Advanced Modeling and Static Load Simulation of Chair Design: A SolidWorks-Based Approach

Ameliyana Rizky Syamara Putri Akhmad Yani[1,*], Daru Gilang Kistianto[1], Rovario Aslam Hadib[1]

[1]Department of Mechanical Engineering, Universitas Jenderal Soedirman
Purbalingga, Jawa Tengah, 53371
Email korespondensi: ameliyana.yani@unsoed.ac.id

Abstrak

Studi ini bertujuan untuk melakukan analisis mendalam mengenai peran Computer-Aided Engineering (CAE) dalam pemeriksaan struktural kursi. Penelitian ini berfokus pada investigasi sifat mekanis berbagai material, termasuk kayu balsa, kayu oak, baja paduan, dan baja tahan karat AISI 304. Simulasi dilakukan menggunakan perangkat lunak SolidWorks untuk mengukur perpindahan (displacement), tegangan (stress), dan regangan (strain) melalui iterasi yang berulang. Model Von Mises digunakan untuk menganalisis tegangan, alat URES (Uniformly Distributed Load Equivalent Stress) digunakan untuk memeriksa perpindahan, sedangkan metode estrn (Equivalent Strain) digunakan untuk merekam regangan. Tujuan utama adalah menilai perilaku mekanis berbagai material, yang dianggap sebagai langkah penting untuk meningkatkan strategi pemilihan material dalam proses desain furnitur. Hasil penelitian menunjukkan perbedaan signifikan antara keempat material tersebut. Tegangan tinggi dan perubahan besar terlihat pada kayu oak dan kayu balsa, dengan perpindahan total terbesar terjadi secara vertikal. Sebaliknya, AISI 304 dan baja paduan menunjukkan ketahanan mekanis yang mengesankan, dengan tegangan yang lebih rendah dan deformasi yang sedikit lebih besar. Hal ini sangat sesuai untuk skenario yang membutuhkan kekakuan dan stabilitas struktural, yang menjadi faktor paling krusial. Penelitian ini menekankan pentingnya desain material pembuatan kursi yang tidak hanya memenuhi fungsionalitas penggunaan tetapi juga memberikan kepuasan estetika.

Kata kunci: CAE; SolidWorks, Chair, URES, Von Mises

Abstract

This study aims to conduct in-depth analyses of the role of Computer-Aided Engineering (CAE) in the structural examination of chairs. The study focuses on investigating the mechanical properties of various materials, including balsa wood, oak wood, alloy steel, and AISI 304 stainless steel. Simulations were conducted using SolidWorks to quantify displacement, stress, and strain through repeated iterations. The Von Mises model is used for stress, URES (Uniformly Distributed Load Equivalent Stress) was the tool most used to examine displacement, while for recording strain, the method used was estrn (Equivalent Strain). Assessing mechanical behavior is the goal concerning various materials, which are viewed as a stepping stone to significantly improving the furniture design process's material selection strategies. The results of the study showed significant differences between the four materials. High stress and considerable changes were seen in oak and balsa wood; their biggest total displacement was recorded vertically. AISI 304 and alloy steel, on the contrary, showed impressive mechanical resistance, with lower stress and slightly bigger deformation occurring. In scenarios demanding rigidity and structural stability, this is suitable, emphasizing the utmost importance. Stressed is the designing of chair-making materials that strive to achieve usage-related functionality and aesthetic satisfaction

Keywords: CAE, SolidWorks, Chair, URES, Von Mises.

1. Introduction

Computer-Aided Engineering (CAE) is an important technology in modern engineering [1]. This technology enables engineers to design, analyze, and simulate products virtually prior to physical manufacturing. CAE enhances efficiency by enabling designers to test their ideas without the high costs and time associated with physical prototyping [2].

In furniture design, chairs are a crucial element, serving both functional and aesthetic purposes. In addition to its function as a seat, a chair should combine attractive aesthetics with adequate structural strength to support the load exerted by the user in daily activities [3]. Ideally, chairs are designed to fulfill functional needs while still maintaining visual appeal, creating a cozy atmosphere within the home.

In the modern era, computer-based simulation methods, particularly through Computer-Aided Engineering (CAE), have proven effective for designing and testing innovative, high-quality products [4]. Advances in CAE software have changed the way designers and engineers face product development challenges. This technology enables simulation of stress analysis prior to physical production, which is critical for efficient product development [5]. For example, design optimization or pressure analysis is easier to perform with the help of simulation tools. The CAE approach accelerates development time while improving product accuracy and performance.

