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A New Approach of Study Towards Environmental Impact Assessment for Sustainable Product Design

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Abstract. Environmental impact assessment is essential to meet the objectives of sustainable product design. The environmental impact should be measured at the initial stages of product design to minimize the impact. In this paper, we demonstrate the application of a computer-aided design (CAD) tool to measure the environmental impact during the design stage. SolidWorks software uses the Life Cycle Assessment (LCA) model to measure the environmental impact such as energy consumption, carbon footprint, and air-water pollution. The spur gear model is used to demonstrate the process of assessing environmental impact using the CAD tool. The input parameters such as material, manufacturing process, region, transportation method, and product usage play an essential role in the environmental impact. The results indicate that the environmental impact can be reduced by optimizing the parameters by selecting alternatives using the CAD tool at the initial design stage.

INTRODUCTION

Bruntland Commission reports sustainability as “development that meets the needs of the present without compromising future generations’ ability to meet their own needs” [1]. Sustainability has become an essential topic for researcher communities across the world. In a competitive market environment, the concept of sustainability is critical for survival. The most challenging part is attracting the attention and focus on realigning the development on the sustainable path concerning all the sectors such as society, manufacturing, and engineering. The life-cycle of any manufactured part or product impacts the three components of sustainability; environment, society, and economy are shown in **Error! Reference source not found.**. As a result, a multidimensional and integrated approach is required to establish the connection between society, environment, and economy [2, 3]. The life-cycle of a product represents the production until the end of the product’s life, including the design stage, material extraction, manufacturing, transportation, usage duration, and recycle. The decisions made at the product design stage produce a maximum impact on sustainability. Modern designers, engineers, and technicians need a tool that automates and supports the selection

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of various parameters [4]. Sustainable design is a thorough, systemic approach to develop a sustainable environment, socially equitable, and economically viable products. Sustainability can be amalgamated in all the stages of the product design process, and many standalone software tools have been developed and applied.

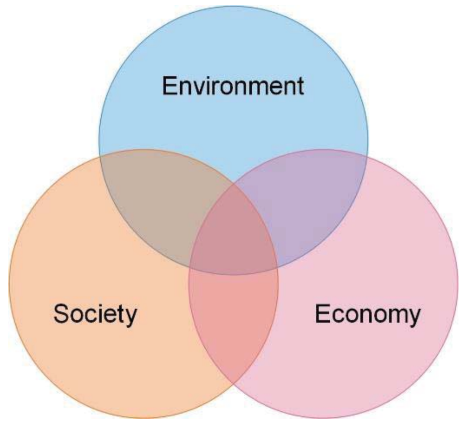


Figure 1. Dimensions of sustainability

The concept of sustainable design is understood by defining the term "design". According to Ahmad et al. (2018), the design is assumed to be an idea, conceptual sketch, or object [5]. An effective generation and development of an idea convert into a product. The four stages in a conventional design process are shown in **Error! Reference source not found.**. The first stage consists of planning and defining the problem statement. The conceptual design aims to identify the function, specification generation, and generation of alternate conceptual design. The preliminary design stage enables the comparison and assessment of the conceptual design. The preliminary design stage helps to create metrics to select the best conceptual design for the final stage. The final stage is a detailed design that includes more detailing and embodiment of the selected design.

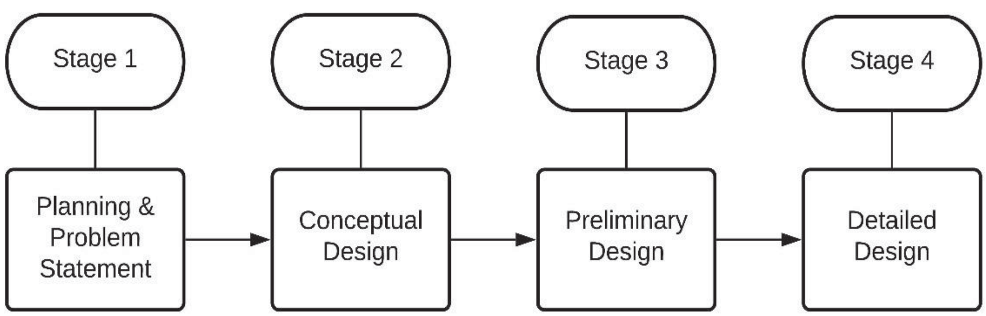


Figure 2. Design process

Sustainability should be implemented at all stages of the conventional design process to create a sustainable product design. Sustainable product design plays a significant role in the life-cycle of a product from extraction of raw material, processing, part manufacturing, assembly, usage, and disposal.

In this context, the environmental impact assessment of spur gear is presented to understand the concept of sustainability by using a computer-aided design (CAD) tool. The part modeling of a spur gear, assignment of materials followed by the sustainability analysis to find the environmental impact in terms of environmental indicator provided by the CAD tool [6, 7]. The main objective is to reduce the environmental impact by trying out different alternatives or options with certain constraints. This paper is divided into six sections: Section (II) provides an overview of methodology implemented in SolidWorks sustainability; Section (III) describes the SolidWorks sustainability interface; Section (IV) provides an overview of input parameters; Section (V) presents the results and discussions, and Section (VI) draws the conclusion.

METHODOLOGY

Figure 3 shows the methodology for sustainability by using SolidWorks during the design stage. The initial step begins with converting a 2D sketch into a 3D part model in SolidWorks. The SolidWorks sustainability add-in is activated to perform the sustainability analysis. The input parameters such as material, manufacturing process, manufacturing region, transportation, and product application are given to the sustainability module. The sustainability assessment based on the input parameters is processed to display the environmental indicators such as carbon footprint, energy consumption, air acidification, and water eutrophication [8]. SolidWorks Sustainability provides real-time feedback depending upon the user input and dynamically updates the dashboard data.

