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Article

Analysis of a homokinetic joint subjected to torsional stresses as an educational innovation based on a case study

Análisis de junta homocinética sometida a esfuerzos de torsión como innovación educativa basada en caso de estudio

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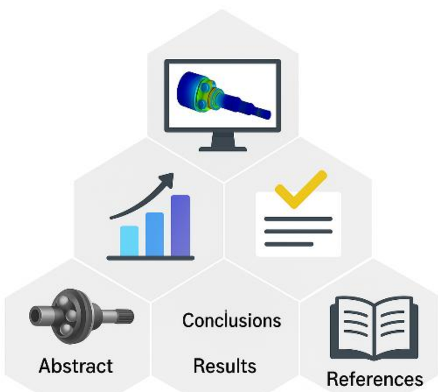
Abstract

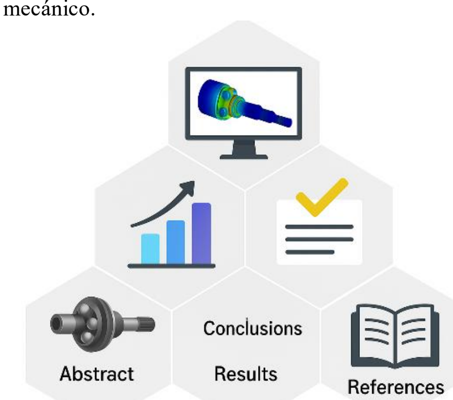
The evolution of industry 4.0 calls for a rethinking of teaching-learning models in engineer training. This paper analyzes the impact of project-based learning and the integration of design and simulation tools such as SolidWorks® and ANSYS®, supported by the finite element method and fatigue theory, in the acquisition of key industrial competencies. The results highlight the relevance of implementing innovative educational strategies based on real-world case studies in mechanical design.



Educational Innovation, Finite Element Method, CAD/CAE Analysis

Resumen

La evolución de la industria 4.0 exige un replanteamiento de modelos de enseñanza-aprendizaje en la formación de ingenieros. Este trabajo analiza el impacto del aprendizaje basado en proyectos y la integración de herramientas de diseño y simulación como SolidWorks® y ANSYS®, sustentadas con el método de elementos finitos y teorías de fatiga, en la adquisición de competencias clave para la industria. Los resultados subrayan la importancia de aplicar estrategias innovadoras en la formación basada en casos reales de diseño mecánico.



Innovación Educativa, Método de Elementos Finitos, Análisis CAD/CAE

Area: Dissemination and universal access to science

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Introduction

The boom in the automotive sector in the state of Guanajuato, particularly in the Bajío industrial corridor, reached a turning point almost three decades ago with the installation of the General Motors plant in the municipality of Silao. This event marked the beginning of a solid industrial infrastructure, catalysing the growth of industrial parks and attracting public and private investment. As a result, an ecosystem of supplier companies has been created that provide specialised inputs and services to large assembly plants, which represent one of the main sources of employment for graduates of programmes such as Electromechanical Engineering [Razón-González, 2019].

Transnational automotive companies operate under rigorous international quality standards, which require graduates to have certified technical skills that guarantee their effective insertion into the global market. Accordingly, the mission of the National Technological Institute of Mexico [TecNM] emphasises the provision of relevant, high-quality educational services that promote an equitable and sustainable society [TecNM, 2014].

The growth of the automotive cluster has accentuated the need to integrate cutting-edge technologies into design and manufacturing processes, with the aim of optimising costs, ensuring quality and offering competitive products. In this scenario, the continuous updating of teachers and their links with the productive sector becomes indispensable for strengthening institutional objectives in the academic and technological fields [Hernández, 2018].

The use of CAD/CAE/CAM tools in the classroom is an effective strategy for linking theoretical knowledge with real-world problem solving, in line with the mentefactura approach. Although the term 'mentefactura' may seem recent, it was introduced in 2012 by Juan José Goñi Zabala as part of a proposal to transform the production model through the strategic use of knowledge.

This philosophy, in conjunction with the principles of Industry 4.0, promotes the intensive use of information and its conversion into useful knowledge, leading to more efficient and innovation-oriented industrial processes [Goñi Zabala, 2012; Granados, 2020].

This context of digitalisation and automation poses new challenges for engineering education, as it requires graduates who are capable of solving complex problems, using emerging technologies and learning actively. Industry 4.0, together with mindfacturing, has led to the transformation of educational models towards more dynamic approaches, where practice-based learning and the acquisition of cross-cutting skills take centre stage.

