v. 4, n. 15, 2024

Journal of
Engineering
Research

STRUCTURAL ANALYSIS AND OPTIMIZATION APPLIED TO THE FINITE ELEMENT CHASSIS OF TRAIL TYPE MOTORCYCLES

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Journal of Engineering Research ISSN 2764-1317 DOI https://doi.org/10.22533/at.ed.3174152421051

Abstract: In this work we intend to carry out a structural analysis of an off-road motorcycle chassis, as this sport is characterized by a high rate of mechanical failures in the vehicle and damage to the motorcyclist's physical integrity. All structural components of the motorcycle must resist high dynamic loads, due to impacts caused by maneuvers and radical movements. This project will be mainly based on finite element analysis, using Solidworks software, to validate and optimize the concepts presented in structural terms. For this, it is a basic condition to obtain the necessary mechanical properties, keep weight reduced to a minimum and manufacturing costs low. To analyze the structure, the finite element method (FEM) was used to obtain its structural response (displacements, deformations and stresses in the material). Based on the results, it was concluded that the motorcycle's rear fork containing the 2014 aluminum alloy is capable of resisting the analyzed boundary condition, without compromising its structural integrity.
Keywords: Structural analysis. Modal. Chassis. Motorcycle. MEF.

INTRODUCTION

Aerospace engineer and researcher Theodore Von Karman (THE NATIONAL AVIATION HALL OF FAME, 2011), said ''Scientists discover the world that exists; engineers create the world that never existed''. This phrase reveals how important science and engineering are in the development of humanity, showing the immensity of possibilities for increasingly technological innovations, resulting from science and engineering, that is, from the knowledge of new discoveries and tools capable of performing its functions efficiently and innovatively.

One of the mathematical models achieved was the development of the finite element mathematical method (MEF), which in practice translates into a computational tool that performs engineering analyses, enabling the obtaining of approximate results, subdividing the domain of a problem into smaller parts., called finite elements (AZEVEDO, 2003).

The finite element method has its development and formulation, which is seen today, in the 1950s. Through the researchers who pioneered the method, Turner and Clought, Martin and Topp, having their work published in 1956, where it was presented the matrix stiffness equations for bars, beams and other elements (ALBUQUERQUE, 2014).

In science and engineering there are many physical phenomena that are described by extremely complex partial differential equations, as they require alternative calculation techniques, different from resolution by the classical analytical method. However, by using finite element methods, these partial differential equations can be easily solved. With this method it is possible to solve routine engineering problems such as stress analysis, heat transfer, fluid flow and electromagnetism through computer simulation (Fish and Belytschko, 2007).

Engineers have become very interested in using the MEF, as they are moving away from calculations using the classical method, which does not predict real physical behavior, in order to optimize their projects through the MEF in calculating the prediction of the behavior of structures, mechanical, electrical and thermal systems. This consideration is based on when it is possible to view search results on Google compared to previous years. According to Fish and Belytschko (2007), in 2006 the word ''finite element'' resulted in around 14 million pages of results. In 2022, this amount rose to 133 million pages, representing a percentage increase of 850%.

With the advancement of computational technology, there was a rapid expansion of computer hardware resources, enabling efficient and precise matrix resolution, in addition to computer graphics, which allowed the visualization of the pre-processing stages of model construction, such as in the generation automatic adaptive meshing. This advance also allowed visualization in the post-processing review of the results obtained (BUDYNAS and NISBETT, 2016).

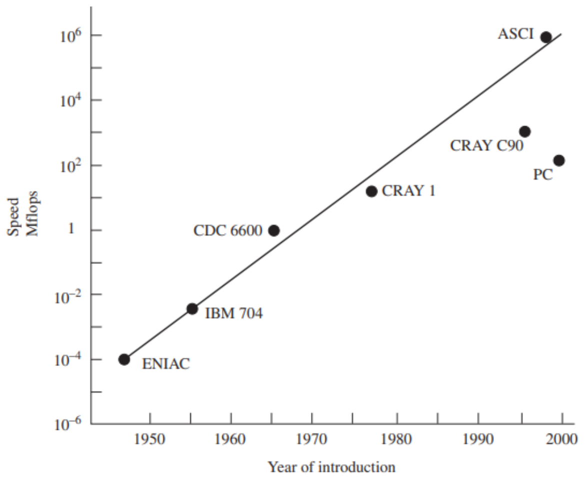


Figure1- Evolution of micro computers

Source: BUDYNAS and NISBETT (2016).

First disclosed by Moore (Figure 1.1), in the 1990s, the geometric progression of processor speed revealed the advancement power of computers, the result of the discovery regarding the packaging of transistors in increasingly smaller spaces.

This speed doubled every 18 months, and this was named Moore's law (Fish and Belytschko, 2007).

