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NUMERICAL STRENGTH OPTIMIZATION OF STRUCTURAL DESIGN MADE OF DATE PALM FRONDS LEAVES WOOD PARTICLEBOARD

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Particleboard is a good substitute for costly wood/plywood boards. Particleboard can be developed from Date-Palm Leaves (DPL) as an annually renewable agro waste. DPL has a higher ultimate fiber length (1.25-2.50 mm) and higher α-cellulose content (about 60%) than hardwood/plywood and jute stick. In this present research, a numerical analysis focused on predicting the optimum strength for a selected chair style based on the mechanical strength behavior of the date palm leaves particleboard. This analysis is based on employing a chair model generated by Solidworks software and simulated by ANSYS software using the experimental mechanical properties of the selected material. Results show that the numerical analysis can predict a precise strength and safe behaviour for the selected chair shape and size according to the material properties without the manufacturing process taking part.

Keywords: numerical analysis, date palm fronds leaves particleboard, chair style, strength behaviour

1 INTRODUCTION

Movable furniture such as chairs, stools, sofas, cupboards, tables, beds, etc., were intended to be placed into the houses or building to ensure they become comfortable, appropriate for living and working, also to support various human activities. Since centuries ago, the population began fabricating and carving their furniture through using wood, rocks, and animal bones. The design of furniture has a wide range of environments, including homes, offices, restaurants, hotels, shopping centers, and hospitals. The design of furniture has many applications, including homes, offices, restaurants, hotels, shopping centers, and hospitals. The varieties of furniture types depend on their function and concept or style[1]. Manufacturing multipurpose furniture becomes common style sense in modern lifestyle needs such as practicality, environmentally friendly[2], and attractiveness[3]–[5]. Researchers have made furniture design important as more economy and ease[6]–[8]. The increase of the value of furniture products depends on style and effect and environment agreement[9], [10], which could be approved by the consumer regarding factors mentioned above[11]–[13]. The designer does an important role in using and developing these aspects because of their role in consumer decision to buy or not[14]–[16]. Woods have been used for many decades in furniture manufacturing[17]–[19]. Nevertheless, the modifications of the materials used in furniture manufacturing have experienced many new transformations[20]–[22]. Many mixtures of materials, including wood and other new materials[23], [24], were done to improve the furniture industry[25], [26]. The high need for new wooden designs and growth in agricultural research and the fires of the forest led to an increase in the importance of composite.

Many researchers have been taking the strength analysis of furniture frames studies under consideration, Ali Kasal[27] and Erdil, et al., [28]conducted a comparative strength analysis for different glued dowel frames of sofa made of solid wood and wood composites. The actual testing results were assessed with the numerical finite element analysis, intended to find out the possibility of employing finite element modelling and simulation in furniture production engineering. Results show that there isn't an important difference in the mechanical behavior. While the numerical analysis gives an acceptable general strength estimation for the sofa frame.

Novotný, M. et al., [29] **e**xamined the mechanical performance of an office desk under static loading in different positions looking for the stability and mechanical resistance attitude. The examination is based on a 3D modelling numerical analysis employing CAD software Autodesk Inventor 2011 to evaluate the maximum and minimum strength points and the stability of the constructed structural model so that to find out the best-modified shape. Results show the critical positions of breaking were on the upper part of the desk leg, and also the stability calculation was produced. Moreover, the solution of preventing the deformation progress was proposed.

G. Cueff et al. [30] developed a wood-based fire degradation numerical model. Then, they presented the results of wood-based products (particle boards) mechanical and thermal characterizations. Finally, they carried out a small-scale door simulation of thermomechanical behaviour and thermal transfers. They compared the experimental data with the numerical results and show good agreement on temperatures and thermal transfers on the product's unexposed side. The observation during the test is similar to the simulated deformation of the panel.

