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Research Article

3D Yazıcıların Termal Verimliliğini Artırmak için Yeni Ekstrüder Isı Bloğu Tasarımları

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Öz

3 boyutlu yazıcılar eklemeli imalat teknolojisinin en yaygın ve popular methodudur ve termal etkileri kullanarak malzemelerin füzyonunu sağlarlar. Bu fenomen sıcaklığı baskı kalitesini etkileyen en önemli faktör haline getirir. Sıcaklık ektrüderdeki alüminyum ekstrüder ısı bloğu tarafından sağlanır ve sıcaklık rejimi baskı malzemesinin tipine göre sabit olmalıdır. Bu çalışmanın amacı, sıcaklık rejimini sabit tutmak için ısıl verimi yüksek alüminyum ekstrüder ısı bloğu tasarımları yapmak ve yeni tasarımların ısıl davranışını ANSYS simülasyonu kullanarak ticari bir ürün bloğu tasarımı ile analiz etmektir. Blokların malzemeleri aynı seçilmiş ve sınır koşulları belirlenerek blokların sıcaklık dağılımı ve ortalama ısı akısı hesaplanmıştır. Simülasyondan elde edilen sonuçlar, ticari bir ürün bloğunun termal davranışı ile karşılaştırıldığında tatmin edicidir.

Anahtar Kelimeler: Ekstrüder ısı bloğu, Isı akısı, 3 boyutlu yazıcı, ANSYS.

Novel Extruder Heat Block Designs to Improve the Thermal Efficiency of 3D Printers

Abstract

3D printers are the most common and popular method of additive manufacturing technology and provide fusion of materials using thermal effects. This phenomenon makes that temperature the most important factor affecting printing quality. The temperature is provided by the Aluminium Extruder Heat Block in the extruder and the temperature regime must be constant according to the type of printing material. The objective of this study is to make aluminium Extruder Heat Block designs with high thermal efficiency to keep the temperature regime constant and to analyse the thermal behaviour of new designs with a commercial product block design using ANSYS simulation. The materials of the blocks were chosen the same and the temperature distribution of the blocks and the average heat flux were calculated by determining the boundary conditions. The results obtained from the simulation are satisfactory when compared with the thermal behaviour of a commercial product block.

Keywords: Extruder heat block, Heat flux, 3D printer, ANSYS.

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1. Introduction

In the last 30 years, the Additive Manufacturing (AM) method has developed rapidly and has been used in production processes from rapid prototype to the production of functional parts (Demir & Coşgun, 2019; Turner et al., 2014; Turner & Gold, 2015; Wong & Hernandez, 2012). AM method has become popular in the last 7 years with the rapid decrease in cost of it (Cojuhari et al., 2017). With some companies producing affordable 3D printers, AM has become one of the today's production methods. One of the most researched topics in AM is Fused Deposition Modeling (FDM) (Coppola et al., 2018). FDM methods with 3D printers have been used in many areas such as aviation, medicine, education, military industry, etc (Vukicevic et al., 2017). Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA) are used as standard materials in AM and academic research continues to develop for new materials (Enrique & Vega-rios, 2019; Gregor-Svetec et al., 2020; Kariz et al., 2018; Singh et al., 2019).

In 3D printers, the mechanical structure and printing quality of the printed item are affected by parameters which are design of the part, printing speed, extruder temperature, etc. (Chacón et al., 2017; Dizon et al., 2018; Song et al., 2017). Since fusion of the material is required in the printing of objects, some studies have focused on the melting model and the flow of molten material (Comminal et al., 2018; McIlroy & Olmsted, 2017; Osswald et al., 2018; Peng et al., 2018). However, few authors have investigated the effect of printing temperature required for fusion (Abbott et al., 2018; Yang et al., 2017).

In 3D printer, the extruder is the core of the printer. As shown in Fig. 1, the extruder consists of nozzle, aluminum heat block, heated liquefier and filament feed. Extruder temperature generally does not have a major effect on the mechanical performance of the print object, but increasing temperature causes an increment in tensile strength and contact length (Abbott et al., 2018). In additive manufacturing, layers combine with each other to form objects and the combination of these layers is directly related to the extruder temperature (Bellehumeur et al., 2004). Extruder temperature affects the crystal structure of the material, creating an incomplete fusion process. Fluctuations in temperature adversely affect the fusion process (Yang et al., 2017). In addition, heat losses on the Aluminum Extruder Heat Block (AEHB) cause fluctuations in the extruder temperature and increase energy consumption. Therefore, it is very important to control the extruder temperature with high precision (Cojuhari et al., 2017).

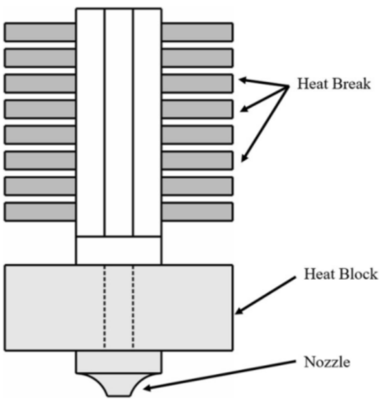

Figure 1. Extruder (Shah et al., 2019).