In the 1960s, when the speed of computers was beginning to bring results to several areas of engineering, software called NASTRAN was created, financed by the United States space exploration program (NASA). This software was the first to enable finite element calculations, as it partially solved the problem of solving very large matrix operations. After NASTRAN, other software packages came that also played important roles, such as ANSYS, ALGOR and GOSMOS/M. (HUTTON, 2004).

An extremely valuable application of finite element analysis is the design of vehicle chassis. This is the component that resists the weight of the vehicle and dynamic shocks arising from the conditions of use, considered by many to be the backbone of the vehicle. For this purpose, it is possible to obtain engineering results such as the verification of structural resistance in potentially critical locations and modal analysis to determine the natural frequency, in addition to other types of analyzes (FOALE, 2002)

The off-road type of sport for motorcycles has been gaining prominence for adventurers who wish to use their vehicles for extreme competitions. And given the growth of this sport, the market has been offering increasingly technological vehicles for good performance in competitions.

All structural components of the motorcycle must resist high dynamic loads, due to impacts caused by maneuvers and radical movements.

Therefore, this work focuses on a study carried out on an off-road motorcycle, which was developed by a North American company, which promises to offer a different model of motorcycles for this category, with much lower weight and at competitive prices. The present study will use computational resources, such as *solid works* software, as well as its finite element structural analysis tool.

This project will be mainly based on finite element analysis to validate and optimize the concepts presented in structural terms. For this, it is a basic condition to obtain the necessary mechanical properties, keep weight reduced to a minimum and manufacturing costs low.

THEORETICAL FRAMEWORKS

CHASSIS

There are two main functions in a motorcycle chassis: static and dynamic.

In a static sense, the chassis must support the weight of the driver, passenger, engine, transmissions and the necessary accessories such as the fuel and oil tank. The dynamic function of the frame is important, as in combination with the rest of the components such as suspension and wheels, it must provide stable steering, with good grip, control and comfort (FOALE, 2002).

Every chassis is subject to different types and loads, such as stresses, bending moments and vibrations resulting from road irregularities. However, for there to be no mechanical failure, the chassis requires mechanical properties, such as strength, stiffness and fatigue resistance (Agrawal & Razik, 2013; Bhunte & Deshmukh).

According to Verma and Gangrade (2022), only 7% of failures that occur with motorcycles are caused by poor chassis sizing, however, when failures occur, the results are catastrophic, resulting in serious injuries and the recall of all vehicles. with problem.

SCOOTER CHASSIS

The geometric and structural characteristics of the scooter-type chassis are perfect for those who want to transport something between the seat and the handlebars, however, structurally the frame has no advantages, being considered the worst type of chassis in terms of resistance and rigidity. According to Cossalte et al. (2007), the structural rigidity of this chassis model notably reduces the stability and handling of this type of vehicle). Figure 3 exemplifies this type of chassis.

Figure 2: Scooter Chassis

Source: SHOP (2023).

SINGLE CRADLE CHASSIS

The characteristics identified in this type of chassis are more advantageous than the Scooter model, as there is more rigidity due to the presence of a cradle that connects the table to the chassis body, providing more stability. Its constructive form allows the installation of a 1-cylinder engine (FAEZ, 2017). Figure 3 exemplifies this type of chassis.

Figure 3: Single cradle chassis.

Source: RESEARCH GATE (2023),

DOUBLE CRADLE CHASSIS

This chassis model is an evolution of the Simple Cradle, in which two beams support the lower part of the engine, allowing the chassis to support more weight and have greater rigidity when carrying out a comparative analysis between the two. The advantage of using double cradle chassis is that they offer a good performance between lightness, rigidity and strength, although they have now been technically surpassed by perimeter structures (GARI, 2016). Figure 4 exemplifies this type of chassis.

Journal of Engineering Research ISSN 2764-1317 DOI https://doi.org/10.22533/at.ed.3174152421051

Figure 4: Double cradle chassis.

Source: MOTOBAZAN (2023),

TRUSS CHASSIS

These types of chassis consist of several tubes welded together to form a robust network of transverse and longitudinal bars. As a result, it is exceptionally strong with a comparatively low weight. Its latticed appearance that makes up the body of the frame guarantees high robustness (FAEZ, 2017). Figure 5 exemplifies this type of chassis.

Figure 5: Truss chassis.

Source: MOTORCYCLE VALLEY (2023).

MONOTUBE CHASSIS

This type of chassis is commonly called a backbone. It is a simple model, easy to manufacture and relatively low cost (FOALE, 2002).

According to Faez (2017), these structures are rarely used, with other designs being better in terms of strength and rigidity. Figure 6 exemplifies this type of chassis.

Figure 6: Monotube chassis

Source: MOTORCYCLE VALLEY (2023).

LOAD AND STRESS ANALYSIS

To understand the behavior of forces and moments acting on a machine or equipment, it is necessary to have full knowledge of statics and dynamics of rigid bodies (BUDYNAS and NISBETT, 2016).

