CHALMERS
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New Concept Design for Power Distribution Unit Housing within Electric Truck, Achieving ~50% Weight Reduction

Usage of Metal Coating and 2D Material, Graphene, on Polymer

Master’s thesis in Mobility Engineering

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Abstract

This project presents a new concept design for housing of PDU (Power Distribution Unite) in electric truck. The purpose of the study is to design a new concept with different configuration and other materials to reduce the weight of PDU and thereby weight of electrical truck get reduced. Also, the project considering more sustainable materials and hopefully cheaper cost.

In the first the chapter Introduction, the purpose of the project is introduced, were weight reduction, hopefully cost reduction and choosing more sustainable materials in electric truck helps moving to more effective and cleaner transport. Further in background the current concept is introduced, where today's solution is a housing with integrated cooling system is and alloy EN AC-AlSi10Mg(Fe) is used as material. The requirements of PDU housing that are covered by EN AC-AlSi10Mg(Fe) are divided into four categories, EMC, electrical, mechanical, and IP requirements. The new concept design is configurated by separating the cooling plate from housing without any changes and choosing plastic as material for housing. Plastic will cover mechanical and IP requirements, and it needs to be coated with conductive material to cover EMC and electrical requirements. Choosing plastic instead of aluminum reduces the weight of PDU housing. The requirements are explained in more detail in chapter one.

In the second chapter technical background, other projects are introduced, where weight has been reduced by reducing usage of metal. This chapter introduces plastic usage in the automotive industry where weight can be reduced. Also, the 2D material Graphene is introduced and different coating methods to use graphene coating on plastic to cover EMC and electrical requirements.

Methods and software like System P-Diagram, Granta EduPack, strategy of using new materials to current design and schelkunoff formulas were used to get results. PEEK (10% glass fiber) is the chosed plastic that can cover mechanical and IP requrements. PEEK (10% glass fiber) has ~50% less weigh than EN AC-AlSi10Mg(Fe) and is more sustainable. To cover EMC and electrical requirements and get a complete solution, two solutions are presented. Solution 1: Coated graphene on PEEK (10% glass fiber) and solution 2: Coated metal (aluminum, copper or nickel) on PEEK (10% glass fiber). All solutions are confirmed to cover all requirements by CAD simulations and theoretical calculations. Each solution has advantages and disadvantages, and it's up to Volvo Trucks to choose the best solution.

Contents

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1. Introduction

The future of the automotive branch is moving further to electrifying, which means the demand for sustainable transportation solutions and infrastructure will continue to increase. Volvo Group is committed to driving the transition to sustainable, safe and productive transport and infrastructure solutions. Since 2019 Volvo Trucks has started to produce new electric trucks and become the first global manufacturer to start series production of heavy electric trucks. The batteries in every electric vehicle storage chemical energy and convert it to electricity. All components such as compressor, electric motors etc. receive the electricity needed from batteries through PDU (Power Distribution Unit) PDU is a part of the electrical driveline used in commercial vehicle applications, such as electrical busses, trucks, construction equipment or marine applications. The PDU's main function is to distribute electricity within the system, Pole chassis isolation monitoring and HVIL monitoring. The main driver for the development of PDU is to reduce assembly time and improve current capacity to support Combined Charging System and Mega Charging System.

Today the chosen material of PDU housing is alloy EN AC-AlSi10Mg(Fe). The benefit of choosing this alloy is its excellent castability, corrosion resistance, suitability for high -pressure die casting (HPDC) processes and great strength-to-weight ratio. Aluminum covers all housing requirements such as mechanical properties, IP requirements and EMC shielding. However, we still want to move further to more sustainable solutions. To have better recycling opportunities and reduce weight and cost, this project will be investigating the possibilities of using other materials instead of aluminum for housing of PDU. By changing the material of PDU housing we can reduce weight and hopefully cost, also we go further sustainability.

1.1 Background

Changing material to product is not easy, as material changes the characteristics of the equipment get affected and this should be studied before any material changes. As mentioned above, Volvo Group Technology is using alloy EN AC-AlSi10Mg(Fe) to housing PDU in the electric truck, and there're several factors behind choosing aluminum to battery packaging housing. The material of PDU housing should cover four main requirement categories: IP (Ingress Protection), Mechanical, EMC (Electromagnetic Compatibility) and Electrical requirements:

1. IP requirements refer to the protection provided by mechanical casings and electrical enclosures against intrusion, dust, accidental contact, and water.

2. Mechanical requirements refer to the mechanical properties of housing, for example, stiffness and strength of housing should be high enough to protect the components inside from any mechanical damage.

3. EMC requirements refer to the ability of electrical and electronic equipment to function satisfactorily in its electromagnetic environment without causing or experiencing unacceptable EMI (electromagnetic interference). EMC encompasses two main aspects: the ability to work properly amidst electromagnetic radiation and the ability to avoid generating additional EMI that could disrupt other devices. To protect PDU from EMC, the housing material should be conductive with enough shielding effectiveness by >70 dB

4. Electrical requirements refer to the whole electrical circuit in electric trucks. All components inside the PDU are connected electrically, and any change of material is not allowed to affect the electrical

components connection. The main electrical requirement for housing is that the material must be conductive to make the PDU able to be grounded to chassis of electric truck.

The alloy EN AC-AlSi10Mg(Fe) has good mechanical properties to protect the PDU from dust, water and mechanical damage. It’s also conductive, thereby it grounds the PDU to the chassis electrically and protect the equipment from EMC. Choosing any other material should cover all four main requirement categories.

Since the purpose of investigation is to reduce weight and aluminum is already a low weight metal, checking other metals will not reduce the weight significantly. Although, there are light conductive composites with high mechanical properties that have been used for housing in some companies, for example, carbon fiber. Carbon fiber is not recyclable and choosing these kinds of composites will harm the environment significantly, since Volvo produces a big volume product in big numbers of series every year, thereby in this case the rest of carbon fiber components in electric trucks after lifetime will not be recycled. This large volume of products will cause non-recyclable waste that affects the ecosystem. Sustainability and safety are important factors at Volvo since the mission of Volvo Trucks is to move further to sustainable, safe and clean transportation.

Plastics have good mechanical properties and are much lighter than aluminum. Also, plastics have easier manufacturability and recyclability than aluminum, some plastics are cheaper in manufacturing and are more sustainable than aluminum. But plastics are not conducive and therefore plastics cannot cover the EMC and electrical requirements. Metals are conductive, but metals have higher density than plastics.

Although, using plastic as the main material and coating it with a conductive material will make the plastic housing conductive and therefore this concept covers all main requirement categories. The concept design is to check plastic material that covers IP and mechanical requirements and coat the plastic with conductive material to cover EMC and electrical requirements. The concept design will reduce the weight of PDU significantly and hopefully cost. At the same time, plastic is more sustainable and is easier to recycle than aluminum. This combination will introduce lighter and more sustainable conductive housing of PDU.

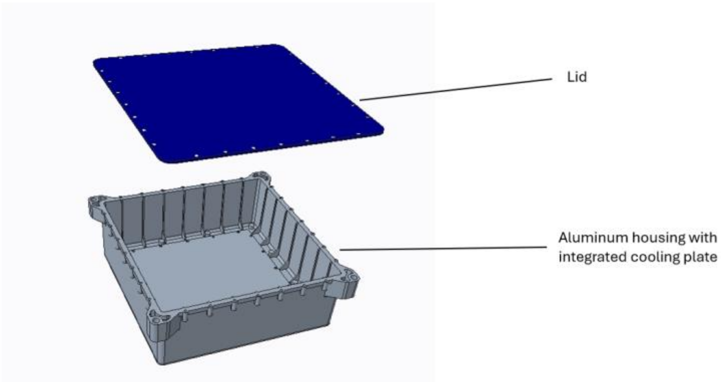


Figure 1: Current concept design of PDU (Power Distribution Unit)

1.2 Objectives

This study is based on the following four questions:

- How can we change the concept design of housing to be able to use plastic?
- Is there plastics that have similar properties to EN AC-AlSi10Mg(Fe)?
- Is there a conductive material that has good enough conductivity and shielding effectiveness?
- Covers conductive material coating the electrical and EMC requirements?

