

DESIGN AND PRODUCTION OF MOTORCYCLE REAR SHOCK ABSORBER PROTECTION USING THE LAMINATION PROCESS

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Abstract: *This paper presents a case study focused on the rapid development of a replacement product, exemplified by the design and production of a protective cover for a motorcycle rear shock absorber, with the objective of mitigating potential supply chain disruptions. The development process encompasses product design, mold fabrication, and prototype manufacturing using composite materials and a hand lay-up lamination technique. The mold is designed through 3D CAD modeling of the component and produced using additive manufacturing (3D printing), which serves as a cost-effective and time-efficient solution for prototype tooling.*

Keywords: *composite material, lamination process, 3D CAD modeling, mold fabrication, 3D printing, prototype, replacement product.*

1. COMPOSITE MATERIALS

Composites are materials obtained by artificially combining two or more different materials (matrix and reinforcement) to achieve properties that neither component possesses on its own. They are multiphase materials with clearly defined phase boundaries, where two or more materials of different chemical compositions (metals, ceramics, polymers) and/or forms (particles, fibers, laminates or layers) form a unified structure with distinct phase boundaries.

The properties of composites depend on the properties of their components, as well as their chemical and constitutional compositions. By combining components, composites can achieve various combinations of properties, such as strength, stiffness, toughness, weight, high-temperature resistance, chemical stability, corrosion resistance, hardness, and electrical and thermal conductivity.

They are designed to provide high strength while maintaining low weight. When replacing steel, a weight reduction of 60 to 80% can be achieved, and in the case of replacing aluminium, the reduction ranges from 20 to 50%.

There are two primary constitutive components of composites:

- matrix – the base material with specific properties,
- phase or reinforcement – a material added to achieve the desired properties of the composite. The most common reinforcements are glass fibers, but they can also include carbon fibers, polymer fibers and others.

Composites are classified based on the matrix as:

- Metal Matrix Composites (MMC) – composites with a metallic matrix,
- Ceramic Matrix Composites (CMC) – composites with a ceramic matrix,

- Polymer Matrix Composites (PMC) – composites with a polymeric matrix.

Purpose of the matrix:

- it binds and integrates the reinforcement phase, transferring the load to it, while providing shape and rigidity to the structure,
- it protects the reinforcing phase (e.g. fibers) from chemical effects and mechanical damage,
- it ensures a good surface quality.

The matrix supports the fibers and binds them together in the composite material. It transfers all loads to the fibers, keeps the fibers in their designated positions and orientations, provides the composite with resistance to environmental conditions, and determines the maximum operating temperature of the composite (AMTH – Airframe, 2023).

Purpose of the Reinforcement Phase:

- load-bearing – in structural composites, fibers bear 70 to 90% of the load,
- providing strength, stiffness (elasticity), thermal stability, and wear resistance,
- ensuring electrical conductivity or insulation, depending on the intended use of the composite.

Based on the reinforcement phase, composites can be classified as:

- particle-reinforced composites,
- fiber-reinforced composites,
- layered composites – laminates and sandwich structures (laminated structures with a core).

1.1 Particle-Reinforced Composites

Particle-reinforced composites consist of uniformly distributed particles made of a hard and brittle material, embedded within a softer and more ductile matrix (Figure 1). The particles are typically composed of oxides, nitrides, and carbides.

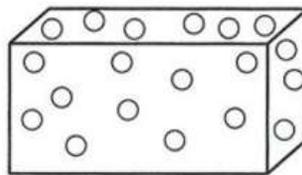


Figure 1: Illustration of Particle-Reinforced Composites (Filetin, 2006.)

1.2 Fiber-Reinforced Composites

In fiber-reinforced composites, the incorporation of strong, stiff, and brittle fibers into a softer, more ductile matrix significantly enhances strength, toughness, stiffness, and the "strength-to-density" ratio. The fibers can be ceramic, carbon (graphene), polymeric (e.g., aramid fibers known commercially as Kevlar fibers), glass fibers, metallic fibers, etc.

Fiber-reinforced composites are considered anisotropic materials because they exhibit significantly improved properties along the fiber direction.

The discontinuous fibers are also called whiskers. Whiskers are tiny single crystals that have very short fibers. They can be made of graphite, silicon carbide, silicon nitride, and aluminum oxide.

In Figure 2, various arrangements of fiber reinforcements are shown as described:

- a) continuous unidirectional fibers,
- b) randomly oriented discontinuous fibers (whiskers),
- c) orthogonally arranged fibers,
- d) multidirectionally oriented fibers.

