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Thermal Analysis on Transformer In Substation: Transformer Material Selection

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Abstract A transformer substation is an electrical system that includes switchgear as well as distribution and transmission line terminations. Transformer substations convert voltage from high to low or possibly even better. The thermal performance of power substations is a major topic, especially for distribution networks. The heat produced by the transformer operation elevates the temperature of the transformer's internal structures. More efficient transformers have a lower temperature rise, whereas less efficient units have a higher temperature rise. One of the main sources of damage is heat damage to the transformer windings during regular operation. Thermal method analysis, which is simulation software, SolidWorks was used to evaluate thermal performance. In this project, the simulation Solidworks is used to simulate the thermal analysis in rising temperature and heat flux by comparing two material cores, which are amorphous metal and amorphous steel. From this simulation, the result helps in choosing suitable material due to the thermal cause compared to the physical test that had a limitation on the thermal result. From the simulation between amorphous metal and amorphous steel, the result shows a maximum temperature is 60 ^{o}C. The heat flux results show an initial value reaching 6.00+04 W/m^2, and the thermal conductivity of metal and steel is increased to 60 ^{o}C due to the optimum temperature. From that result, amorphous metals are proposed as suitable material core transformers.

Keywords: Transformer Substation, Simulation, Heat, Temperature, Thermal

1. Introduction

1.1 Background study

A transformer substation is an electrical system that contains the distribution and transmission line terminations as well as switchgear. Transformer substations change the voltage from high to low or another way around. Electric electricity may pass through many transformer substations at higher

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voltage levels before being delivered. The problem with the substation transformer in electrical terms is called a fault. Transformer substations change the voltage from high to low or another way around, as well as perform a variety of other important tasks [1]. The temperature performance of the transformer's windings has a major effect on its life. Many transformer designers have currently estimated heat transfer to analyze winding temperature rise [2]. Transformers are highly efficient because they do not have any moving parts, but a very small air gap. When the core of different materials is used to increase the efficiency of transformers, core loss shows differences in energy efficiency. Energy efficiency is one of the important parameters of every electric machine. Efficiency is one of the important parameters of transformers like every electric machine [3]. The method of employing a thermal imager to detect radiation (heat) incoming from an object, convert it to temperature, and show an image of the temperature distribution is known as infrared thermography. Measurement is images of the measured temperature distribution that allow you to view thermal things that aren't apparent to the human eye [4]. Infrared thermography's major purpose is to test that machinery is functioning normally. It can detect abnormal heat patterns within a machine that indicate inefficiency and faults [5]. Cores composed of high-grade wrought iron were used in the first converters created in the 1880s, although Swedish iron was afterward chosen. However, in about 1900, it was discovered that adding a small amount of aluminum or silicon to the iron as an impurity reduced magnetic losses [6].

1.2 Problem statement

All electrical equipment generates waste heat as a result of its operation. Transformers are no exception. The heat created during transformer operation raises the temperature of the transformer's interior structures. More efficient transformers have a lower temperature rise, whilst less efficient units have a larger temperature rise. The heat damage of the transformer windings during normal operation is one of the main causes. Convectional heat transmission is the most important way of heat transfer. To avoid insulation issues, the hottest spot temperature must not exceed the prescribed limit situation on the operation process of transfer, the energy loss may exist in the core and winding, and it affects the operation efficiency, meanwhile, when the loss converts into heat, the transformer generates heat, and the winding and iron core are the main heat source. The effect of increasing temperature on operational reliability is found not only on transformers but also when operating power semiconductor devices. As an outcome, thermal method analysis is required to improve reliability. Simulation software is used to evaluate power transformer reliability. However, this method lacks information on power transformer modes and operating conditions, as well as the specification of sample items for testing. In this study, simulation is utilised to compare the heating process and magnetic flux between two material cores: amorphous steel and metal.

1.3 Objective

The objectives for this project are:

a) To study and compare the transformer material in a substation that contributes to the thermal problem.
b) To develop the simulation modeling for thermal analysis.
c) To propose the suitable transformer material based on the analysis result.

1.4 Scope of study

For this project, the scope will be focusing on:

a) This project is focused on transformer material that may cause thermal problem at the substation.
b) By using Solidworks software, simulation testing on the thermal process can be done to compare two materials which is amorphous metal and amorphous steel.

c) From the simulation and data manufacture, the difference such as heat transfer, heat flux and the location of the starter heat process can be compared and suitable material will be proposed based on the comparison.