1.3 Limitations
Since one of the purposes of this investigation is to reduce weight and aluminum is already a low weight metal, checking other metals will not reduce the weight significantly. Therefore, all metals, except the metal coating for mechanical and IP requirements, are excluded from this study. Since the time is not enough, the project will only be based on a theoretical level. In other words, there will not be time for making a final design, physical prototype and physical tests for verification and validation. Thereby the quality of coating, quality of coating adhesion, and lifetime of coating or aging will not be considered during the study. The study only considers the housing, components inside and cooling plate will not be investigated.

2. Theory

2.1 Usage of EN AC-AlSi10Mg (Fe) Alloy in Electric Vehicles Housing Applications
Pan, L et al (2024) writes that the electrification of automotive is spreading rapidly, which increases the demand for aluminum alloys with high electrical conductivity. HPDC (High Pressure Die Casting) alloys, particularly aluminum alloys with high electrical conductivity, are suitable for electric motor components, which are crucial in electric vehicles according to Pan, L et al (2024). Aluminum is widely used for electromagnetic compatibility (EMC) shielding in electric vehicles (EVs) due to its high electrical conductivity and lightweight properties. Uğur, S (2023) states in his research that pure aluminum has been shown to be an effective shielding material in the 5G frequency range, with its shielding effectiveness increasing with thickness.

Zhu, B and Liu, X (2016 states that HPDC (High Pressure Die Casting) alloys are used to manufacture structural components such as vehicle bodies and chassis due to their ability to produce thin-walled castings with good mechanical properties. Lumley, R (2011) states that recent developments in HPDC alloys, such as Al-Si-Cu and Al-Fe-Ni, have shown improved mechanical properties, including high strength and ductility, which are beneficial for structural integrity and crash resistance. HPCD can also successfully be heat treated without experiencing problems with dimensional instability or surface blistering (Lumley, R, 2011)

HPDC process can also lead to defects such as gas porosity, shrinkage, and inhomogeneous skin structures, which can negatively impact the mechanical properties and ductility of the cast components, as claimed by Magrin, V et al (2023). To reduce the risk of the previously mentions defects, Magrin, V et al (2023) states that you can employ Semi-Solid metal processing with HPDC. Dalai, B et al (2025) writes in their research that inhomogeneous skin formation can cause abrupt fractures and limit the ductility of HPDC castings, posing challenges for their use in critical structural applications.

The initial costs of HPDC molds are high according to Zalaba, B et al (2014), accounting for around 20% of the production costs, which can limit the competitiveness of the process. Zalaba, B et al (2014) also mentioned that the HPDC casting needs better understanding of wear mechanisms nature and the parameters affecting them. Ding, R et al (2021) claims that HPDC dies are subject to severe conditions such as high pressure, temperature, and corrosion, leading to wear and frequent maintenance requirements, which can increase operational costs

Although HPDC is efficient, the process can contribute to greenhouse gas emissions during processing and melting. Advanced methods like ATM HPDC aim to reduce these emissions by improving casting integrity and enabling lighter components. (Gunasegaram, D.R et al., 2009)

2.2 Usage of Plastic in Electric Vehicle Housing Applications

The usage of plastic in Electric Vehicles housing applications is driven by several key factors, those include weight reduction, cost efficiency, design flexibility, durability and performance. The usage of plastic in electric vehicles is a growing area where more and more research and development is made. Rosato, D (2011) states that plastics offers design flexibility, high performance and fuel savings at a lower cost.

2.2.1 **Weight reduction**

Miller, L et al. (2017) states that plastics are significantly lighter than traditional materials like metals, which helps in reducing the overall weight of the vehicle. This weight reduction is crucial for improving the range and efficiency of EVs. Plastics can both be used as a replacement for the heavier materials, but it can also be an addition to the materials for consumer comfort purposes (Miller, L, et al. 2017)

2.2.2 Cost efficiency

According to Jacob, A (2004), plastics can be more cost-effective than metals due to lower material costs and the ability to integrate multiple components into a single module, reducing assembly costs. The use of plastic composites can reduce production and assembly costs while producing a more functional and attractive design (Jacob, A., 2004). Haspel, J and Höfs, C (2023) claims in their research that the manufacturing process for plastics, such as molding, are generally less expensive and more flexible than those for metals. Furthermore, today’s battery housings are mostly made of metallic materials, despite plastic offering a cost-efficient manufacturing process and reduced weight (Haspel, J and Höfs, C, 2023).

2.2.3 Design flexibility

Plastics offer greater design freedom, allowing for more complex shapes and integrated functions that are difficult to achieve with metals according to Gupta, P, et al (2022). Rosato, D (2011) states that the plastics flexibility is particularly beneficial for creating innovative and aesthetically pleasing designs in EVs. Continuously, plastic requires little maintenance, is durable and does not corrode.

2.2.4 Durability and Performance

Haspel, J and Höfs, C (2023) claims that plastics are resistance to corrosion and can be engineered to withstand high mechanical and thermal loads, which is essential for components like battery housings.

According to Sebö, P (2017), advanced plastics can also improve the thermal management of EV components, such as battery cooling systems, by using thermally conductive fillers. By adding fillers to the plastics, you can increase the thermal conductivity significantly. The fillers also grant better thermal and mechanical strengths in thermosets and thermoplastics (Sebö, P, 2017).

2.2.5 Applications in EV housing

In research conducted by Ugare, C and Sibirko, A (2022) it states that plastics are used in power inverters and coolant housings to enhance power density, reduce costs and meet electromagnetic compatibility (EMC) requirements. These applications require advanced mechanical designs to ensure reliability under heavy-duty conditions. Ugare, C and Sibirko, A (2022) writes that the use of plastics in coolant housing, reliability and electromagnetic compatibility (EMC) has both advantages and complications.

2.2.6 Environmental impact

The end-of-life disposal of plastics components poses environmental challenges, as plastics are not biodegradable and can contribute to landfill waste. Miller, L et al (2017) claims that the result in the overall reduction in environmental impacts when using plastics is a question that is up for debate. Efforts are being made to improve the recyclability of plastics used in EVs to mitigate these environmental impacts. Ortego, A et al (2023) states that by understanding the criticality of the different car parts containing plastics, targets efforts in material selection, design and end-of-life management are made to promote circularity and recycling.

2.3 Nissan inverter case project

Ishii, S et al. (2023) caried out a project with the goal of reducing the size and weight of the traction inverter, with the goal to ensure a satisfactory driving range of an electrical vehicle. Ishii, S et al (2023) writes that "in this paper, we report the technical features of the resin water jacket and solve its major technical challenges such as EMC and cooling performance" (S.1)
By doing this, they had to chance the materials of the inverter case to resin, from aluminum. When changing to resin, they encountered technical issues, specifically with the collision and cooling performance, but also with the electromagnetic compatibility (EMC). Ishii, S et al. (2023) discovered that the material properties differed between the resin and the previously used aluminum.

They solved the previously described issue by adopting a resin water jacket case with inverters designed for electric powertrains. By switching to resin, they had the advantage of reducing the weight of the case by roughly 35% and decrease the amount of parts to approximately 3/5, when compared to the conventional case (Ishii, S et al, 2023).

Furthermore Ishii, S et al. (2023) writes that a new inverter case was designed consisting of a box-shaped aluminum case and a flat resin water jacket in hopes to ensure collision safety assurance. This structure makes it possible for the aluminum case to shield the resin water jacket but also the parts inside the inverter case. To ensure electromagnetic wave shielding a protection plate was placed on the bottom side of the resin water jacket. Ishii, S et al (2023) described that it was difficult to attach the resin to the ground and hence, there was a need for a part that can secure the noise filter to the ground. For that reason, they had to incorporate nuts for earthing into the resin water jacket and grounded it to the metal shield plate. Moreover, they had to guarantee the cooling performance by installing special nuts to cool the busbars of the DC capacitor. (Ishii, S et al, 2023)

2.5 Graphene

Introduction to Graphene

Graphene is a single layer of carbon atoms arranged in a hexagonal lattice, making it the thinnest, strongest and most conductive material known, according to Else, H (2011). Discovered in 2004, graphene has since captivated scientists and engineers due to its extraordinary properties and potential applications across various fields. Graphene is not a bulk material; it's a two-sided surface. Guo, C.X., et al (2017) states that the unique structure of graphene provides extraordinary and interesting properties including strong mechanical strength, good chemical/physical stability, high electron mobility, a tunable bandgap, room temperature quantum Hall effect, and high transparency.

