

CAE

University of Wales Trinity Saint David

Application of Computer Aided Engineering Processes

ACHA6010

Automotive Engineering BEng

Wales Institute of science and Art



DEC 2022

Contents

Introduction	2
Validation	3
Mathematical solution in validation:	3
Different types of Ansys CAE studies:	3
Finite element calculation:	3
Validation in CAE:	4
Finite element method (FEM):	5
CAD Modelling & Assembly	6
Finite Element analysis (FEA):	6
Kinematic Simulation, Thermal Influence & Structural Analysis	7
Development of CAE:	7
Rigid Study:	7
Steady-State Thermal:	9
Static-Structural study:	10
References:	12

Introduction

Applications of Computer Aided Engineering (CAE) helps develop simulations which could further influence the automotive industry. Finite element analysis (FEA) and CAE will work together to experience change in this sector and help it move into the future.

FEA (Sanjaya, Prabowo et al. 2021) helps conceptualise models and structures into a detailed graphical and data filled solution. Without requiring the need of time consuming and potentially inaccurate results from extremely complicated mathematics. CAE completes the maths through access to mesh sizing which breaks down the information into smaller chunks of data. A device called error ratio is used to provide a safety barrier of results. What this means to the industry is less time is taken up with time consuming physical and destructive testing on models outside the engineering facility. It also gives results quicker which allows for further development. This means a solution will be found more easily and quickly.

In (Monti, Palenzona et al. 2022) a study given between the testing of different types of composites. These composites are Polycarbonate and Carbon fibre composites. The mechanical boundaries are found by computational testing which gives insight if physical testing needs to occur. FEA helps speed up a process that could take longer if material properties are not understood. This saves time and money, when setting up experiments and gives ideas of what the results are.

Validation in CAE and Computer Aided Manufacturing (CAM) area are an indispensable solution to accuracy to complex designs. Validation can consist of mathematical solutions and comparable studies as well as CAE in making items of design and manufacture more accurate.

Kinematic solution encourages further study into thermal, structural and rigid analysis. These studies help to understand the properties and solutions that help to make the component or system better. Furthermore, this study focuses on the analysis of engine parts and their system and why they may behave differently to other sections.

Validation

Mathematical solution in validation:

A method of validation could be given as a non-computational maths solution solved using equations and calculations to give an approximate answer to the problem. If the analysis is of the cantilever beam then the equations are $\frac{FL^2}{2EI}$ and $\frac{FL^3}{3EI}$ which are then used to substitute numbers to find the results. In a nonlinear situation then Euler Bernoulli differential equations applies. The equations look like this $EI \frac{d^2y}{dx^2} = m$ and are worked out using Macaulay's method and double integration. Cantilever is split into uniform and axial load equations. Therefore, it differs during such circumstances. For example, uniform is $\frac{WL^3}{6EI}$ and $\frac{WL^4}{8EI}$ these work for slope and deflection respectively. The same equation as above works for nonlinear on axial loads (Euler Bernoulli).

Different types of Ansys CAE studies:

The Ansys software package has different levels of studies depending on the usage of automotive or mechanical parts. Thermo-mechanical contains software that is built to replicate the conditions that may occur in an engine or a structure. In this case it can use convection as a form of force when replicating an engine piston or connecting rod. Mechanical loads can also be added if the engine requires this aspect. Structural study contains software that could measure the strength and displacement of an engine, chassis or suspension member. In which it could apply force or pressure to the component part. Rigid dynamics study allows motion loading in a process which measures deformation and compression over joint probes. This is done as a motion study rather than a static study.

