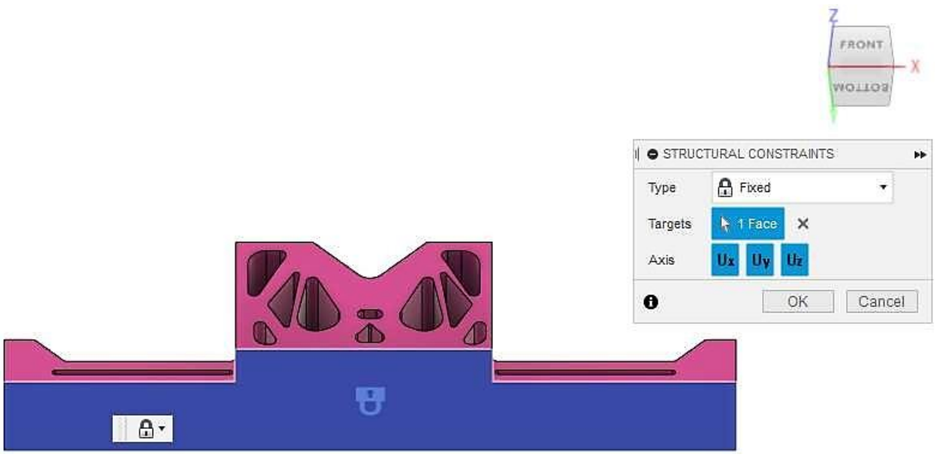


Figure 25. Constraints on Die

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LOADS APPLIED ON OPTIMISED DIE:

A force of 1220.52N along the Z-axis was applied on the highlighted faces (Figure 26).

Following were the results after perming the simulation:

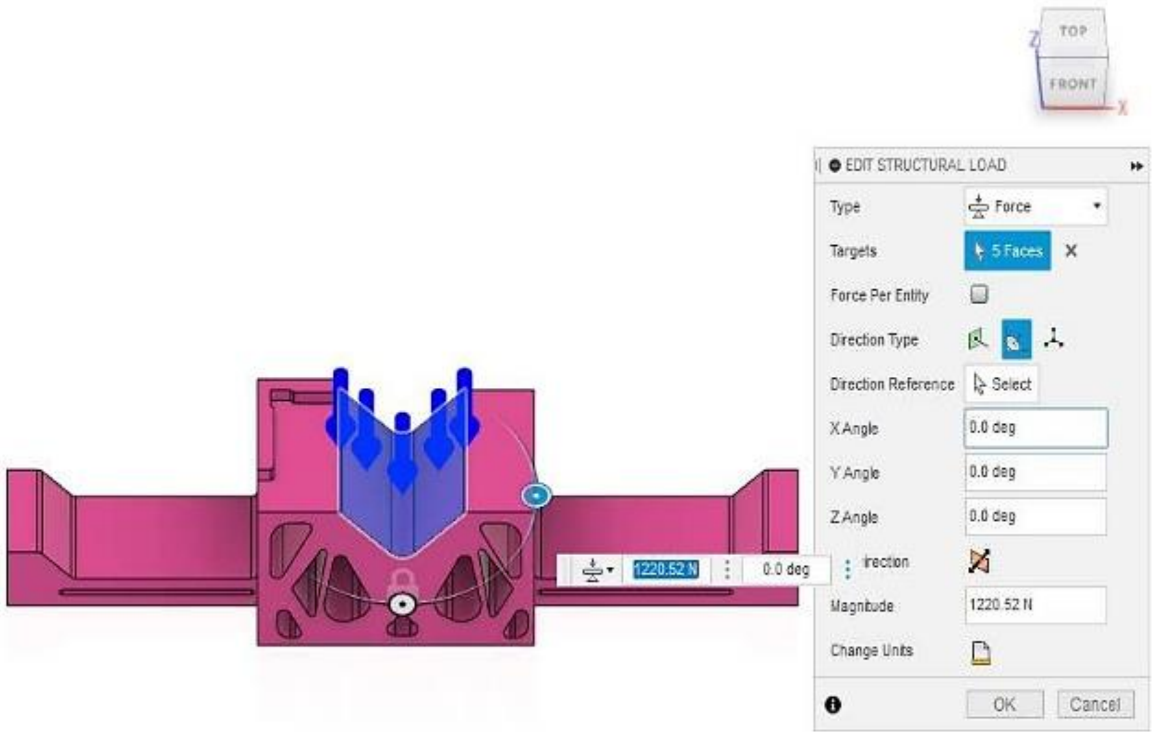


Figure 26. Load applied on the optimized design of Die

FACTOR OF SAFETY FOR OPTIMISED DESING OF DIE

From the above results, we can see that with the optimized geometry a minimum safety factor of 4 (Figure 27) is achieved. Also, regions of lower stress concentrations have been removed (Figure 28). This, collectively, enables us to produce parts that can provide the same performance while being able to be produced relatively quickly.