Thickness and Structure

Graphene is one-atom-thick planer sheet of sp2-bonded carbon atoms arranged in a honeycomb structure, according to Guo, C.X., et al (2017). Muthuvinayagam, M., et al (2023) claims that graphene is knows to be the strongest material because of the existence of the strongest C-C bonding.

Mechanical strength

Ovid´ko, I.A (2017) states that Graphene exhibits the highest tensile strength and Young's modulus ever measured, making it incredibly strong yet lightweight. The mechanical property of Graphene is very important for both its structural use and exploitation in graphene-based electronic devices.

Electrical Conductivity

Graphene has high electron mobility and can support ballistic transport, making it ideal for electronic applications. Bryner, M (2013) writes that the peculiar electronic structure of graphene gives rise to thermal conductivity and high electrical.

Thermal Conductivity
It has excellent thermal conductivity, which is benificial for heat dispation in electronic devices. Ajay, A., et al (2023) writes that graphene has astonishing capabilities in terms of robustness, conductivity, termal conductivity and great electron mobility.

Graphene Applications:
Graphene is used in transistors, sensors, and flexible electronic devices due to its high electron mobility and conductivity. Obeng, Y., Srinivansan, P., (2011) claims that it also has applications in MEMS-based applications and chemical sensors. There are also potential near-term applications, one example is a transparent touch screen exhibited by Samsung. Ajay, A ., et al (2023) continues to write that graphene can also be used in areas like fuel cells, photonic devices, supercapacitors, photovoltaic devices and batteries. According to Muthuvinayagam, M., et al (2023), graphene can be used in batteries and supercapacitors since it enhances the performance and increases the energy storage capacity and efficiency.

Graphene is used to reinforce polymers, improving their mechanical and electrical properties (Zhang, B., et al 2014). By combining graphene with metal phosphate, you create a composite that enhances the thermal stability, electrochemical performance and mechanical robustness, according to Samal, A., et al (2024).

Challenges of using graphene in applications
Xie, F., et al (2024) claims that high cost, low yield and scalability issues is a challenge when producing high-quality graphene. Techniques like chemical vapor deposition (CVD) and mechanical exfoliation, while producing high quality graphene, are not cost-effective for large-scale production. Methods such as liquid phase exfoliation (LPE) and reduction of graphene oxide (GO) offer potential for scalability but still face challenges in achieving consistent quality and efficiency according to Galindo-Uribe, C., et al (2024) . Izzaty, N and Sastra, H.Y., (2019) states that the massive production scale still encounters challenges such as feasible fabrication techniques, safety issues and high manufacturing costs.

1. **Environmental and safety concerns**
   Amir Faiz, M.S., et al (2020) writes that traditional chemical methods for producing reduced graphene oxide (rGO) involve hazardous chemical like hydrazine, posing environmental and safety risks. Alternative green methods, such as using palm oil leaves extract, are being explored but are not yet widely adopted. Continuously, Ramenzani, M.J and Rahmani, O., (2024) claims that the environmental footprint of graphene production processes needs to be minimized to make them more sustainable. Bonde, S.B., Bhanvase, B.A (2024) states that the challenges in cost-effectiveness, scalability and environmental impact must be solved for widespread use.

   2. Standardization and Quality control
   Kong, W., et al (2019) writes that there is a need for standardization synthesis techniques to ensure consistent quality of graphene across different batches and applications. The synthesizing of graphene can be done using several different methods, including chemical vapor deposition, mechanical exfoliation and electrochemical synthesis, according to Ramezani, M.J and Rahmani, O (2024). Xie, F., et al (2024) claims that ensuring the uniformity and purity of graphene materials remains a significant challenge, affecting their performance in various applications.

   The integration of graphene into existing manufacturing processes, such as in composites and electronics devices, requires overcoming technical complexities and developing new fabrication techniques according to Shahnaz, T., et al (2024).

2.5 Graphene production methods

2.5.1 Chemical Vapor Deposition (CVD) Method – CVD graphene

Chemical Vapor Deposition (CVD) is a widely used method for synthesizing high-quality graphene. This technique involves the deposition of carbon atoms from gaseous precursors onto a substrate, typically a metal, to form a graphene layer. CVD is believed to be a leading approach to manufacture graphene, since you can control the amount of graphene layers and produce high-quality graphene (Ishraq, S., et al 2022). CVD is favoured for its scalability and ability to produce large-area, uniform graphene films, according to Reina, A and Kong, J (2012). Moreover, Jia, K., et al (2021) states that CVD allows to produce large-area graphene films with high crystallinity and low defect density, essential for electronic and photonic applications.

Challenges :
Traditional CVD processes require high temperatures (around 1000°C), which increases the cost and complexity of the equipment needed. Both Wang, J-B et al (2020) and Qi, T et al (2023) has conducted research with efforts to try and lower the growth temperature to below 600°C are ongoing, but this often results in lower quality graphene

2.5.2 Chemical Graphene Exfoliation – (r)GO/EGO

Chemical Graphene exfoliation is a chemical treatment of graphite to produce graphene oxide, which is then reduced to graphene. Traditional methods like Hummers method and its modifications are commonly used for Chemical exfoliation, according to Chen, L., et al (2017). The chemical exfoliation is an alternative method for safe and fast industrial exploitation, since its low cost, eco-friendlier electrolytes and basic equipment requirements (Konstantopoulos, G., et al 2021).

Conductivity of reduced graphene oxide rGo flakes obtained by thermal annealing at 600 °C is 1.46 10^7 S/m (Lim, S., et al, 2021).

Zhang, P., et al (2018) states that chemical methods can produce graphene with high crystallinity and fewer defects when optimized. Chemical methods allow for the functionalization of graphene, enhancing its properties for specific applications. Chemical methods often result in high levels of oxidation and structural defects, which can impair the material's properties. Additional reduction steps are often required to improve the quality of the graphene produced (Zhang, P, et al 2018). Chemically exfoliated graphene has been used to fabricate Chemi resistor devices. The method is employed to produce biocompatible and toxin-free graphene for various biomedical applications, including tissue engineering and cell imaging. Chemical exfoliation is used for preparation of graphene nanosheets for biomedical use due to their scalability and high yield (Parviz, D and Strano, M., 2018).

2.5.3 Electrochemical Graphene Exfoliation – (r)GO/EGO

Electrochemical graphene exfoliation is recognized for its environmentally friendly and scalable approach to producing graphene, Lee, H., et al (2024) states in their research. This method involves applying voltage to graphite in an electrolyte solution, causing ionic species to intercalate into the graphite, leading to the expansion and exfoliation of graphene sheets (Achee, T.C., et al, 2018). Electrochemical exfoliation is ideal for large-scale production due to its low cost and simple implementation. Methods like anodic oxidation and encapsulated electrodes can achieve high yields and produce graphene with fewer defects (Qiu, Z., et al 2023) (Xia, Z., et al 2021).

Key methods:
Xia, Z., et al (2021) states in their research that anodic Exfoliation utilizes anodic oxidation in acidic or salt solutions, then ions are electrochemically driven in between the graphene sheets. Leading to high-yield production of graphene oxide (GO). Cathodic Exfoliation focuses on generating few-layer graphene with minimal defects using a binary solvent system (Lee, H., et al 2024). Encapsulated Electrodes enhances yield and quality by using flexible encapsulated graphite, which allows for continuous exfoliation. By using flexible

encapsulated graphite with a filter cloth as both cathode and node for the electrolyze, you can achieve a high yield of graphene, according to Qiu, Z., et al (2023).