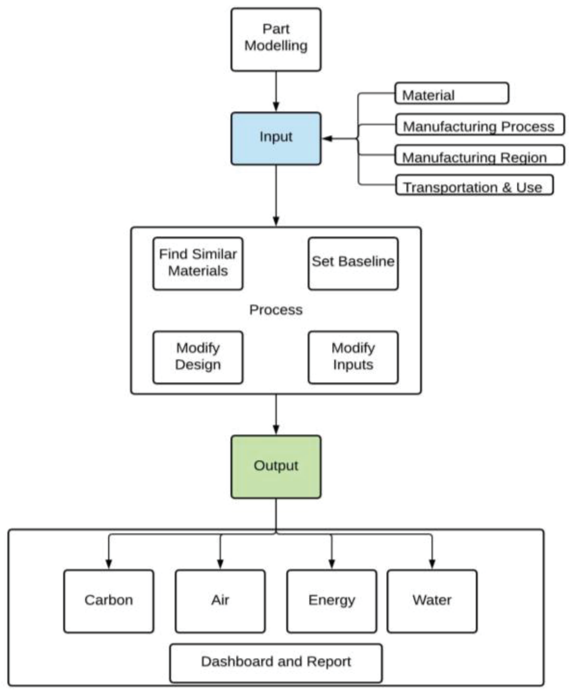


Figure 3. Methodology

Material is selected and applied from the material database provided in SolidWorks. Material is classified based on the type of the material, such as steel, iron, alloys, plastics, metals, non-metals, woods, as shown in Fig. 3.

SOLIDWORKS SUSTAINABILITY

Figure 4 shows the SolidWorks Sustainability interface integrated into the software. The Sustainability add-in can be activated in part or assembly mode in SolidWorks. The SolidWorks sustainability needs input parameters such as material, manufacturing process, manufacturing region, transportation, and usage details. Different types of materials and their properties are available in the SolidWorks database, such as metals and non-metals depending upon the application of the part. SolidWorks allows the selection of an alternate material to minimize the environmental impact by keeping the existing material as a baseline material [9]. The manufacturing region shows the geographical map or regions to select the manufacturing location such as India, Asia, Australia, Japan, etc. The manufacturing process enables the selection process to be followed to manufacture the parts. The transportation option provides to select the mode of transportation of the part or assembly by train, boat, plane, and road—finally, the selection of the region, where the part or assembly is going to be used. There are other input options such as built to last, recycling method, paint option, etc., as input parameters for SolidWorks sustainability.

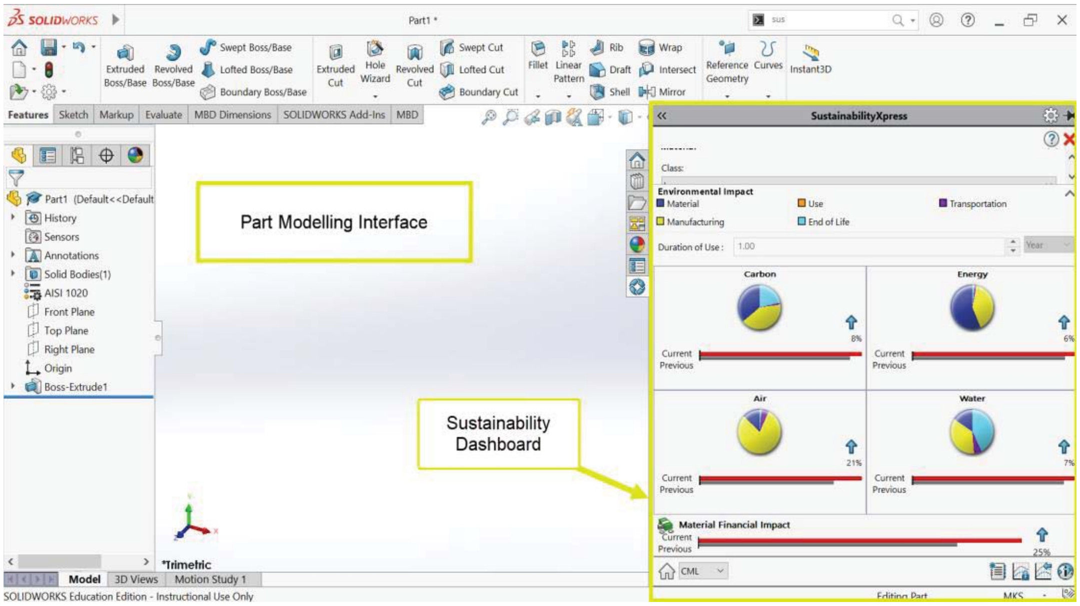


Figure 4. SolidWorks Sustainability interface

Environmental Factors

Carbon footprint, total energy consumption, air acidification, and water eutrophication are the four measurable environmental factors to display the environmental impact based on the input parameters for the entire life-cycle of a product [10]. Figure 5 shows the environmental factors [8].

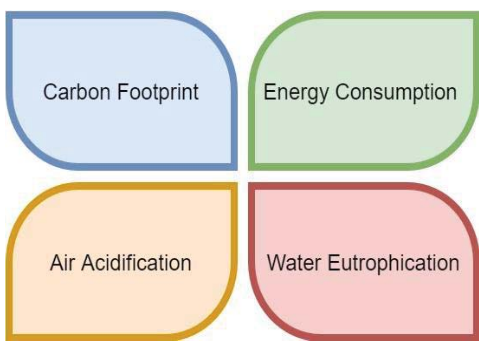


Figure 5. Environmental factors

- Carbon Footprint: Measures the amount of carbon dioxide and equivalent elements due to the burning of fossil fuels.
- Total Energy Consumption: The amount of energy spent on the product life-cycle.
- Air Acidification: Sulphur dioxide (SO_2) and Nitrogen dioxide (NO_x) are the main constituents of air pollution. The emissions due to fossil fuel burning lead to acidification and acid rain.
- Water Eutrophication: It is a measure of contamination of the water ecosystem due to chemical fertilizer and wastewater. Eutrophication causes an imbalance in the water ecosystem and disturbs aquatic life.

PARAMETERS

In this section, a simple part model of spur gear is used to demonstrate the process of SolidWorks sustainability. Figure 6 shows the spur gear part in the SolidWorks interface. The sustainability option is available in part and assembly mode in SolidWorks and is accessed under the “Evaluate” tab of the SolidWorks interface.