The distortions in printing quality caused by fluctuations in extruder temperature are shown in Fig. 2. Fig. 2a shows Curling or Rough Corners fault. This fault is caused by the extruder overheating or the printing material not cooling fast enough. The fault that occurred in Fig. 2b is Overheating. In this case, it is necessary to work at the correct balance between temperature and cooling. The effects of extruder temperature on printing quality are great and for a high quality printing, control of extruder temperature should be done well (Print Quality Guide, 2020).

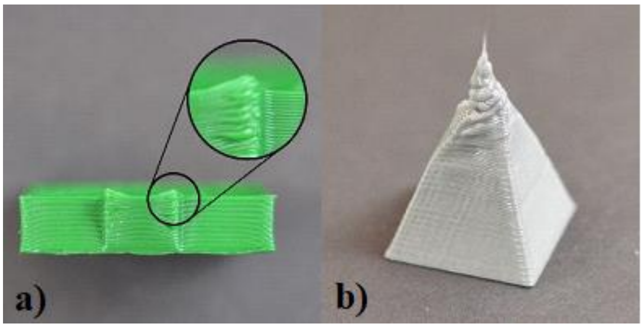

Figure 2. a) Curling or Rough Corners, b) Overheating (Print Quality Guide, 2020).

The aim of this study is to make thermal analysis by making different AEHB designs. Extruder temperature has a great effect on Fused Deposition Modeling (FDM). The heating of the extruder is carried out by the aluminum heat block. In this study, thermal analysis of three AEHB models was performed. One of the designs is the extruder heat block of a commercially available (Leapfrog creatr HS) 3D printer. Thus, two aluminum block designs were considered and thermal analysis of a commercial product was compared with two aluminum block designs because there is no study on AEHB thermal efficiency in the literature. Surface areas, average and total heat flux of the designs are calculated. The technological contribution of this study is to reduce heat losses on the extruder, prevent energy losses and increase printing quality. As a result of the thermal analysis, the parameters of the three models were compared and the design that caused the least heat loss was found.

2. Numerical Modelling of the Thermal Problem

The 2nd Law of Thermodynamics states that if there are two environments with a temperature difference between them, the heat will pass from the high temperature environment to the low temperature environment. The energy transition caused by the temperature difference between the two systems is defined as heat transfer. Heat can be transferred in three different ways: conduction, convection and radiation.

The heat transfer that occurs between a solid surface and the fluid in motion is called convection. Convection is divided into two categories according to flow type: forced convection and natural convection. In forced convection, fluid motion is caused by external factors such as a fan or pump. On the contrary, there is no fluid motion in natural convection. Forced convection and natural convection are shown in Fig. 3.

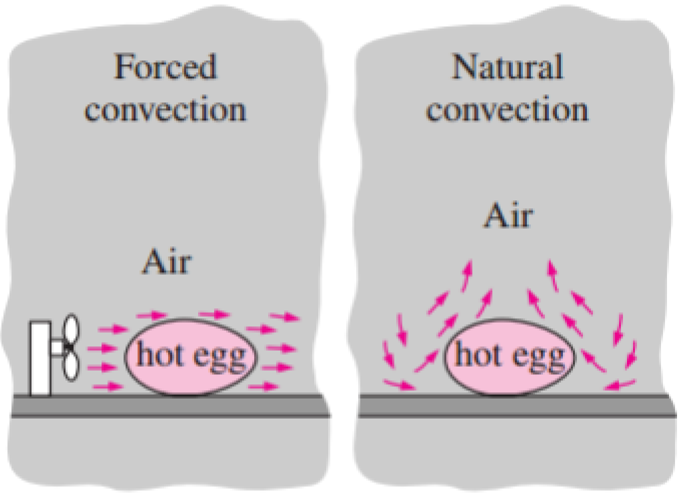

Figure 3. Forced convection and natural convection (Çengel & Ghajar, 2015).

In this paper, extruder models in an unforced air environment were created. Since there is no air flow, heat transfer occurs on the models by natural convection. The amount of heat transferred per unit time by convection is expressed as in Equation 1 with Newton's law of cooling.

$$\dot{Q} = h.A_s.(T_s - T_\infty) \quad (1)$$

Where, $\dot{Q}$: the heat flux (W), h: the convection heat transfer coefficient (W/m2.C), A: the surface area (m_2), T_s: surface temperature, T_∞: temperature of the fluid.

When Newton's law of cooling is examined for convective heat transfer, it is seen that cooling depends on the temperature difference, surface area and heat transfer coefficient. Temperature difference and surface area affect the amount of heat transferred in direct proportion. It is known that increasing the surface area will cause to increase convection and heat transfer. Based on this principle, fins are used in cooling systems.

The aim of this simulation is to prevent the cooling of the system. When the convection equation is examined, it is seen that the cooling can be reduced by reducing the surface area. Static thermal analyses were made based on the surface area and it was aimed to reduce the average heat flux.