DEFORMATION

From the above results, we can see that there will be a maximum displacement of 0.02 mm under loading (Figure 29).

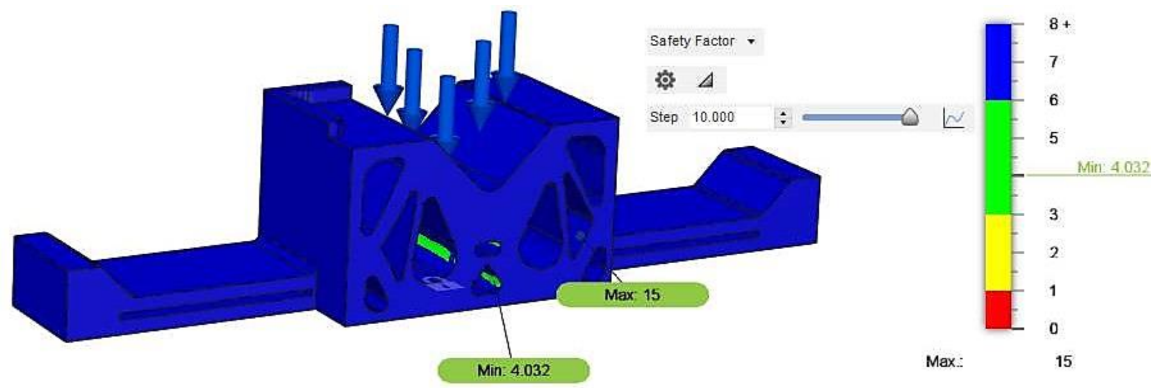


Figure 27. Factor of Safety for optimized design of Die

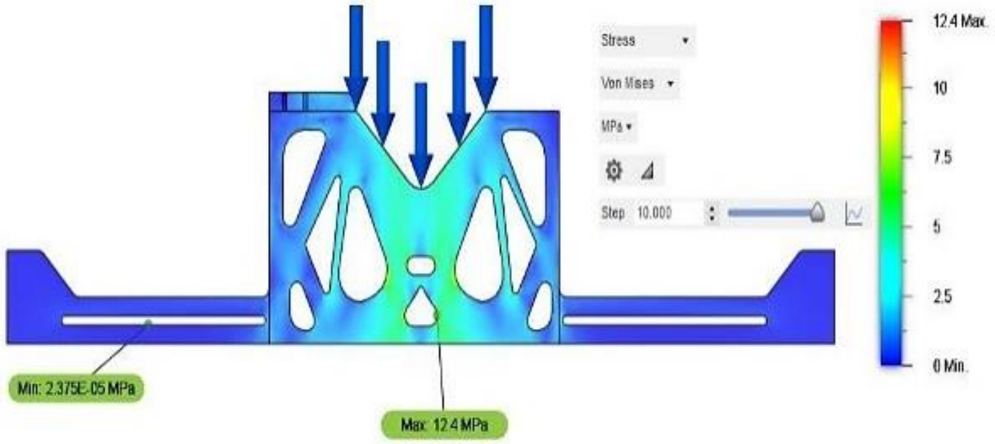


Figure 28. Stress acting on the Die

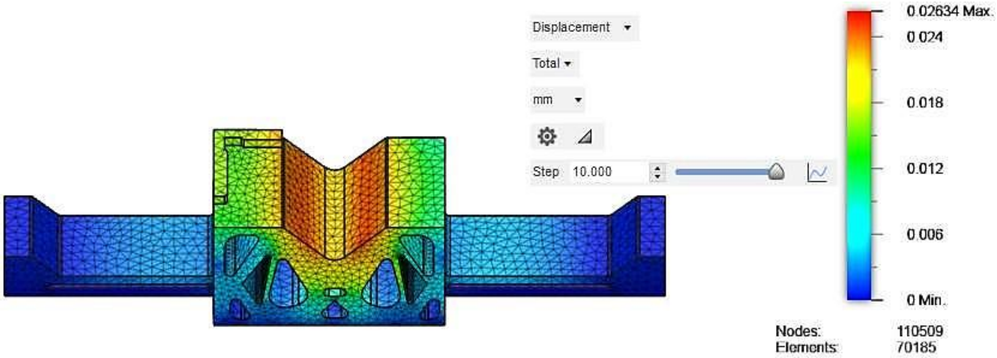
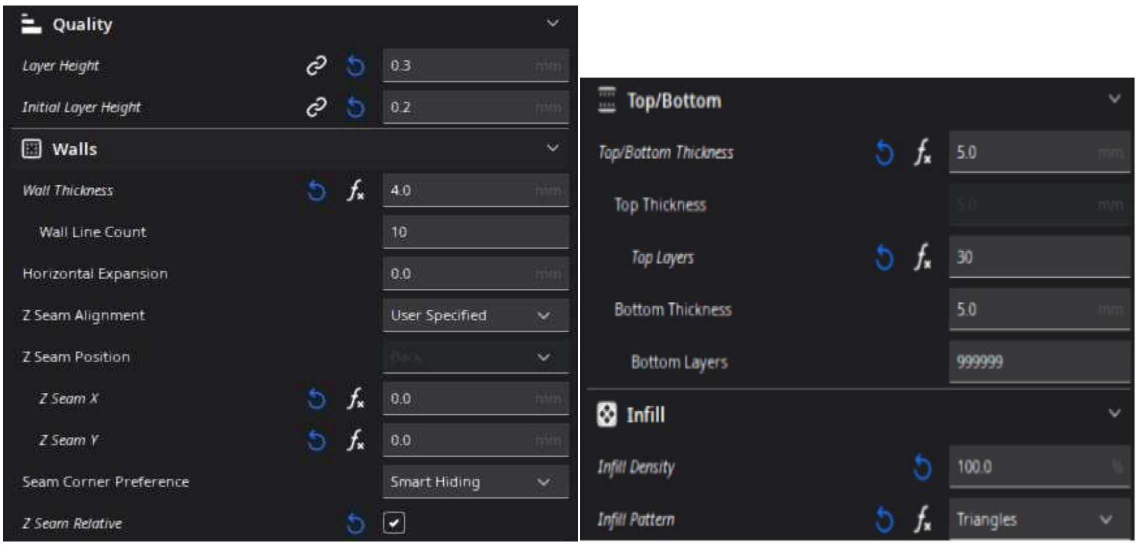


Figure 29. Deformation of optimized design of Die

Manufacturing Feasibility and Manufacturing Time Calculation for Optimized press tools

Unoptimized punch and die CAD models were exported in .3MF format. These .3MF format files were used as input for Slicing software (CURA). Slicing software is used