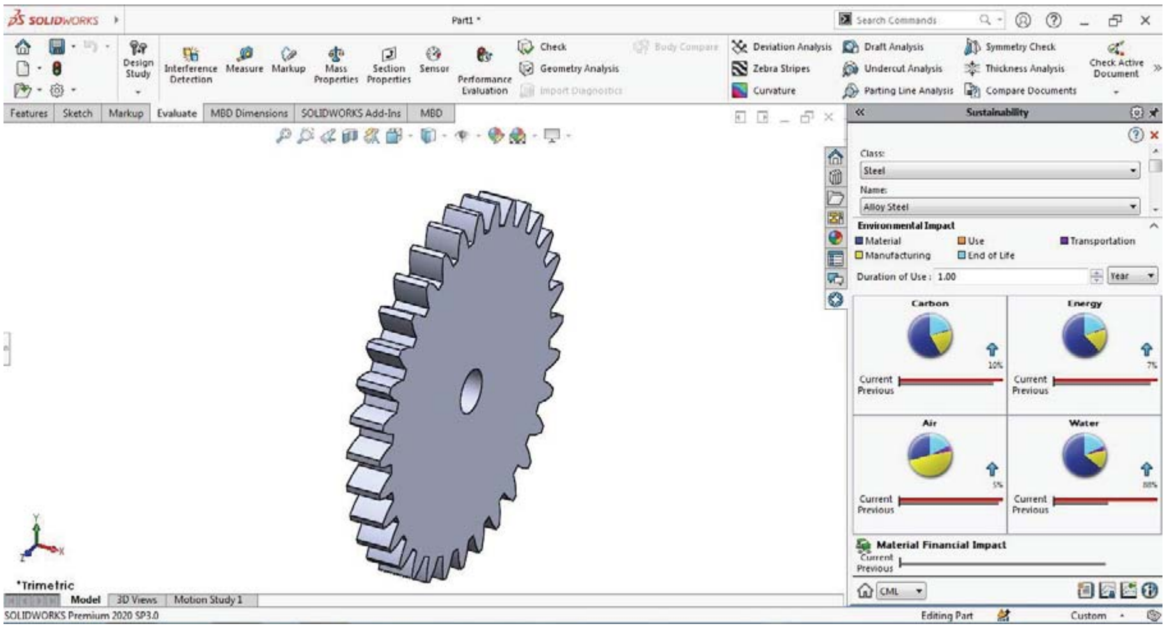


Figure 6. Spur gear model

The environmental impact is carried out by selecting the class or name of the material in the sustainability. In this case, Alloy Steel is selected for the initial readings. The other parameters selected for the assessment is shown in Table 1.

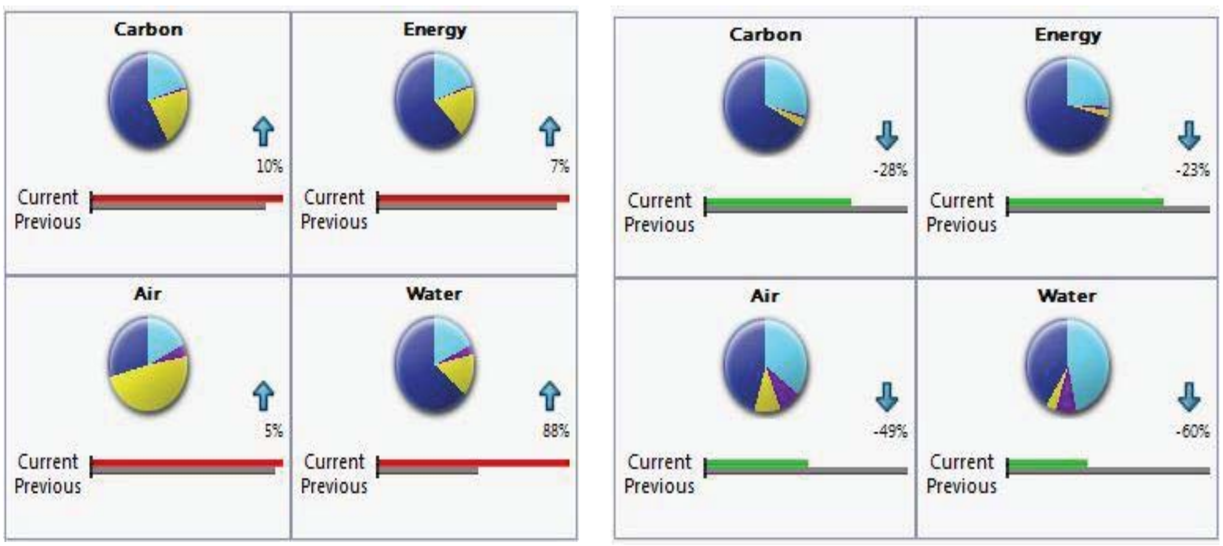
TABLE 1. Input Parameters

	Input	Option
Materials	Class	Steel – Alloy Steel
	Weight	2388.93 grams
Manufacturing	Region	Asia
	Built to last	1.00 year
	Process	Milled
	Paint	No Paint
Use	Region	North America
Transportation	Boat	12392 km
End of Life	Recycled	33.00 %
	Incinerated	13.00 %
	Landfill	54 %

The input parameters offer different methods to manufacture the part, such as milling, die casting, extrusion, forging, sand casting, sheet metal, stamped sheet metal, turning, etc. Furthermore, electricity consumption rate, natural gas, and scrap rate can be added depending upon the current market rate to improve the assessment. If the part is undergoing the painting process, the type of paint is selected from the drop-down menu [11]. Different types of paint, such as water-based, solvent-based, and powder-coated options, are available as input parameters.