Finite element calculation:

Aprianur (Fajri, Prabowo, Muhayat et al. 2021) uses FEA to explain its function. FEA can be used to add up complex mathematical problems. This study has used bending beams. In an FEA calculation it uses meshing to divide up the calculations further to process quickly. Another approach for the FEM process would be a S-N curve which would show the stress value and fatigue data. It is important when considering different materials for certain projects and there for stress, strain and fatigue life. It is also important to realise where the part is located and consider it that it could have dynamic or cyclic loading (Fajri, Prabowo, Muhayat et al. 2021). The cyclic loading is important as it is repeated loading occur successively and probable in suspension components. In the automotive spectrum because it occurs in suspension, chassis and engine components.

Validation in CAE:

Validation (Fajri, Prabowo, Surojo et al. 2021) is an integral part of the CAE and CAM research, design and test process. It is important that this work is carried out to check parts to find errors before a later stage of the project. Previously this work could have been carried out by complex maths regarding bending, pressure vessels, complex loading, fatigue and failure. These can be used to check answer but become hard to understand as object get larger and more complicated. Comparison data could also be used through other results which gives a baseline in which to base the outcome of the study on. This comparison data could be derived from mathematical studies or computational data.

Increased (Kärger, Bernath et al. 2015) steps and extra items include data on devices around improving work to include validation. Comparisons between components help to make sure that there is more data. Further sensors and parameters help to improve results.

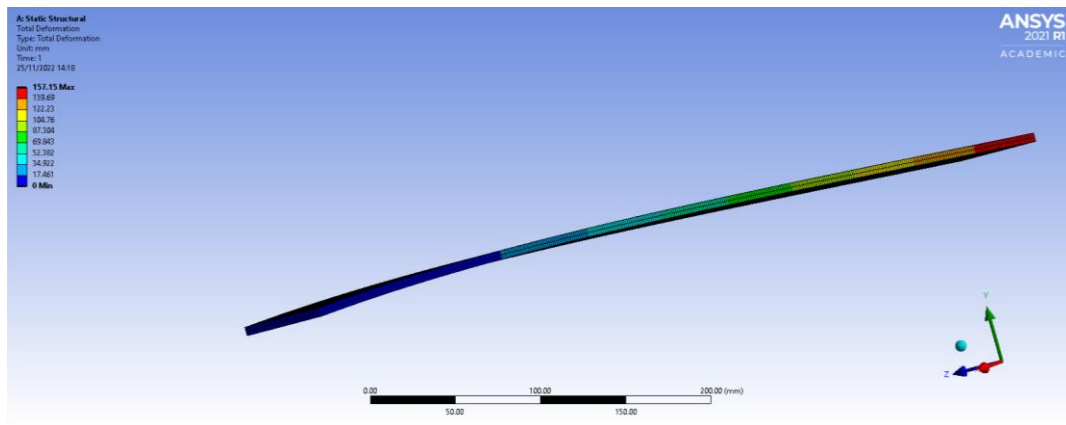


Figure 1-UDL static structural results

The cantilever beam has been validated via beam bending example in this case it is represented above with beam with a load of 2750 Pa at one side and fixed on the other side. This deforms greatly showing the most on the red at 157mm of deflection.

Tabular Data			
Time [s]	☒ Minimum [m]	☒ Maximum [m]	☒ Average [m]
1 1.	0.	0.15715	6.2889e-002

Figure 2-data from Static structural study

The study shows that the material has lengthened when the deformation occurred due to the force applied to it.

CAE Analysis

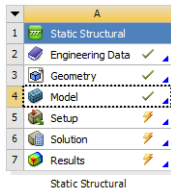


Figure 3-example of static structure box

The process box for the studies that take place within the Ansys environment. These boxes can be linked together to move or use the same geometry, model, engineering data or setup.