The process can introduce defects and oxidation, which can affect the quality of the graphene. It can affect the quality of the graphene sheets in terms of lateral size, defect densities, layer numbers and carbon/oxygen ratios. Various strategies, such as using specific electrolytes and optimizing process parameters, are employed to mitigate these issues (Ummer, F.C., Kalarikkal, N., 2024). The disintegration of the graphite electrode during the process can be significant challenge, which can be addressed by using containment systems (Achee, T.C., et al 2018).

Electrochemically exfoliated graphene is extensively used in energy-related applications, such as in the development of anode materials for Li-ion batteries and other energy storage devices (Yang, Y., et al 2013). The high surface area and conductivity of graphene make it suitable for supercapacitors and other energy conversion systems (Paredes, J.I., Munuera, J.M., 2017). Zhang, P., et al (2022) states that graphene produced via electrochemical exfoliation has been used to create membranes with superior EMI shielding performance, outperforming traditional materials like metals.

2.5.4 LPE (Liquid Phase Exfoliation) - GNPs

LPE (Liquid Phase Exfoliation) is an adopted method for producing graphene due to its scalability, cost effectiveness, and compatibility with industrial production requirements (Tyurnina, A.V., et al 2020). This method involves the exfoliation of graphite into graphene flakes using various solvents and mechanical forces, such as sonication or sheet forces (Li, Z., et al 2020).

Jung, J.G., et al (2025) states that shear-induced exfoliation uses mechanical shear forces to delaminate graphite. The efficiency of this process can be influenced by the solvent's viscosity, polarity and surface tension.

Solvents and surfactants:
Organic solvents like N-methyl-2-pyrrolidone (NMP) and methyl-5-(dimethylamino)-2-methyl-5-oxopentanoate (PolarClean) have been shown to improve exfoliation efficiency due to their suitable polarity and surface tension (Jung, J.G., et al (2025). However, these solvents can be toxic and environmentally harmful and there is currently ongoing research regarding the use of green solvent for LPE production of graphene (Fernances, J., et al 2022).

Aqueous Solutions using water with surfactants, such as tea extracts, can reduce surface tension and facilitate exfoliation. Green tea, for instance, has been found to be particularly effective due to its high polyphenol content, according to Ismail, F.S., et al (2019). Ionic Liquids can be tailored to optimize exfoliation by adjusting their molecular structures and physicochemical properties. They offer a balance between exfoliation efficiency and environmental impact (Bordes, E., et al 2019).

The yield of graphene from LPE can be influenced by the size and crystallite structure of the starting graphite. Smaller graphite flakes tend to exfoliate more easily, leading to higher productivity (Mori, F., et al 2018). The quality of graphene produced via LPE is generally high, with fewer defects and oxygen-containing groups compared to other methods like oxidation-reduction, according to Xiong, X., et al (2018). The choice of solvent and surfactant plays a crucial role in determining the defect density and stability of the graphene dispersion (Arao, Y., et al, 2017).

Graphene produced via LPE is suitable for various applications, including:
- Electronics: Thin film for transistors and transparent electrodes (Tong, X., et al 2013).
- Composites: Nanofillers to enhance mechanical properties of polymers (Jung, J.G., et al 2025).

- Energy Storage: Materials for supercapacitors and batteries (Li, J., et al 2019).

2.6 Different coating methods

2.6.1 Metal Flame Spray

The family of processes for spraying material contain of wire flame spraying, arc wire thermal spraying, powder flame spraying and plasma arc spraying. All of the previously mentioned use a high velocity gas jet to shatter it into small droplets and drive them to the surface to be coated. They also use a heat source to melt the coating material. In wire flame spraying, an uninterrupted wire or tod is brought into an oxyacetylene flame, that melts it and scatters it into droplets 10 to 100 microns in diameter. The gas stream increases them to 90 to 25 m/s and launches them towards the surfare at a space of 100 to 250 mm for the launch. The melted particles hit the surface and flow into slim, flat droplets that interlock, overlap and bond as they solidify. Thicker coatings can build up through multiple passes (Granta Edupack, 2024B, R1)

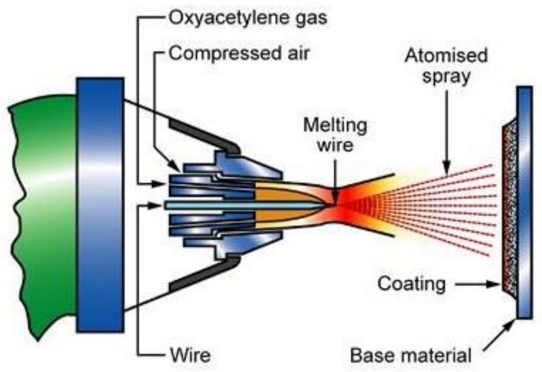


Figure 2: Metal Flame Spraying, Schematic Drawing

2.6.2 Vapor metallizing (PVD)

Mirrors were once made using a complex process requiring silver to be dissolved in mercury. Today they are made through a process in with a small coating of metal, usually aluminium, is deposited from a vapor onto a part. The previously described process is called PVD metallizing. Vapor is generated in a vacuum chamber by electron beam or direct heating of the metal; it then condenses onto the cold part. Ion plating is a process where the vapor is ionized and accelerated by an electric field (the metalizing source material is the anode, and the component is the cathode). In sputtering, the argon ions are accelerated by the electric field and spread onto a metal target, this process ejects metal ions onto the component surface. Lastly by introducing a reactive gas into the process, compounds can be formed (Granta EduPack, 2024c, R1)

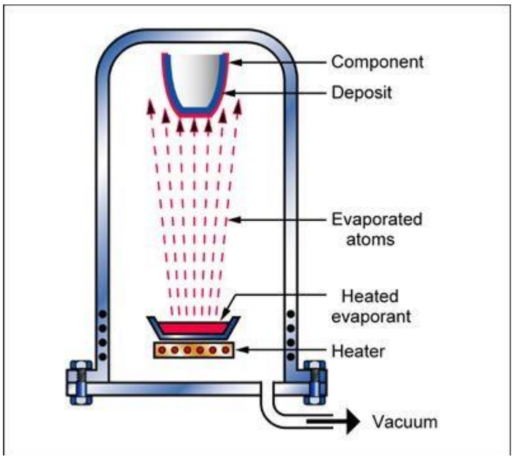


Figure 3: Physical Vapor Deposition, Schematic Drawing

2.6.3 Electroplating

The metal coating process is where a metallic coat is spread onto the workpiece by using a ionized electrolytic solution. The cathode (workpiece) and the anode (metallizing source material) are brought into the solution and submerged; a direct electrical current then causes the metallic ions to shift to the workpiece from the source material. The source metal and workpiece are fastened by insulated rods in the ionized electrolytic solution. It is important that thorough surface cleaning is made since it precedes the plating operation. Plating is executed for many reasons: improved appearance, wear resistance, corrosion resistance, higher electrical conductivity, light reflectance, better electrical contact and grater surface smoothness (Granta Edupack, 2024d, R1)

The majority of metals can be electroplated. Non-conductive materials and polymers must be coated with a conductive material to be electroplated. To prevent the coating breaking or peeling, surface preparation, cleaning and case are essential. The thickness in coating usually ranges from 1 to 50 microns, though the routine thickness Is up to 1mm. By using other processes e.g. hot dipping, cladding or thermal spray you can spread a thicker coating while also producing more conveniently and cheaper. The range for temperature in the process is between 5-80 Celsius. The easiest metal where electroplating can be applied is aluminium, it has the best coatability. After that comes mild steel and brass copper. Some electroplating can have internal stresses, this can be reduced by heat treatment. (Granta EduPack, 2024d, R1)

