Application of topology optimization technique in sand casting process of a complex product based on FDM 3D printing technology

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Abstract
Design optimization is one of the emerging CAE technologies thanks to the robust and strong structure of the computer and the ability to create complex designs using material additive technology. Recent modern innovations in 3D printing technology have made metal casting new breakthroughs. The demand of many products with complex shapes and geometries becomes very high. This makes the 3D printing more helpful and meaningful to contribute in the field of product design and development. This study presents an integrated framework for the implementation of complex 3D product design from fundamental technologies of CAD/CAE/AM (Computer Aided Design/Computer Aided Engineering/Additive manufacturing). Then, we apply casting technology to create models for products with complex shapes from FDM 3D printing technology. This integrated process is essential in assisting engineers to quickly design and create prototypes, and to fully control errors occurring during prototyping through CAD/CAE simulation to improve production efficiency of businesses and reduce time to bring products to customers. The experiment of sand casting based on the mold core from AM technology confirmed that the integrated approach is effective and applicable in the practice at manufacturing enterprises.
Keywords: Optimal design; FDM; 3D printing technology; CAD/CAE; Casting.

1. Introduction

Over the past decade, with the advent of 3D printers, rapid prototyping technology is developing strongly and has many potential applications in practice to satisfy customers' needs for product designs. In particular, FDM (Fused Deposition Modeling) technology is being invested in universities as well as manufacturing companies to develop and rapidly evaluate new product models before mass production. However, 3D printing for complex shapes based on powdered metals is currently very difficult and is still under research in developing countries and has had a few successful applications in advanced countries. In Vietnam, metal 3D printing technology has not been studied much and has not yet been transferred technology for trained skilled personnel in this field. Therefore, this study builds an integrated frame for the implementation of complex 3D product design from FDM technology based on two main sources: sketching of CAD (Computer Aided Design) models and scanning 3D models. Then, we apply casting technology to create models for products with complex shapes from FDM 3D printing technology. This integrated process is really essential in assisting engineers to quickly design and create prototypes, and to fully control errors occurring during prototyping through CAD/CAE (Computer Aided Engineering) simulation to improve production efficiency of businesses and reduce time to bring products to customers.

Recent modern innovations in 3D printing technology have made metal casting new breakthroughs. The molded product can now be created using 3D printed plastic models to make a mold. In particular, this development has allowed sand molds to be 3D printed directly with part cores to be printed from plastic materials. The direction from concept to molded product has many practical potential applications in the future. This is especially true of the vast advances in CAD technology, CAE analysis supporting the product development process.

Design Optimization is one of the emerging CAE technologies thanks to the robust and strong structure of the computer and the ability to create complex designs using material additive technology. CAE technology uses both structural design and analysis methods. The software optimizes the model's topology design to satisfy the applicable load conditions and the joint constraints... This allows mechanical parts to retain their desired strength properties while its volume is the smallest. Consequently, the product will be guaranteed in terms of improved strength and the smallest volume possible. Extremely complex shapes can be obtained from topology design optimization.

Therefore, the combination of 3D printing technology to create product prototypes for mold cores, molds, and topology optimization enables improved durability with light product weight. Finally, the casting method based on the above combination will yield metal products with

complex designs, satisfying customer needs, desired durability and light weight. Building a process framework from model design to sand molding experiment will be tested and evaluated as the goal of this study. In summary, this research explores the applicability of tools that integrate 3D printing with the FDM method and topology design optimization techniques to create complex products based on sand molding.

2. Related works

The continuous development and increasingly perfect of 3D printers, along with a variety of printing materials. 3D printing technology has conquered almost every field of industry and our life. Currently, the developed countries in the world have the research, development and application of 3D printing in many different fields in general and in particular real conditions. They have made numerous achievements in fields such as electronic devices, smartwatches, manufacturing and machining, automotive, fashion, food, healthcare, and education, etc. The research team showed that, if the 3D printing method was applied using FDM technology compared to the conventional method, the total time saved was 66%. Lifespan of ABS models is higher than wood models.

Casting is one of the oldest manufacturing methods in the world, with a history of thousands of years. Casting is widely used in the manufacture of complex structural metal parts and parts that require high precision and good surface finishing. However, it is not easy to create molds with traditional machining methods, it takes a lot of time and machining costs. Currently, with the advent of rapid prototyping method, specifically 3D printing method using FDM technology, the above limitations will be gradually overcome. FDM technology allows the creation of molds with different wall thicknesses, with parts that protrude or concave, thereby allowing us to increase the complexity of the designs. If a product has a design defect, while it is still in beta production, then the design change means increased costs and production delays. Models made with FDM technology can easily be edited via a computer drafted CAD file and a new model can be created instantly.

In short, the process of integrating 3D printing uses FDM technology into casting technology. This is a perfect combination for rapid prototyping, thereby fully controlling errors occurring in the prototyping process through simulations to improve products and production efficiency. During product development, time is a key factor in assessing the direction of development and the success of new methods and technologies applied in that process. This also means that we need to create product models quickly, in order to satisfy customer design requirements while still ensuring the technical requirements of the product. However, using traditional machining methods to manufacture samples will take a lot of time and the level of perfection of the product is not high, and will not respond promptly to the diversity of products . Currently, with the advent of 3D printers, rapid prototyping technology is developing strongly and is increasingly being applied in fields such as architecture, construction, industrial design, and automotive industry, aerospace, biotechnology, fashion, etc. and many other fields.