C. Rößler et al. [31] presented a simulation and mathematical model for wood particle glueing designated for particleboards to obtain a better glueing process understanding. The wood particles behaviour was investigated during glueing and they analysed the resulting adhesive distribution across the wood particles surface. “Random walk” and “lattice gas cellular automata” were used as the modelling methods, which were then implemented in MATLAB software and various scenarios were simulated. The results of their simulations reported that the model can feasibly be adopted for investigating the wood particles glueing process for possible industrial applications.

M. Autengruber et al. [32] developed a simulation concept based on the FEA. They reported very good prediction of failure behavior, load-carrying capacities, and stiffness values of the experimentally investigated I-joist wood composite beams at different moisture states. The modeling approach performance was observed by three different moisture level experiments simulation, reporting different situations of mechanical loading. They concluded that their complex composite wood beams testing programs would further improve beam geometries in different moisture states.

Çolakoĝlu and Apay[33]presented a finite element analysis (FEA) study for a wooden chair under impact test. The study employed ANSYS software to simulate chairs made of three types of wood materials. They were analyzed under several drop velocities and also different damping coefficients, aiming to find out the weak points in the chair design and construction. FEA results evaluated that the degree of safety increased, so the final product cost will be decreased and agrees with the objective function of furniture style and manufacturing. This is through minimizing the wooden components manufacturing and maximizing its strength. So confirms that the FEA technique can be successfully utilized for the mechanical strength analysis of wooden furniture.

Nemeş and Cionca[34]dedicated a study of finite element method for a chair made of ash wood (*Fraxinus excelsior*). Three different geometrical designs of the wooden chair were modelled with and without stretchers, also, a lounge chair with stretcher type. In this study, the TactilusBodyfitter, which is a surface pressure mapping technology, was used to obtain the effective pressure loading value of the seat surface, back, and rest for several human body weights, so as, to recognize the pressure region to be applied as a static load in the simulation. The simulation was done by ProEngineer software based on considerable Poisson's ratio and mechanical properties. The results show that the maximum position for the chair without stretchers at the upper part of the leg, but doesn't reach the critical value. While the chair with lateral stretchers acts very well under load and produced medium values in the middle, it's not reaching the critical value. In the lounge chair, the higher tensions are indicated at the lower part of the legs, but without reaching critical values. Therefore, it can be concluded that the Finite Element Analysis can be a reliable method for providing an acceptable evaluation in the design phase.

Yildirim, et al. [35] presented a comparative analysis between the finite element method (FEM) and experimental examination for mortise and tenon armchair joining under static and fatigue loading. The finite element analysis was done by ANSYS Workbench software includes modelling and simulation. In the simulation, the mechanical properties of Scots pine wood were imported. While the fatigue loads and stresses were estimated by the ANSYS fatigue tool. The experimental testing shows that the failure appears between the top side rail and back legs around the mortise. In comparison with the finite element results, the failure in the joining parts was occurring. The FEM produced a results convergence of about 81.25% with the experimental. From that, it is confirmed that FEM is applicable for providing strength and safety information in furniture design and manufacturing, to improve the product quality without the need for experimental testing.Chevalier, et al. [36]introduced a numerical simulation of the furniture response under cyclic mechanical loading. The Monte Carlo stochastic analytical method was employed, due to the non-homogeneity of the wood material. Different cyclic compression loading tests were executed a fixed maximum pressure on the bolt head for spruce specimens cut from the bunk bed so to evaluate the gap behaviour of the bed junctions due to the permanent local strain increment with the number of cycles, which would impact the furniture integrity in the future. The results of the experimental tests show quite symmetry with a large scattering from one specimen to another. Therefore, due to the experimental result curves, a simple analytical model was proposed to identify the values of residual penetration with the cycles’ number, taking into consideration the uncertainty of wood behaviour. The numerical analysis presented that under cyclic loading, the natural dispersion of the wood behaviour might reach three times the predicted value.

This research paper tries to discover numerically the optimum strength behavior of a new artistic chair style design made of modified particleboard wood composite. This numerical analysis employs modelling and simulation concepts based on the mechanical properties of the selected material experimentally.