3. Designs of Extruder Aluminium Heat Block

Generally, rectangular prism geometry of AEHB is used in conventional and commercial 3D printers. The rapid heating of the 3D printers and the stability of their temperature during manufacturing increase the print quality. Three different extruder heater blocks were used in the simulations. First, the AEHB of a commercial product leap frog creatr HS model 3D printer is modelled and Fig. 4 shown the extruder heater model, which we call the classic design.

Based on the classical design, 2 AEHBs were designed. In new AEHB designs, surfaces and endpoints are reduced because heat transfer occurs from surfaces. The material of the new designs has been chosen aluminium to be the same as the classical design. Thus, only the effect of surface and end points on heat transfer was examined. New extruder designs are given in Fig. 5.

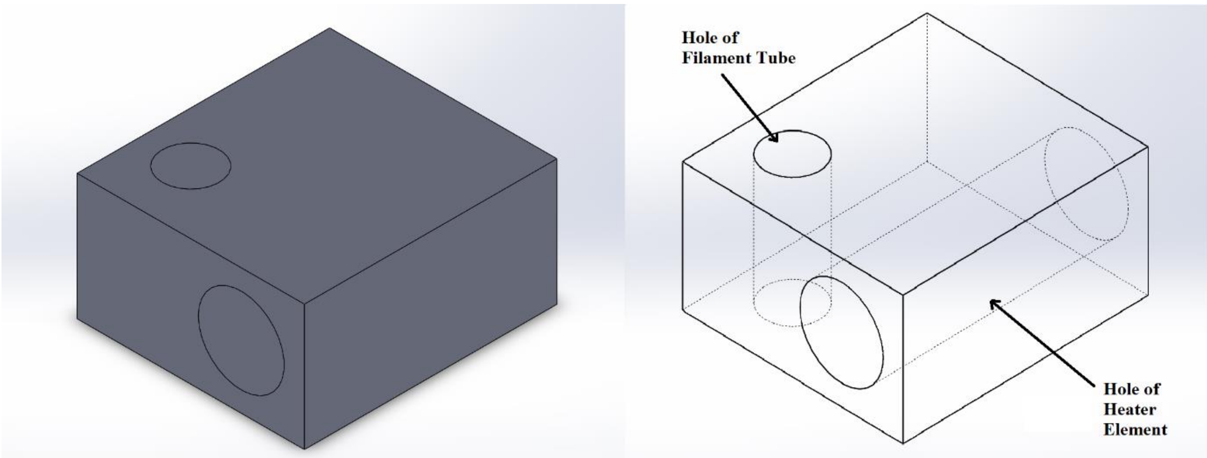

Figure 4. The classic design (extruder heater of leapfrog creatr HS 3D printer).