3D printing technology is constantly being improved and increasingly perfected. Materials used for 3D printing are increasingly diverse and rich. The application of 3D printing technology is present in many places in production and life, contributing to the industrial revolution 4.0 of the world. The FDM machine consists of two main parts including the frame and the nozzle assembly. The nozzle assembly can move at the same time along two XY axes to build up the cross-section of the part, with the support table lowered in the Z direction after each nozzle has created a layer of material. The combination of the nozzle movement and the support table results in 3-axis printing. The thickness of the material layer depends on many different factors such as the ability of the machine, the design parameters, the quality requirements of the face. Therefore, research on the parameters that affect this technology is essential in order to optimize the prototyping process at its best. The raw materials of FDM technology are plastic wires melted by the heat supplied from the nozzle, there are many types of materials such as ABS, PLA ... to choose for FDM technology depending on the requirements of each different product.

Process parameters of FDM technology

The rapid prototyping methods all have their own technological parameters, from here we can know the technological capabilities of the machine. From the optimization of these parameters, it is possible to create templates with specific requirements. The technological parameters of FDM prototyping method are extrusion direction (which is the direction showing product development through each material layer), layer thickness (is the thickness of a material layer based on the extrusion head, this thickness is partly dependent on the filament diameter and the head ruler glass), and the air clearance (which is the distance between two extrusion strokes of an adjacent print head on the same print layer).

General RP process

General RP process consists of several steps as follows.

CAD modeling

After surveying the market, we determine technical requirements, and product specifications. We conduct sketching models on paper or on a computer with the support of modern CAD systems. This is the first step in the rapid prototyping process, used for all technologies. First, this work is done by graphics software to create 3D models, the fabrication model must be similar to the physical model of the object. Second, reverse techniques are now used to create samples from existing objects through many scanning procedures, MRI scans, CT scans, etc. This is the most important and time consuming step of the process of rapid prototyping technology.

CAD data exchanges to STL file

Many computer design software uses a number of different algorithms to represent 3D objects. To establish stability, the STL format was born and adopted as a standard in rapid prototyping technology. This is the intermediate file extension (*.STL) between CAD data and rapid prototyping systems. During this period, 3D cube faces are represented as triangles. They are then saved as STL files containing all the triangular data of the object block. The larger and more complex the objects, the more triangles, the larger the file size.

Layer slicing and investigation

During this stage, common errors in prototyping are detected. These errors can be caused by many of the most common reasons being CAD to STL conversion. These failures must be corrected before the manufacturing stage can be carried out. After checking the errors, cut the model of the part into cross sections. The settings are all related to influence the section thickness when fabricated. Auxiliary parts (auxiliary structures - support) are also examined during this period. After slicing STL file, export the data to a Gcode file containing the program control codes. The pre-processing program will receive the Gcode file to manufacture the part. Most of the available software allows the user to adjust the size, position and fabrication direction of an object.

Part fabrication

At this stage, normally the entire operation is automated, the fabrication time varies depending on the size and quantity required, which is limited by the size of the rapid prototyping system.

Post processing

This is the final step, which involves removing fabricated part from the machine, removing auxiliary structures and cleaning unnecessary parts from the fabrication pattern. Photosensitive materials need to be completely disposed of before use.

Product is cleaned and surface treated. Product/part polishing and plating will improve its exterior quality and durability. This phase is performed by a number of methods and depending on the rapid prototyping device.

Topology design for complex products has been paid more attention to many researchers during recent years. For example, Gebisa and Lemu [1] focused on topology optimization to apply for additive manufacturing technology. They have used a case study on jet enginee bracket with the aim of lightweight design. They also confirmed that product design based on topological optimization made its weight reduced significantly. This research was continued with the product of triangular bracket [2]. Martin and Kedziora [3] designed automative road racing rim using topology optimization. They have used Hyperworks 14/Inspire 2015 software and Autodesk Inventor 2015 to implement the topological optimized design for rim. In particular, the rim was reduced about 1.8 kg compared to initial total mass of 7.9 kg. Next, Rezaie et al. [4] also presented the topology optimization for FDM process with the aim of weight reduction. Zegard and Paulino [5] have built a bridge between topological optimized design and additive manufacturing (AM) technology. Besides, Ranjan et al. [6] integrated manufacturing technology and topology optimization in to 3D printing. For understanding deeply on the opportunities and challenges as well as the future trends of generative design and topology optimization for AM, please refer to several valuable references [7-9]. From several ideas of attracted technology on topology design and AM, an integrated framework is built to make the design become the real product in the practice based on the integration of many techniques such as topological optimized design, rapid prototyping technology, and sand casting technique.

3. Research methodology

This section introduces in detail the research methods from the design phase to practical product implementation through the molding process. Furthermore, this section will guide in detail and outline a streamlined process to illustrate the integration capabilities of today's advanced technologies.

Step 1: The research process was performed as shown in Figure 1. First of all, product models can be designed based on CAD software systems of Autodesk Inventor (or we can actually scan existing product models in practice using laser scanner to get geometrical point data and reverse engineering to interpolate geometric surfaces/profiles for product).

Step 2: Next, we apply CAE techniques in product topology analysis. In this step, we need to define the product features, the technical requirements for

constructing the objective function and the design constraints such as joints, fixings, and loads acting on the product. Design optimization techniques can use CAE software such as ABAQUS, ANSYS, NASTRAN, Autodesk Fusion 360, Solidworks 2018, Hyperworks Altair or Autodesk Inventor Pro 2017. In this study, the CAE module of Autodesk Inentor Professional (from version 2017 and later) is used to determine the optimal design. Then, based on the proposed results, we reconstruct the product geometry and proceed to assign the constraint and the applied load to CAE analysis again to investigate that the designed product satisfies the durability requirements such as stress, deformation, and displacement, etc.