2 MATERIALS AND METHODS

2.1 Chair Shape Style Selection

The shape design of the chair should be an attractive, beautiful, and artistic style to provide the comfort of the occupant, as well as the functional requirements like; stacking ability, folding ability, size, weight, durability and strength. Moreover, with these mentioned requirements, the style chosen is made to be suitable for manufacturing the chair by DPL wood composite material taking into consideration the compact casting process in the manufacturing. So, for the DPL manufacturing process, the (Balinese style outdoor furniture) was chosen as shown in Fig. (1).

Fig. 1. Balinese outdoor chair style.

2.2 Numerical Analysis

The numerical study of the present work is looking for predicting the strength behaviour of the selected shape design based on the type of the particleboard wood composite material and how will be the range of loading occupation of this chair design. The numerical analysis is classified into three stages; Firstly, preprocessing stage, is an important step in the numerical work, where the model generation will be done and the type of materials employed will be selected. Also, a process for presenting the model into small parts (elements) is called meshing. The second stage is the solution, where a direct or indirect iterative numerical method to solve the engineering concept of the modelling based on the boundary conditions is initially submitted. Finally, the postprocessing stage, where the presentation types of the simulation results take place, depends on the type of the modelling and simulation software. In this numerical analysis work the modelling has been done by using Solidworks version 2015 software to generate the chair model and the simulation was done by ANSYS version 16.1 software.

2.3 Geometrical Modelling

The selected shape of the chair was three dimensional (3D) modelled using Solidworks version 2015, taking into account the standard dimensions of the chair. The 2D drawing with dimensions and the 3D model are illustrated in Fig.2.

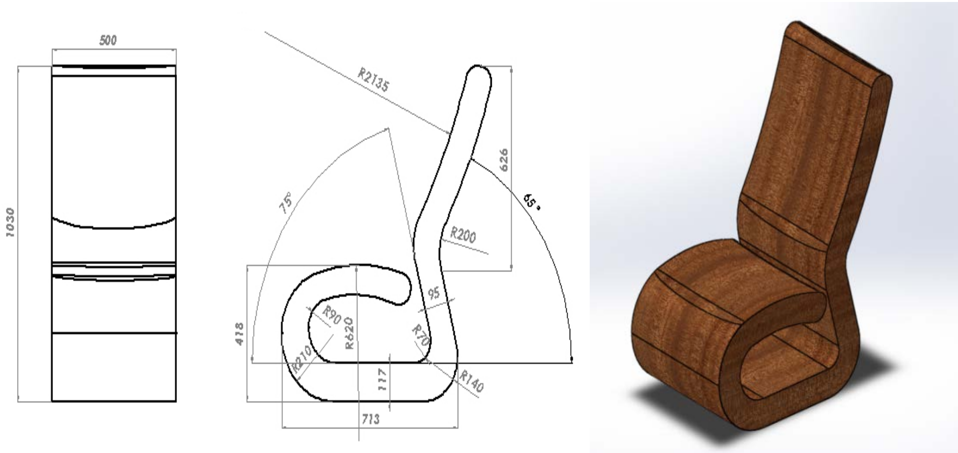


Fig. 2. The 2D and 3D geometrical model of the chair with dimension.

2.4 Material Selection

The raw material employed to produce particleboard in this research was a date palm (Phoenix dactylifera. L). The date palm fronds were collected and dried, then the leaves were trimmed from the fronds and cut into strips with a minimum length of 50 mm. A white wood glue, Poly Vinyl Acetate (PVA), which is an aliphatic rubbery thermoplastic polymer was used as a binder for particleboard fabricating. The particles raw materials (strips) were mixed with the PVA binder in the polymer blender for 5 min, according to the weight ratio 2/1 of the glue binder to the wood particles. The gradients amount of the particles in the process of fabricating the particleboard was managed basically on the weight quantities in the mat production. The mixture was placed and distributed uniformly in the iron mould so to produce a mat with dimensions (120 x 100 x 10) mm. Mats were pressed under (1 MPa) for one day at room temperature (22 °C), and at the end of the process it was kept under 150 °C for 15 min, then later, it was conditioned at 22 °C for one week. This manufactured data palm frond leaves particleboard (Fig. 3), has a bulk density (559 kg/m3).