to convert .STL, .3MF or other compatible files into G-Code. This G-Code is used as an input for the 3D Printer. A slicer also helps us to visualize the 3D Printed part and provide manufacturing times. For the purposes of this research paper, the following parameters were set for slicing the .3MF files in the CURA slicer (Figures 30 (a) and (b)].



(a) **(b)**

Figure 30 (a) and (b). Parameters for Slicer for optimized press tools

Predicted Manufacturing time for unoptimised Punch: 2 hours 39 minutes (Figure 31).

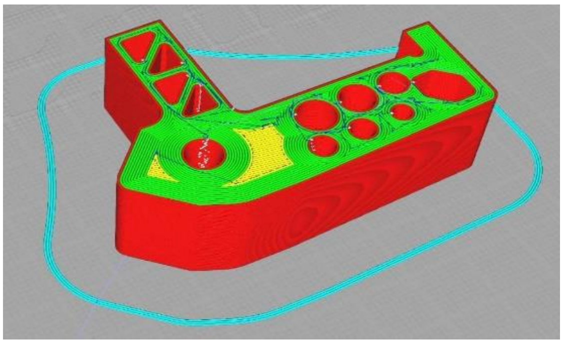


Figure 31. Preview of sliced optimised Punch

Predicted Manufacturing time for unoptimised Punch: 2 hours 50 minutes (Figure 32).