Each part that makes up the machine must be analyzed as if it were a member within a system (machine), and its connections as support or technically called reaction (BUDYNAS and NISBETT, 2016).

There are several machines that suffer mechanical action from other coupled machines, however, in this work only the actions of forces originating from the motors and weight force will be taken into consideration. The accelerations generated during the entire operation process of this machine are negligible, for all parts, so the effects of dynamic loading are also negligible (BUDYNAS and NISBETT, 2016).

Every loading calculation is the result of Newton's second law which states: The derivative in relation to time of the momentum of a body is equal to the magnitude of the applied force and acts in the direction of the force. For a rigid body, the equilibrium equations can be written for linear forces or moments or torques, according to equation (1) (HIBBELER, 2018):

$$\sum F = ma \qquad \sum M_G = \dot{H}_G \tag{1}$$

Where:
F = strength
m = mass
a = acceleration
M_G = moment about the center of gravity
H_G = temporal rate of the momentum in relation to the CG (center of gravity).

When there is no dynamic loading in the system, in all orthographic axes, equation (1) reduces to equation (2) (HIBBELER, 2018).

$$\sum F_x = ma_x \qquad \sum F_y = ma_y \qquad \sum F_z = ma_z$$
$$\sum M_x = 0 \qquad \sum M_y = 0 \qquad \sum M_z = 0 \tag{2}$$

Knowledge of load requests is not important if it does not enable knowledge of the internal forces acting on the material. In engineering, knowledge of all internal stresses along with the intrinsic characteristics of the material makes it possible to size parts, as well as their materials, so as not to fail under mechanical stress. (HIBBELER, 2018) defines internal forces, as:

> **Normal Force, N**: Force that acts perpendicular to the area. It is developed whenever external loads tend to pull or compress the two segments of the body;
>
> **Shear forces, V:** This force is found in the Area plane. It arises when external forces tend to shear the two segments of the body;
>
> **Torque moment or torque, T:** It arises when external forces tend the body to twist relative to each other on an axis perpendicular to the area.
>
> **Bending moment, M:** It arises when external forces tend to bend the body on an axis in the plane of the area.

STATIC FINITE ELEMENT ANALYSIS

Structural metals are classified as being ductile or brittle, therefore, the failure criteria for these materials have different foundations and methods. The known methods used for different conditions, according to Budynas and Nisbett (2016, p. 231) are identified in Table 1.

Ductile material	Fragile material
Maximum shear stress (Tresca)	Maximum normal voltage
Distortion Energy (Von Misses)	Fragile Coulomb-Mohr
Ductile Coulomb-Mohr.	Modified Mohr

Table 1: Failure theories.

Source: Budynas and Nisbett (2016, p. 231).

In this work, the distortion energy theory or commonly called von Mises theory will be used. However, the use of this theory does not disqualify the others, as each one has its due importance and application.

According to Budynas and Nisbett (2016, p. 233):

> Distortion energy theory predicts that yield occurs when the distortional strain energy in a unit volume reaches or exceeds the distortional strain energy per unit volume in flow under simple tension or compression of the same material Budynas and Nisbett (2016, p. 233).

According to Norton (2013), distortion energy is one whose stored energy is the result of an action of shear force on the material, causing distortions in its crystalline structure. The mathematical deduction that defines the von misses tension according to the same author follows equation (3):

$$U = \frac{1}{2}\sigma\varepsilon \tag{3}$$

According to Norton (2013), the equation (3) for the triple voltage state, we have equation (4)

$$U = \frac{1}{2E}[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\nu(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_1\sigma_3)] \quad (4)$$

According to Norton (2013), the total distortion energy can be represented as the sum of the distortion and volumetric components and all necessary mathematical manipulations, the Von equivalent voltage Mises for cases where the plane is three-dimensional becomes equation (5):

$$\sigma' = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_2\sigma_3 - \sigma_1\sigma_3} \quad (5)$$

According to Norton (2013), the same can also be expressed in terms of applied voltages, according to equation (6):

$$\sigma' = \sqrt{\frac{(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)}{2}} \quad (6)$$

The equations above are mathematical foundations used by the Solidworks Simulation software to analyze deformations in structures or materials subject to loading.

MATERIALS AND METHODS

The first chapter will introduce the text, introductory questions to the topic, the problems encountered, and motivation to study it.

The second chapter will highlight the main parameters that are part of the design of a motorcycle chassis, as well as the different types of geometry and possible materials, in addition to the necessary requirements. Dynamic and mechanical models will also be exposed, as well as issues related to mathematical formulation.

In chapter four, chassis geometry will be studied. This process will be iterative, therefore, several modifications to the geometry will be presented in order to achieve satisfactory results, using Solidworks software.