RESULTS AND DISCUSSIONS

SolidWorks sustainability dynamically updates the environmental impact depending upon the input parameters. In this paper, the environmental impact is measured based on the "Centre for Milieukunde, Leiden (CML)" method. SolidWorks sustainability also provides "The Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI)" method for the assessment [12]. Figure 7 shows the pie chart of environmental impact. The pie chart consists of quantitative distribution of input parameters such as material, manufacturing, transpiration, and end of life. The carbon footprint is measured in kilogram (kg) of carbon dioxide equivalent (CO_{2e}), including other greenhouse effect gases. The energy consumption is measured in terms of Joules (J) or Mega Joules (MJ). Air acidification is measured in terms of a kilogram (kg) of sulfur dioxide equivalent (SO_{2e}). Finally, the water eutrophication is measured in terms of a kilogram of phosphate (PO_{4e}) or nitrogen (N) equivalent, indicating the concentration of nitrates and phosphates in the water, leading to algae growth due to the reduction in oxygen level in the water.



(a) (b)

FIGURE 7. Environmental impact assessment for Alloy Steel (a) and AISI 2020 (b)

Figure 7 (a) shows the environmental impact measured for the alloy steel material. The alloy steel material is selected as a baseline or a reference, and all other input parameters are unchanged. SolidWorks sustainability also offers the material financial impact depending upon the current market rate. In this analysis, the material financial impact is not included in the assessment. The software allows selecting other material from the database depending upon the requirement or condition. The alternate materials can be selected, and the graph is dynamically updated, which becomes easier to choose the materials. Figure 1 (b) shows the graph for American Iron and Steel Institute (AISI) grade steel (AISI 2020). The graph indicates that the carbon footprint is reduced by 28%, energy consumption by 23%, air acidification by 49%, and water eutrophication reduced by 60% with respect to the base material.

Furthermore, each graph provides more insight and the parameters responsible for the environmental impact. SolidWorks sustainability allows generating a report on the analysis, including the input parameters and environmental impact data. Figure 8 shows the report generated for the AISI 2020 material. The report consists of detailed information regarding the environmental impact, such as the quantity of carbon dioxide equivalent, amount of energy consumption in Joules (J) or Mega Joules (MJ), the quantity of sulfur dioxide equivalent, and phosphate content. From the report, 6.7 kg of CO_{2e} is released compared to 9.3 kg of CO_{2e} produced by the alloy steel. A total of 84 MJ of energy is consumed for AISI 2020 material compared to 110 MJ by the alloy steel [13-16]. A 0.02 kg of SO_{2e} is produced from the AISI 2020 compared to 0.056 kg of SO_{2e} by alloy steel, and 2.9E-3 kg of PO_{4e} is produced from AISI 2020 compared to 7.2E-3 kg of PO_{4e} by alloy steel.

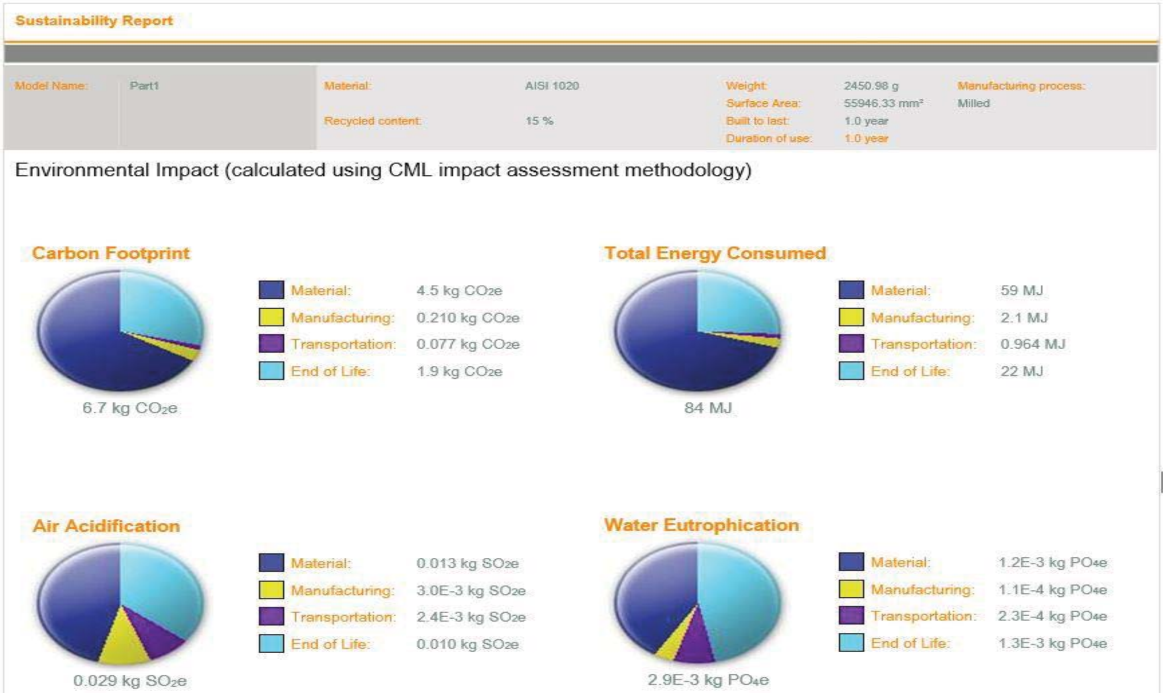


Figure 8. SolidWorks sustainability report

CONCLUSION

The CAD model of spur gear is designed in SolidWorks to perform the sustainability analysis. The input parameters such as material, manufacturing region, transportation, and usage region are entered. SolidWorks sustainability performs the Life-cycle assessment (LCA) starting from the raw material to the end of life. The environmental impact is measured in terms of carbon footprint, energy consumption, air acidification, water eutrophication for the baseline material (alloy steel) assigned for the spur gear. This is followed by selecting alternate materials from the database to minimize the environmental impact. The metrics indicate that selecting AISI 2020 material for the spur gear over the alloy steel reduces the environmental impact without disturbing the other constraints. Furthermore, the environmental impact can be reduced by selecting other parameters such as modifying the design, manufacturing process, region, mode of transportation, etc. The results show that SolidWorks sustainability can be used during the initial stage to implement the sustainable design factor and support the decision-making process.