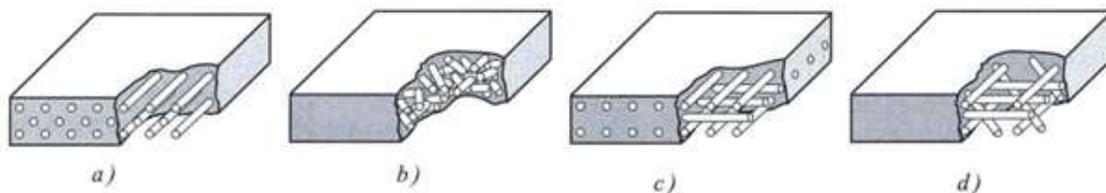


Figure 2: Fiber Orientation in Composite Materials (adapted from Filetin, 2006.)

1.3 Layered composites – laminates and sandwich structures

Layered composites can be constructed as solid laminates or as sandwich structures (Figure 3). A laminated structure with a core at the center is called a sandwich structure (AMTH – Airframe, 2023). Unlike laminate construction, which is solid, rigid, and heavy, a sandwich structure is equally strong but with much less weight (AMTH – General, 2023). Different types of cores used for manufacturing sandwich laminated structures include rigid foam, wood, metal, or a honeycomb layer made of paper, Nomex, carbon, fiberglass, or metal (AMTH – General, 2023).

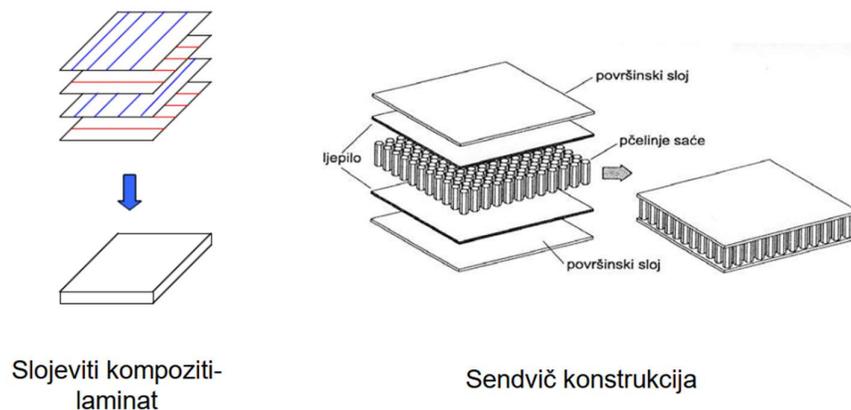


Figure 3: Layered composites (adapted from Filetin, 2006.)

2. DAMAGE TO COMPOSITES

2.1 Damage During Composite Production

Damage during production (Figure 4) includes porosity, microcracks, and delamination. Damage may involve edge notches, scratches, and cracks on the surface, damaged bolt holes, or impact damage. Production defects can include (AMTH – Airframe, 2023):

- delamination,
- areas with resin deficiency,
- areas with excess resin,
- bubbles, air pockets,
- wrinkles,
- voids,
- degradation due to temperature.

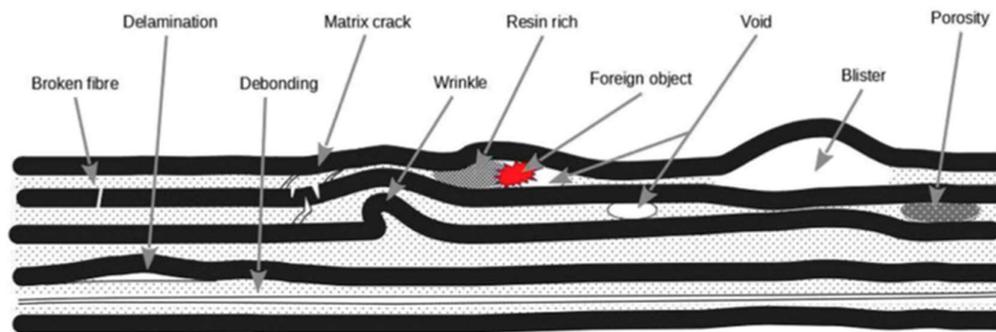


Figure 4: Composite damage during production (AMTH – Airframe, 2023.)

Delamination

Delamination or blooming/separation of layers (Figure 5) occurs due to cracks within the matrix or due to insufficient adhesion of the two materials to each other. Under higher loads, the delamination can expand and create major damage. The criticality of delamination depends on: dimensions, number of delaminations in a certain place, location (thickness of material, proximity or distance from edges) and load – compression or shear load leads to structural failure.