Step 3a: After the CAD model of the product is designed and CAE tested, we will perform the export step to the STL file. An STL file is an intermediate file of the rapid prototyping process. This file export process has many steps such as determining important parameters such as number of vertices, number of triangles, raw or fine mesh mode depending on the machine configuration and product requirements. Then, the STL file is exported to the Ultimaker CURA software to conduct the layer cutting process, creating layers of a certain thickness that the 3D printer understands. In the CURA software, we set the parameters to operate the 3D printer. Then, the G-code is exported from CURA software for 3D printing on the real 3D printer machine. Through this step, we have a complex plastic product (PLA) model with complicated shape for molding in sand mold.

Step 3b: This step is conducted in parallel with step 3a. After having the CAD model, we proceed to simulate the molding process in the sand mold. Altair Casting simulation software is used to analyze CAE molding process, temperature field distribution, and flow into the mold to evaluate the quality of the mold before deployment in practice.

Step 4: Deploy product casting in sand mold. This step requires us to create sand molds and plastic samples as core molds. Then, we carry out casting the actual product. After the completion of the molding process, sample the product and conduct the post-treatment steps, then evaluate the quality of the cast with the bearing capacity, and the simulation results to demonstrate the effectiveness of the proposded framework which is recommended in this study. This integration process is clearly illustrated in Figure 1.

4. Results and discussion

Autodesk Inventor is software for 3D modeling, design, prototyping and concept testing of products. Inventor creates prototypes that accurately simulate volume, pressure, friction, load, ect of product features in 3D environment. Inventor's built-in simulation and analysis tools allow users to design from basic to advanced molds such as part design, product visualization. Inventor also integrates CAD and design communication tools to improve CAD productivity and reduce errors and save time.

Design optimization always exists in parallel and is inseparable from the design process of the product model, especially the mechanical components. After building the product model in 3D design software as in Figure 2 and Figure 3a, we use tools specialized in calculating the parameters to balance the elements: style, volume, durability, machining cost, etc.

The purpose of shape optimization is to determine the best material distribution for the structure to achieve the minimum or maximum value for a given standards (total hardness, strain energy, natural frequency, etc.) satisfy the constraints (volume reduction, stress, etc.). Thus, the designer can remove unnecessary material locations, the biggest cost savings in production is the removed material.

Shape Generator is one of the optimization tools provided by Autodesk Inventor that make design even easier. Here are the steps to optimize the product's appearance with the Inventor Shape Generator.

Step 1: Choose Shape Generator
Step 2: Select design materials in Assign Materials, the selected material is Aluminum
Step 3: Select a fixed support on the surface of the part at Fixed Constraint and select the fixed surface
Step 4: Apply force exerting on the part at Force and select the exerted surfaces
Step 5: Select the area kept in the Preserve Region
Step 6: To optimize the symmetrical part or component customized in Symmetry Plane
Step 7: Set the optimal parameters such as 60% weight optimization at Shape Generator Settings
Step 8: Meshing for optimal performance at Mesh Settings
Step 9: Optimally run at Generate Shape.
The results obtained at the end of the optimization: After the end, weight loss was 61% to 0.267 kg as shown in Figure 3b.

Redesign

The complicated product after optimized by Inventor Shape Generator need to redesign to be complete. The redesign steps are as follows:
Step 1: Select Promote Shape to switch to design interface.
Step 2: Use the design tools of Autodesk Inventor to redesign the allowed area, and the completed product shown in Figure 4 a, b, and c.
The redesigned post-stress test is important to check. To do so, we implement the following steps.
Step 1: To enter the stress test interface, choose Stress Analysis
Step 2: Create the optimal environment with Create Study and choose Static Analysis