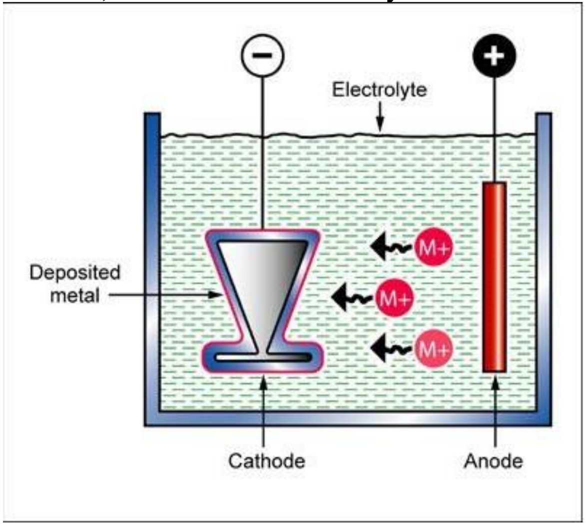


Figure 4: Electroplating, Schematic Drawing

2.7 EMC (Electromagnetic Compatibility)

Adamczyk, A (2023) explains EMC (Electromagnetic Compatibility) at the ability of electronic devices and systems to function correctly in their electromagnetic environment without causing or experiencing interference. EMC ensures that devices can operate as intended without introducing intolerable electromagnetic disturbances to other devices in the same environment (Shao, Y.C, 2022). EMC is crucial in the design and operation of electronic systems to prevent malfunction and ensure reliable performance. It is essential for maintaining the quality standards of products and improving industry competitiveness. EMC compliance is necessary for all modern electronics, which must meet specific standards to avoid interference (Shao, Y.V., 2022).

EMI (Electromagnetic Interference) is the disturbance caused by electromagnetic waves that adversely affect the performance of electronic circuits or systems. EMI can originate from various sources, including power systems, electrical devices and environmental factors (Trzynadlowski, A.M., 2007). EMI shielding is essential to prevent electronic malfunctions and ensure the proper functioning of devices. EMI can cause minor annoyances or severe disruptions, including safety-critical system failures (Williams, T., 2010) EMI shielding materials, such as, graphite, graphene nanoplatelets, graphene oxide, carbon black cobalt and nickel, are necessary to protect human health from the harmful effects of electromagnetic radiation (Mousave, S.M ., et al, 2022). Shielding helps maintain the reliability and efficiency of electronic systems, especially in environments with high electromagnetic pollution (Sharma, G.K., James, N.R., 2021). EMI shielding ensures that the devices meet regulatory standards for electromagnetic emissions and immunity (Mathur, P., Raman, S., 2020).

Sathish, K.K., (2021) states that metals and alloys have been commonly used for EMI shielding due to their high electrical conductivity and shielding effectiveness. However, they have drawbacks such as heavy weight, corrosion and rigidity. Modern EMI shielding materials include polymer composites, nanomaterials and conductive polymers, which offer advantages like lightweight, flexibility, and better corrosion resistance (Sharma, G.K., James, N.R., 2021). These materials can be tailored to specific applications, including aerospace and automotive industries.

3. Methodology

3.1 Strategies for using a new material – System P-Diagram

3.1.1 System P-Diagram

System P-Diagram is method that is developed by Von Regius, B., (2006), to describe a system as defined by system boundary. It describes measurable system input and output signal(s). By identifying the input and output signals designers get a clear idea of what the designed component is expected to do and what is required to provide the intended system output/function. In this method, control parameters are also identified that designers can use to change output. These control parameters affect the system output and can be changed by the engineering team in development phase. To get a complete picture of the whole system the noise parameters are also identified in the System P-Diagram. The noise parameters are unavoidable parameters that disturb the intended output of a system and are often not easy to control (Von Regius, B., 2006). This method makes it easier to determine a new concept design.

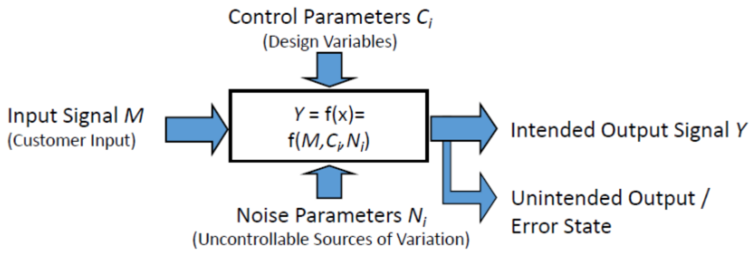


Figure 5: System P-Diagram

3.1.2 The strategy: translation, screening, ranking and documentation

Ashby, M (2014) explains in his book, chapter 3.4 The Strategy: translation, screening, ranking and documentation (Figure 3.6), the strategy of matching a material to design by four steps; translating, screening, ranking and documentation. Ashby, M explains the following steps like this (p. 38-42):

- **Translating:** This step is about converting the design requirements into a prescription for selecting a material. This happens by identifying the constraints that the material must meet and the objectives that the design must fulfil. To help identifying the translating requirements in Ashby book, chapter 3.4, table 3.1 Function, constraints, objectives and free variables shows strategy of four steps that helps the boundaries of the design. In Ashby book, chapter 3.4, table 3.1 (page 40) Function, constraints, objectives and free variables shows strategy of four steps that helps the boundaries of the design. Table 3.1; The steps are explained in this way:
    - **"Function**: What does the component do?" (p.40)
    - **"Constraints**: What non-negotiable conditions must the material meet?" (p.40)
    - **"Objectives**: What aspects of performance are to be maximized or minimized?" (p.40)
    - **"Free variables**: What parameters of the problem is the designer free to change?" (p.40)

- **Screening:** This step is about eliminating candidates that cannot do the job at all because one o more of their attributes don't meet the requirements set by the translating.

- **Ranking:** This step is about finding the materials that survive the screening step. Here how well a candidate that has passed the screening gets measured. Here, maximising or minimising a single property maximising performance. The best materials for a light, stiff tie-rod are those with the greatest value of the *specific stiffness*, E/ρ , where E is Young's modulus and ρ is the density.

- **Documentation:** After ranking a short list of candidates that meet the constraints and that maximize the stiffness and minimize the mass, research case study or prevoius use of each material to know more details about each material. Pricing, availability, details of corrosion behavior environments and warnings of its environmental impact or toxicity are important factors to help choose the material that is most suitable for the design.

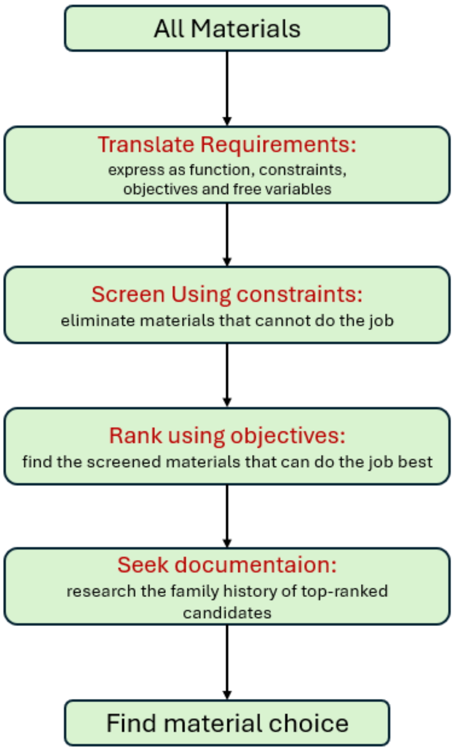


Figure 6: The strategy: Translation, Screening, Ranking, and Documentation

3.2 Granta EduPack

Granta EduPack offers interactive and visually engaging software designed to support student learning. It comes in two editions, with the full version including a complete set of data and tools. This version is structured into three progressive levels, ensuring that students access materials relevant to their stage of study. Across all levels, the software provides an extensive and regularly updated database of materials and manufacturing processes. Additionally, it includes self-guided learning resources to challenge advanced learners and support those who need extra help, making it a versatile asset for educators.

3.3 Schelkunoff Formulas

The schelkunoff formulas, also known as Schelkunoff's method, are primarily used in the field of electromagnetics, particularly for analyzing wave propagation in waveguides. This method is a semi-numerical approach that helps compute electromagnetic waves in hollow and cylindrical pattern and the propagation constant, which are essential for understanding how electromagnetic waves behave in these structures (Pham, H.D., et al 2018).