Pressure simulation is an important element in product testing, such as in chair design, to ensure durability [6]. This durability is necessary for the chair to be able to withstand daily operational loads. Therefore, proper pressure simulation is essential in the development of a chair design so that it can function properly and is safe to use.

Placing objects such as books or personal belongings on a chair, or using it regularly as a seat, requires attention to the strength of the material [7]. Chairs are also often the first choice in living rooms or other public areas. Stress simulation is important to ensure that the design and materials used can withstand the load of these activities without damage [8]. Through comprehensive simulations, product developers can understand the structural behavior of the chair under various usage conditions.

Living room design is very important to create a comfortable and aesthetic atmosphere at home [9]. A chair not only serves as a seat but also as a decorative element that enhances the overall look of the room. A good chair design reflects the personality of the homeowner and helps create a warm and welcoming atmosphere for guests [10]. In interior design, an in-depth understanding of design principles such as material selection and layout arrangement is essential. This helps in choosing the right furniture and ensuring each element of the room complements each other harmoniously. Attention to detail in the living room can create a pleasant environment for residents and guests.

When choosing chairs for the living room, it is important to consider the balance between function and aesthetics. Chairs contribute to the ambience of the room, and the color and texture of the chair greatly influence the atmosphere you want to create.

Choosing the right material is key to the quality and visual appeal of the chair. Innovations in modern furniture and material technology enable interior design that meets both functional and aesthetic needs [11]. Understanding different materials such as wood, tempered glass and metal helps in choosing the most appropriate material. The balance between functionality and aesthetics creates visual harmony in the living room while ensuring the chair is efficient and durable for daily use [12].

Interior design is not only functional, it also affects the mood and well-being of individuals [13]. Every element, from wall color to furniture, has an emotional impact on the occupants. Therefore, in designing a living room chair, it is important to consider its functionality while creating a cozy and relaxing atmosphere.

Awareness of environmental issues makes sustainability very important in interior design [14]. This includes the use of eco-friendly materials and sustainable production methods. Thus, we can create an aesthetically pleasing and functional living room, while supporting environmental conservation efforts. Living room chair design needs to combine aesthetics with ecological responsibility to improve the quality of life for residents.

This study focuses on the development of efficient meja designs with various specifications. Using SolidWorks and Computer-Aided Engineering's (CAE) methodology, researchers will simulate model data to analyze structural failure under various extreme conditions, both every day and extreme [15]. This analysis helps identify problems in the initial design and allows for corrections to be made before production so that the final product is more robust and meets user needs as well as quality standards.

2. Method

Pre-Processor. The process begins with creating a model using SolidWorks, a powerful tool for designing three-dimensional structures. After creating the model, the next step involves selecting material properties that align with the intended application. Subsequently, the loads applied to the table structure are defined to accurately represent potential forces and stresses. In addition, the specification of constraints, or boundary conditions, is established to simulate real-world limitations that the structure will face. Finally, the meshing processes are executed, which involves breaking down the model into smaller, manageable elements for analysis.

Solver / Solution. After completing the pre-processing steps, the focus shifts to the Solver / Solution phase, where the actual analysis occurs. This phase involves applying the loads and constraints defined earlier to determine how the model will behave under various conditions. Following the solution process, the results are analyzed using the Post-Processor, which allows for the interpretation of data and visualization of the outcomes, providing valuable insights into the performance of the table structure.

In general, modeling is executed through a series of phases, which include design, meshing, defining boundary conditions, followed by the execution of the simulation process. The simulation execution involves mathematical algorithms applied by the software to derive the desired outcomes. The resultant data from the modeling encompasses values, vectors, and pressure distribution contours.

There are four materials used, namely oak wood, balsa wood, AISI 304, alloy steel. These materials have limitations that will affect the simulation results. These limitations can be seen on the Table 1, Table 2, Table 3 and Table 4:

Table 1. Oak Wood Boundary Condition

Property	Value	Units
Elestic Modulus	9000000000	N/m^2
Poisson's Ratio	0.3	N/A
Shear Modulus	7720000	N/m^2
Mass Density	560	kg/m^3
Tensile Strength	5500000	N/m^2
Compressive Strength	8600000	N/m^2

Table 2. Balsa Wood Boundary Condition

Property	Value	Units
Elestic Modulus	2999999232	N/m^2
Poisson's Ratio	0.29	N/A
Shear Modulus	299999910.5	N/m^2
Mass Density	159.989899	kg/m^3
Tensile Strength		N/m^2
Compressive Strength		N/m^2
Yield Strength	19999972	N/m^2
Thermal Expansion Coefficient		/K
Thermal Conductivity	0.05	W/ (m.K)