2. Methodology

In this chapter, the process of completing the analysis of thermal substation distribution an appropriate plan was made to ensure that the project can be completed and implemented smoothly before any action is taken on to the project. This project's workflow included a list of which procedures needed to be completed first and which would take longer to complete. The project name, workflow system, and testing on the components utilised in this project will all be explained in further detail.

2.1 Transformer Selection

The selection of transformers was chosen based on the similarity of power used by Tenaga Nasional Berhad at the distribution substation. For transformer selection, a site visit to the industry at Malaysia Marine and Heavy engineering on 14 April 2022 was used to discover a transformer that was suited for this study. As a result of the site visit, a transformer in Figure 2.1, the 66kV/470V transformer, was selected for this study.

Figure 1: Transformer 66kv/470V

2.2 Details of transformer

Design of three-phase transformer of rating 3500KVA 6600/470 V by using parameters obtained from a site visit is shown in Table 1 and Table 2 for material amorphous steel and amorphous metal.

Table 1: Parameter for amorphous steel

Parameter	Specification
KVA rating	3500
Voltage rating	6600/470V
Maximum magnetic flux	1.1Wb/m
Window space factor (Kw)	0.273
Stacking factor	0.9

Table 2: Parameter for amorphous metal

Parameter	Specification

KVA rating	3500
Voltage rating	6600/470V
Maximum magnetic flux	1.2Wb/m
Window space factor (Kw)	0.273
Stacking factor	0.9

2.3 SolidWorks Simulation

The detailed design for the transformer core has been drawn using 3D modeling SolidWorks software in Figure 2. Before beginning the detailed design of the selected concept, the overall dimension must be determined, since this will make drawing the detailed design easier later. SolidWorks makes the design process easier, and it can also convert drawings into 3D models. The particular technical dimensions on core transformers that are only available from the manufacturer.

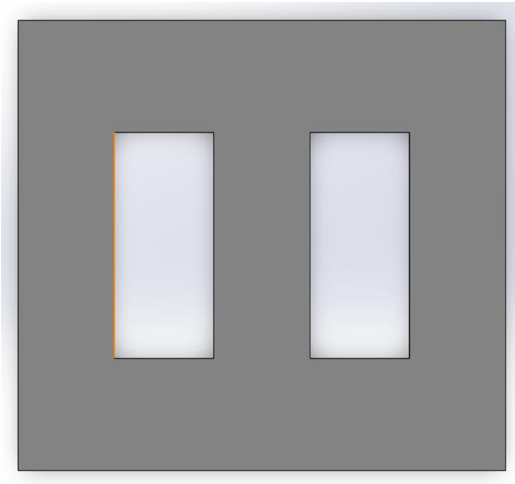


Figure 2: Transformer core

2.4 Simulation Based on Core Material.

The Solidworks 3D modelling is used to simulate the designed transformer. Following the import of the model, material attributes are assigned to each part. This simulation will show amorphous metal and amorphous steel as core materials. Some parameters are utilized in the same way as the production parameters for assigning material characteristics. Thermal analysis was used to mesh the model and simulate it. Three-phase transformers combined volume to produce more accurate findings, fine meshing is required as Figure 3 show mesh 3D modeling.

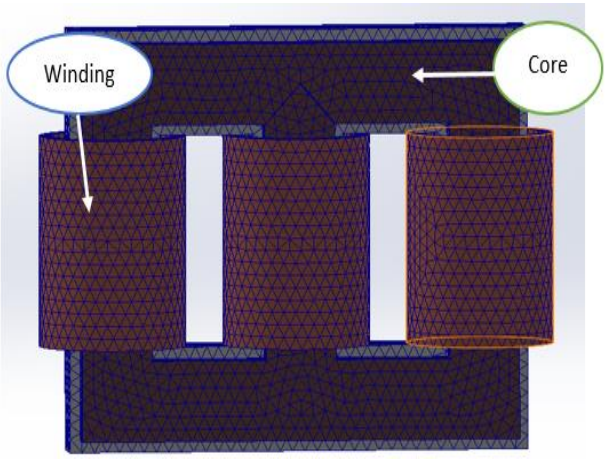


Figure 3: mesh 3D modeling

2.5 Simulation Finite Element Analysis (FEA) using SolidWorks

In this study, the material is heated in 3D modeling to do a simulated thermal analysis, as shown in Figure 4. The different colors show how hot it is because heat and infrared radiation are being sent out. For example, red means that the temperature is high and blue means that the temperature is low.