Step 3: Select the fixed point at Fixed and select the fixed area

Step 4: Apply force and select the starting point and direction of effect at Force
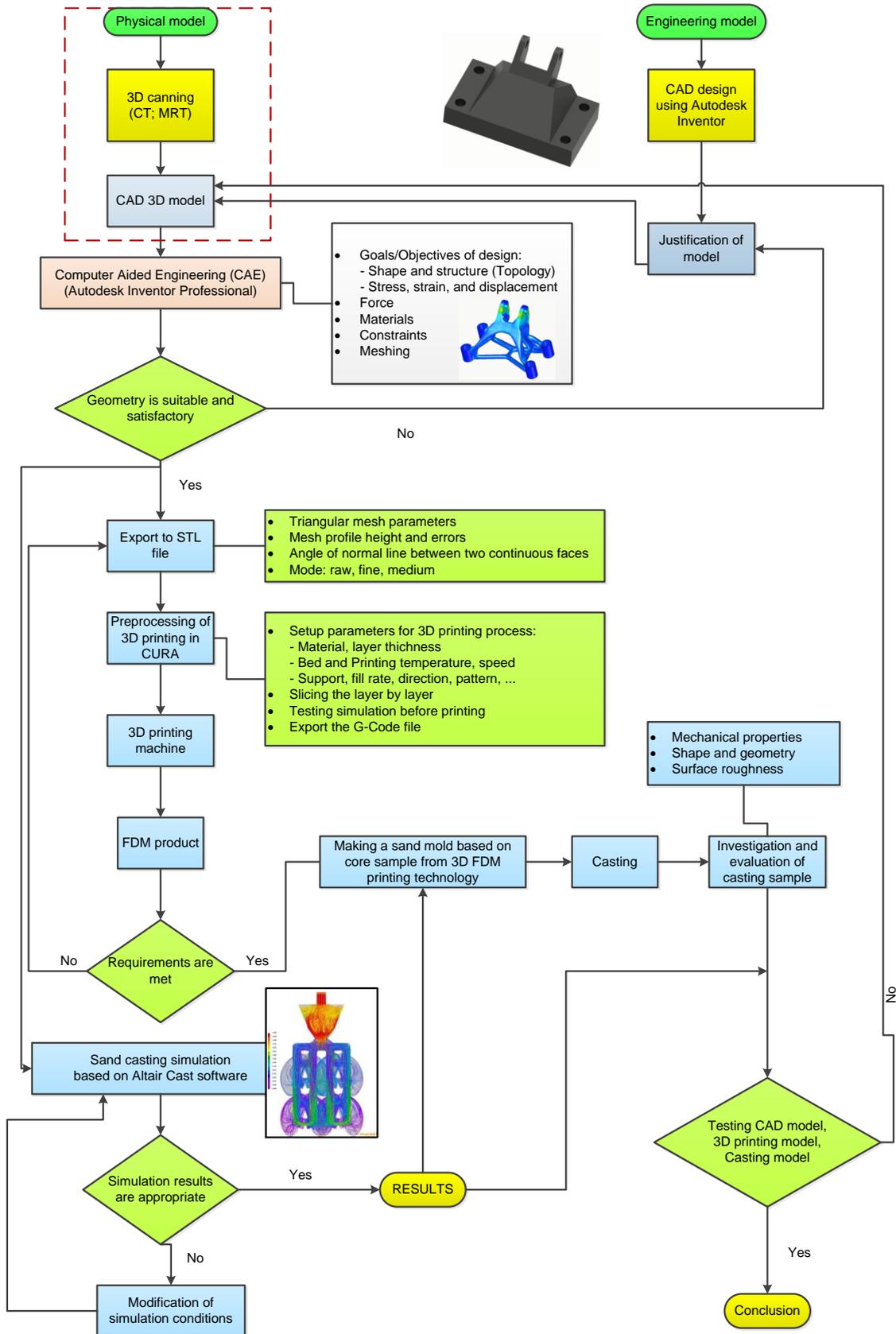
Figure 1. The integrated framework of Topology optimization, FDM and Casting technology for a complex product
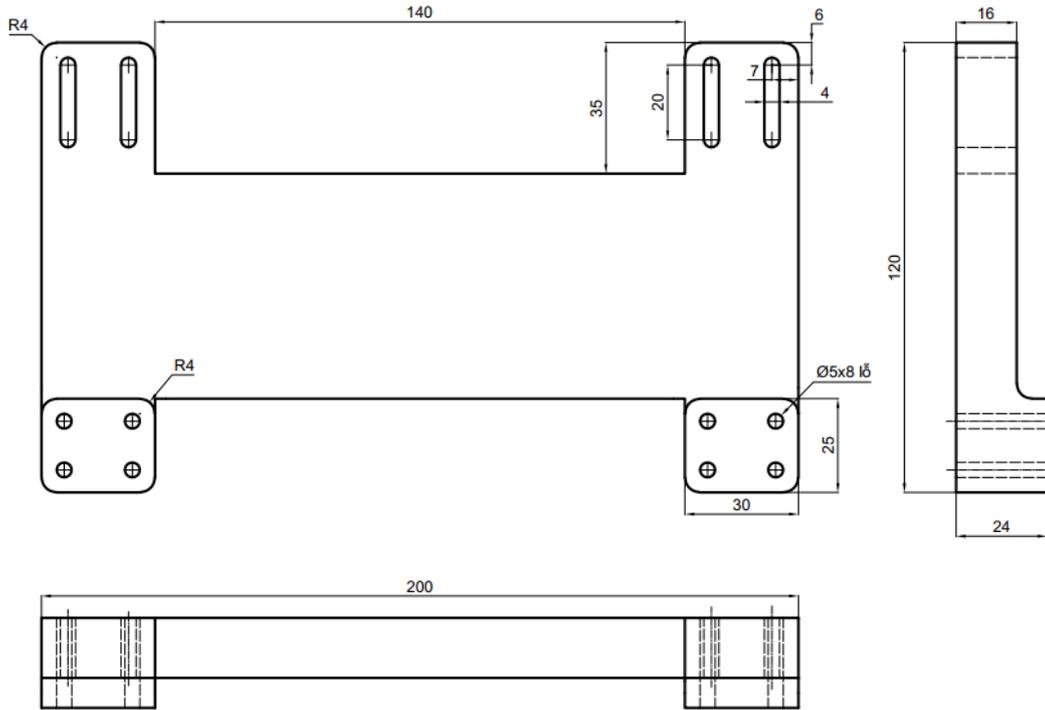
Figure 2. CAD model of proposed product (adapted from Autodesk Inventor)
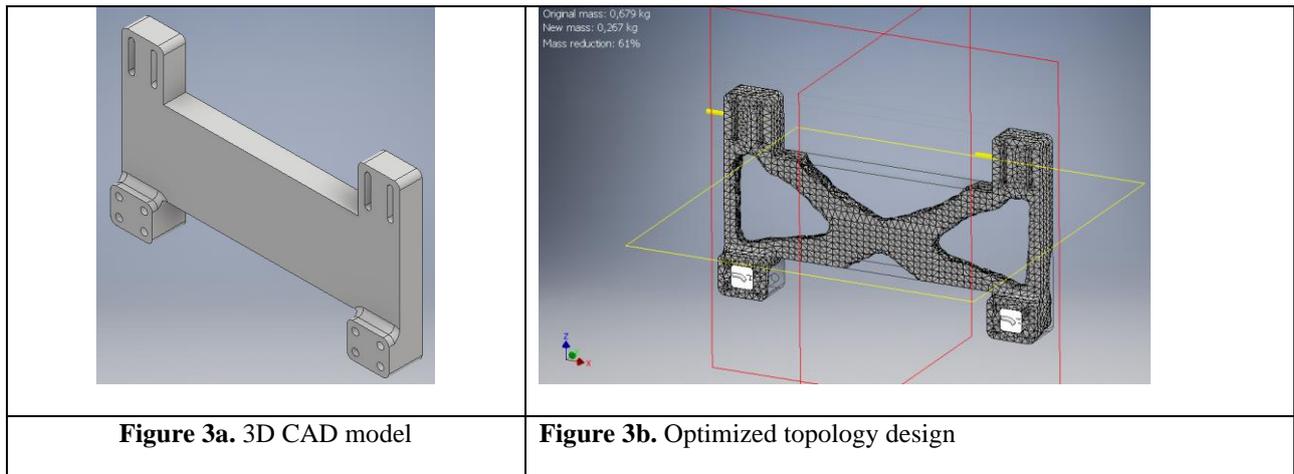
Figure 3a. 3D CAD model	**Figure 3b.** Optimized topology design
Figure 3. 3D CAD model and optimized topology design model	
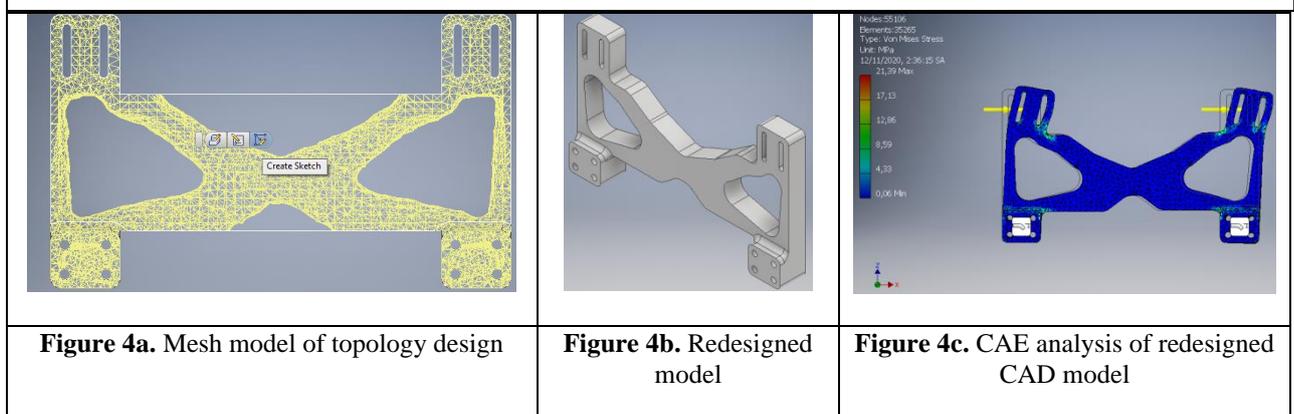
Figure 4a. Mesh model of topology design	**Figure 4b.** Redesigned model	**Figure 4c.** CAE analysis of redesigned CAD model
Figure 4. Redesigned CAD model of proposed product		