Then, after the previous steps listed, the finite element analysis will be explained in detail, in chapter 4, on results and discussions. The boundary conditions, applied stresses, mesh and other characteristics of the model will also be discussed in this chapter. And finally, the results of the analysis of the load distribution in the structure will be calculated by computer simulation.

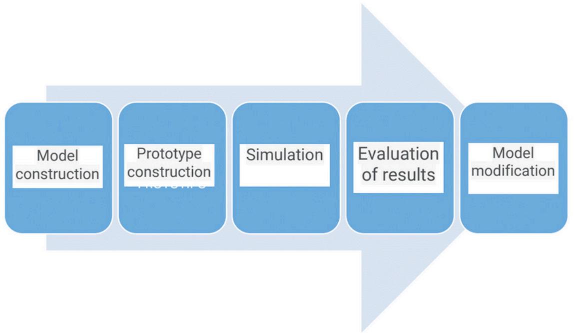
RESULTS AND DISCUSSIONS

To analyze the resistance of specific points on the chassis, the simulation resources of Solidworks Simulation were used, where it was possible to statically analyze stresses and deformations in critical regions using the Von Misses criterion.

The benefits generated by using the *Solid works* according to the information available on the Dassault Systèmes website are:

- Reduce cost by simulating model testing on the computer instead of expensive field testing;
- Reduce time to market by reducing the number of product development cycles;
- Improve products by quickly testing many concepts and scenarios before making a final decision, creating more time to think about new designs.

The stages of events that were carried out in order to obtain answers from the computational analyzes such as the resistance of the material in a given section, followed a defined sequence, according to flowchart 1.



Flowchart1: Steps for model validation.

Source: Prepared by the author.

The boundary condition for structural analysis purposes applied to motorcycles is considered a very common example for those who practice the sport with radical maneuvers using motorcycles.

The kinematics and dynamics of movements and reaction forces are part of the study, being detailed in figure 7. The study considered a motorcycle falling from a ravine to the ground with a height of 3 meters, so that both wheels touched the ground simultaneously, generating reaction forces that transmitted to the chassis and rear fork.

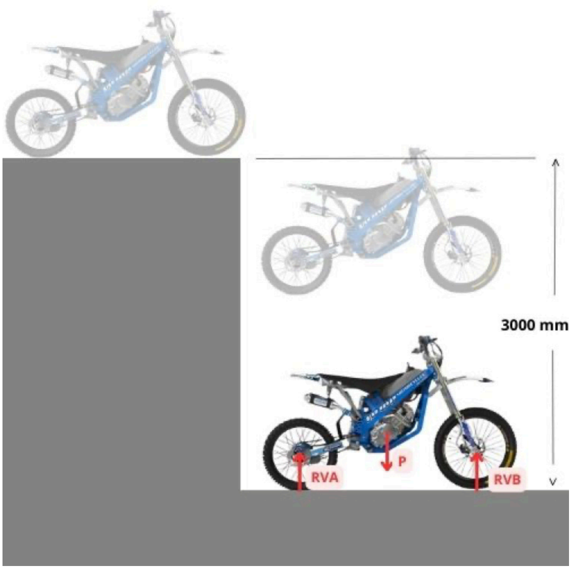


Figure 7: Boundary Condition

Source: prepared by the Author.

Motorcycle + rider weight	210 kgf
Length between the axis	1296mm
Total length	2185mm
Total height	1260mm
Drop height	3000mm
Tire-ground displacement	342mm
Shaft Diameter	25.4mm

Table 1: Initial data

Source: Prepared by the Author.

When loads are applied to a body, the body deforms and the effect of the loads is transmitted throughout the body. External loads induce internal forces and reactions to leave the body in a state of equilibrium. Linear static analysis calculates displacements, deformations, stresses and reaction forces under the effect of applied loads (HIBBELER, 2018).

The studied chassis model subjected to finite element analysis was a double cradle chassis, as shown in figure 8.

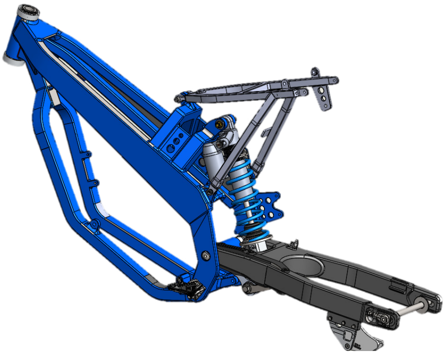


Figure 8: Double cradle chassis.

Source: Prepared by the author.

To mathematically model the boundary condition exposed in this work, we resorted to the study and application of the concept of impact force, which by its definition corresponds to the quotient of the dynamic force (Pmax) and the static force (Pest). This method is based on the concept of strain energy and is used, for example, to calculate the behavior of a rigid body in contact with another body (HIBBELER, 2018).