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Aerodynamic simulation of car bumper products made of rattan fiber composite material

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Aerodynamic Simulation of Car Bumper Products Made of Rattan Fiber Composite Material

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Abstract. The development of composite materials by utilizing environmentally friendly natural fibers aims to become an alternative material to replace conventional materials. Natural fiber composite materials are continuously being developed to make automotive components. This study aims to develop a car bumper made of rattan fiber composite material combined with fiberglass. The research is focused on simulating the aerodynamics of the designed bumper. The simulation uses Computational Fluid Dynamics (CFD) software, with an assumed maximum speed of 120 km/h. Based on the simulation results, it is found that the maximum pressure that occurs on the surface of the bumper is 8,421e+02 Pa, where this pressure is almost evenly distributed on the frontal surface of the front bumper. Surface pressure due to air flow when the vehicle is running at high speed certainly has an influence on the strength and rigidity of the structure of the bumper. Therefore, this study will continue with a structural strength analysis. The results of this study will be a reference for further research.
Keywords: Simulation, CFD, aerodynamics, bumper, rattan composite material.

INTRODUCTION

The use of rattan fiber as a composite material in the automotive sector is very open. On the other hand, Indonesia has an enormous potential in producing rattan fiber. Rattan fiber has numerous beneficial characteristics such as recyclable, renewable, environmentally friendly, and having a good strength [1], [2].

In this study, a car bumper product was developed using epoxy rattan fiber composite material. Bumper products serve to protect the car from collisions, provide an aerodynamic effect on the car, and give an impression on the car's aesthetics. The higher the speed of the car, it requires good and precise aerodynamic support. The aerodynamic component at the front of the car is very important because it splits the wind first when the car is moving at high speed. Therefore, to create balance at the front, the designers were very concerned about the bumper. At the same time, cars also use air as a cooling aid. A good bumper design will increase the aerodynamic effect and at the same time help cool the radiator and intercooler. A good bumper design can also help bypass the wind that passes through the engine bay. Air volume and air velocity entering from the front can function to cool the intercooler [3-10].

The focus of the research is to analyze the aerodynamics of the car bumper product design which was developed using rattan fiber composite material. Aerodynamic analysis is very important because a good bumper product provides good aerodynamic effects, making the car safer and more comfortable when used, especially at high speeds. [5], [6], [11-15.] The results of the aerodynamic simulation are the basis for the further development of car bumpers, especially in terms of safety.

METHOD

Aerodynamic analysis is done by conducting simulations using Computational Fluid Dynamics (CFD) software. The software used is Siemens Simcenter Star CCM+ version 2021.1.1. In this study, the front bumper of the car was developed. The rattan fiber composite material has the following characteristics:

TABLE 1. Properties of rattan fiber reinforced composite material

Density	4.7E-2 kg/m^3
Young's modulus	6280 MPa
Poisson's ratio	0.27
Yield strength	22.1MPa
Ultimate tensile strength	32.65MPa

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In CFD analysis, the number and type of mesh cells are important factors for the success of the simulation iteration process in order to achieve a convergent value with high accuracy, along with data on the type of mesh and the number of cells built from the meshing process [3], [6], [7], [9], [11].

TABLE 2. Meshing Process

Name	Feature of mesh	Parameter of mesh
Mesh of totally domain	Automatic meshing Tetrahedral mesh Prism Layer Volume mesh refinement Surface remaster	Number of Cells: 10,277,402 Number of Faces: 20,343,978 Number of Vertex: 1,996,125
Mesh of solid domain	Tetrahedral mesh Volume of mesh refinement	Number of Cells: 257,812 Number of Faces: 431.098 Number of Vertex: 85.143
Mesh of fluid domain	Tetrahedral mesh Prism Layer Volume of mesh refinement	Number of Cells: 10,019,590 Number of Faces: 19,912,880 Number of Vertex: 1,910,982

Boundary Conditions in the aerodynamic simulation process as shown in Figure 1.

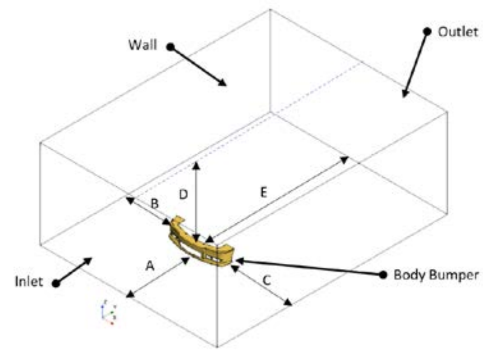

FIGURE 1. Isometric Boundary Conditions

TABLE 3. Data of Simulation

Parameters	Condition	Parameters
Fluid	Air Temperature: 30°C Dimension: A, B, C & D = 1x length total of bumper E= 2x length total of bumper	ρ: 1.164 kg/m^3 µ: 1.872e-5 kg/m·s v: 1.608e-5 m^2/s Dimension of Domain Fluid: P: 6,500mm L: 5,000mm T: 2,500mm
Inlet	Velocity inlet:	U: 120 km/h (orientation: Y+)
Outlet	Pressure Outlet	P: 0 Pa (Gauge Pressure)
Wall	Non-Slip Wall Conditions	Symmetry wall is applied to the left, right, and top wall surfaces. Wall condition is applied to the lower wall surface
Body Bumper	Non-Slip Wall Condition Smooth surface	P: 1620.56mm L: 472mm T: 313.27mm Frontal surface area A: 3.562856e-01m^2
Gravity	Orientation: -Z	g: 9.81m/s^2
Computations	-Reynolds-Average Navier- Stokes (RANS)	-Realizable k-$\mathcal{E}$ two layer -Standard k-$\mathcal{E}$
Simulation solver	Implicit unsteady, Constant density Fluid, Segregate flow, two-layer Y+ wall treatment. Solid mechanics stress with Fluid to Structure Interactions, Rayleigh damping for stability	Material properties: Rattan fiber reinforced composite material Density: 4.7E-2 kg/m^3 Young's modulus: 6280 MPa Poisson's ratio: 0.27 Yield strength: 22.1MPa Ultimate tensile strength: 32.65MPa

The type of mesh used is a tetrahedral mesh type because it has a relatively optimal level of accuracy for computational effort and is suitable for reliable external flow simulations. The application of surface remesher is carried out so that the interface between the mesh surfaces of the fluid domain and solid domain can have a high level of interfacial conformity.