Step 5: Meshing in Mesh Setting
Step 6: Run Simulate analysis

Results obtained after the stress test as shown in Figure 4c.

Product prototyping using FDM technology

Model CAD model after being designed with Autodesk Inventor software and exported to file with STL format, with support from MeshLab software only fixes common errors in STL file format, the sample will be layered and set parameters thanks to CURA software. From this software, we obtain a G-code file to load into the 3D printer to print the product. Based on previous studies [10-14] on the mechanical strength of this study, we have the following factors that have a direct impact on the objectives of the study including:

• Construction/extrusion direction: is the direction showing the development direction of the sample through each material layer.
• Print speed: is the moving speed of the extruder (60 mm/s).
• Extrusion temperature: is the temperature of the extrusion head (210°C).
• Layer thickness: is the thickness of a printed material layer (0.1 mm).
• Fill rate: is the rate of inner filling that makes up the void.
• Fill type: is the internal grid structure that makes up the pattern as described in Figure 5.
• Raster angle: it is the angle merged by the direction of filling inside the product with the x-axis in the horizontal plane.
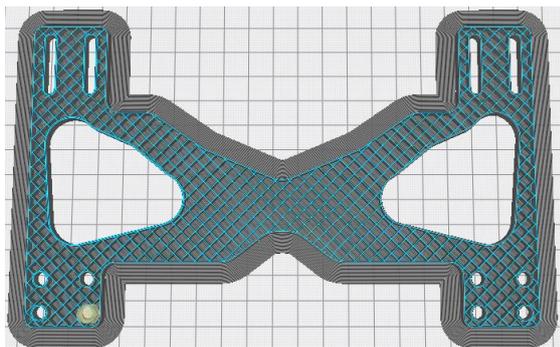
Figure 5. Pattern model in Ultimaker CURA software for 3D printing

Sand casting simulation based on CAE software

Sand casting is one of the most popular casting processes as it is used to manufacture a wide variety of parts from simple gears and pulleys to complex components like automotive engines. This process uses a sand mold that is used to form metal parts called casting, which can be made of almost any alloy. The metal is melted and poured into a mold cavity: There are no defects in the furnace and then poured into the cavity of the sand mold. Once the object has solidified, it is removed from the sand mold. Gravity sand casting has few restrictions on size, shape and weight, with low text and material costs. However, it is often less precise than die casting. The inlet port system deals with all the details relating to the flow of molten metal from the pot to the pot cavity. The various factors that come with the charging port system are pouring basin, sprue base wall, runner, runner extension system, input gate, sprue well, down sprue.