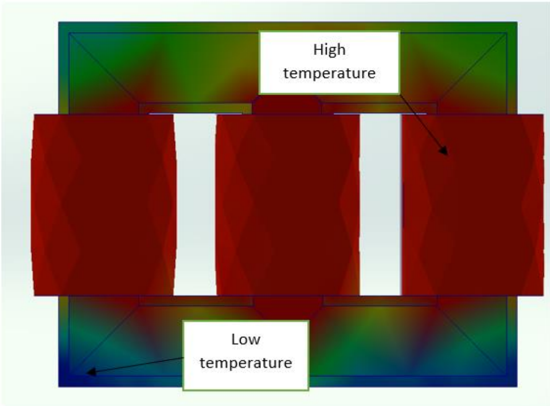


Figure 4: Simulation Finite Element Analysis (FEA)

2.6 Core Material Comparison.

For this project, two cores will be compared which are amorphous metal and amorphous steel. These materials are usually used the make core transformer. Amorphous metal, sometimes known as vitreous metals, are glassy or non-crystalline. High-performance transformers are made from these metals. Low conductivity of the materials helps to decrease eddy currents. Next are amorphous steel cores are made up of numerous paper-thin metallic tapes that serve to minimize eddy current flow. Amorphous steel cores charge lower losses than other magnetic cores and may act at higher temperatures than normal lamination layers. Following the simulation of the design through SolidWorks methods, these two material's properties were used on simulation it is necessary to compare and evaluate the design efficiency with the existing and proposed designs. The comparison result for temperature and heat flux between two materials can be obtained after the comparison.

2.7 Data from Site Visit

Data from a site visit at Malaysia Marine Heavy and Engineering were given as shown in Table 3 transformer specification data obtained and utilised as a reference in the simulation.

Table 3: Specification of transformer

Rated power (KVA)	3500
Phase	3
Frequency	60
High voltage / low voltage	6600/470
Winding temperature rise ^{o}C	60/65

3. Results and Discussion

This chapter focuses on the analysis and discussion of acquired results, as well as comparisons from result simulation in relation to the project aims. This project seeks to provide a thermal analysis that outputs temperature and heat flux with two materials on simulation using Solidworks.

3.1 Simulation Result.

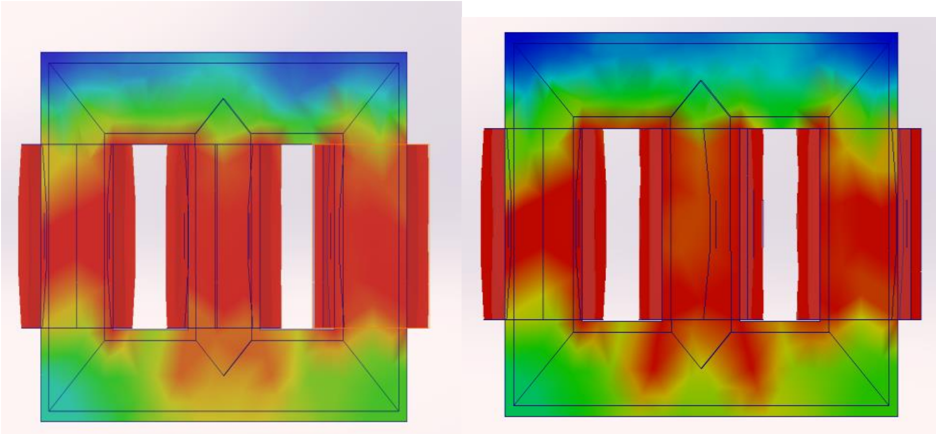
The simulation is performed on a three-phase 3500 kVA 6600/440 V system. The mesh data in Table 4 includes the total number of nodes and elements created, as well as the element size and tolerance.