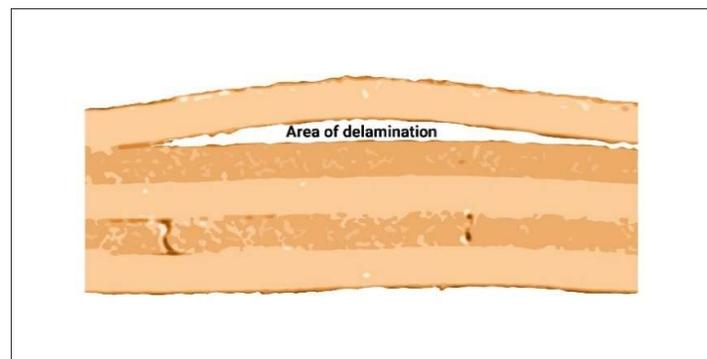


Figure 5: Delamination (AMTH – Airframe, 2023.)

Areas with resin deficiency or excess

A material with resin deficiency occurs when too much resin is released during the curing process or if not enough resin is applied during the wet application process. Areas with poor resin are indicated by fibers that come to the surface.

It is not bad if the material has too much resin, but it also adds weight to the structure.

Fiber breakage

Fiber breakage (Figure 6) occurs due to impact loading or overloading. Fiber breakage is an undesirable event because the fibers in a composite structure carry most of the load.

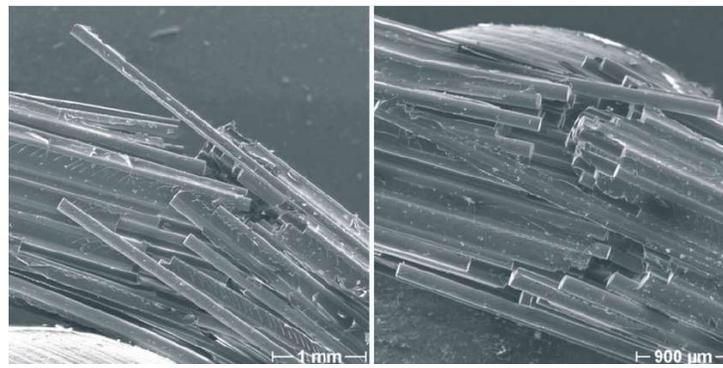


Figure 6: Enlarged view of fiber breakage in a composite (adapted from Filetin, 2006.)

2.2 Damage During the Use of Composite Materials

Damage during the use of composite materials includes:

- degradation of the composite due to environmental factors,
- impact damage,
- material fatigue,
- cracking due to local overload,
- fiber breakage,
- separation of the structure,
- delamination of layers,
- erosion.

Degradation Due to Environmental Factors

Degradation due to environmental factors, or material damage under the influence of external factors, can be caused by exposure to sunlight, moisture, chemicals, and extreme temperatures.

Cracking Due to Material Fatigue

Material fatigue occurs when the material undergoes constant changes in stress and load. Dynamic stress on the material leads to weakening and potential failure of the structure. Material fatigue can be prevented by proper dimensioning of the structure to avoid excessive loading at one point, as well as regular material inspections.

Fatigue damage or material fatigue can be broken down into three phases: crack initiation, crack propagation, and final rupture. Fatigue cracks in materials are detected during routine

inspection. The detected crack size and its critical dimension are key parameters for assessing damage tolerance as a function of material properties (Tavares, 2019). Cracks are generally detected using non-destructive testing techniques.

Material Erosion

Material erosion is the destruction of the material on the surface due to the action of a fluid jet (liquid, steam, or air). Erosion most commonly occurs on parts exposed to direct fluid impact. Figure 7 shows the process of erosion of composite material on the leading edge of an aircraft wing.