The formula decomposes the shielding effectiveness in two main components according to Peng, M and Qin, F (2021):

- Reflection Loss (R): This term accounts for the loss of electromagnetic waves due to reflection at the surface of the shielding material.
- Absorption Loss (A): This term represents the loss of electromagnetic waves as they propagate through the shielding material and are absorbed.

Curtiss Fox. J (n.d) created, during a project, a calculator with the purpose of calculating the shielding effectiveness. The formula below is used to calculate shielding effectiveness at certain thickness of material:

$$20\log \quad \cdot \frac{\eta 0}{4\eta s} + 20\log \quad \cdot e^{\frac{t}{\delta}} = R(dB) + A(dB)$$

- where $\eta 0$ is the intrinsic impedance of free space ~337 [ohms]
- ηs is the impedance of shielding material $\frac{1}{\sqrt{2\pi f \mu \sigma}}$ [ohms]
- t is the thickness of shielding material [mm]
- δ is the skin depth of shielding material $\frac{\sqrt{2\pi f \mu}}{\sigma}$ [μm]
- f is frequency [Hz]
- μ is permeability of free space $4\pi \cdot 10^{-7}$ H/m
- σ is the conductivity of material 10^{7} S/m

By using this formula, the shielding effectiveness can be calculated for copper, aluminum, nickel and CVD graphene. Conductivity of copper and aluminum is 5.80 x 10^{7} S/m respective 3.78 x 10^{7} S/m Conductivity of nickel is 1.43 x 10^{7} S/m, according to the Matmake website (2025). As mentioned in *2.5.1* the conductivity of CVD graphene layer is 1.46 10^{7}S/m.

The relative magnetic Permeability of copper and aluminum is 1 according to Curtiss Fox, J (n.d). Glathart, J.L (1939) claims that the relative magnetic permeability of Nickel is 3.6. The magnetic relative permeability of CVD Graphene is chosen to be 1.

The thickness of metals is 65 μm and the thickness of CVD graphene is zero since it's a 2D material. To measure the shielding effectiveness at different frequencies, the materials will be tested at high and low frequencies, 300 MHz respective150 KHz.

3.4 Creo Parametric 3D Modeling Software

Creo is a 3D CAD solution that helps accelerate product innovation to build better products in a fast way. Creo allows engineers to seamlessly make concepts, designs, analyze and validate products. The software has features technologies thar allow design engineers to simulate and optimize products for weight, performance, cost and sustainability.

4. Results

4.1 Strategies for using new materials

4.1.1 System P-diagram

System P-diagram introduces boundaries of housing. The system shows the input signal that gets processed by the control parameters and noise parameters that affect the output signal.

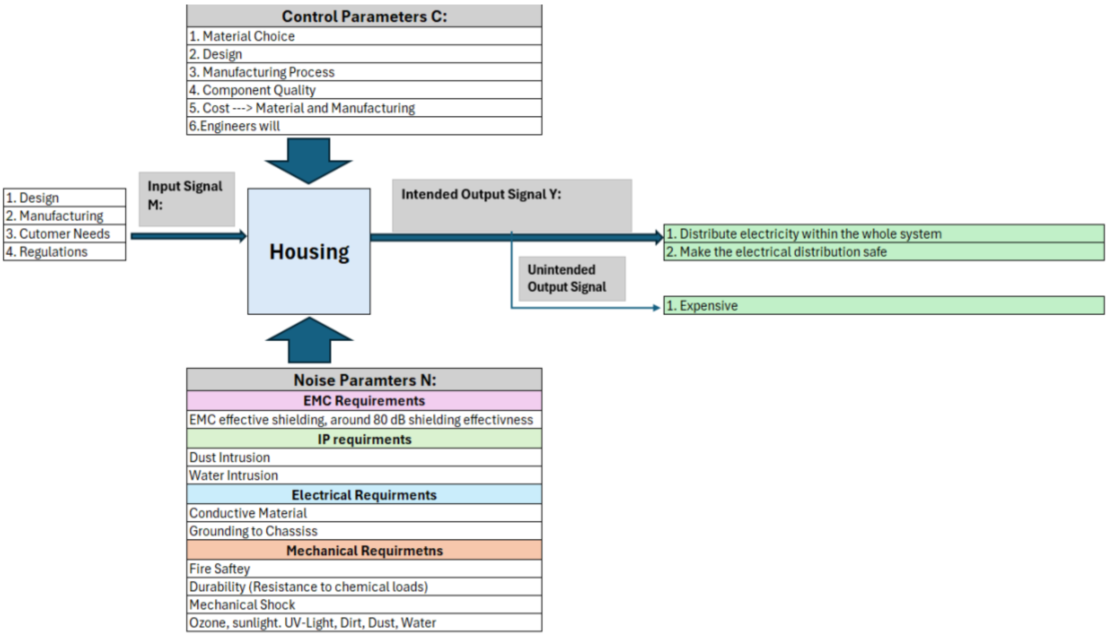


Figure 7: System P-Diagram for PDU (Power Distribution Unit) Housing

4.1.1.1 New concept design

Understanding the boundaries of the system using method 3.1.1, a new concept design is introduced. In this concept design the cooling plate is separated from the housing and it’s introduced using the CAD software Creo Parametric. The new concept design has 4 assembled parts.

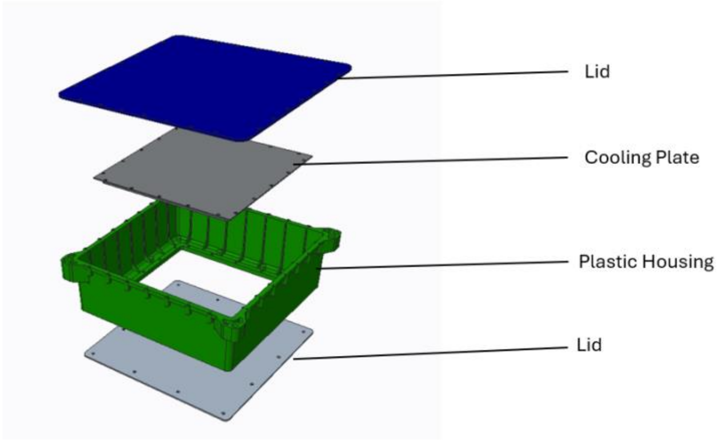


Figure 8: New Concept Design of PDU (Power Distribution Unit) Housing

4.3 Material Properties using EduPack

After searching through all available polymers in EduPack using 3.1 and 3.2, it turns out that PEEK (10% glass fiber) covers the mechanical and IP requirements and it’s also recyclable. PEEK(10% glass fiber) has almost similar properties to today's used alloy EN AC-44300+DF. The table below contains relative properties of EN AC-44300+DF and PEEK (10% glass fiber). Granta EduPack (2024a) R1.

Table 1: Plastic Material for New Concept Design PEEK (10% glass fiber) VS Current Alloy EN AC-44300+DF Used in Current Design

Propertis	**PEEK (10% glass fiber)**	**Today used alloy (EN AC-44300+DF)**
Density	1370 – 1390 kg/m^3	2650 – 2710 kg/m^3

Price	690 – 767 SEK/kg	29.6 – 40.4 SEK/kg
Young’s Modulus	5.52 – 6.5 GPa	73.5 – 76.5 Gpa
Yield Strength	103 – 120 Mpa	124 - 137 Mpa
Tensile Strength	107 – 125 MPa	228 - 252 Mpa
Elongation	4 – 4.5 % Strain	1 – 1.2 % Strain
Hardness	27 – 29 HV	75 – 83 HV
Fatigue Strenght at 10^7 cycles	41.1 – 49.7 Mpa	81 – 94 MPa
Melting point	343 °C	582 – 648 °C
Maximum Service Point	220 – 250 °C	170 – 200 °C
Thermal Conductivity	Low/Insulater 0.3	124 – 166 W/m.°C
Flammability	Self-extinguishing	Self-extinguishing
Climate Change CO2-eq, recycling	5.05 – 5.58 kg/kg	11.8 – 13 kg/kg
Embodied Energy, recycling	90 – 99.5 MJ/kg	162 – 179 MJ/kg

4.4 CAD Simulation Results using Creo Parametric

4.4.1 Stress Simulation Result

The simulations show the behavior of aluminum and PEEK (10% glass fiber) when a force is applied on the housing. The pick stress of aluminum and PEEK (10% glass fiber) is around 66 MPa respective 48 MPa.