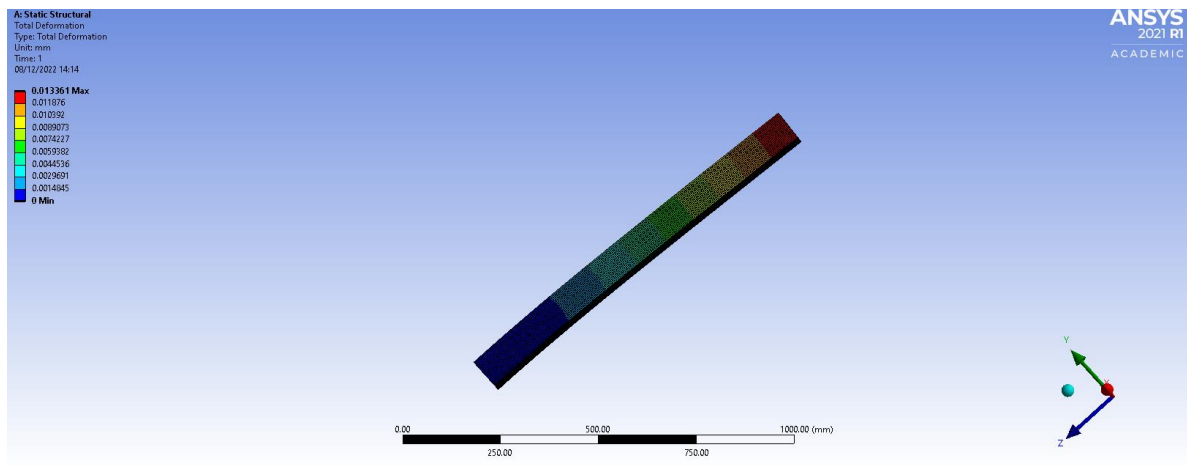


Figure 4-2nd static structural study

Second validation is an axial structural using force in 2 directions from a fixed area. It shows total deformation in both the directions on the z and y axis.

Tabular Data			
Time [s]	☒ Minimum [mm]	☒ Maximum [mm]	☒ Average [mm]
1 1.	0.	1.3361e-002	5.3683e-003

Figure 5-data from 2nd static structural study

Finite element method (FEM):

Widiyanto (Widiyanto, Sutimin et al. 2021) uses FEM within their studies to find the maximum deformation in their chassis. This can be translated into use with validation as it can be checked against similar chassis or models. This is useful further to understand the deformation of compression of a material.

CAD Modelling & Assembly

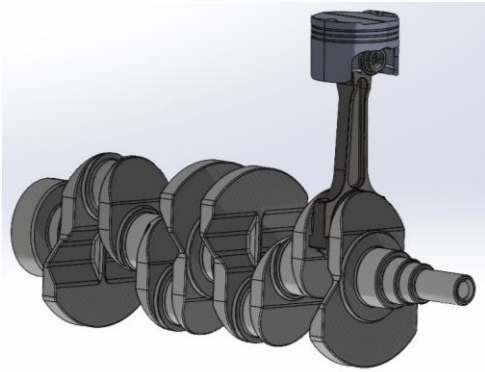


Figure 6-Supplied Assembly of engine components

This is the assembly provided for the kinematic simulation studies. This included thermal, structural and rigid studies.

Finite Element analysis (FEA):

FEA helps to give a tougher load on components used in all forms of the automotive environment which include engine design, chassis designs and suspension design. Widiyantoa (Widiyanto, Sutimin et al. 2021) helps understand why mechanical loadings may be anticipated on chassis design. It could be worth noting beyond the pressure loads that structure may break (Widiyanto, Sutimin et al. 2021).

Further investigation in FEA has led to analysis of different kinds of structures with reference to a tubular monocoque structure of a ford GT40. Majid uses (Majid, Laksono et al. 2021) a modified ladder frame chassis evolved from more basic systems of previous. This study looks at the AC Cobra chassis. This chassis assumes a fixed point at either end or a maximum loading in Y plane acting downwards. From this the analysis shows a displacement of the chassis in the middle area. This is likely due as the materials are the furthest away from the strong points of the ends and give most displacement. If the middle area is triangulated the structure would benefit from greater residual torsion. This was seen by looking at the analysis in the CAD program which result showed displacement and the graph or scale which illustrates load or pressures based on blue to red.