Table 3. AISI 304 Boundary Condition

Property	Value	Units
Elestic Modulus	1.90E+11	N/m^2
Poisson's Ratio	0.29	N/A
Shear Modulus	7.50E+10	N/m^2
Mass Density	8000	kg/m^3
Tensile Strength	517017000	N/m^2
Compressive Strength		N/m^2
Yield Strength	206807000	N/m^2
Thermal Expansion Coefficient	1.80E-05	/K

Table 4. Alloy Steel Boundary Condition

Property	Value	Units
Elestic Modulus	2.10E+11	N/m^2
Poisson's Ratio	0.28	N/A
Shear Modulus	7.90E+10	N/m^2
Mass Density	7700	kg/m^3
Tensile Strength	723825600	N/m^2
Compressive Strength		N/m^2
Yield Strength	620422000	N/m^2
Thermal Expansion Coefficient	1.30E-05	/K
Thermal Conductivity	50	W/(m.K)

3. Results and Discussion

The case was solved using SolidWorks software. The settlement process is carried out through the following stages:

1. The first step in the process is to create a workpiece model using the provided technical drawings. These drawings serve as the blueprint for the model, ensuring that all dimensions and features are accurately represented. By adhering to these specifications, the model will closely match the intended design. Figure 1 illustrates the completed model, which serves as the foundation for the subsequent analysis and simulation steps.

Figure 1. Modelling

2. After modeling the workpiece, the next step is to define the fixed geometry. Fixed geometry refers to parts of the workpiece that remain stationary and do not move during analysis. These regions simulate real-world constraints, ensuring accurate results. Figure 2 shows the areas of the workpiece identified as fixed geometry.

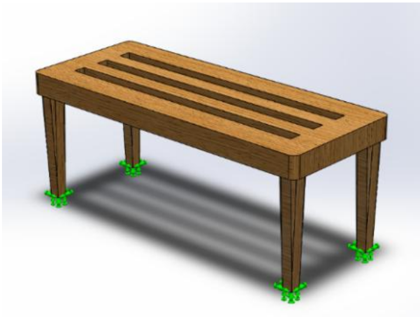

Figure 2. Fixed Geometry

3. Determination of External Loads. This stage is the stage of giving load on the surface of the workpiece. The load given in this simulation is 500 N. In Figure 3, we can see the distribution of the load acting on the workpiece.

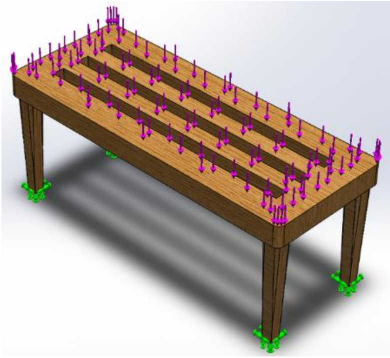

Figure 3. External Loads

4. The meshing stage is a crucial step in the finite element analysis (FEA) process. During this stage, the workpiece or model is divided into numerous smaller, discrete elements, often referred to as a mesh. This division allows for more accurate calculations by breaking down the structure into manageable parts. Each element of the mesh can individually be analyzed to determine how it will respond to different forces or stresses. The finer the mesh, the more precise the results, though it may also increase computational time. The goal is to create a balance between accuracy and efficiency. Figure 4 illustrates the results of the meshing process, showcasing how the model has been partitioned into these smaller elements, which are critical for facilitating the subsequent calculation and analysis stages.

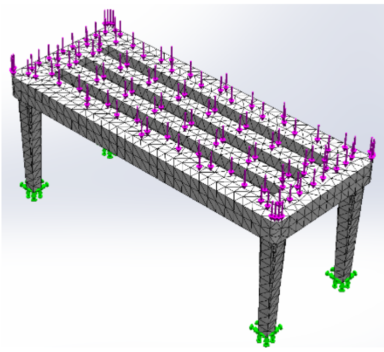

Figure 4. Meshing Result.

The design is then simulated to produce a picture of what happens to the chair when a load is applied. Figure 5 shows the difference in simulation results between four different materials.

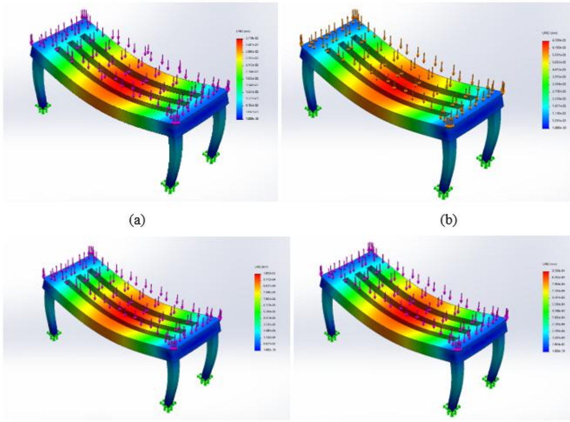

Figure 5. Displacement in materials (a) Oak Wood, (b) Balsa Wood, (c) AISI 304, (d) Alloy Steel.