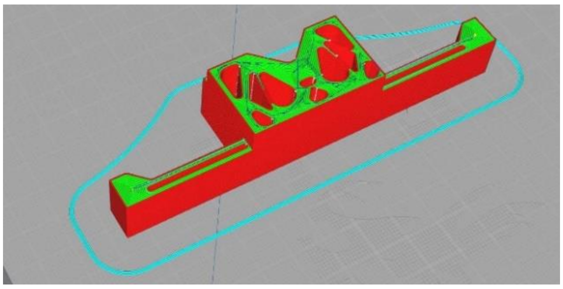


Figure 32. Preview of sliced optimized Die

Weight estimation of Optimized Punch and Die

Weight of the optimized punch and die can be estimated using the density of PLA and volume of the punch and die respectively. Autodesk Fusion 360 was used as the 3D Modelling software for the purposes of this research project. This software enables us to view the properties of individual parts, including the weight of the selected part.

Following are the values for weights of the unoptimized Punch and Die.

- The weight of the optimized Punch came out to be 26.38 g.
- The weight of the optimized Die came out to be 26.59 g.

RESULTS

Finite element analysis of unoptimized press tools was performed. Simulation results indicated a minimum safety factor of 1.686 for Punch and a minimum safety factor of 9.466 for die. Both of which are not suitable for the intended application.

After topology optimization, simulation results indicated a safety factor of 4.058 for Punch and a minimum safety factor of 4.032 for Die. Both satisfy the target factor of safety determined for the intended application.

Punch weight was reduced from 39.37 g to 26.38 g, which is a reduction of 12.99 g (32.99% of initial weight). The manufacturing time for punch was reduced from 3 hours 28 minutes to 2 hours 39 minutes, which is a reduction in time of 49 minutes.

Die weight was reduced from 36.58 g to 26.59 g, which is a reduction of 9.99 g (27.31% of initial weight). The manufacturing time for punch was reduced from 3 hours 13 minutes to 2 hours 50 minutes, which is a reduction in time of 23 minutes.

CONCLUSION

In this paper we started with a basic, unoptimized, V-Die press tool consisting of a punch and die. We calculated the maximum force required for bending. We used this value of maximum force as an input, along with constraints, to perform finite element analysis on the unoptimized punch and die. The output of the simulation study on the unoptimized punch and die revealed that the punch had a safety factor of 1.686, which was low for the intended usage, and the die had a safety factor of 9.466 which was high for the intended usage.

Topology optimization of the punch and die enabled us to achieve a safety factor of 4.058 for the punch and 4.032 for the die. Significant weight reduction was also done for both, the punch (reduction of 32.99%) and die (reduction of 27.31%).

Reduction in weight enabled us to reduce manufacturing time for Punch by 49 minutes and for Die by 23 minutes.

All the above material savings will result in time and cost savings. Enabling cost and time-effective prototyping processes for press tools for application in various industries such as automotive and aerospace.

REFERENCES

1. Klocke F, Beck T, Hoppe S, Krieg T, Müller N, Nöthe T, et al. Examples of FEM application in manufacturing technology. Journal of Materials Processing Technology (2002) 120(1-3):450–7.
2. W.D. Pilkey, "FINITE ELEMENTS IN ANALYSIS AND DESIGN", An International Journal for Innovations in Computational Methodology and Application (2023).
3. Vinod Laxman Hattalli, Shivashankar R. Srivatsa "Sheet Metal Forming Processes — Recent Technological Advances", ICAMA (2016)
4. Masoud Kardan, Ali Parvizi, Ali Askari "Experimental and Finite Element Results for Optimization of Punch Force and Thickness Distribution in Deep Drawing Process", Arabian Journal for Science and Engineering (2017)
5. Fabrizio Fina, Alvaro Goyanes, Simon Gaisford, Abdul W. Basit "Selective laser sintering (SLS) 3D printing of medicines", International Journal of Pharmaceutics (2017)
6. Ruben Bayu Kristiawan, Fitrian Imaduddin, Dody Ariawan, Ubaidillah, Zainal Arifin "A review on the fused deposition modeling (FDM) 3D printing: Filament processing, materials, and printing parameters", De Gruyter Open Access (2021)
7. N. Shahrubudin, T.C. Lee, R. Ramlan "An Overview on 3D Printing Technology: Technological, Materials, and Applications", Procedia Manufacturing (2019)