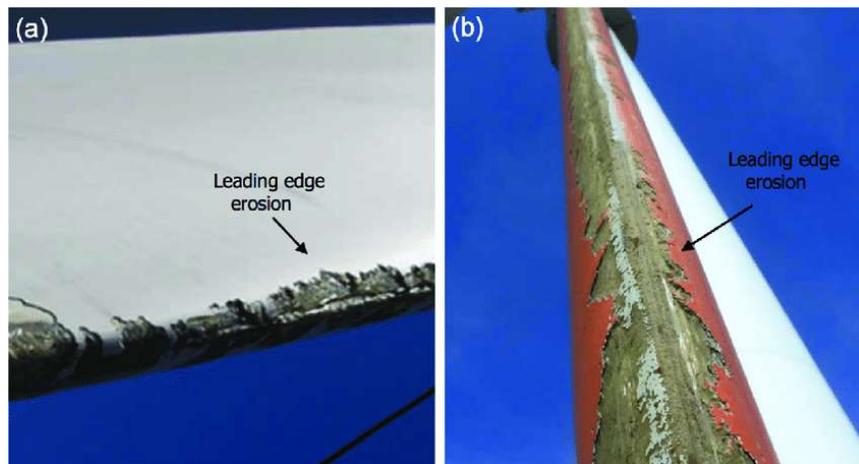


Figure 7: Erosion on the leading edge of an aircraft wing (AMTH – Airframe, 2023.)

3. FIBER-REINFORCED LAYERED COMPOSITES

Components made of reinforced plastic can be manufactured from solid laminates and sandwich structures. Layered composites are made of three or more layers of resin-impregnated fabrics laminated together in a wet state to form a solid flat surface or a surface shaped by a mold, representing solid laminates.

Fiber-reinforced fabric impregnated with resin in multiple layers constitutes a composite reinforced material. This is a high-tech material consisting of two primary components: the matrix and the reinforcing fibers. This type of composite stands out due to its excellent mechanical properties, including high strength, flexural strength, and low weight (Agarwal, 2006).

The matrix material, or matrix, can be polymeric (such as epoxy, polyester, or vinyl ester), metallic, or ceramic and serves as a carrier and support for the reinforcing fibers. The function of the matrix is to distribute the load to the reinforcing fibers, protect them from damage, and provide shape and stability to the entire composite.

The reinforcing phase or reinforcing fibers can be glass, carbon (carbon fiber), aramid (Kevlar), boron-based, or other types, depending on specific application requirements. The fibers give the composite exceptional strength, flexural strength, and durability, often surpassing the properties of traditional materials.

3.1 Advantages and Disadvantages of Fiber-Reinforced Composites:

Carbon and glass fibers offer an excellent strength-to-weight ratio, which makes fiber-reinforced composites highly suitable for structural applications where minimizing mass is of primary importance. Furthermore, these materials demonstrate good corrosion resistance, ensuring durability in various environmental conditions. The presence of reinforcing fibers substantially improves the mechanical performance of the composite, particularly its resistance to bending, tensile, and impact loads.

However, fiber-reinforced composites also present certain disadvantages and potential risks. Manufacturing processes are relatively complex and sensitive to processing parameters, which may lead to defects such as porosity, delamination, or improper fiber distribution. Their anisotropic behavior requires careful structural design, since mechanical properties strongly depend on fiber orientation.

3.2 Applications of Fiber-Reinforced Composites:

Fiber-reinforced composites are widely used in the production of lightweight and solid aircraft and automotive parts, thereby improving fuel efficiency. They are also used in the manufacturing of bicycles, tennis rackets, skis, and other sports equipment. Additionally, they are applied in the production of components for energy systems due to their high strength and resistance to extreme conditions. Their role is essential in driving innovation across many industries, and their widespread and growing use highlights their significance.

4. CASE STUDY OF MOTORCYCLE REAR SHOCK PROTECTION DESIGN AND MANUFACTURING

4.1 Product Development – Design and Tooling Model Creation

Product design is a key phase in the product development process. By combining engineering knowledge, creativity, and practical application, a product is created. The design process consists of multiple steps, from the initial idea to final production, ensuring that the product is designed and manufactured according to the desired requirements. It is essential to balance functionality, aesthetics, and economic factors to achieve a successful outcome.

So, product development begins with an idea. After the idea is conceived, the development strategy, marketing, and cost assessment are planned. This planning phase can be referred to as the "zero phase" because it is crucial for the project's further development. During this product creation process, various elements should be defined such as form and function of a product. The appearance and dimensions are determined to ensure compatibility in an assembly. Dimensions can be set at the beginning or the end of the design process, depending on the desired appearance. They must be adjusted for usability and aligned with other components if the product is intended to connect or integrate with another.

Once a variant is selected, the product is shaped using a 3D CAD application such as SolidWorks. SolidWorks is a widely used modeling software applied globally for product development, design and manufacturing. (Tran, 2022).

The design process as part of product development is as follows:

- Creating the basic shape of the rear shock absorber protection for a motorcycle (Figure 8),
- Final shaping 3D model of the product (Figure 9),
- Mold design process based on 3D model as its negative surface (Figure 10).