This method makes it possible to treat dynamic loading through static loading, as long as the static load amplification factor is known:

$$n = 1 + \sqrt{1 + 2 * (\frac{h}{\Delta est})} \quad (7)$$

In equation 7, h represents the fall height, while the static delta represents the static displacement caused by the impact force. Substituting the values, the impact factor can be written as:

$$n = 1 + \sqrt{1 + 2 * (\frac{(3)}{0,342})} = 5.30$$

The result obtained for the impact factor resulted in 5.30, which was rounded to 6 to simplify the calculations.

According to the distance between the axle centers and the positioning of the motorcycle's center of gravity, the equation that describes the static tension in the rear wheel at this boundary condition is:

$$\sigma est = \frac{w/2}{Atras.}$$

The letter W represents the total force-weight, which includes the motorcycle's own weight and the rider's weight. The expression w/2 is due to the positioning of the bi rear axle supported on the fork, 1296/2 away from the front fork, resulting in:

$$\sigma est = \frac{210 * 9,81/2}{\frac{\pi 0,025}{2} . 217,5 * 10^{-3}} = 0,12\ Mpa$$

The maximum dynamic stress can be written as:

$$\sigma máx = n * \sigma est \quad (8)$$

Substituting the Values in equation 8, we have:

$$\sigma máx = 6 * 0,12 = 0,72\ Mpa$$

This value corresponds to a tension with an impact factor of 6 from the rear axle to the rear fork, equivalent to a shear force according to equation 9:

$$\sigma máx = \frac{F}{A} \quad (9)$$

Considering the diameter of the shafts equal to 25mm and applying equation 9, the resulting force on the shaft is equivalent to 6,145.92 N.

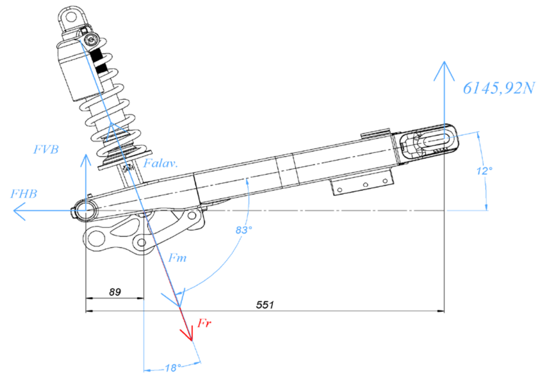


Figure 9: Analysis of stresses on the rear wheel.

Source: Prepared by the author.

Considering that a spring k factor equal to 25N/mm was adopted, and that a portion of the applied force was absorbed by the spring, it was necessary to find a resultant normal to the spring direction. This resulting force resulted from a lever force caused by the impact of the wheel on the ground as shown in figure 9.

$$\sum M_b = 0 \quad (10)$$

Using equation 10 and adopting that at the moment the spring reaches its maximum displacement, so that there was no relative movement of the rear fork, it was possible to calculate the resulting force that is transmitted to the rear fork structure, which resulted in 37.351, 7 N or equivalent to 3.735 tons. This greatness in the result is the product of a very common physical principle in engineering, called the lever principle. The spring force resulted in 8550N, that is, it can absorb only 22.8% of the force on the rear wheel caused by the impact of the wheel on the ground.

The condition in which the rear fork was exposed was considered critical, assuming that the spring and shock absorber were at their maximum deformation, so that a portion of the force applied to the wheel was transmitted by the effect of the reaction generated inside the chassis to resist external force. Figure 10 represents the fork with the fixing points, as well as the mesh assignment and the action of the reaction force. The models were subjected to simulation based on three materials: Alloy 1060, 2014 and 7075.

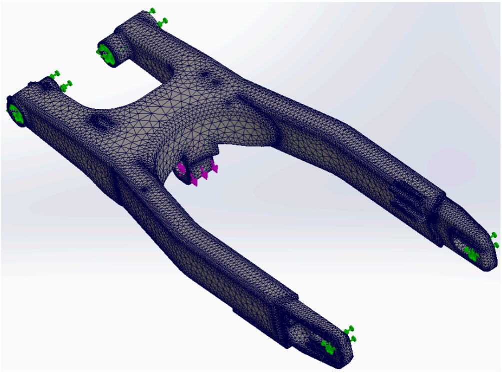


Figure 10: Application of fixings, force and mesh.

Source: Prepared by the author.

The green arrows in figure 10 represent the faces that are being fixed, without any degree of freedom (GDL), while the lilac arrows represent the force vectors that are being applied to the circular section that connects the spring and the damper.

In figure 11, it is possible to verify the configuration of the mesh assigned to the model, whose defined parameters were selected according to the computational processing capacity.