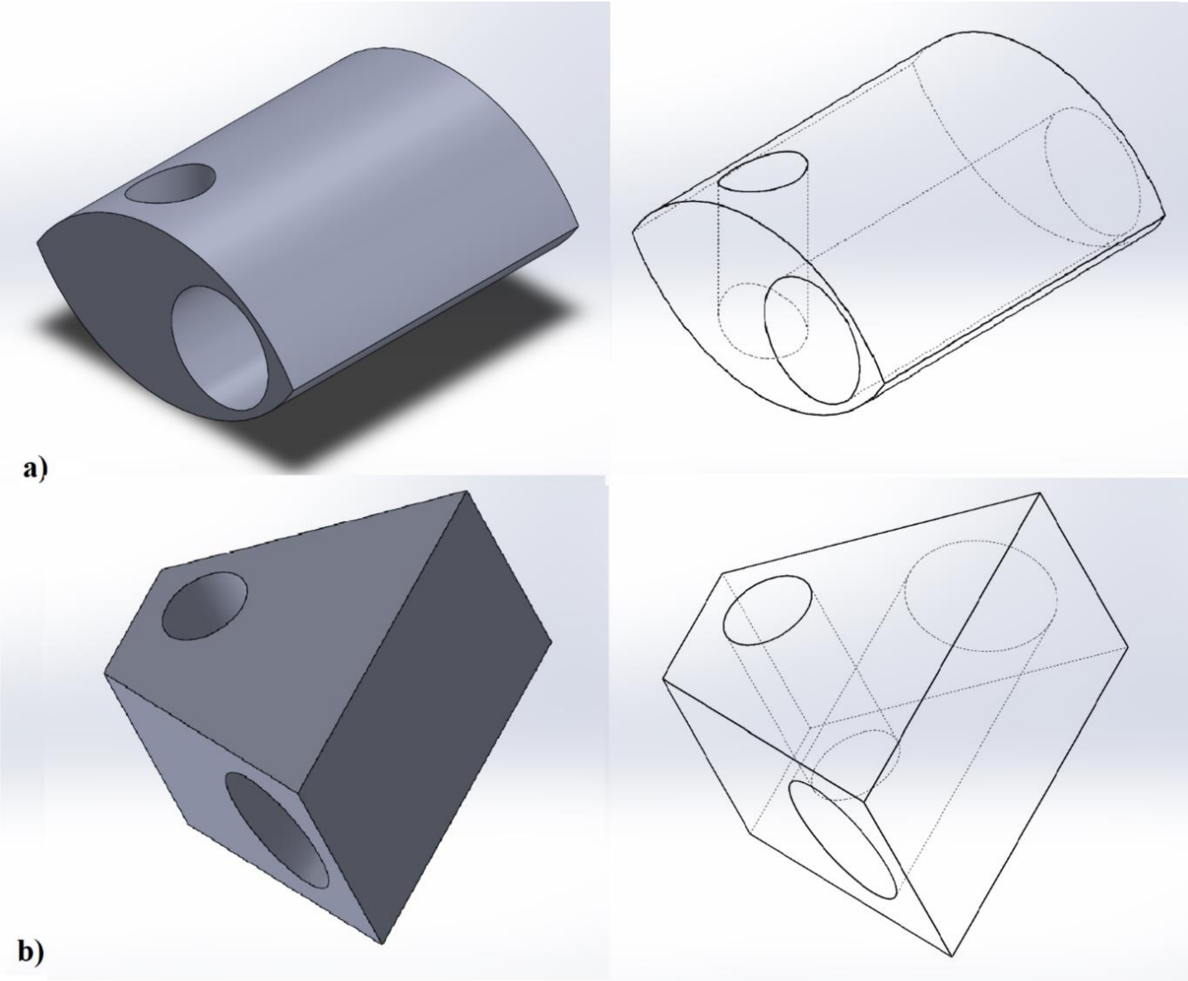

Figure 5. a) The design 1, b) The design 2.

4. Simulation of Finite Element Method

ANSYS is an engineering software program to solve the problem of strength, toughness, elasticity, deformations, heat transfer, fluid flow, electromagnetism, etc (Belhocine & Bouchetara, 2012; Çayıroğlu et al., 2017; Recebli et al., 2016; Selimli et al., 2015; Selimli & Recebli, 2018). Most users prefer to the ANSYS Workbench system for simulations. After the weight, temperature and other physical properties of an object is defined, analyses such as temperature distribution, fluid flow are performed using ANSYS software and engineering information related to the problem is obtained.

The material of the two AEHB models has been selected from aluminium, which is the same as the classic model. In this case, the static thermal analysis of the three blocks can be compared with each other. The isotropic thermal conductivity of the material used is given in Fig. 6.

Before starting the simulation, the mesh of the designs was produced using the ANSYS ICEM CFG module. The purpose of mesh is to separate into small parts of a complex volume to easy simulate. Mesh is a network of elements and nodes. It can have almost any shape in any size. Mesh quality is very important for the reliability of the results. In the simulation, three different mesh structures are used: default, skewness and orthogonal quality mesh. Default meshing of the models is shown in Fig. 9. The number of elements and nodes forming each meshing is given in Table 1.

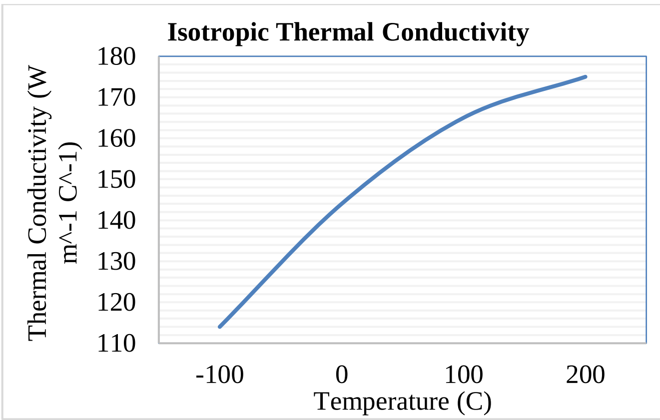

Figure 6. The isotropic thermal conductivity of aluminium.

The skewness is the difference between a cell shape and the shape of an equilateral cell of equal volume. The cells with high skewness affect the solution by reducing the accuracy. Fig. 7 is given the skewness mesh metrics spectrum. Spectrum is rated between 1 and 0. The values approaching 1 refer to the cells with high skewness and values close to 0 refer the density of cells with low skewness.

Figure 7. Skewness mesh metrics spectrum (Gök & Gök, 2020).

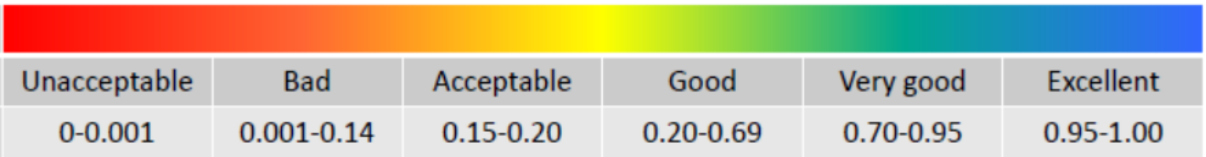

Figure 8. Orthogonal quality mesh metrics spectrum (Gök & Gök, 2020).