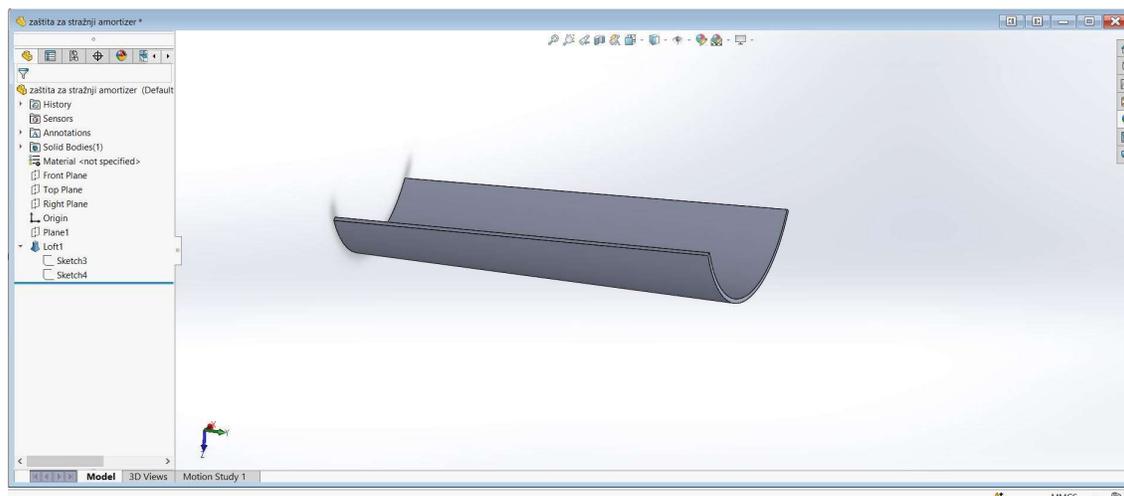


Figure 8: Basic design of the rear shock absorber protection – CAD model (author)

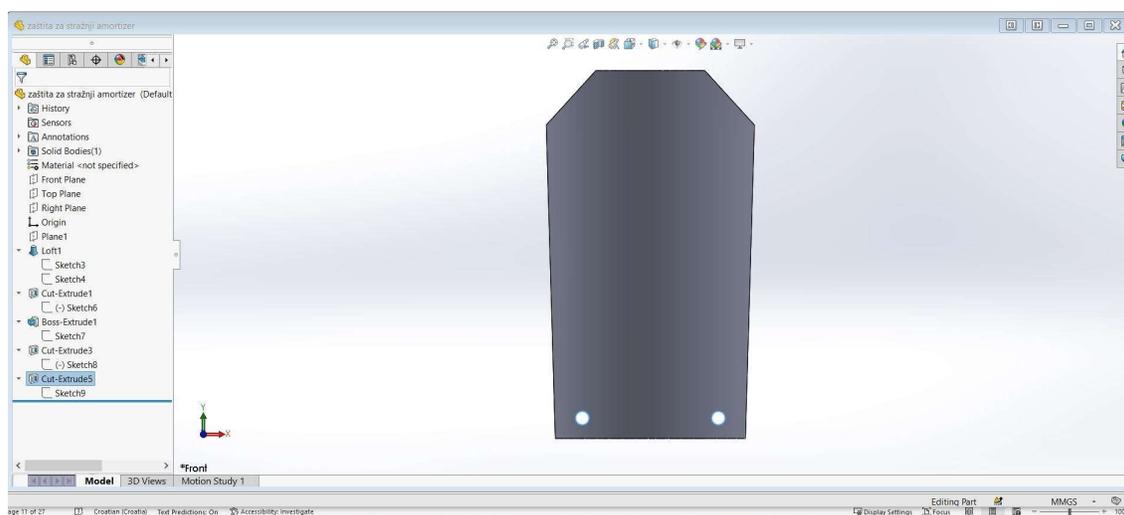


Figure 9: Final design of the rear shock absorber protection – CAD model (author)