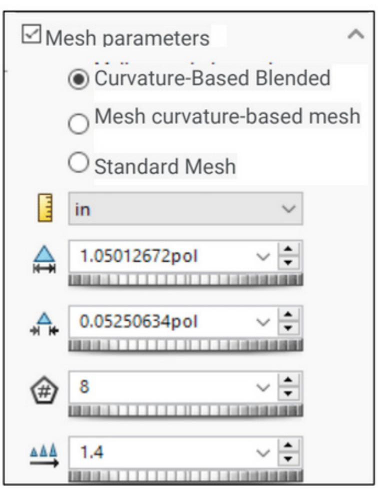


Figure 11: Definition of the mesh type.

Source: Prepared by the author.

In figure 12 it is possible to see that the maximum Von Misses stress in the model was 273.062 MPa, which is greater than the yield stress of aluminum alloy 1060 (27.574 MPa). It is clear that the regions close to the fixings, such as the wheel, chassis and shock absorber fixings, are the most requested areas.

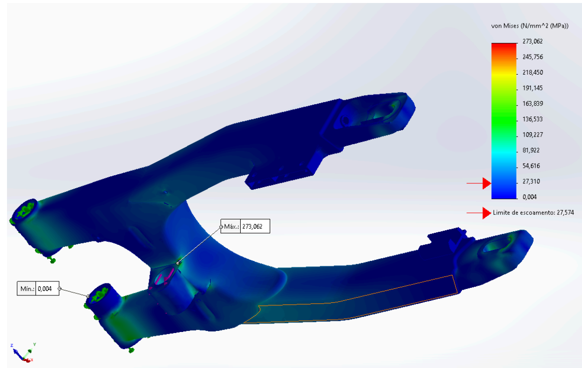


Figure 12 - Stress analysis-Alloy 1060

Source: Prepared by the author.

Another important data is the displacement, as shown in Figure 13, which resulted in a maximum value of 0.807 mm. The reason why the most displaced region was on the right side of the rear fork is due to the positioning of the eyelet where the shock absorber is located, which in this case is positioned further to the right.

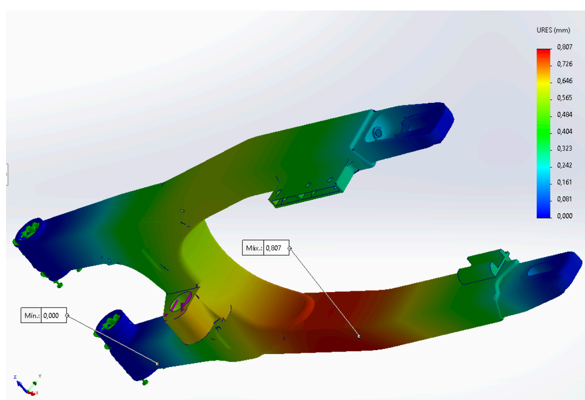


Figure 13: Displacement analysis-Alloy 1060

Source: Prepared by the author.

In figure 12, the same maximum acting

stress is evident, but with a higher yield limit value, when using the 2014 alloy, equivalent to 317.104 Mpa, which represents a higher limit than the Von Misses stress.

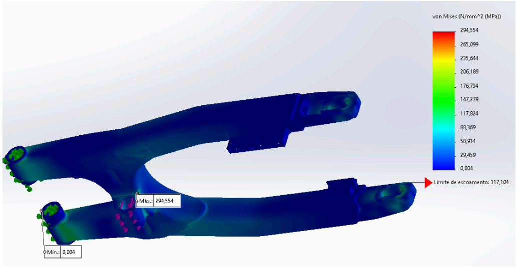


Figure 14: Voltage analysis-Alloy 2014
Source: Prepared by the author.

In figure 15 it is possible to see a decrease in the maximum displacement of the model for the 2014 alloy, equivalent to 0.759mm.

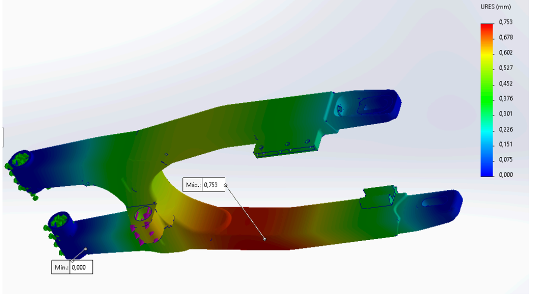


Figure 15: Displacement analysis - League 2014
Source: Prepared by the author.

In figure 16, the Von Misses stress remains constant, however, with a yield limit value for alloy 7075 higher than alloys 1060 and 2014, equivalent to 505 Mpa.

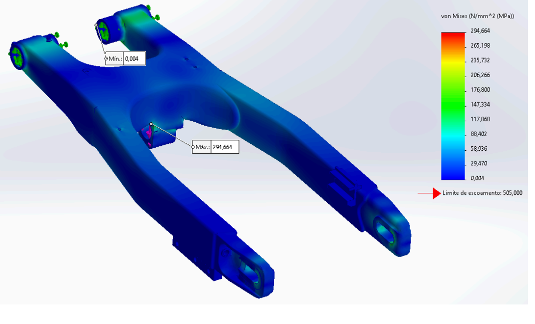


Figure 16: Stress analysis-Alloy 7075
Source: Prepared by the author

In figure 17, it can be seen that the maximum displacement of the model for the 7075 alloy is equivalent to 0.774mm, a slightly different result compared to the 2014 alloy.