Step 1: Set up the force casting simulation: there are 5 basic steps to setup the simulation: Determination of gong on input gate; Determine the parameters; Run the analysis. The components are core, chiller, riser, sleeves, overflow, molding, cooler, filter, short sleeve, and crucible.

Step 2: Select materials

Step 3: Preprocessing parameters setup

By clicking on the preprocessing parameter, we can set the initial velocity, filling time. The filling time is nothing but the time required to cast the product. Casting efficiency is often affected by 2 scenarios.

- Slow Filling: If the head filling velocity is very low, it leads to cold shuts and misruns. Slow filling is avoided because it pre-solidifies in thin sections before completing the filling process.

- Fast Filling: fast filling is monitored by surface instability. Optimal fill time lies between the slow and fast omen. It also depends on factors such as metal casting, weight, pouring temperature, and minimum area.

Step 4: 3D FDM product casting implementation
Requiring pouring metal during gravity casting as well as other processes: avoid turbulent flow when pouring. If possible, we do filling product from bottom to top to avoid tangling and free fall of liquid. We use gravity option for sand casting. Gravity sand casting has some limitations on size, shape, and weight with low material and sample cost. Sand casting uses materials such as stainless steel, carbon steel, cast iron, etc. After importing the CAD model as *.part file, we set the material for the casting. In this study, A7075 Aluminum material is used and a yield point of 1044.14 K is set for the simulation. The typical parameters for the A7075 aluminum material are defaults. Set the gravity field for simulation. This is of utmost importance in sand molding, where the flow of metal fills the mold by gravity. Use the Add/Edit input gate option to design virtual load ports. Once we locate the inlet port, we need to design the sprue system. This is an excellent tool for analyzing the pour system out of turbulent flow, creating a lot of air bubbles that move through the mold. Next, we design silicon-sand cores for some small hole and groove parts.

The initial setup process for gravity casting: there are different options for setting up using basic parameters:

- Initial speed: determine the speed at the pre-determined inlet port. In process of sand-casting, we input velocity tends to be about $0.5 \div 1.0$ m/s. If we do not know which value, use the same value and then check the solidification on the first fill to determine the correct velocity (no premature solidification occurs).

- Fill Time: Use this option if you have calculated the exact fill time required for the casting process. The unit is the second. To calculate the exact time required for the casting process. The program converts internally the filling time into input velocity. During the experiment, we set the metal pouring time to 30 seconds. The temperature of molten aluminum metal is 850℃.

- Spoon Height (Spoon Height): flow depends on the defined area at the input port. You can also choose the ladle pouring height (mm) relative to the mold. Spoon height is the distance between spoon and mold when liquid is pouring. If we do not know this value, we use a value between 10-30 mm.

- Flow rate: is the volume of metal poured divided by the time of filling (unit: seconds). This parameter can be calculated using automatic ladles, bottom ladles, or stop-and-rod ladles, etc.