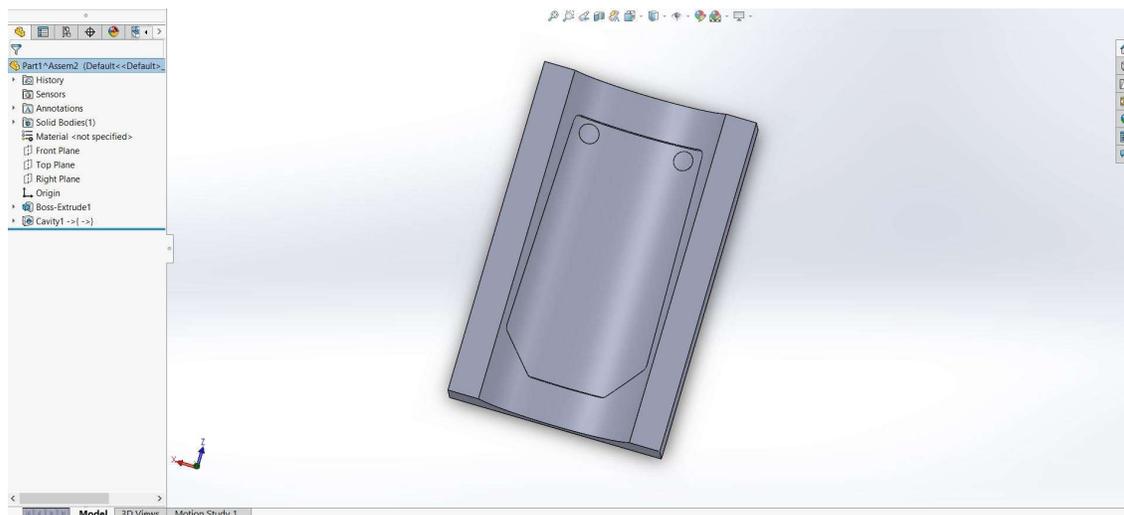


Figure 10: Final design of the mold for the rear shock absorber – CAD model (author)

4.2 Mold Production Using 3D Printing

For 3D printing of the mold, the fused deposition modeling (FDM) technology was selected. Fused deposition modeling is sometimes referred to as fused filament fabrication (FFF). FDM builds parts layer by layer by selectively depositing melted material along a predefined path based on a 3D model (Figure 11) (Kerr, 2022).

Thermoplastic polymers are available in filament form, including acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyethylene terephthalate glycol (PETG), and thermoplastic elastomer (TPE), as well as thermoplastic polyurethane (TPU) (Wallach Kloski, 2021). Polylactic acid (PLA) was used for 3D printing of the final physical mold.

The operation of a 3D printer is managed by a program called a slicer. The mold is positioned in a way that allows for simple and safe printing, preventing any damage during the 3D printing process. As a slicer program, OrcaSlicer was used (Figure 12).

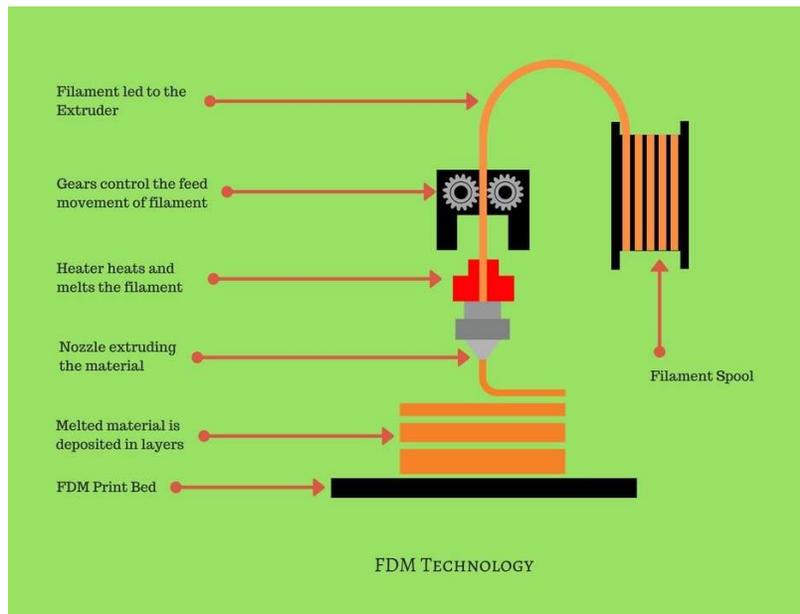


Figure 11: Illustration of FDM 3D printer operation (“FDM 3D Printing,” 2024)

The internal structure of the printed product is selected, and if necessary, a support structure is created to prevent cracking or tipping during printing. The 3D printing of a mold for the protection of a motorcycle's rear shock absorber requires a support structure to prevent deformation of the mold in certain areas (colored green in Figure 12).