Sanjaya suggest that (Sanjaya, Prabowo et al. 2021) mesh sizing is important because it determines an error ratio, this study concludes that the smaller mesh sizes conclude a high level of accuracy on the wheel objects. The study includes that even with large mesh sizes the result should follow a similar pattern. It is important to add that when measuring wheels that a higher level of accuracy and a lower level of errors can help to understand the safety aspect of the wheels.

Kinematic Simulation, Thermal Influence & Structural Analysis

Development of CAE:

Fajri (2021) (Fajri, Prabowo et al. 2021) uses Physical testing and development of advanced test mules can be an expensive and time-consuming process and take a long time to receive results. It is considered now that advanced CAE and CAM is a partial replacement for early test mules of 20 years ago.

Fajri uses (Fajri, Prabowo et al. 2021) FEM based CAE software can now include different mesh sizes in the software. These include macro and micro sizing scales which could investigate fatigue life during dynamic or cyclic loading. This can more easily spot cracks which could occur when testing used a vehicle.

Rigid Study:

The rigid study in this kinematic analysis was of the piston, connecting rod, Gudgeon pin and crank. This shows up in a graph which has a process of information on deflections, compressions and forces. Industry uses this study to further develop engine and suspension components.

Rigid dynamics (Bilancia, Berselli et al. 2019) helps to understand the analysis in joints or movements of materials. Within this source it helps to understand the geometry and movement of structures and devices. This links back to crank and pistons by understanding its flexibility and deformation that may occur in an engine or similar application.

Further force loads during engine operation may occur if types of fuel vary. If the move to more sustainable fuels is the future, then the design may have to change to suit different conditions. Further example leads to alternative fuels. These may have different properties from faster flame speed to lower calorific values. This could lead for higher levels of force or lower levels of force leading to have components designed for both. Force limitation is another investigation to be carried out as well.

CAE Analysis

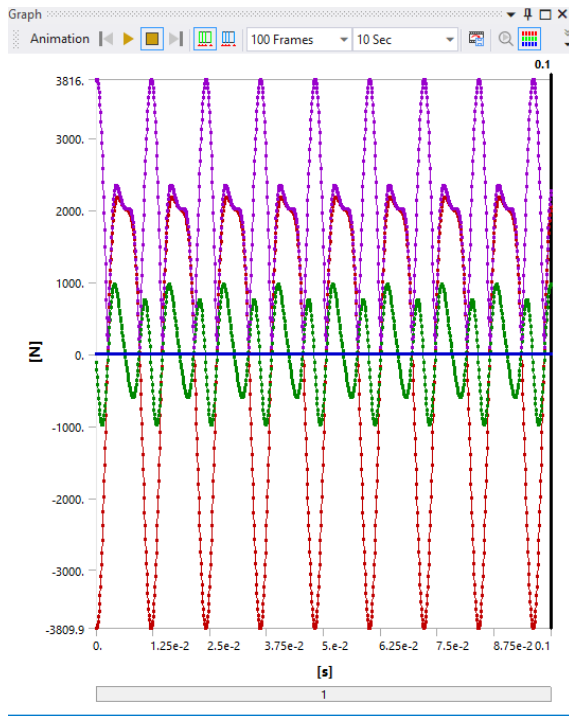


Figure 7-Graph Rigid Study

Different colours for the lines upon the graph represent the reciprocal joint probes and therefore the forces change at their studies moving phases. This is supposed to represent the different areas of motion within the engine area. It is important to understand how this may relate given a real-world situation.