Fig. 3. The palm frond leaves particleboard Panel.

The mechanical properties of the fabricated wood particleboard were analyzed using a tensile test machine according to BS.EN:310, *ČSN EN 527-3 (911105),* and *TS 2474* [37]–[41]. The selection of these testing methods was based on the most practical loading that can be applied to the particleboard in real applications[42], [43]. The testing mechanical properties results are given in Table 1.

Table 1. The mechanical properties of the date palm frond leaves particleboard material.

Sample	Poisson's Ratio	Tensile Yield Stress (MPa)	Tensile Ultimate Stress (MPa)	Modulus of Elasticity (kPa)	Flexural Yield Stress (MPa)	Flexural Ultimate Stress (MPa)	Modulus of Rupture (kPa)	Elongation (Tensile to Flexural) (%)
Pure date palm frond leaves	0.35*	1.5	5.04	393	5.41	9.39	499	7.26 - 21

* This data is based on the references [29, 33, and 34].

2.5 Meshing and Boundary Conditions

Numerical design analysis has many steps to be achieved, one of them is meshing. The simulation software divides the generated model into many pieces of small elements connected using common nodes. FEA programs deal with the whole model a group of discrete connected elements. Meshing is a very important step in numerical design analysis. It is a technique that subdivides the whole geometrical model into small 3D tetrahedral solid elements connected at common nodes depending on the generating account in the simulation. Where the finite element analysis programs look at the whole model as a network of discrete interconnected elements. The magnitude of mesh generation (number of elements and nodes) depends on the model geometry and many other factors such as; contact specification, mesh control, mesh tolerance, element size, and model dimensions, also more refining in the curved areas. Therefore, a medium meshing control was used with the number of nodes and elements in the presented meshed model are (68629) nodes and (14688) elements as shown in Fig.4.

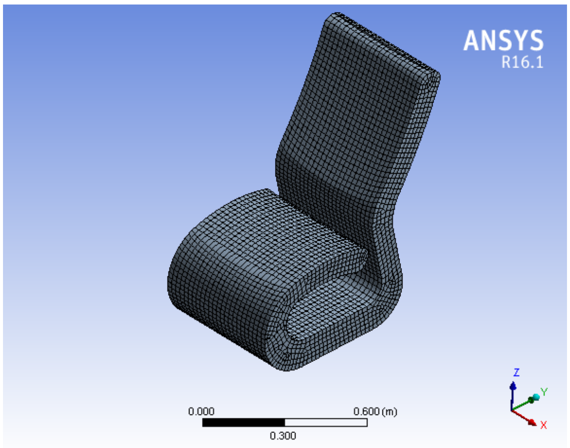


Fig. 4. The meshing distribution of the chair model.

The boundary conditions created in this simulation are classified into fixtures and external loads.
The fixture is at the lower base of the chair, while the external loads are considered as a human weight, which is used as a pressure loading on the top base and back of the chair. This pressure is estimated by dividing the applied range of human weight (1000 - 3000 N) by the top base and back chair areas, which are determined by using Solidworks software as follows; chair back area is (500 mm x 517 mm) and the top base chair area is (500 mm x 353 mm). The external loading ranges are detailed in Table 2.