The results of CAE casting simulation is described in Figures 6 and 7.
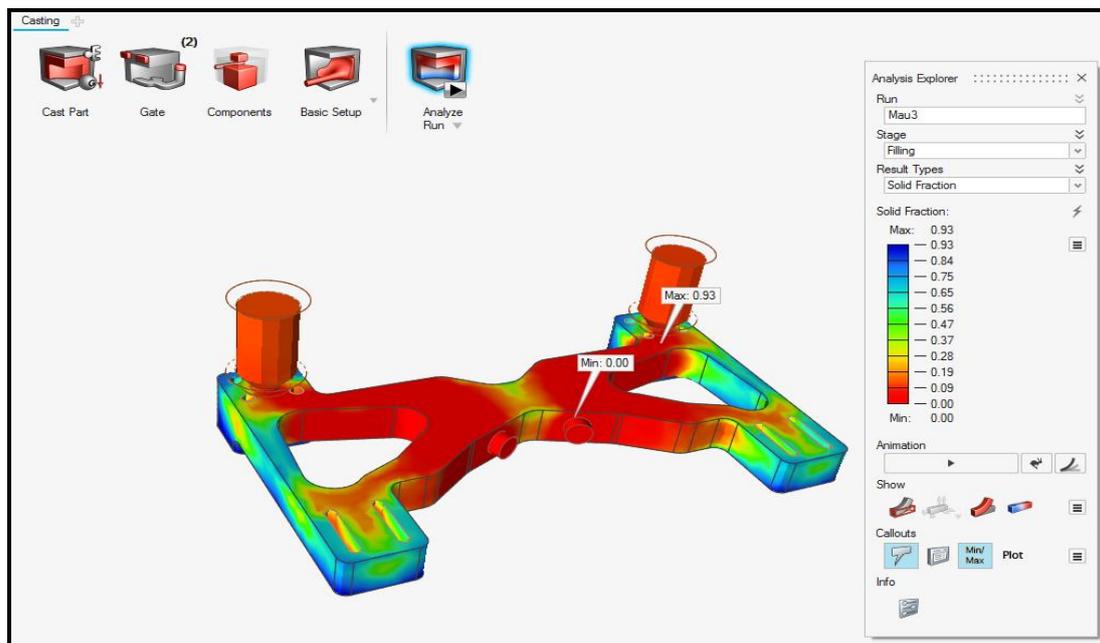
Figure 6. CAE simulation of solid fraction at the stage of filling
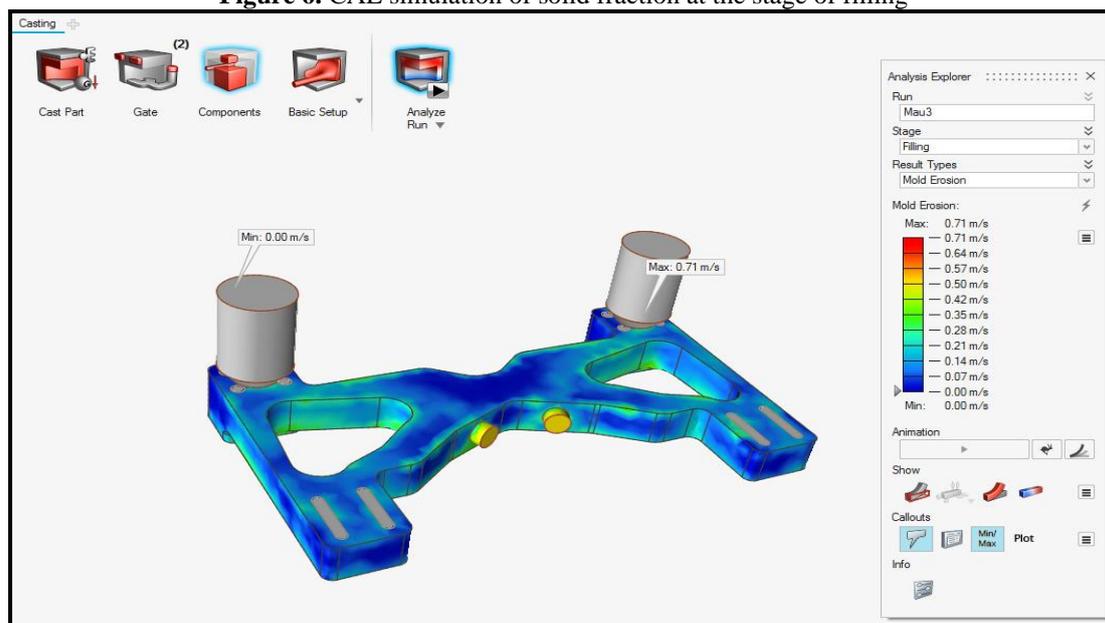
Figure 7. CAE simulation of mold erosion at the stage of filling

Sand casting experiment

Casting is the process of creating a workpiece by fusing metal, then pouring molten metal into a mold with the size and shape of the object to be cast. After the liquid metal solidifies in the mold cavity, we open the mold to obtain casting part. We have done the casting experiment with the following steps:

Step 1: Learn the sample set, the set of molds, filling system, steam bean, bean sprout, wood sample plate.

Step 2: Make the mixture to make the mold

Step 3: Place the lower part of the FDM 3D printed sample and the runner pattern (if any) on the wood plate.

Step 4: Apply anti-stick powder to the sample and wood plate

Step 5: Sift the mold-making mixture (sand coat) into the mold box and gently press the mixture with your hands to shape the casted object.

Step 6: Add cushion sand to the mold box layer by layer and compact, to secure the mold, the last layer must be leveled.

Step 7: Turn the lower mold case upside down, insert the upper part of the sample to complete the sample set (apply to the sample set with stool only).

Step 8: Assemble the sample and the upper mold case, place the filling tube, sprue and repeat steps 4 to 6 to create the above mold.

Step 9: Create a pouring cup at the pouring tube. Use a spreader to create a pouring cup at the pouring tube.

Step 10: Separate the top and bottom mold boxes to remove the sample, remove the pouring cup, remove the sprue and create a metal flow channel into the mold cavity (Figures 8a and b).

Step 11: Create a metal groove liquid into the mold cavity, then use the tool to take the sample out.

Step 12: Use heat to dry the mold, the intestines (if any) help increase the durability of the mold and reduce the moisture content of the mold, then install the intestine and install the mold to wait for liquid metal pouring.

Step 13: Melting aluminum alloy.

Step 14: Pour liquid metal into the mold continuously at the right speed (Figure 8c), when you see liquid metal rise to the spot, stop pouring, note that if pouring too slowly, the metal will not be able to fill the crystallized mold. If pouring is too fast, it will erode the mold.

Step 15: Wait for the liquid metal to fully solidify, which will break the mold (Figure 8d) to get the product in Figures 8e and 8f.

After cutting the extra parts, cleaning the surface, we achieve a final product with the product's shape and size as the product made by FDM 3D printing technology.