Tabular Data					
	Time [s]	✓ Joint Probe (Total Force X) [N]	✓ Joint Probe (Total Force Y) [N]	✓ Joint Probe (Total Force Z) [N]	✓ Joint Probe (Total Force Total) [N]
1	0.	-3806.6	-109.57	2.4688e-013	3808.2
2	1.e-004	-3809.9	-215.4	2.4681e-013	3816.
3	2.e-004	-3796.2	-320.	2.4564e-013	3809.7
4	3.e-004	-3765.4	-421.8	2.4336e-013	3788.9
5	4.e-004	-3717.5	-519.26	2.3999e-013	3753.6
6	5.e-004	-3652.8	-610.9	2.3555e-013	3703.6
7	6.e-004	-3571.5	-695.26	2.3004e-013	3638.6
8	7.e-004	-3474.	-771.	2.235e-013	3558.5
9	8.e-004	-3360.7	-836.85	2.1597e-013	3463.3
10	9.e-004	-3232.2	-891.69	2.0748e-013	3353.

Figure 8-Data from Rigid study

CAE Analysis

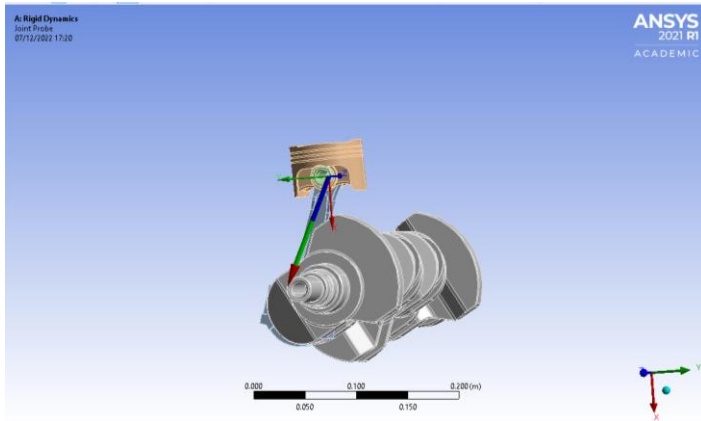


Figure 9-Rigid dynamics study

The image above shows the rigid study in motion which then generates results.



Figure 10-Rigid study tree

This image shows an Ansys analysis study tree which depicts the different studies of rigid dynamics, thermal and structural. These studies include engineering data, geometry and model which are shared between the studies.

Steady-State Thermal:

The thermal study indicates to us where the hot and cold areas of the piston are. These areas have been indicated to be the crown and top groove area. It the study illustrates these as red or orange areas. It informs how the metals and alloys perform under varying temperatures and conditions. This can future proof our designs. It could also necessitate a change to another alloy or aluminium.

(Lu, Li et al. 2013) uses thermal analysis an engine component is a marine diesel. In this case it studies the piston to explain the differences between heat transfer regarding the different areas of the piston. This could determine what material or alloy may be used to improve the efficiency of the engine. Furthermore, it could develop to improve the profile or deign of the piston and its area. Using CAE, it helps to study the data so that a solution can be found more easily and accurately. An error analysis is applied here to factor for outliers which do not fit the trend. It is useful to understand why these anomalies happen and to learn why they happen.

CAE Analysis

Tabular Data			
Time [s]	☒ Minimum [°C]	☒ Maximum [°C]	☒ Average [°C]
1 0.1	92.459	92.536	92.493

Figure 11-steady state thermal study

This box provides information of the min, max and average temperature that the study was conducted at. These provide data to improve the design of the components which could factor into the specification of improving efficiency and emissions.