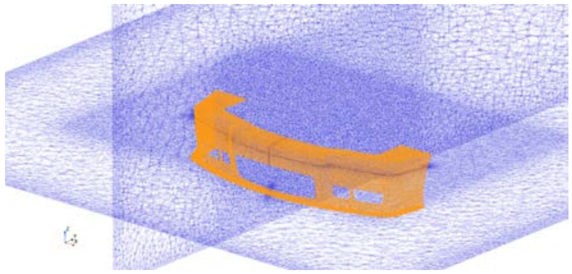

FIGURE 1. Isometric of Mesh

RESULT AND DISCUSSION

As shown in Figure 4, the residual value in the iteration decreases with the increase in the number of iterations. At the 300th iteration and above, the residual value in the continuity parameter is close to constant, namely 5e-6. It can be concluded that the results of this simulation have reached a converged condition.

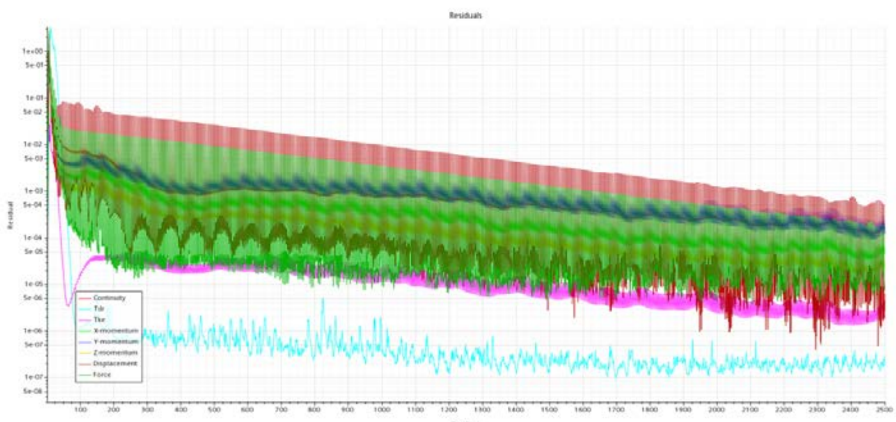

FIGURE 4. Iteration graph against residuals in bumper simulation

In addition, the convergence level is also indicated by monitoring the drag force results from the bumper as shown in Figure 5. The drag force values appear to be close to stable.

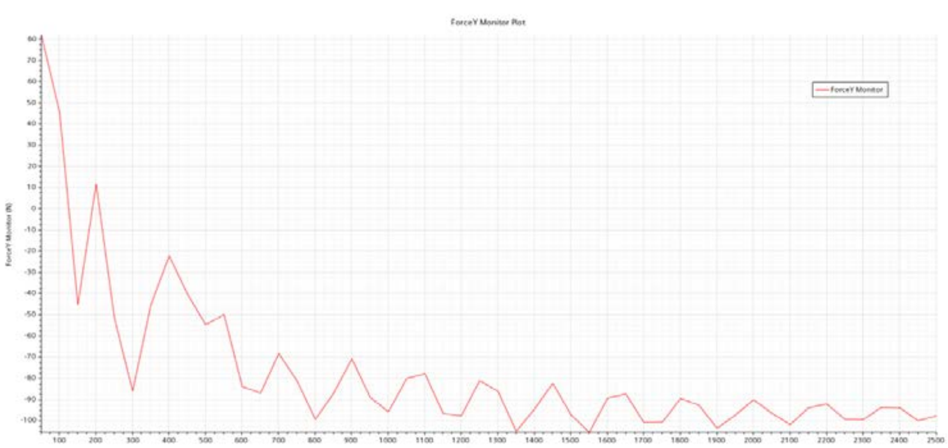

FIGURE 2. Iteration graph of the drag in the direction of Y axis

This study aims to determine the effect of air pressure on the vehicle bumper when the vehicle is moving at a speed of 120 km/h. The air flow that hits the surface of the bumper will cause surface pressure, measured by pressure per unit area. The pressure data is then integrated to get the drag force value. Then, the drag force in the frontal direction of the vehicle can be known. Figure 5 shows that the total value of the frontal force in the Y-axis direction is 97.774 N.

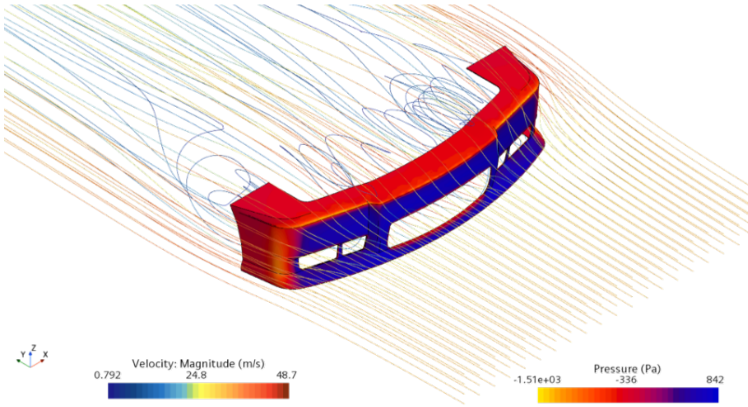

FIGURE 3. Streamline simulation results and pressure distribution on the bumper surface

The maximum pressure that occurs on the surface of the bumper is 8.421e+02 Pa, where this pressure is almost evenly distributed on the frontal surface of the front bumper. Surface pressure due to air flow when the vehicle is running at high speed certainly has an influence on the strength and stiffness of the bumper structure, so this research will continue with structural strength analysis. Figure 6 shows the results of the simulation of the pressure distribution on the surface of the bumper with the CFD process. In the middle area, there is a relatively uniform and high pressure, where the maximum surface pressure due to air velocity is 842 Pa. This is because stagnation pressure occurs in the middle of the bumper area where the surface of the bumper is in the form of an arch with a large enough curvature value, so that the air flow hits the surface near the perpendicular so that the normal force tends to be higher than the shear force. This stagnation pressure is also very clearly seen in Figure 8 where the greatest pressure occurs in that area. On the front surface of the left and right sides of the bumper, the air pressure is relatively lower due to the smaller curvature value of the curved surface of the bumper in this area. In this part of the bumper, the air is relatively easily deflected towards the side of the bumper so that the shear force is higher than the normal force [12-18].