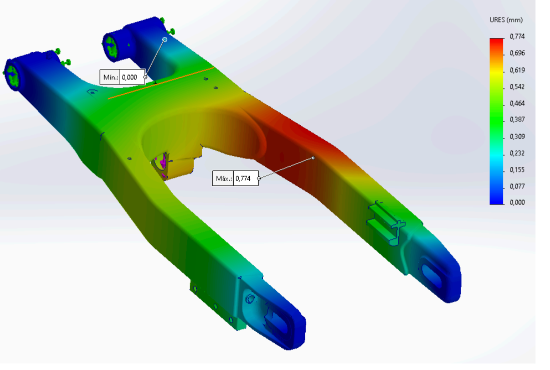


Figure 17: Displacement analysis-Alloy 7075.
Source: Prepared by the author.

In addition to the Stress and Displacement results, deformation was evaluated, depending on the aluminum alloys selected. Figures 18, 19 and 20 represent the deformation values resulting from loading.

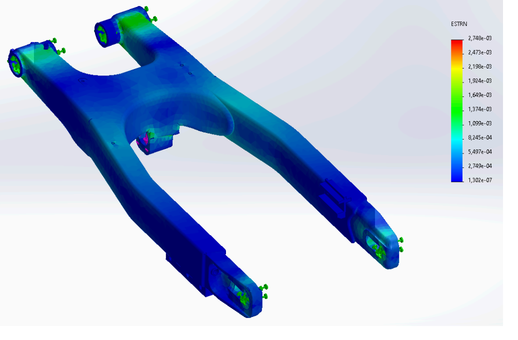


Figure 18: Deformation analysis - Alloy 1060
Source: Prepared by the author.

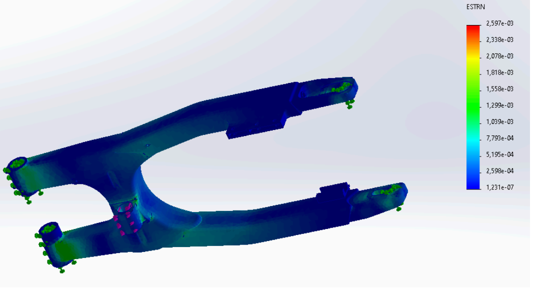


Figure 19 - Deformation analysis-Alloy 2014
Source: Prepared by the author.

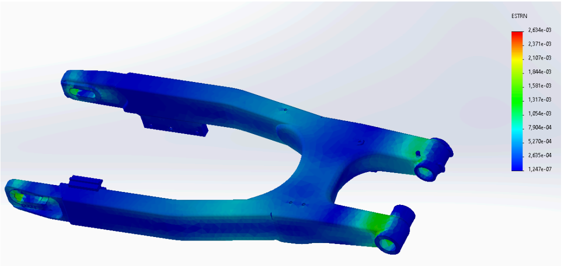


Figure 20: Deformation analysis - Alloy 7075

Source: Prepared by the author.

FINAL CONSIDERATIONS

In this work, a structural analysis was carried out applied to a trail motorcycle subjected to a boundary condition that simulates a fall from a 3-meter-high embankment. The condition was based on a recurring example among practitioners of extreme motorcycle maneuvers, and involved the study of the kinematics and dynamics of movements.

The focus of the analysis was the motorcycle's rear fork, which was considered the most critical part of the structure, due to the transmission of reaction forces from the wheel to the chassis and shock absorber. The rear fork was modeled and subjected to computational tests using finite elements, and the fixing points, mesh and reaction force were assigned.

The results obtained showed that among the aluminum alloys analyzed, the one that most satisfied the structural requirements was the 2014 alloy, which presented a maximum Von Misses stress of 294.664 MPa, which is lower than the yield stress of the material used (317.104 Mpa).

Therefore, the rear fork did not undergo permanent plastic deformation. The maximum displacement of the rear fork was 0.759 mm, being greater in the right region of the shock absorber eye.

Based on the results, it can be concluded that the motorcycle's rear fork containing the 2014 aluminum alloy is capable of resisting the analyzed boundary condition, without compromising its structural integrity. However, it is recommended that other analyzes be carried out with different boundary conditions and geometric and material parameters, to evaluate the behavior of the rear fork in more severe or varied situations.