Under this premise, this study examines an applied case of fatigue analysis in an automotive constant velocity joint, using tools such as SolidWorks® and ANSYS® to support the development of technical skills through active methodologies.

In automotive design, end-user safety and reliability are key elements, which requires detailed analysis of stresses, kinematics, and operating conditions using CAD and CAE tools. Finite element analysis allows the prediction of stress distribution and the evaluation of material behaviour under cyclic loads, including the calculation of fatigue cycles and safety factors, which are essential aspects for the reliability of mechanical systems.

Engineering education has shifted towards student-centred pedagogical approaches. Project-Based Learning [PBL] and Case-Based Learning [CBL] are widely recognised approaches for their effectiveness in strengthening critical thinking and complex problem solving [Prince, 2004; Hmelo-Silver, 2004].

The incorporation of simulators and design software allows theoretical concepts to be validated without incurring high experimental costs, thus optimising teaching resources [Budyna & Nisbett, 2020].

This paper documents a training experience in which Electromechanical Engineering students carried out the modelling, simulation and analysis of stresses in constant velocity shafts, using CAD tools and finite element simulations. Based on the identification of the problem, a solution was designed based on engineering criteria and the results were validated with specialised software, demonstrating the educational value of ABC in consolidating technical skills.

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The results show that this methodology promotes a deep understanding of fundamental concepts and strengthens students' preparation to face real challenges. Consequently, engineering education requires pedagogical environments that stimulate meaningful learning. Case-based learning represents an effective strategy for connecting theoretical knowledge with practical situations, promoting applied research, peer collaboration, and the development of skills aligned with the demands of modern industry.

State of the art

Over the last few decades, engineering education has evolved from traditional models focused on the one-way transmission of knowledge to approaches that promote active student participation in the learning process. Among these methodologies, Project-Based Learning [PBL] and Case-Based Learning [CBL] stand out, both of which have been shown to significantly improve motivation, analytical skills, and complex problem-solving in real-world contexts [Prince, 2004; Hmelo-Silver, 2004].

In particular, CBL has gained relevance in the teaching of technical disciplines by allowing students to analyse real-world situations, formulate viable solutions and develop critical thinking skills. This teaching strategy is aligned with the objectives of training engineers in the context of Industry 4.0, where there is a demand for autonomous, innovative professionals who are capable of adapting to highly technological environments.

At the same time, the integration of Computer-Aided Design [CAD] and Finite Element Analysis [CAE] tools has become an essential resource for linking theory with practice. These technologies make it possible to model mechanical components, evaluate their structural behaviour under real operating conditions, and validate designs without the need for physical prototypes, which significantly reduces development costs and times [Budyna & Nisbett, 2020].

Recent studies have documented the effectiveness of using software such as SolidWorks® and ANSYS® in developing technical skills in engineering students, especially in the analysis of stresses, deformations, and fatigue phenomena in mechanical systems.

This type of analysis contributes to a deep understanding of fundamental concepts such as safety factor, critical stress concentration zones, and resistance to cyclic loads, which are essential in industrial applications, particularly in the automotive sector.

In this context, this article is part of a line of applied research that combines the use of CAD/CAE technologies with active learning methodologies. Through the study of a real case—the analysis of a constant velocity joint—we seek to demonstrate how the implementation of CAA can enhance the development of professional skills and promote a more relevant, contextualised, and innovative engineering education.

Methodology

This study was developed as part of a training experience within the **Computer-Aided Design and Engineering** course of the Electromechanical Engineering programme at TecNM Campus Irapuato. A methodological approach based on **Case-Based Learning [CBL]** was adopted, which allows theoretical knowledge to be linked to professional practice, promoting the development of technical, analytical and collaborative skills in students.

1. Selection of the case study

The case selected was the **structural analysis of a constant velocity joint**, as shown in Figure 1, an essential component in vehicle power transmission systems. This element is subjected to cyclic torsional loads, and its study allows for an integrated approach to concepts of stress, deformation, material resistance and fatigue behaviour.

The case was chosen for its industrial relevance, mechanical complexity and direct applicability in the automotive sector of the Bajío corridor.

Box 1

Figure 1
CV joint a] with bearings b] complete

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2. Three-dimensional modelling in SolidWorks®

The first phase of the project consisted of parametric three-dimensional modelling of each of the parts that make up the constant velocity joint: outer bell, ball cage, inner balls, inner splined part, and splined shaft.

The students used SolidWorks® to create .sldprt files, defining revolution, extrusion, cut, and precise geometric adjustment operations. Subsequently, the complete assembly was carried out in an .sldasm file, establishing position and movement relationships using 'coincident,' 'centred,' and 'aligned' constraints, as shown in Figure 2.