Figure 9: Stress Simulation for PEEK (10% glass fiber) and Alloy EN AC-44300+DF

4.4.2 Displacement Simulation Result

The simulations show the behavior of aluminum and PEEK (10% glass fiber) when a force is applied on the housing. The displacement of aluminum and PEEK (10% glass fiber) is around 0.2 mm respectively 0.9 mm.

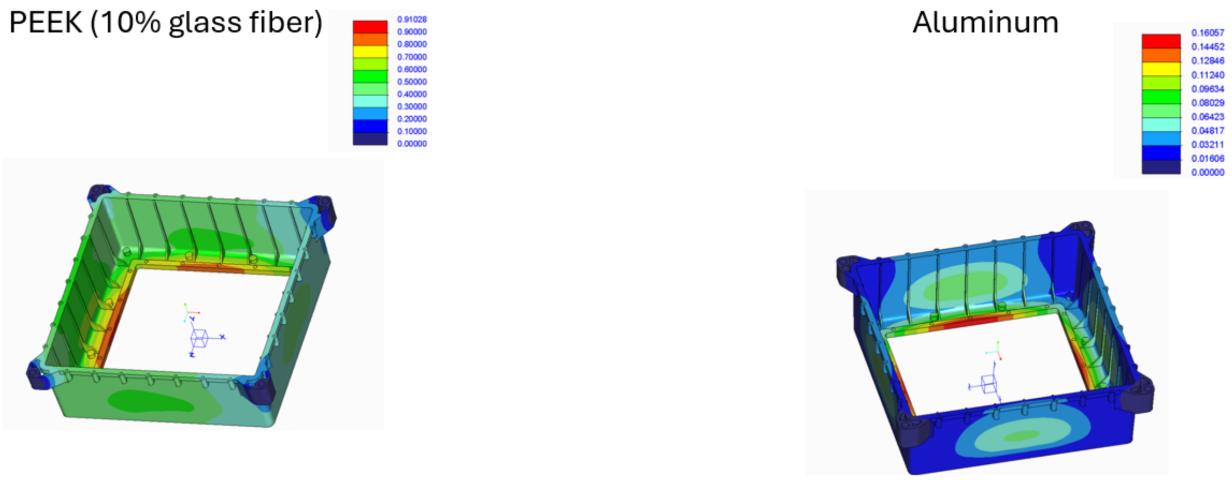
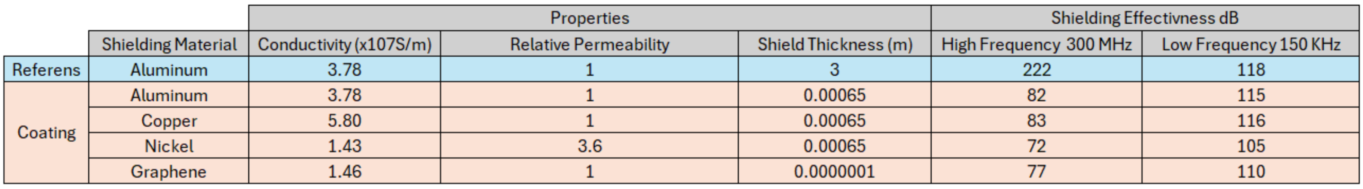


Figure 10: Displacement Simulation for PEEK (10% glass fiber) and Alloy EN AC-44300+DF

4.5 Shielding Effectiveness of coating using Schelkunoff's formula

By using Schelkunoff's formula the table shows results of the shielding effectiveness of different metals and graphene coating at low and high frequency. The thickness of metals coating 65 μm and according to the results aluminum and copper have similar shielding effectiveness. Nickle coating has almost similar shielding effectiveness to aluminum and copper. Graphene has zero thickness since it is a 2D material and the used conductivity is CVD graphene. The relative permeability is chosen to be one. It turns out that graphene has similar shielding effectiveness to other metals.



		Properties			Shielding Effectivness dB	
	Shielding Material	Conductivity (x107S/m)	Relative Permeability	Shield Thickness (m)	High Frequency 300 MHz	Low Frequency 150 KHz
Referens	Aluminum	3.78	1	3	222	118
Coating	Aluminum	3.78	1	0.00065	82	115
	Copper	5.80	1	0.00065	83	116
	Nickel	1.43	3.6	0.00065	72	105
	Graphene	1.46	1	0.0000001	77	110

Figure 11: Shielding Effectiveness of Current Alloy EN AC-44300+DF VS Shielding Effectiveness of Metal and Graphene Coating

5. Discussion

5.1 New concept design

Since the cooling requires thermal conductivity and other requirements it gets separated from the housing in this concept design. By separating the cooling plate from housing, it becomes easier to choose a plastic material that meets mechanical and IP requirements. In this concept design the housing is divided into four parts, the manufacturability of each part gets easier since the parts are designed in simple forms. Thereby the cost of this concept is probably higher than the current design, due to increased assembly time. Since the study is only on a concept level it's not possible to determine a final cost. The final cost considers the material and manufacturing cost. Using plastic in this concept will reduce the weight of housing significantly, since plastic is lighter than aluminum in general.

Plastic housing can cover mechanical and IP requirements such as fire safety, durability, water and dust intrusion. Electrical end EMC requirements will still not be covered by only using plastic, since plastic is not conductive. Plastic can be conductive by getting coated with a conducive material, the coating gives the material more protection from fire and plastic aging. The combination of conductive material coating on plastic covers all four requirements' categories.

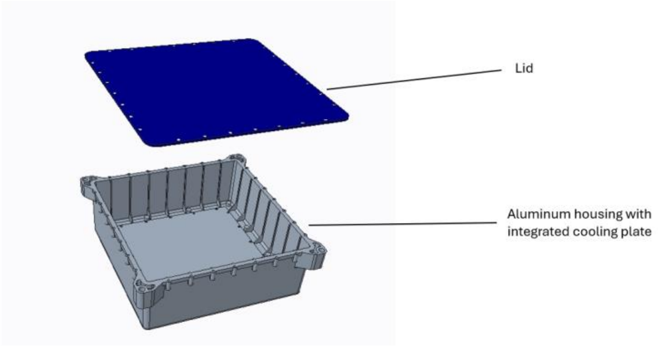


Figure 12: Current Design of PDU (Power Distribution Unit) Housing

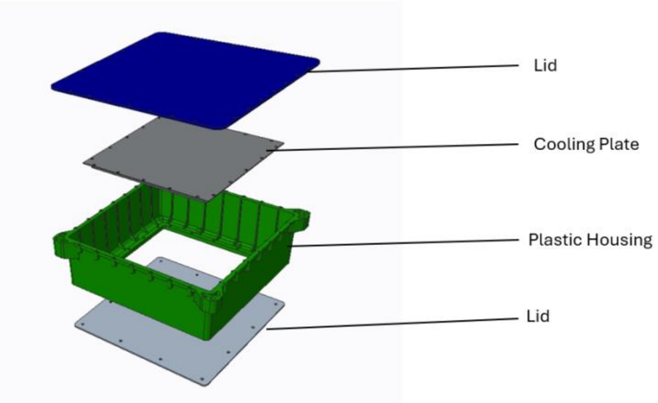


Figure 13: New Concept Design for PDU (Power Distribution Unit) Housing

5.2 PEEK (10% glass fiber) VS Aluminum

PEEK (10% glass fiber) is widely used in the automotive industry due to its high mechanical properties and low density. The mechanical properties of PEEK (10% glass fiber) are almost close to the current used alloy EN AC-AlSi10Mg (Fe) except the young's modules. By using this plastic, the weight of housing gets reduced by 48%.