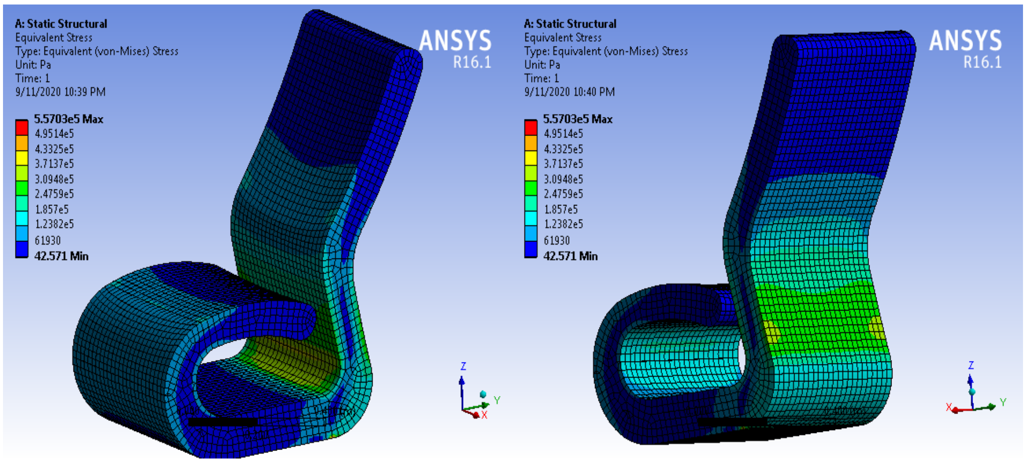
Table 2. The pressure loading was applied on the top base and back of the chair due to the human weights.

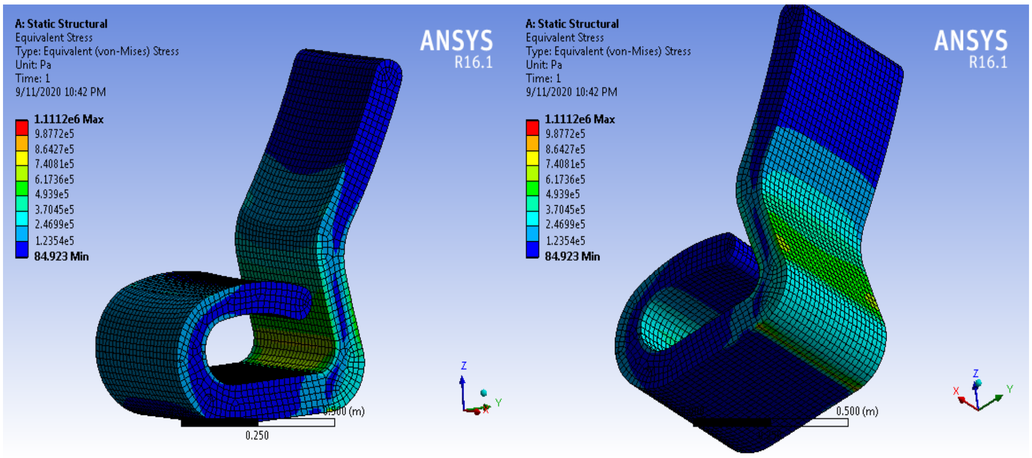
Human weight (N)	Pressure loading applied at the top base of the chair (kPa)	Pressure loading applied at the back of the chair (kPa)
500	2.83	1.94
1000	5.67	3.87
2000	11.33	7.74

3 RESULTS AND DISCUSSIONS

The main idea of this numerical analysis is to discover the optimum strength behaviour of the selected geometrical design of the chair based on the date palm frond leaves particleboard material tested mechanical properties[44]. The primary analysis for manufacturing a new design should be analyzed depending on the material properties, to approximate the size and geometrical shape of the design without taking the experimental work part. So that, to reduce the manufacturing cost. The cause for selecting a date palm leaves particleboard is due to the low cost of the raw material as waste wood and easy manufacturing using the compact pressing process in a mould. For these reasons, the numerical simulation employed according to the collected data of the mechanical properties of the material as tensile strength and flexural strength. The external loading subjected to the chair is measured as pressure load for different human weights applied to the top base and the back of the chair. The simulation results focused on the chair strength indicated by equivalent von Mises stress and the possibility of deformation through the total deformation, also the importance of looking to the safety factor of the design due to the external loading. The equivalent von Mises stresses resulting on the chair under a range of pressure for the tensile strength properties of the material are shown in Fig.5. While for the flexural strength properties are shown in Fig.6. From Figs. (5,6), indicated that the critical sections in the chair geometrical design are the curved sections, especially at the back and lower base of the chair, which is due to the stresses concentrated significantly. From the numerical analysis, it is clear that the highest stress obtained under the high applying load is lower than the yield strength of the material according to the two types of testing properties. While, when the applied load goes higher at (2000 N), the von Mises stress demonstrates a little bit higher value than the tensile yield strength in a localized place, which can be ignored. Moreover, according to the mechanical properties of the material in Table 1, the flexural strength properties are higher than the tensile properties, giving an indication that the strength of the chair based on bending property will endure under all applied loading. For that, the attention will be turned into the tensile properties because it is of lesser strength. The second option is the total deformation, where the back of the chair will be subjected to range bending loads, so the flexural strength properties of the material will be taking place as shown in Fig.7. It is clear from the figures that the total deformation never exceeds the total elongation of the material (21%) as indicated in Table 1. Finally, the third option for checking the optimum strength of the chair design is the safety factor and in this, the low tensile strength properties will be taking place and the results are shown in Fig.8.