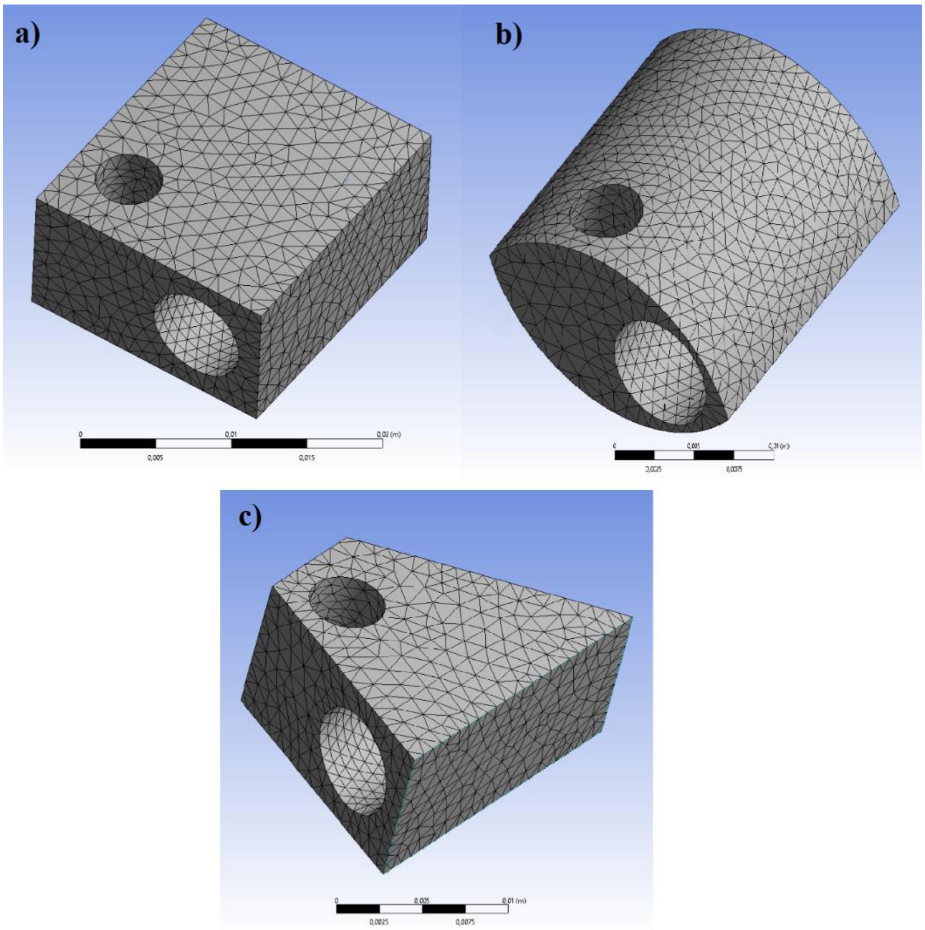

Figure 9. Default meshing of a) the classic model, b) the design 1 and c) the design 2.

Table 1. Number of elements of extruder heaters meshes.

	Default mesh		**Skewness mesh**		**Orthogonal Quality mesh**	
	The elements	**The nodes**	**The elements**	**The nodes**	**The elements**	**The nodes**
The classic model	10020	16951	10053	16957	5078	8851
The design 1	9439	16430	9463	16463	9463	16463
The design 2	7094	12307	7164	12373	7164	12373

The orthogonal quality defines as the angle between the vector connecting the centres of adjacent cells and the normal vector. The orthogonality is scaled from 0 to 1 as shown in Fig. 8. In the spectrum it is seen that the value of 1 is excellent and the values approaching zero, is the unacceptable.

The heater cartridge controlled by the control card is placed in the slot on the left side of AEHB and it is expected to keep the extruder heater at a certain temperature. In the simulation, this temperature was determined as 260 º C. The temperature of the environment where the extruder works is set to 22 º C. Static thermal analysis of the extruder heater under constant temperature will be carried out. There are two boundary conditions in this study:

- There is no air flow in the working environment of the extruder and the ambient temperature is 22º C.
- Extruder temperature is 260º C (for ABS material, it is 3D printer temperature).

5. Results and Discussion

The average heat flux in the extruder aluminium heat block will be carried out by taking account of designs. When the natural convection function is examined, it is seen that the temperature difference and the surface area increase the heat transfer as well as the thermal properties of the material. The temperature regime of the extruder heater block must be maintained when the 3D printer reaches its operating temperature. Therefore, heat losses should be reduced the temperature of the extruder heater block. In this study, two new designs were created by changing the geometric structure of the AEHB in order to reduce heat losses. Surface areas have been reduced and surface temperatures have been changed by changing surface geometries. In this case, the heat flux over the block to the environment has been changed.

Fig. 10, Fig. 11 and Fig. 12 show the temperature variation for model and designs of the extruder blocks with each mesh. We also note that the temperature decreases in the direction of left plane to reach its minimal value for all meshes. Since the heater cartridge is placed in the hole on the right side of the AEHB, the temperature around this hole appears to be high. Considering the temperature distributions, it is seen that the temperature is low due to the high heat transfer on cold surfaces. In design 2, it is seen that the temperatures on the surfaces are lower than design 1 due to the intensity of cooling. As a result of rapid cooling, the extruder temperature decreases and thermal stability deteriorates. Depend on this result, the amount of energy consumed for heating increases. In addition, the fact that the volume to be heated is less in design 2 compared to other blocks, which reduces heat transfer.