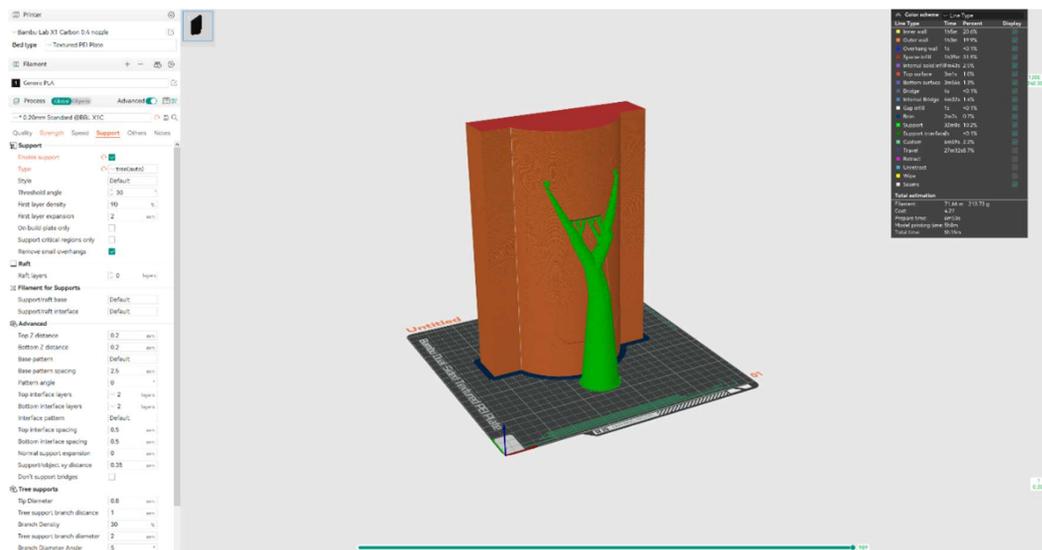


Figure 12: Part of the mold with a support structure – CAD model (author)

4.3 Physical 3D Printing of the Mold

After completing the previous design phases, the 3D printing of the mold begins. Before starting, the printer is calibrated and heated. Figure 13 shows the mold for the protection of the

motorcycle's rear shock absorber during the 3D printing process. The finished mold serves as a tool for further prototype development. 3D printing was done on the Bambu Lab X1C 3D printer.



Figure 13: Final appearance of the mold, using FDM printing technology (author)

4.4 Preparation for the Lamination Process

The rear shock absorber protection for a motorcycle is made from composite carbon fibers using the lamination process. Lamination is a complex process that involves bonding two or more layers of prepreg material. Prepreg (short for "pre-impregnated") is a composite material made from fibers (typically glass, carbon, or aramid) that have been pre-impregnated with resin, usually epoxy, before being used in production. The layers are stacked to achieve the predetermined mechanical properties of the composite.

The preparation of the mold consists of several steps. The first step is mold processing, specifically sanding, to eliminate any unwanted indentations, protrusions, or sharp edges. The second step is cleaning the mold to remove any unwanted substances that could later affect the quality of the final product. The third and most critical step is treating the mold with release agents. Release agents are specialized chemicals that prevent the product from sticking to the mold during production. After applying the release agent, the mold must be cured at the same temperature as the final product. In this case, mold was cured on 70°C. Once this process is completed, the mold is ready for use. Figure 14 shows the mold after sanding, while Figure 15 shows the mold after applying the release agents.

The carbon fiber material, designated LTC216-3 (Figure 16), which is impregnated with resin, is cut according to pre-determined patterns and is placed onto the mold. The first layer must be applied with precision to ensure both structural integrity and visual quality. Figure 17 illustrates the appearance of the first laminate layer. A high-temperature peel ply fabric is applied to the sixth and final laminate layer. This fabric is removed after curing, leaving a neat, textured surface on the outer layer of the product.

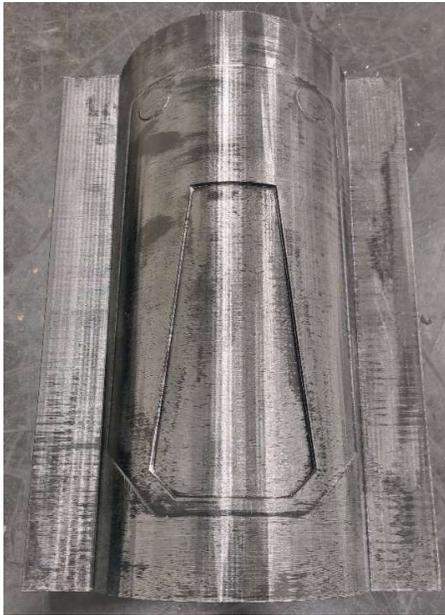


Figure 14: Mold after sanding (author)