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Box 2

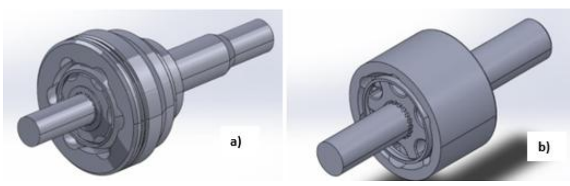

Figure 2

CV joint assembly, a] wheel side, b] housing side

3. Structural analysis setup in ANSYS® Workbench

Once the modelling was complete, the assembly was exported to **ANSYS® Workbench** for structural analysis using the **Finite Element Method [FEM]**. At this stage, the students configured the simulation environment by following these steps

:

- **Assignment of materials:** Hardened and tempered AISI 4045 steel was selected, with mechanical properties previously documented in ASTM standards: modulus of elasticity, ultimate stress, yield stress, density and Poisson's coefficient.

- **Definition of contacts:** Contacts between moving components were defined as frictionless or bonded, using the augmented Lagrangian formulation, which guarantees adequate coupling to transmit load and correctly simulate the interaction between parts.

- **Boundary conditions:** The end of the splined shaft was fixed by means of fixed supports, and a torsional torque was applied to the bell, simulating the typical torque transmission condition in operation [figure 3].

Box 3

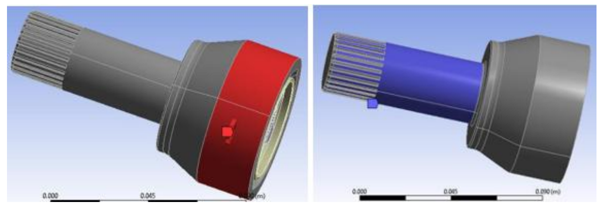

Figure 3

Boundary conditions: Fixed support [blue] and momentum [red].]

- **Meshing:** A high quality tetrahedral element mesh was implemented, using a mesh size control of 1.5 mm in critical contact areas and 2 mm in areas of low stress concentration. A mesh convergence study was carried out to ensure that the element size provided accuracy without compromising computational efficiency, the 1mm edge mesh can be seen in figure 4.

Box 4

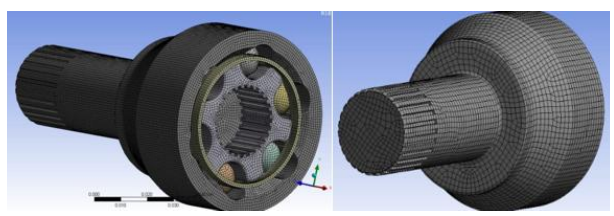

Figure 4

Mesh composed of tetrahedral elements with edge size 1mm

4. Simulation and analysis of results

During the simulation, Von Mises equivalent stress, shear stress and nodal displacements maps were generated, which allowed the identification of stress concentration zones, torsional behaviour of the material and potential fatigue failures. With these data, the factor of safety [FS] was calculated and the number of cycles to failure under a cyclic loading regime was estimated, using Goodman's criteria modified by Soderberg, as shown in figure 5.

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Box 5

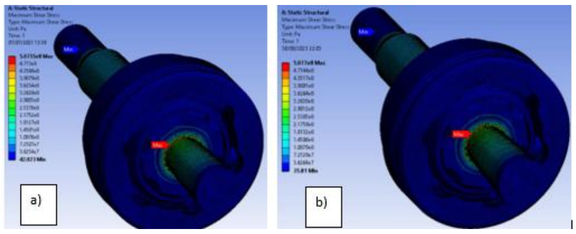

Figure 5
Von-Mises stress a] and b] shear stress within the safe allowable range

5. Documentation and pedagogical reflection
Each team of students prepared a technical report documenting:

- The design rationale.
- The modelling and simulation process.
- The interpretation of results.
- The mechanical redesign recommendations based on the analyses performed.

In addition, as part of the pedagogical reflection, a group discussion was held on the experience, the applicability of the knowledge acquired and its relevance in the automotive sector work environment.

6. Evaluation of the educational impact

Finally, a **competency-based assessment rubric** was applied to evaluate student performance in areas such as CAD/CAE software proficiency, critical data analysis, teamwork, technical communication, and application of knowledge in real-world contexts. This assessment was supplemented by self-assessment and peer co-assessment.

Results

The results obtained from the structural analysis of the constant velocity joint validated both the mechanical design of the component and the effectiveness of the teaching methodology based on real cases. The main technical and educational findings derived from the modelling and simulation process are detailed below.