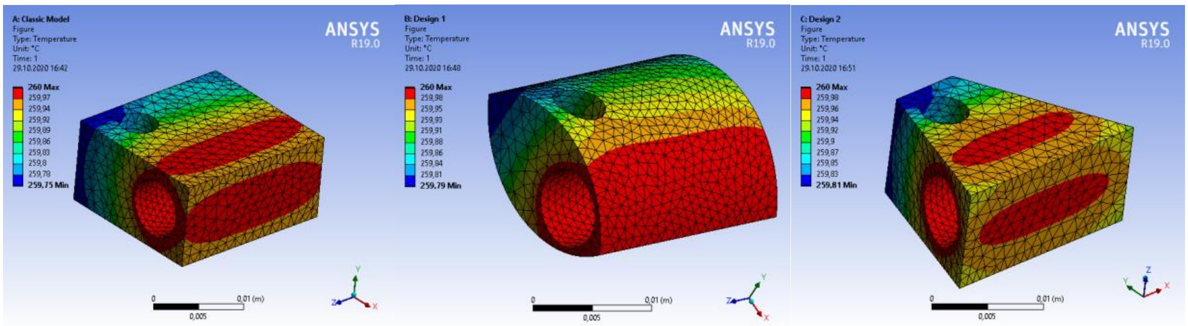

Figure 10. Temperature variation with default mesh for three extruder blocks.

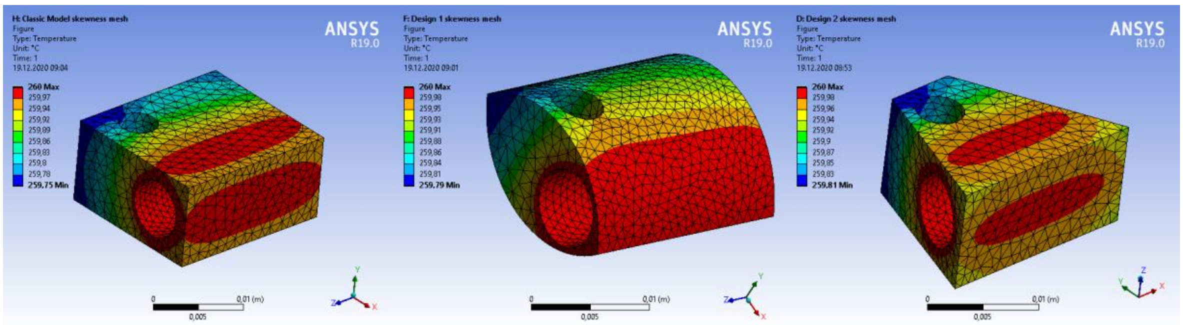

Figure 11. Temperature variation with skewness mesh for three extruder blocks.

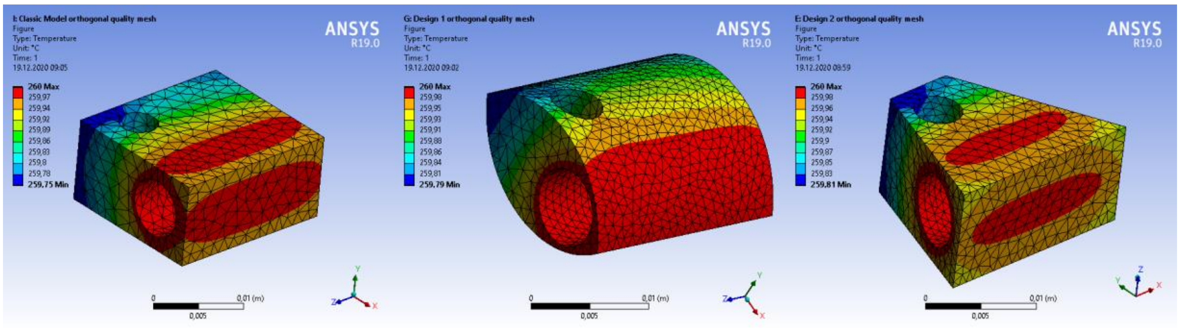

Figure 12. Temperature variation with orthogonal quality mesh for three extruder blocks.

Fig. 13, Fig. 14 and Fig. 15 show the total heat flux obtained as a result of the analysis of three blocks with each mesh. Considering the distribution of the total heat flux on the blocks, it is seen that the heat flux is less on the surfaces in design 1. In design 1, reducing the corner points prevents heat losses. In Fig. 16, the surface areas of the models and the average heat flux are given in a single graph. The design with the least surface area is the second design, but the average heat flux of the first design is the lowest. The reason for this is that the heat in the core is closer to the cold surfaces due to the lower mass of the second design. In design 1, the temperature is maintained in the core as well as kept away from the cold outside environment. In addition, the number of corner points was reduced in the first design, as a result, heat transfer is reduced.