In this analysis, a mechanical simulation was conducted for chairs made from four types of materials: oak wood, balsa wood, AISI 304, and alloy steel. The testing involved calculations of Von Mises stress, total displacement (URES), and strain (ESTRN). The results obtained from the simulation demonstrated distinct characteristics of each material.

a. Material: Oak Wood

The simulations indicate that oak wood experiences Von Mises stress, with a maximum value of 1.981 × 10^5 N/m² and a minimum value of 3.390 × 10^2 N/m². In terms of total displacement, the maximum value was recorded at 3,710 × 10^{-2} mm, while the minimum value was barely detectable at 1,000 × 10^{-30} mm. For strain, oak wood showed a maximum value of 1,547 × 10^{-5} and a minimum value of 4,209 × 10^{-8}. Despite experiencing significant stress distribution in some areas, the total deformation in oak wood is relatively low, with minimum displacements that are barely noticeable. Oak wood shows a significant stress distribution in certain areas, but the total deformation is relatively low, with the minimum displacement being almost undetectable

b. Material: Balsa Wood

Balsa wood, being lighter and less rigid than oak wood, exhibited different behavior under stress. The Von Mises stress in balsa wood recorded a maximum value of 1,518 × 10^5 N/m² and a minimum value of 2,010 × 10^2 N/m². The resulting total displacement was larger, with the maximum value reaching 6,709 × 10^{-2} mm and the minimum value also barely detectable at 1,000 × 10^{-30} mm. The measured strain showed a maximum value of 3,592 × 10^{-5} and a minimum value of 5,616 × 10^{-8}. This indicates that balsa wood is more susceptible to deformation, especially in areas that receive heavy loads. Balsa wood, which is lighter and less rigid than oak, shows greater displacement as well as higher strain, especially in areas that receive large loads.

c. Material: AISI 304 (Stainless Steel)

AISI 304, known for its high stiffness, exhibited a maximum Von Mises stress of 1.518×10^5 N/m² and a minimum of 2.010×10^2 N/m². The maximum total displacement was recorded at 1.059×10^{-3} mm, with an almost imperceptible minimum. In terms of strain, the maximum value produced was 5.672×10^{-7} and the minimum 8.868×10^{-10}. These results show that AISI 304 has very small displacements and strains, as well as Von Mises stresses that remain at a lower level than wood material. The AISI 304 material, with its higher stiffness characteristics, produces very small displacements and strains. The Von Mises stress also remained at a lower level than the wood material.

d. Material: Alloy Steel

Alloy steel, characterized by its high strength, demonstrated the best performance in terms of stress resistance. The Von Mises stress reached a maximum value of $1{,}531 \times 10^5$ N/m² and a minimum of $2{,}014 \times 10^2$ N/m². Despite producing the highest stress among the other materials, the total displacement recorded was $9{,}580 \times 10^{-4}$ mm, with the minimum value barely detectable at $1{,}000 \times 10^{-30}$ mm. The maximum strain measured was $5{,}103 \times 10^{-7}$ and the minimum $7{,}968 \times 10^{-10}$. This shows that the alloy steel has high stability in bearing load, with minimal displacement and strain. Alloy steel, which has high strength, produces the highest stress among other materials, yet with minimal displacement and strain, showing high stability in withstanding loads.

4. Conclusions

The simulation results reveal that oak wood and balsa wood exhibit greater stress and deformation compared to other materials, with balsa wood showing the highest deformation. This indicates that both types of wood are more prone to deformation when subjected to high loads. These wood materials tend to be flexible, but their resistance to large stresses is relatively lower than metal materials.

In contrast, AISI 304 and alloy steel, as metallic materials, demonstrate superior performance in load resistance. The Von Mises stresses in these two metallic materials are more controllable, with very minimal displacement. Their resistance to deformation makes them an ideal choice for applications that require high stability and rigidity.

Therefore, material selection should be based on the specific design objectives. For applications that require rigidity and stability, alloy steel and AISI 304 are more appropriate choices. Meanwhile, for designs that prioritize light weight and flexibility, oak wood and balsa wood can be suitable alternatives.

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