The young's modulus of PEEK (10% glass fiber) is low, which refers to the stiffness. Young's modulus refers to how much a material can stretch or compresses at pulls or pushes. This means that PEEK (10% glass fiber) is more flexible, and the housing can be bended easily because the young's modulus is low. The flexibility affects the water and dust intrusion in the housing. Since the lids are assembled on the housing in both top- and downside the flexibility will be prevented. Also, a clever design can make sure that the structure of housing is non-flexible (rigid). The tensile strength of plastic is 107 MPa while it's 228 MPa in the current used alloy EN AC-AlSi10Mg (Fe). The tensile strength refers to the maximum force a material takes before it brakes. By designing the housing with clever structure, the mechanical properties of the PEEK (10% glass fiber) housing can be as strong as the current aluminum housing. According to EduPack (2024e), PEEK (10% glass fiber) can be processed by using one of the methods, injection molding.

The results show that the climate change CO2-eq and the Embodied energy of PEEK (10% glass fiber) are almost 50% less than in the current alloy EN AC-AlSi10Mg (Fe). It means that PEEK (10% glass fiber) emitts 50% less carbon dioxide and needs 50% less energy to recycle one kg. Both PEEK (10% glass fiber) and EN AC-AlSi10Mg (Fe) are recyclable, but PEEK (10% glass fiber) has less environmental impact. The housing of PEEK (10% glass fiber) can be manufactured in the required size by injection molding, according to Ashby, M (page 27)

As mentioned above the housing must be conductive to make the concept design complete with all requirements. To make the plastic housing conductive two different solutions are presented in the study. Solution 1 is using graphene on PEEK (10% glass fiber). Solution 2 is coating metal (Aluminum, Copper or nickel) on PEEK (10% glass fiber). In the next chapters both solutions are discussed further.

Table 2: Plastic Material for New Concept Design PEEK (10% glass fiber) VS Current Alloy EN AC-44300+DF Used in Current Design

Propertis	**PEEK (10% glass fiber)**	**Today used alloy (EN AC-44300+DF)**
Density	1370 – 1390 kg/m^3	2650 – 2710 kg/m^3
Price	690 – 767 SEK/kg	29.6 – 40.4 SEK/kg
Young’s Modulus	5.52 – 6.5 GPa	73.5 – 76.5 Gpa
Yield Strength	103 – 120 Mpa	124 - 137 Mpa
Tensile Strength	107 – 125 MPa	228 - 252 Mpa
Elongation	4 – 4.5 % Strain	1 – 1.2 % Strain
Hardness	27 – 29 HV	75 – 83 HV
Fatigue Strenght at 10^7 cycles	41.1 – 49.7 Mpa	81 – 94 MPa
Melting point	343 °C	582 – 648 °C
Maximum Service Point	220 – 250 °C	170 – 200 °C
Thermal Conductivity	Low/Insulater 0.3	124 – 166 W/m.°C
Flammability	Self-extinguishing	Self-extinguishing
Climate Change CO2-eq, recycling	5.05 – 5.58 kg/kg	11.8 – 13 kg/kg
Embodied Energy, recycling	90 – 99.5 MJ/kg	162 – 179 MJ/kg

5.3 CAD Simulations Results

The simulations are done to compare the behavior of today used alloy EN AC-44300+DF. A force that is equal to the weight of components inside PDU are applied to check the behavior of these two materials. Thereby these simulations provide the designers a good picture of how the final housing design of plastic should be to meet all requirements.

5.3.1 Stress Simulation Results

According to the CAD simulation stress and displacement results different behaviors between Aluminum and PEEK (10% glass fiber) are observed. The stress simulations show that the stress forces are higher in aluminum and are concentrated on the ribs in the. While on PEEK (10% glass fiber) the stress forces are lower and not concentrated on the ribs. This is because of the low young’s modulus of PEEK (10% glass fiber) where it has more flexibility and there by the stress forces get distributed throughout the housing.

5.3.2 Displacement Simulation Results

The displacement CAD results show that Aluminum has much less displacement and as seen in the results the displacement appears on the edges. While in PEEK (10% glass fiber) the displacement is much higher and distributed throughout the housing. This confirms that the low young’s modulus of PEEK (10% glass fiber) where it has more flexibility and thereby the stress forces get distributed throughout the housing and cause high displacement in the whole housing.

5.4 Alternative solution 1: Coated Graphene on PEEK (10% glass fiber)

Using graphene in the industrial heavy applications is still new and under development. However, to coat graphene on a plastic we need to consider the type of produced graphene graphene that meets the electrical and EMC requirements. The coating method of graphene must also be considered since it affects the adhesion and the quality of graphene. Electrochemical graphene exfoliation or Liquide phase graphene exfoliation are recommended production methods to use for the PDU housing. According to the results we observe that graphene has better EMI shielding effectiveness than other metals. Although, graphene has difficulties in its production methods and processability. The balance between the production cost, quality processability of graphene makes it difficult to use in the industry. Since the standards of graphene processability, production methods and graphene types are not described commonly in the world, the properties of produced graphene can be different. As today there is not an exact definition that define the type of graphene based on exact characteristics. In other words, the properties of for example electrochemical graphene exfoliation can be different from place to another depending on the quality of production method. Electrochemical Graphene Exfoliation or Liquid Phase Exfoliation are recommended to be used for PDU housing.

The high surface area and conductivity of graphene makes electrochemical graphene exfoliation suitable EMI shielding and electrical requirements in PDU housing. Electrochemical exfoliation is ideal for its large-scale production due to its low cost and simple implantation. During that process defects and oxidation can appear and thereby the quality could be affected. Strategies such as using specific electrolytes and optimizing process parameters are recommended to consider during the production process.

Liquid phase graphene exfoliation gives the surface of housing high scalability and compatibility with few defects and oxygen-containing. This method produces graphene with scalability on the surface of PDU housing.

Graphene enhances the mechanical properties of the polymer PEEK (10% glass fiber). Which improves mechanical properties of PDU housing.

5.5 Alternative solution 2: Coated Metal (Aluminum, Copper or Nickel) on PEEK (10% glass fiber)

Using metal coating on PEEK (10% glass fiber) are the second solution to meet the EMC and electrical requirements. This solution is probably cheaper than graphene coating due to its easy processability and production. Metal coating makes PDU housing conductive and thereby EMI get shielded and the housing can be grounded to the chassis. According to the results Aluminum, Copper and Nickel can shield the EMI in different qualities of shielding effectiveness. By using 65 microns thickness of these metals the shielding effectiveness differs from 72 dB to 82 dB of emissions depending on the metal. This depends on the conductivity and the relative permeability of these metals. Coating two different metals with the same thickness for each metal can potentially improve the shielding effectiveness, but since one-metal coating meets the EMC requirements two-metals coating is not considered in this study.

To use this solution the plastic housing must be non-bendable to avoid cracking in the coated metal since it's not as flexible as plastic. Metal Flame Spray coating method is recommended in this solution due to its easy processability and adhesion. Electroplating coating could also be used in this solution, but it requires more steps than Metal Flame Spray coating since the surface of plastic housing must be plus charged in this case.

6. Conclusions

Theoretically, changing the design of PDU housing and using PEEK (10% glass fiber) will reduce the weight of housing by ~50% and this is an important purpose. The final cost of the new design must be sorted out and compared to the cost of the current design. The cost can be calculated by adding the cost of materials, manufacturing, coating, and assembly.

Technically in solution alternative number 1, in the practical world the production of graphene must be confirmed and tested. To produce graphene, a standard of production must be made and considered to assure the same quality and properties of each manufactured PDU housing. After having standard of graphene production, a graphene coating method on PEEK (10% glass fiber) must be developed and standardized to assure the needed quality of graphene for conductivity and EMC shielding.

If solution alternative number 2 is considered, the differences between aluminum-, copper-, and nickel coating must be studied more in technical, economical and practical terms.

After final design is done the housing must pass the requirements tests according to the following:

- Mechanical shock test according to ISO 16750-3 test 4.2.2.2.
- Durability (Resistance to chemical loads) test according to ISO 16750-5.
- Moisture test according to Volvo STD 515-0004
- Dust intrusion test according to ISO 20653, IP first code number= IP6KX
- EMC testes and certification according to UN/ECE R10.06
- Grounding housing to chassis shall be tested.

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