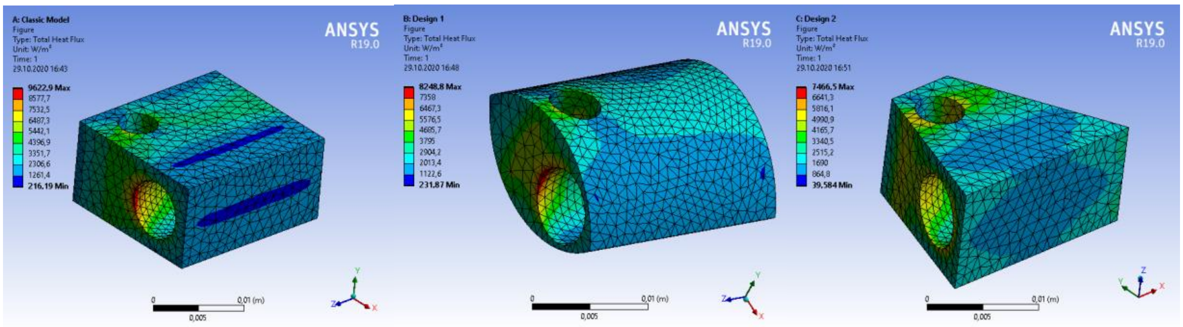

Figure 13. The total heat flux of the three models with default mesh.

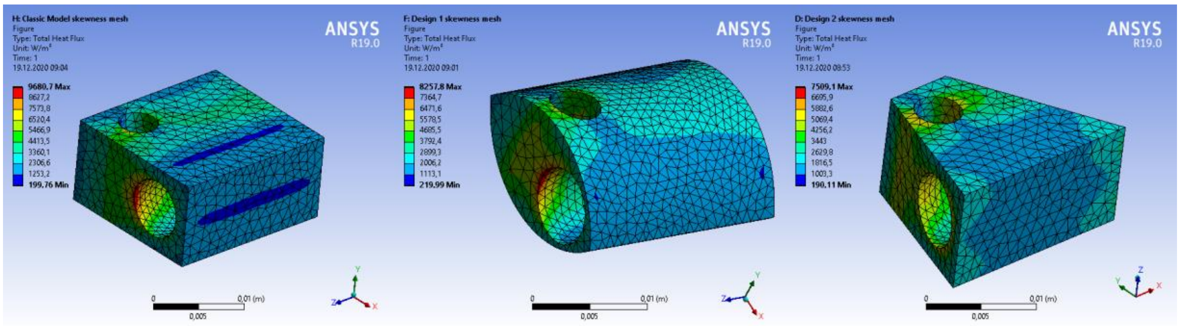

Figure 14. The total heat flux of the three models with skewness mesh.

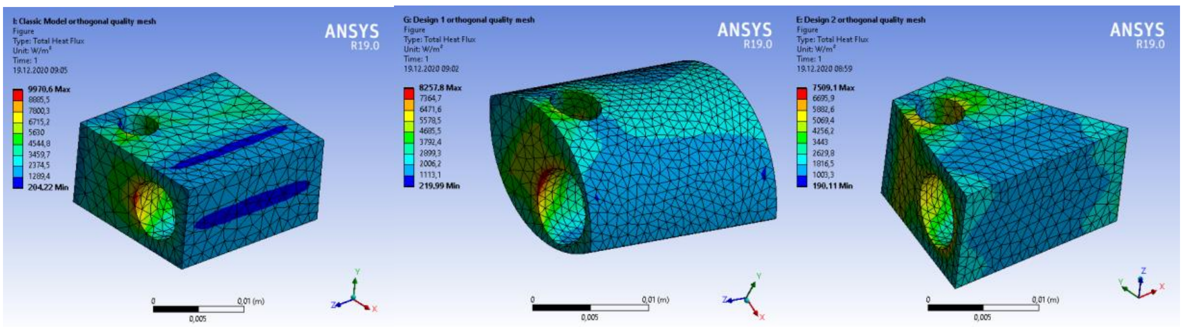

Figure 15. The total heat flux of the three models with orthogonal quality mesh.

In the graphic in Fig. 16, the analysis results obtained for each mesh structure and the surface areas of the blocks are given together. Table 2 shows numerical results for analysis and average values for skewness and orthogonal quality mesh structure. When Table 2 and Fig. 16 are evaluated together, it is seen that the result does not change much in different mesh types for design 1 and 2. The classic model gave different results in different mesh structures. The best result was given in orthogonal quality mesh structure, but the average value was found to be 0,67735. When the average value of skewness (0,28612) and orthognal quality mesh structures are evaluated with the spectrum in Fig. 7 and 8, it is found that the average value of skewness is closer to excellent. The best analysis result for the classic model was obtained with the skewness mesh structure. It was found that design 1 has an average heat transfer rate of 16,51% less and design 2 has an average heat transfer rate of 8,06% than the conventional AEHB. As a conclusion of the numeric simulation, it is seen that design 1 has the best thermal efficiency. In addition, both new designs were found to have better average heat flux than conventionally used AEHB.