Table 4: Mesh data

No. of node	Number of element	Element size (mm)
1339	3761	70.502

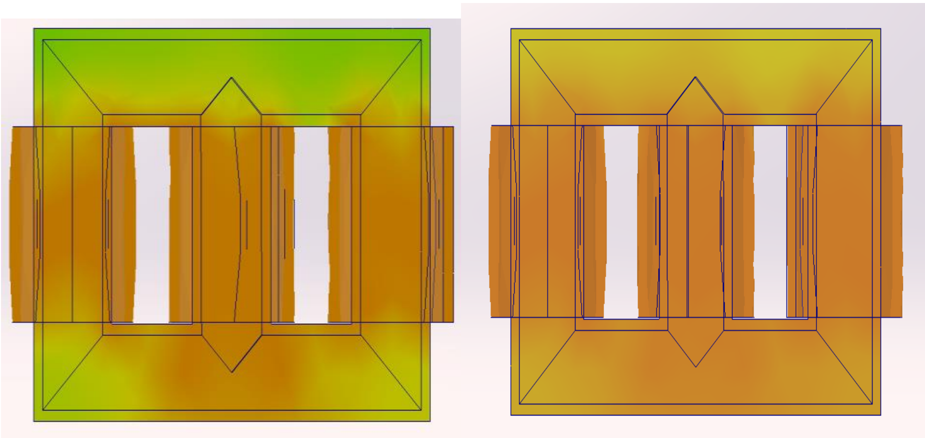
3.2 Temperature rise analysis.

In Figure 5, the hot-spot temperature for cores is in the middle of the core, whereas Figure 6, the temperature rise is evenly distributed around the surface. The hot-spot temperature rise determined by linked analysis is 60 ºC, because the beginning and ambient temperatures of thermal analysis are both 40 ºC. These settings Celsius are based on data from site visits on parameter simulation shown in Figure 7.



(a) (b)

Figure 6: **Temperature of amorphous metal with different time (a) t = 10s (b) t= 20s**



(a) (b)

Figure 7: Temperature amorphous Steel with different time (a) t=10s (b) t= 20s

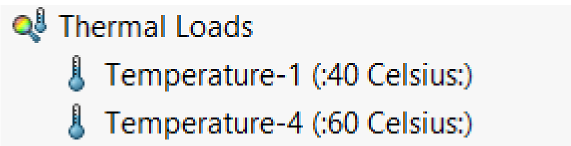


Figure 8: Parameter of ambient temperature

Figure 9 show the graph of comparison between two core materials which is amorphous steel and amorphous metal based on temperature vs time(s). From the graph, it shows the amorphous steel responds faster than the amorphous metal on the temperature in one second which is the steel is 45 °C and the metal is 35 °C. It can response metal material is fast response than steel material by the time of temperature rise. This is due to the material used in electrical power transformers, motors, and generators, amorphous steel, which is a soft magnetic substance. Amorphous steel cores offer lower losses than other magnetic cores and may respond at higher temperatures than conventional lamination stacks. These amorphous metals are utilized to make high-performance transformers but have a lower response when the transformer is in use. In that graph also shows that the steel begins to heat at 45 °C but it reacts more slowly than metal which begins at 35 °C. However, a quick reaction rate leads the metal to reach 60 °C in 10 s, whereas steel takes 20 s to reach 60 °C.