Figure 15: Mold after applying release agents (author)

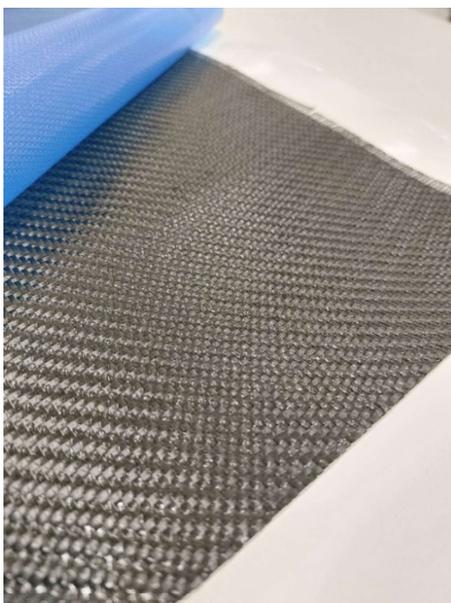


Figure 16: LTC216-3 material (author)



Figure 17: First layer of prepreg (author)

4.5 Manufacturing the Rear Shock Absorber Protection Using Lamination Process

The lamination process consists of laying multiple layers of prepreg into the mold. The layers are arranged in a predefined manner and must be placed carefully and precisely. Each layer of material can consist of one or more cut pieces. The number of cut pieces per layer is determined based on the desired appearance and the technical specifications required for the product. In this case, one cut piece of material was applied per laminate layer. During the lamination process, the product must be vacuumed (up to 1 bar) to ensure optimal bonding between the layers (Figure 18).



Figure 18: Vacuuming the laminate (author)

The production process begins with curing the product in an autoclave (Figure 19). An autoclave is a pressure chamber designed to optimize various processes by maintaining constant control over parameters such as temperature, pressure, and vacuum throughout the entire curing cycle. Typical autoclave conditions for epoxy prepregs are temperature 120 – 180 °C and pressure 5 – 7 bar (0.5 – 0.7 MPa). Because of PLA mold material, the curing temperature was lower than specified and was 60 °C.



Figure 19: Autoclave ("Autoclaves," 2024)

After curing, the mold must be removed from the vacuum bag, and the laminate must be separated from the mold. Any excess material that is not part of the final product but was used to facilitate removal must be trimmed. Figure 20 shows the product immediately after being removed from the mold.

The product is then further trimmed to match the shape of the final design. Cutting lines marked on the product are followed, and the necessary holes for mounting bolts are drilled. The final rear shock absorber protection, made from six hand-cut layers, is shown in Figure 21. After product testing, the installation of the motorcycle's rear shock absorber protection is illustrated in Figure 22.



Figure 20: Product after removal from the mold
(author)



Figure 21: Product after finishing
(author)



**Figure 22: Product installation
(author)**

5. CONCLUSION

The use of 3D printing has greatly improved the manufacturing process. Molds created through 3D printing are highly durable and are produced faster than using other technologies. Molds are mostly resistant to high temperatures, depending on the type and specifications of the printing material used. The design and development of the 3D model was carried out using the CAD applications, and the FDM printing technology. By using 3D printer, the manufacturing process of the motorcycle's rear shock absorber protection was completed very quickly. The lamination process contributes to manufacturing efficiency as well, allowing for a quick transition to a finished product prototype. The use of composite material in the lamination process ultimately ensures a light, strong and durable product. The placement of prepreg material requires great precision. It is essential to follow guidelines for material positioning and vacuuming to ensure proper bonding between layers for a successful final product.

By following all the described steps in the lamination process, the product prototype is ready for mechanical analysis or installation as an individual replacement product that is not available on the market due to interrupted distribution chains, as well as for preparation for serial production as a replacement product. The proposed solution leverages digital manufacturing and composite material technology to enable localized, on-demand production.

Although the rapid development of additive manufacturing technologies suggests the possibility of direct part fabrication, current material and structural constraints still favor composite-based solutions for mechanically demanding applications. Specifically, currently available thermoplastic polymers and short-fiber-reinforced filaments cannot yet match the mechanical

performance, stiffness, and long-term durability of continuous fiber-reinforced composite laminates. Although direct fabrication of the component by 3D printing may be suitable for rapid prototyping or low-load applications, laminated carbon fiber composites provide superior structural performance. Therefore, the proposed hybrid approach, combining additive manufacturing for rapid mold production with composite lamination for final part fabrication, represents a technically justified and efficient solution.

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