REFERENCES

NATIONAL SCIENCE FOUNDATION (Alexandria, Virginia, USA). Theodore von Kármán (1881-1963). In: Theodore von Kármán (1881-1963). [S. l.], 8 mar. 2016. Disponível em: https://www.nsf.gov/news/special_reports/medalofscience50/vonkarman.jsp#:~:text=%E2%80%9CScientists%20study%20the%20world%20as,world%20that%20never%20has%20been.%E2%80%9D. Acesso em: 26 mar. 2022.

AZEVEDO, Álvaro F. M. **Método dos elementos finitos**. 1. ed. Portugal: Faculdade de Engenharia da Universidade do Porto Portugal, 2003. 258 p.

ALBUQUERQUE, Arthur Álax de Araújo. **Implementação de elementos finitos de barra e placa para a análise de esforços em tabuleiros de pontes por meio de superfícies de influência**. 2014. 250 p. Dissertação (Mestrado em Engenharia Cívil) - Escola de Engenharia de São Carlos da Universidade de São Carlos., São Carlos, 2014. Disponível em: https://teses.usp.br/teses/disponiveis/18/18134/tde-28072014-093844/publico/2014ME_ArthurAlaxAraujoAlbuquerque.pdf. Acesso em: 21 mar. 2022.

FISH, Jacob; BELYTSCHKO, Ted. **A First Course in Finite Elements**. 1. ed. [*S. l.*]: John Wiley & Sons, Ltd, 2007. 352 p. ISBN 978-0-470-03580-1.

BUDYNAS, Richard G.; NISBETT, J.Keith. **Elementos de Máquinas**. 10. ed. Porto Alegre: AMGH Editora Ltda, 2016. 1073 p.

COLLINS, Jack A. et al. Projeto Mecânico de Elementos de Máquinas: Uma Perspectiva de Prevenção de Falha. 2. ed. Rio de Janeiro: LTC — Livros Técnicos e Científicos Editora Ltda, 2019. 1559 p. ISBN 978-85-216-3623-6.

NORTON, Robert L. Projeto de Máquinas: Uma Abordagem Integrada. 4. ed. Porto Alegre: Bookman editora LTDA, 2013. 1028 p. ISBN 9780136123705.

HUTTON, David V. **Fundamentals of finite element analysis**. 1. ed. New York: McGraw-Hill Companies, 2004. 494 p. ISBN 0071122311, 9780071122313.

THOMAS. Top USA and International Finite Element Analysis (FEA) Software Companies. *In*: **Top supliers**. [*S. l.*], 2018. Disponível em: https://www.thomasnet.com/articles/top-suppliers/finite-element-analysis-fea-companies/. Acesso em: 22 mar. 2022.

GUGLIELMINO, Claudia; MUSUMECI, Giuseppe. Early elbow osteoarthritis in competitive enduro motorcyclist. **SPORTS MEDICINE UPDATE**, National Library of Medicine, v. 30, n. 7, p. 1287 -1290, 23 mar. 2022. DOI 10.1111/sms.13664. Disponível em: https://www-periodicos-capes-gov-br.ezl.periodicos.capes.gov.br/index.php/buscador-primo.html. Acesso em: 23 mar. 2022.

THE INFLUENCE of compliant chassis components on motorcycle dynamics: an historical overview and the potential future impact of carbon fibre. **Vehicle System Dynamics**, International Journal of Vehicle Mechanics and Mobility, p. 1043-1052, 1 fev. 2012. DOI 10.1080/00423114.2011.647824. Disponível em: https://www.tandfonline.com/doi/full/10.1080/00423114.2011.647824?scroll=top&needAccess=true. Acesso em: 25 mar. 2022.

MOTORCYCLE Handling and Chassis Design: the art and science. 1. ed. Spain: World magazine, 2002. 498 p. v. 1.

VERMA, Shailendra Singh; GANGRADE, Kamlesh. A Review Paper on Automobile Chassis. **International Journal of Research Publication and Reviews**, PG scholar, Department of Mechanical Engineering, SAGE UNIVERSITY, Indore, ano 2002, v. 3, n. 1, 1 jul. 2022. 7, p. 3626-3630.

Agrawal, M. S., & Razik, M. (2015). Finite element analysis of truck chassis frame. International Research Journal of Engineering and Technology (IRJET) ISSN, 2395-0056.

Vittore Cossalter, Roberto Lot & Matteo Massaro (2007) The influence of frame compliance and rider mobility on the scooter stability, Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, 45:4, 313-326, DOI: 10.1080/00423110600976100

GIRI, Barister. DESIGNING OF VIBRATION ANALYSIS OF SCOOTER CHASSIS. **International Journal Of Research Publications In Engineering And Technology [IJRPET]**, Khopi, Pune, v. 2, 1 mar. 2016. 6, p. 2454-7875.

FOALE, Tony. Motorcycle Handling and Chassis Design: The Art and The Science. Espanha: 2002.

HIBBELER, R. C. Resistência dos Materiais. 10. ed. São Paulo: Pearson Education do Brasil, 2019. 754 p. ISBN 9788543024998.