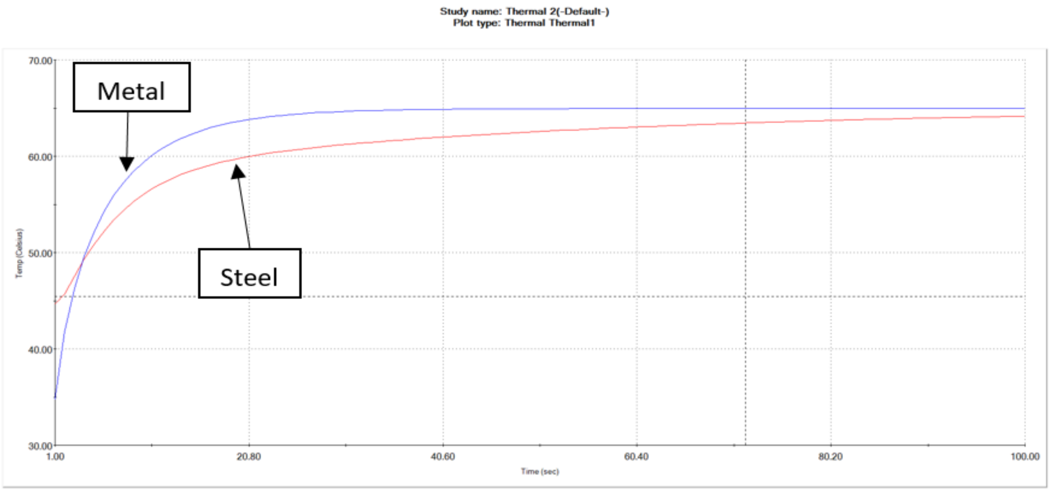


Figure 9: Temperature rise between amorphous metal and amorphous steel

3.3 Heat Flux density

Heat flux simulations in Figures 10 and 11 compare the heat flux between metal and steel. According to Figure 10, the only difference in the surface of the amorphous metal substance is in the winding area, which has a distinct color In addition, red patch is surrounded in winding in the middle and left limb core parts. However, the heat flux in the simulation result of amorphous steel material is not the same as in amorphous metal. In the simulation results shown in Figure 11 the surface area colour change is more apparent than in Figure 10. As a result it can conclude that amorphous metal is better than amorphous steel because the time for heat flow to surface is slower than heat on surface amorphous steel.

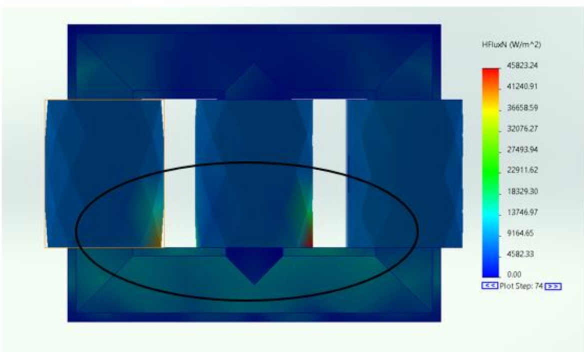


Figure 10: Heat Flux for Amorphous Metal

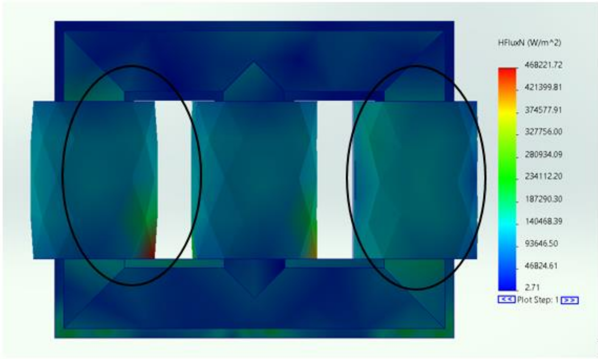


Figure 11: Heat Flux for Amorphous Steel

The heat transfer at the metal and steel interface is a metric that has a direct impact on the final structure of the surface, thus crucial to understand how it changes shape and how it compares to other materials. The simulation temperature in the metal and the steel, which replicates the heat flux change, was used to determine the heat transfer coefficient in the metal and steel interface. As in Figure 12, the variation of the heat transfer coefficient in the metal interface under heat flow is initially large it rapidly reduces with time, reaching a value of roughly 6.00+04 W/m^2, which is stabilised as a result of the gap air that forms owing to the metal's contraction. In comparison, steel has a modest reduction until it reaches 2.00+04 W/m^2.