Figure 9 shows the distribution of air pressure in the XY plane, the left and right-side surfaces and the upper surface have relatively low pressure. Airflow paths can also easily enter the middle and bottom airflow holes on the left and right of the bumper. However, backflow phenomenon occurs as shown in Figure 7 because the model used in CFD analysis does not include the car as a whole. Therefore, the area behind the bumper becomes empty and backflow occurs. However, because the focus of this study is to obtain the distribution of air pressure on the surface of the bumper, this backflow phenomenon can be ignored [12-18].

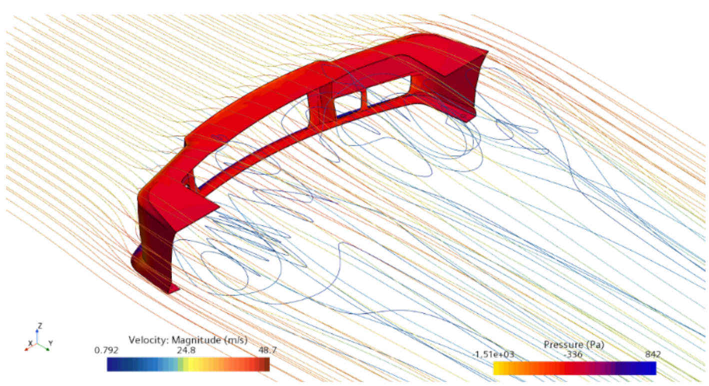

FIGURE 4. Backflow phenomenon on the rear bumper

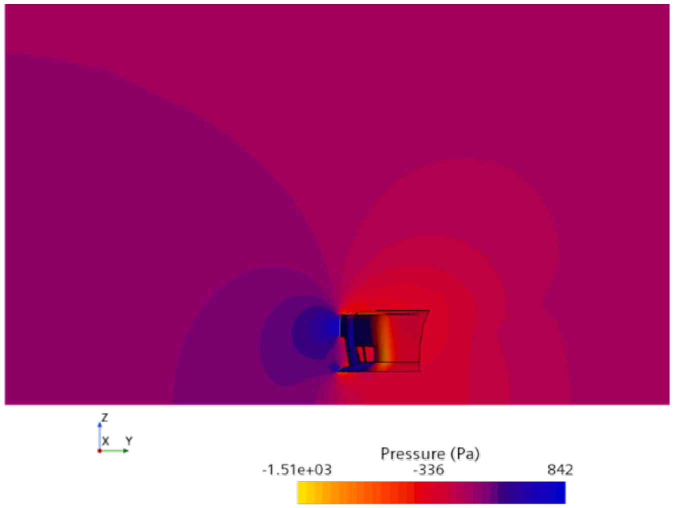

FIGURE 5. YZ plane of air pressure distribution around the bumper surface

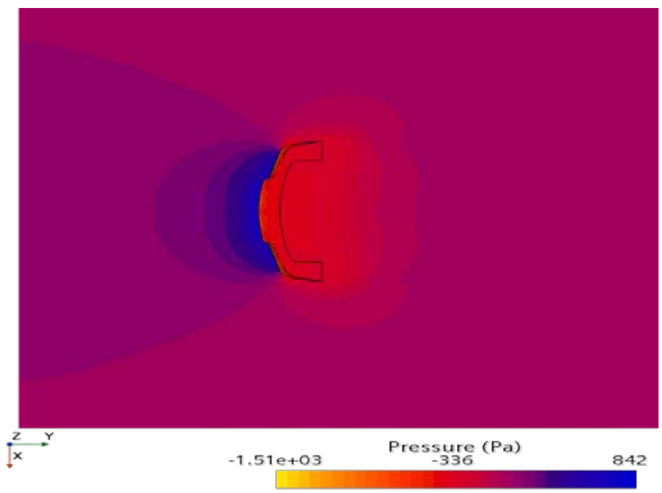

FIGURE 6. Distribution of air pressure in the XY plane

The maximum pressure that occurs on the surface of the bumper is 8.421e+02 Pa, where this pressure is almost evenly distributed on the frontal surface of the front bumper. Surface pressure due to air flow when the vehicle is running at high speed certainly has an influence on the strength and stiffness of the structure of the bumper, therefore this study will continue with a structural strength analysis.

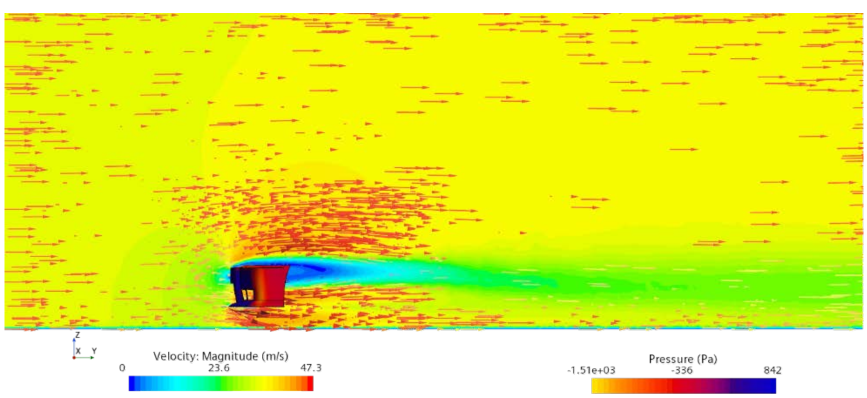

FIGURE 7. Distribution and velocity vector on the YZ plane

As seen in the distribution of velocity and velocity vector in the YZ plane in Figure 10 and 11, the air flow can be easily deflected to the top and bottom of the vehicle.