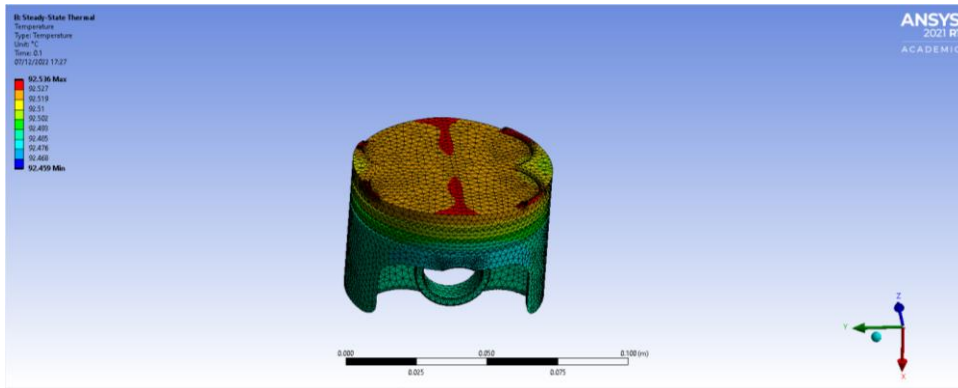


Figure 12-Steady state Thermal

The image above clearly shows the results for thermal studies and the temperatures are indicated through colours. The image above is split into sections, the crown and top groove are where the temperatures are the highest indicated by red and oranges. The sides and underside areas are where the colours are green and blue which indicates a colder environment. These areas are further away from the combustion process.

Static-Structural study:

The structural study shows the connecting rod from the piston on to the crank. Figure 14 from the top holes has transfer the force form the Gudgeon pin which came from the piston. This translates a force acting through the connecting rod and onto the cranks shaft. Figure 14 shows the differing amounts of force acting across the con rod. Shown by the red at the lower part of the hole transferring downwards into the con rod. The lower part transfers the force onto the crank and is blue which means lower force. The top part shows plastic deformation from the forces acting downwards.

FEA demonstrates progress computationally which further moves design for better longevity and lightness for a new engine. It also proves how much force can be applied without fault.

CAE Analysis

Tabular Data			
Time [s]	☒ Minimum [m]	☒ Maximum [m]	☒ Average [m]
1 0.1	0.	5.2155e-004	6.3427e-005

Figure 13-Static structural Con Rod

Results after deflection from the connecting rod. Received from the connecting rod and Gudgeon pin onto the crank shaft.

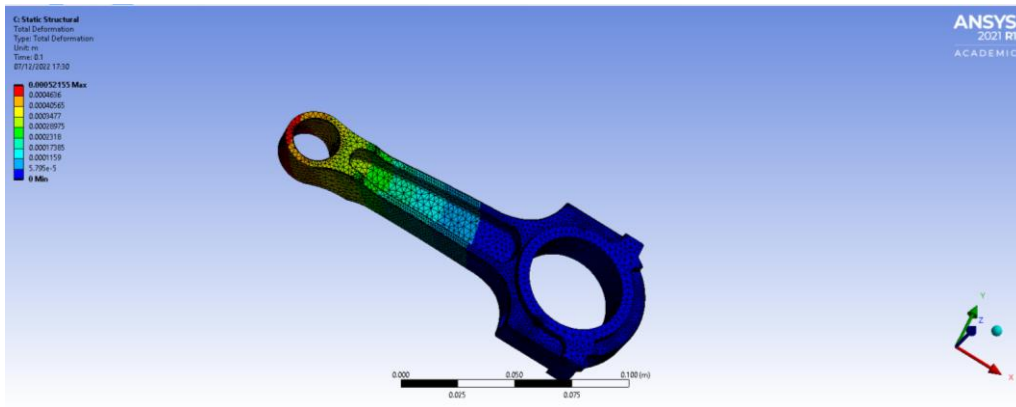


Figure 14-Static structural Con Rod

Feng's work uses (Feng, He et al. 2022) structural FEA to consider understanding why a structure may crack when under mechanical force or pressure. Understanding that forces on a system may include varying ranges of deflection and compression. It is important to see if this is caused by impurities, cyclic or dynamic loadings. Regarding suspension components and mounting areas are considered to have enough strength if pressure has been applied to them. Moreover, if this component is a connecting rod, it would be expected that the material has a high tensile strength so that it would not fail under repeated force from other areas of the system. If the component does not receive high levels of cyclic loading, then it is not expected to be tested at these forces. Therefore, the material used can be of less high strength.