Figure 8a: Above mold	Figure 8b: Below mold	Figure 8c: Pouring
Figure 8d: Break the mold	Figure 8e: Part after casting	Figure 8f: Finished part
Figure 8. Sand casting of 3D printed product from FDM technology		

5. Conclusions

Sand casting is an economical way to manufacture complex parts. Wood product was used as a sample for sand molding of small and medium production have a relatively long working time and high cost. The application of rapid prototyping technology to the fabrication of prototypes can significantly reduce the cost and execution time associated with the production of single, small or medium volume products. In the past, this technology was used to develop prototypes of products. Currently, the research involves making prototypes using the rapid prototyping technique based on the FDM method and sand molding casting. A specific product is designed and optimized with the Shape Generator tool of Autodesk Inventor software. Redesigned the product after optimized topology is implemented for perfection. The CAD design model is then exported to STL file, the cut layers and parameters are set via Ultimaker CURA software. Finally, the CAD model is printed via a G-code file from a 3D printer using the FDM method. CAE simulation for sand molding is conducted to minimize possible defects and efficiency of the casting process. Material for sand molding is 99.98% clean aluminum. As a result, a finished product has the same shape and size as the part made by FDM method. This research has outlined the development process of rapid prototyping technology in general and FDM rapid prototyping method in particular in the context of laboratory. Especially, the application of FDM technology in sand molding process is implemented in the practice of laboratory. Several works performed and completed in this study are as follows.

- Research overview and apply FDM rapid prototyping technology for sand casting.
- Proposing a framework to integrate rapid prototyping technique and sand mold casting process based on the optimized product topology.
- Understand, apply, analyze and evaluate the topology optimization with the Shape Generator tool of Autodesk Inventor software.
- Simulation for sand molding process by CAD/CAE technique to predict casting defects, improve efficiency, etc.
- Experiment on casting in sand mold for proposed products and compare shape and size with products manufactured by FDM approach.

Metal 3D printing technology has not been paid attention and the transfer of technology, and personnel training in this field in Vietnam are still limited. Sand castings give low quality products. Thus, it is necessary to carry out the implementation of complex 3D part design from FDM technology based on 3D physical model scanning technique and using other materials such as cast iron, copper, etc. to cast in sand mold as future research directions. In addition, it is possible to apply casting method in metal molds to improve surface quality for cast products.

References

[1] Gebisa, A.W. and H.G. Lemu, *A case study on topology optimized design for additive manufacturing.* IOP Conference Series: Materials Science and Engineering, 2017. **276**: p. 012026.

[2] Aliyi, A.M. and H.G. Lemu, *Case study on topology optimized design for additive manufacturing.* IOP Conference Series: Materials Science and Engineering, 2019. **659**: p. 012020.

[3] Martin, L. and S. Kedziora, *Design of Automotive Road Racing Rim with Aid of Topology Optimization.* 2016, Faculty of Science, Technology and Communication University of Luxembourg.

[4] Rezaie, R., Badrossamay M., Ghaie A., Moosavi H., *Topology Optimization for Fused Deposition Modeling Process.* Procedia CIRP, 2013. **6**: p. 521-526.

[5] Zegard, T., Paulino, G.H., *Bridging topology optimization and additive manufacturing.* Struct Multidisc Optim, 2016. **53**(1): p. 175-192.

[6] Ranjan, R., R. Samant, and S. Anand, *Integration of Design for Manufacturing Methods With Topology Optimization in Additive Manufacturing.* Journal of Manufacturing Science and Engineering, 2017. **139**(6).

[7] Doubrovski Z., Verlinden J.C., and Geraedts J.M.P., *Optimal Design for Additive Manufacturing: Opportunities and Challenges*, in Proceedings of the ASME 2011 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, 2011, pp. 635-646.

[8] Liu, J., Gaynor, A. T., Chen, S., Kang, Z., Suresh, K., Takezawa, A., Li, L., Kato, J., Tang, J., Wang, C. C. L., Cheng, L., Liang, X., and To, A. C., *Current and future trends in topology optimization for additive manufacturing.* Structural and Multidisciplinary Optimization, 2018. **57**(6): p. 2457-2483.

[9] Tyflopoulos E., Tollnes, Flem D., Steinert M., Olsen A., *State of the art of generative design and topology optimization and potential research needs.* Proceedings of NordDesign 2018, Linköping, Sweden, 14th - 17th August 2018.

[10] Huynh, H.N., Nguyen, A., Ha, N.L., & Thai, T.T. (2017). *Application of fuzzy Taguchi method to improve the dimensional accuracy of Fused Deposition Modeling processed product.* 2017 International Conference on System Science and Engineering (ICSSE), 107-112..

[11] Huynh, N., Tran, T., Nguyen, T., & Thai, H. (2017). *Optimizing process parameters to improve the compressive strength of FDM products (Fused Deposition Modeling)*. Science and Technology Development Journal, **20**(K5), 37-43.

[12] Huu, N.H., Toan, D.T., Huu, T.N., & Thu, H.T. (2018). *Effects of Infill, Infill Patterns and Number of Perimeter Shells on Casting Patterns Fabricated Using FDM Method*. 2018 4th International Conference on Green Technology and Sustainable Development (GTSD), 207-212.

[13] Huynh, H. N., Bui, T. H., Thai, T. T. H., & Nguyen, H. T., *Research on the Effect of Technical Attributes on the Tensile Strength of FDM Products*. Key Engineering Materials, 2020, **863**: p.33-50.

[14] Tho, N.H., T.C. Minh, and N.P. Tai, *The effect of infill pattern, infill density, printing speed and temperature on the additive manufacturing process based on the FDM technology for the hook-shaped components*. POLIMESIN Journal, 2020. **18**(1): p. 1-6.