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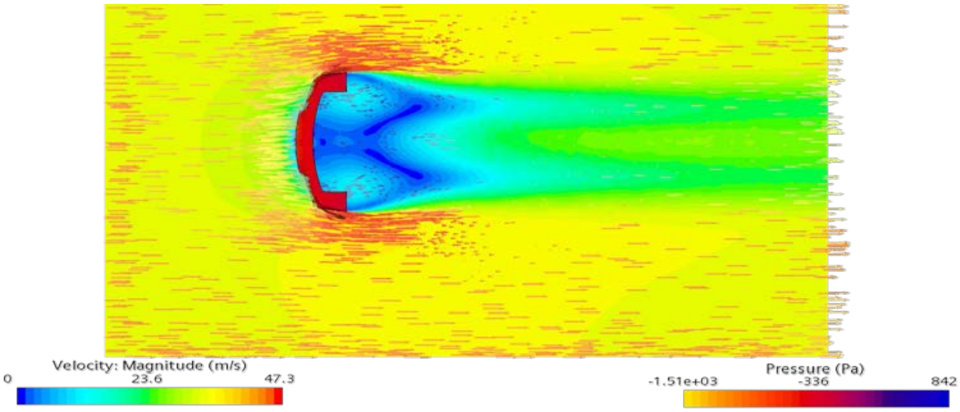

FIGURE 8. Airflow distribution and air velocity vector in the XY plane above view

In the simulation applying the Fluid Structure Interaction (FSI) method, the compressive force that occurs due to the air flow rate hitting the entire surface of the bumper is transferred through the automatic mesh cell mapping method. The accuracy level of this method is relatively higher than the manual mapping method. However, to achieve a high level of accuracy, the interface of each mesh cell must have a high suitability value.

CONCLUSION

Simulations have been carried out to analyze the aerodynamic phenomena that occur in car bumper products made of rattan fiber composite material with a maximum speed of 120 km/h. The maximum pressure that occurs on the surface of the bumper is 8.421e+02 Pa, which is evenly distributed on the frontal surface of the front bumper. Surface pressure due to air flow when the vehicle is running at high speed certainly has an influence on the strength and stiffness of the structure of the bumper. Therefore, this study will continue with a structural strength analysis. The results of this study become a reference for further development.

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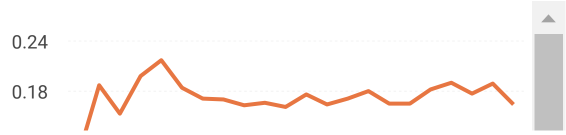

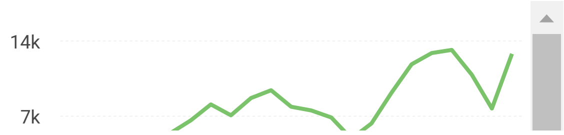

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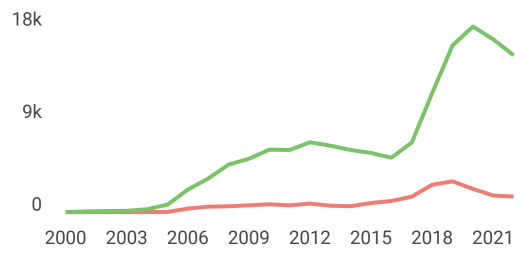

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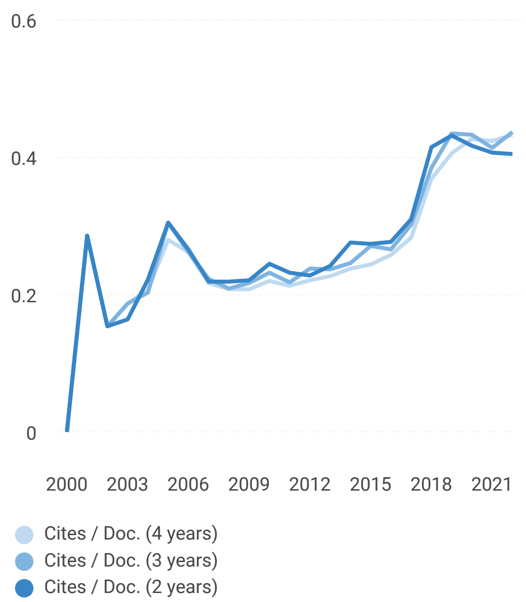

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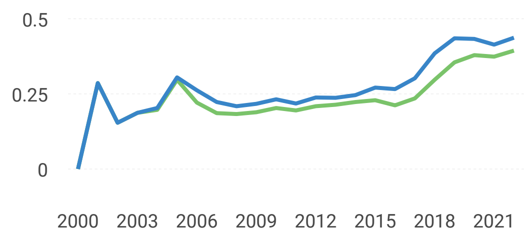

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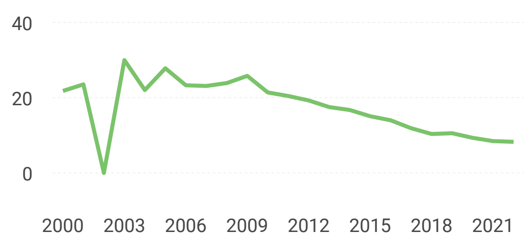

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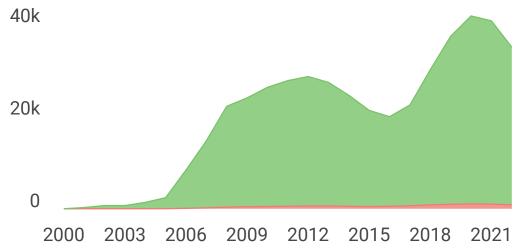

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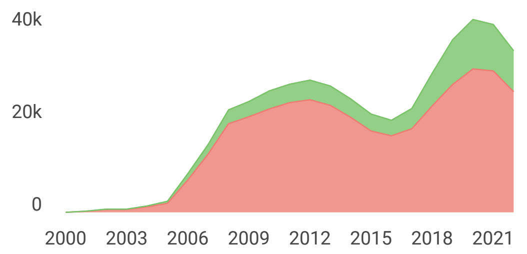

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