1. Structural behaviour under load

The analyses performed using the Finite Element Method [FEM] in **ANSYS® Workbench** showed that the joint components operate within the **elastic range of 4045 steel**, the material used in their manufacture.

The **Von Mises** equivalent stress maps showed maximum concentrations located in the contact areas between the spheres and the retaining cage, as well as in the coupling between the splined shaft and the inner core.

The maximum stress value obtained was 478 MPa, below the elastic limit of the material [approximately 585 MPa], indicating a safe operating condition for the simulated load levels. The maximum displacements recorded did not compromise the functional integrity of the assembly, and the stress distribution patterns were consistent across different mesh configurations.

2. Mesh and convergence study

A mesh convergence analysis was performed using three different configurations [3 mm, 2 mm, and 1.5 mm]. The results showed a **significant improvement in accuracy** as the element size was reduced, with a difference of less than 2% between the solutions of the last two configurations. The mesh with **1.5 mm tetrahedral elements** was identified as the most suitable for balancing accuracy and computational efficiency.

3. Fatigue evaluation and safety factor

Based on the stresses obtained, the **safety factor [SF]** was estimated using the **modified Goodman** criterion. The calculated value was **1.82**, confirming the component's resistance to cyclic loads under normal operating conditions.

An **estimate of the number of cycles to failure** was also made, considering the typical torsional load regime of a utility vehicle, concluding that the joint could operate reliably for more than 1 million cycles [Figure 6].

Box 6

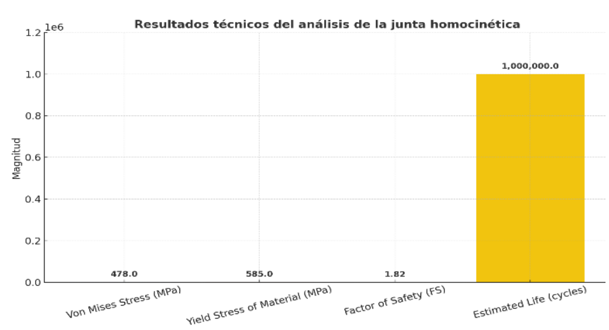

Figure 6
Results of the CV joint analysis

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4. Impact on student learning

From a pedagogical point of view, students showed significant improvement in their understanding and application of the concepts of material resistance, stress, fatigue analysis, and mechanical design.

The development of parametric models in SolidWorks®, the interpretation of results in ANSYS®, and the technical writing of the final report fostered the development of key skills such as technical communication, collaborative work, and informed decision-making.

The products generated by the work teams included:

Complete and assembled three-dimensional models.

Simulation reports with graphic evidence.

Comparative analyses between mesh configurations.

Recommendations for improvements in component design.

The teachers involved in the experience applied a competency-based rubric that showed **satisfactory and outstanding** performance levels in more than 85% of the participating students.

This experience allowed for the effective linking of theoretical content with the resolution of real problems in the professional environment.

Conclusions

The development of this study validated the use of Case-Based Learning [CBL] as an effective pedagogical strategy for linking theoretical knowledge with real situations in the industrial environment. Through the modelling and structural analysis of a vehicle constant velocity joint, students applied key concepts of materials mechanics, computer-aided design [CAD], finite element analysis [CAE] and evaluation of operating conditions under cyclic loads.

From a technical standpoint, the results demonstrated that the system components operate within the elastic range of the selected material [4045 steel], ensuring the structural reliability of the design.

The equivalent Von Mises stresses and shear stresses presented consistent and safe patterns, validated by a mesh convergence study. Likewise, the fatigue simulation yielded a favourable safety factor, confirming the component's viability for automotive applications.

In terms of training, the experience allowed students to develop analytical, collaborative, and technological skills aligned with the demands of the Fourth Industrial Revolution. The use of tools such as SolidWorks® and ANSYS® not only facilitated the visualisation of the mechanical behaviour of the systems but also strengthened technical interpretation and informed decision-making skills.

Furthermore, this study highlights the importance of human talent as a central axis in industrial innovation processes. The training of engineers capable of solving real problems using advanced technologies must be supported by a solid theoretical foundation that allows them to design, simulate, analyse and interpret complex systems with responsibility and critical vision.

Finally, it is concluded that the integration of real cases and computer simulations in the classroom contributes significantly to the improvement of the teaching-learning process in engineering, promoting a comprehensive and relevant education that links theory with practice, preparing students to successfully face the challenges of today's productive environment.

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