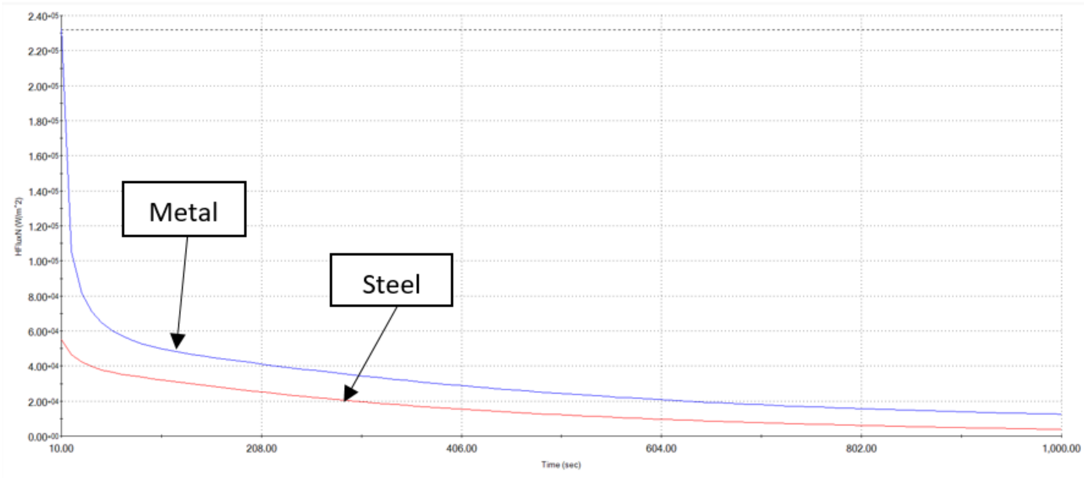


Figure 12: heat flux density between amorphous metal and amorphous steel

3.4 Thermal Conductivity and Temperature.

The ability to conduct heat is described by thermal conductivity, which is a material attribute. The thermal conductivity of metal increased with rising temperatures up to 40 ^{o}C and increase to 60 ^{o}C, as shown in Figure 13. Thermal conductivity of amorphous steel increased with temperature up to 21^{o}C, then thermal conductivity began to decrease slightly at higher temperatures. The amorphous steel has one of the lowest heat conductivity values of all metals as shown in the graph. High thermal conductivity materials, in comparison to amorphous metal, could transport heat more quickly and efficiently than low thermal conductivity materials.

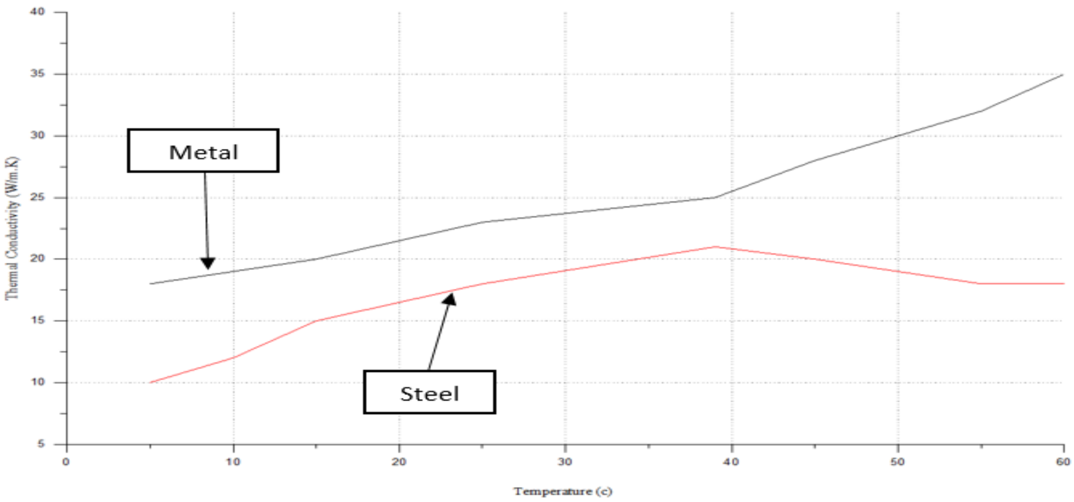


Figure 13: Thermal Conductivity between amorphous steel and amorphous metal

3.5 Comparison based on graph

Based on the three types of testing performed on the two types of core materials, it can be summarized as a result for selected suitable core material for three-phase transformers as shown in Table 5.

Table 5: Comparison of amorphous metal and amorphous steel

Core material / Testing	Amorphous metal	Amorphous steel
Temperature rise	Fast reaction	Slow reaction
Heat flux	Slow on heat transfer	High transfer heat to surface
Thermal conductivity	High conductivity	Low conductivity

4. Conclusion

The thermal flow in the case of a surface core between amorphous steel and amorphous metal was evaluated using Solidworks simulations. The temperature rise and the heat flux transfer were shown in the graph to compare between two materials. The simulation graph was obtained while the simulation was ongoing. In terms of temperature rise and heat flux, two cores are compared. The heat flux graph, as well as the various temperatures and times, demonstrate that metal is more suited than steel, and the heat flux graph also demonstrates that metal is more stable. In terms of thermal conductivity, metal is more efficient than steel.

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