This study includes further (Sahoo, Barua et al. 2022) development of metals and alloys. In this study it considers matrix composite metal to normal formed metal. The process is looked at using the FEA structural analysis. This study considers the dynamic loadings that could take place regarding what the product is used for. It is also considered that the material is proven to be light in the application therefore, an improvement over previous. The new material has an expense factor compared to normal steel due to its combination of other materials, its structural integrity is greater but not much higher than normal steel. Even though the strength is better than normal steel the ductility is shorter which makes failures less easy to predict.

References:

- BILANCIA, P., BERSELLI, G., BRUZZONE, L. and FANGHELLA, P., 2019. A CAD/CAE integration framework for analyzing and designing spatial compliant mechanisms via pseudo-rigid-body methods. *Robotics and Computer-Integrated Manufacturing*, **56**, pp. 287-302.
- FAJRI, A., PRABOWO, A.R., MUHAYAT, N., SMARADHANA, D.F. and BAHATMAKA, A., 2021. Fatigue Analysis of Engineering Structures: State of Development and Achievement. *Procedia Structural Integrity*, **33**, pp. 19-26.
- FAJRI, A., PRABOWO, A.R., SUROJO, E., IMADUDDIN, F., SOHN, J.M. and ADIPUTRA, R., 2021. Validation and Verification of Fatigue Assessment using FE Analysis: A Study Case on the Notched Cantilever Beam. *Procedia Structural Integrity*, **33**, pp. 11-18.
- FENG, W., HE, P. and PAVLOVIC, M., 2022. Combined DIC and FEA method for analysing debonding crack propagation in fatigue experiments on wrapped composite joints. *Composite Structures*, **297**, pp. 115977.
- KÄRGER, L., BERNATH, A., FRITZ, F., GALKIN, S., MAGAGNATO, D., OECKERATH, A., SCHÖN, A. and HENNING, F., 2015. Development and validation of a CAE chain for unidirectional fibre reinforced composite components. *Composite Structures*, **132**, pp. 350-358.
- LU, X., LI, Q., ZHANG, W., GUO, Y., HE, T. and ZOU, D., 2013. Thermal analysis on piston of marine diesel engine. *Applied Thermal Engineering*, **50**(1), pp. 168-176.
- MAJID, I.A., LAKSONO, F.B., SURYANTO, H. and PRABOWO, A.R., 2021. Structural Assessment of Ladder Frame Chassis using FE Analysis: A Designed Construction referring to Ford AC Cobra. *Procedia Structural Integrity*, **33**, pp. 35-42.
- MONTI, M., PALENZONA, M., FIORINO, F., BAUDACH, F., ONNIS, A. and ROMEO, A., 2022. Design, manufacturing and FEA prediction of the mechanical behavior of a hybrid-molded polycarbonate / continuous carbon fiber reinforced composite component. *Composites Part B: Engineering*, **238**, pp. 109891.
- SAHOO, B.B., BARUA, A., JEET, S., KUMARI, K., BAGAL, D.K., PRADHAN, S., PANDA, B.P. and NAIK, B., 2022. Comparative study based on static and modal analysis of existing motorcycle rear Sprocket's material with metal matrix composite using FEA. *Materials Today: Proceedings*, .
- SANJAYA, Y., PRABOWO, A.R., IMADUDDIN, F. and BINTI NORDIN, N.A., 2021. Design and Analysis of Mesh Size Subjected to Wheel Rim Convergence Using Finite Element Method. *Procedia Structural Integrity*, **33**, pp. 51-58.
- WIDIYANTO, I., SUTIMIN, S., LAKSONO, F.B. and PRABOWO, A.R., 2021. Structural Assessment of Monocoque Frame Construction using Finite Element Analysis: A Study Case on a Designed Vehicle Chassis referring to Ford GT40. *Procedia Structural Integrity*, **33**, pp. 27-34.