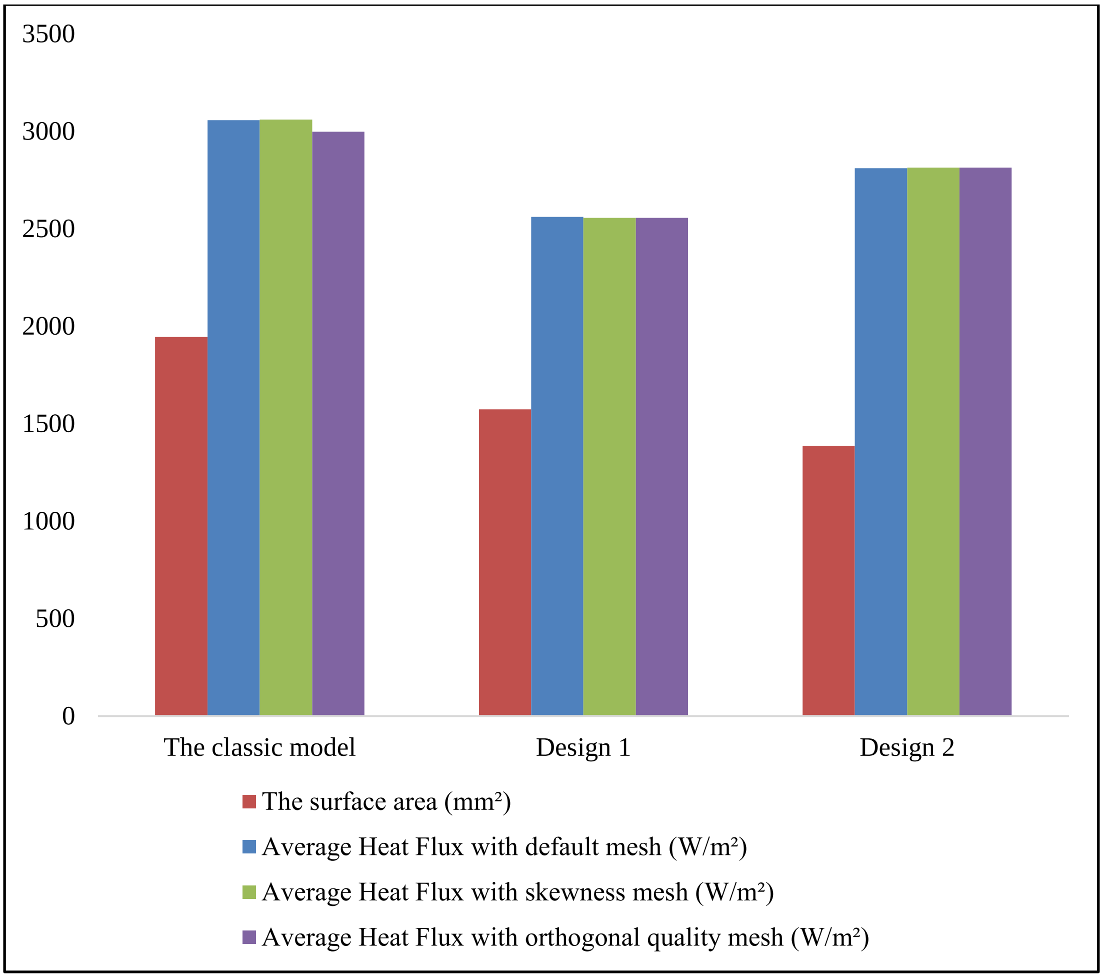

Figure 16. The surface area and the average heat flux for three blocks.

Table 2. The average heat flux (W/m2) for three blocks with three different mesh structures.

	Default mesh	**Skewness mesh / an average value**	**Orthogonal Quality mesh / an average value**
The classic model	3057,2	3061 / 0,28612	2998,3 / 0,67735
The design 1	2561,2	2555,6 / 0,28659	2555,6 / 0,71228
The design 2	2810,4	2814 / 0,2936	2814 / 0,70523

6. Conclusion

In this study, a numerical simulation of the thermal behaviour of AEHB designs was presented. By means the computer code ANSYS 19 was able to study the thermal behaviour of three AEHB. The effect of geometric shape on average heat flux has been investigated. Thermal behaviours of two designs created in new geometries and thermal behaviour of conventional model were compared. The numerical simulation shows that geometric shape plays a very significant role in the average heat flux. It has been observed that thermal efficiency can be increased by 16,51 percent for design 1 and 8,06 percent for design 2 just by changing the geometric shape. The obtained results are very useful for rising the print quality by increasing the thermal stability of 3D printers.

The results obtained from the simulation show that the thermal efficiency of the new AEHB designs is high. The thermal analysis of AEHB used in a commercial product and the designs were compared and new designs were found to be more efficient. AEHB designs with high thermal stability will increase the printing quality of 3D printer technology and take it one step further.

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