a





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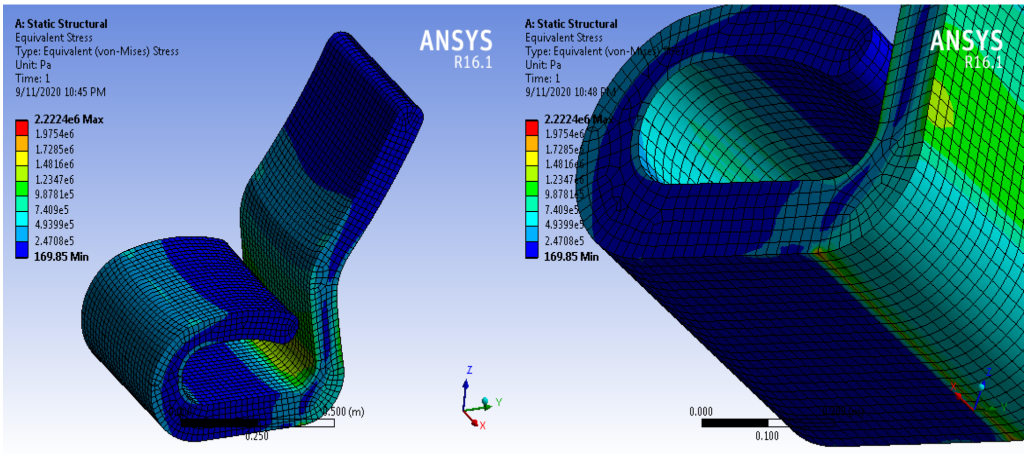

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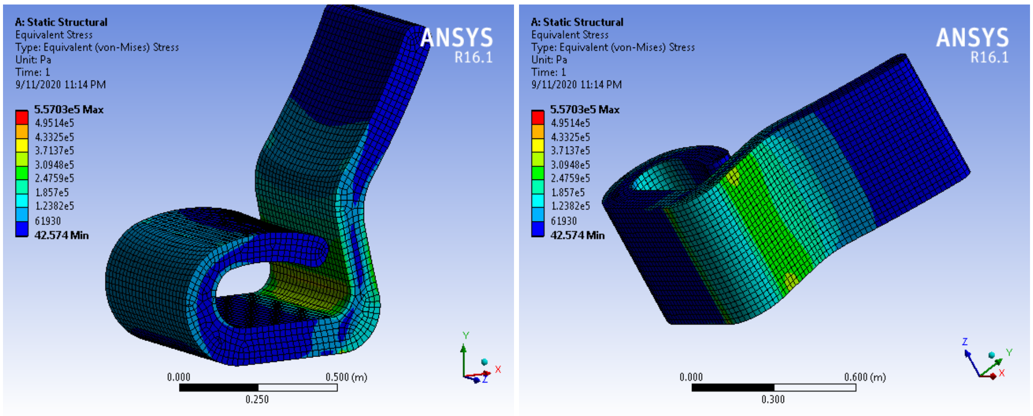
Fig. 5. The Equivalent von Mises stress in the chair is based on the tensile strength properties of the material at different loading. a) 500 N, b) 1000 N, c) 2000 N.



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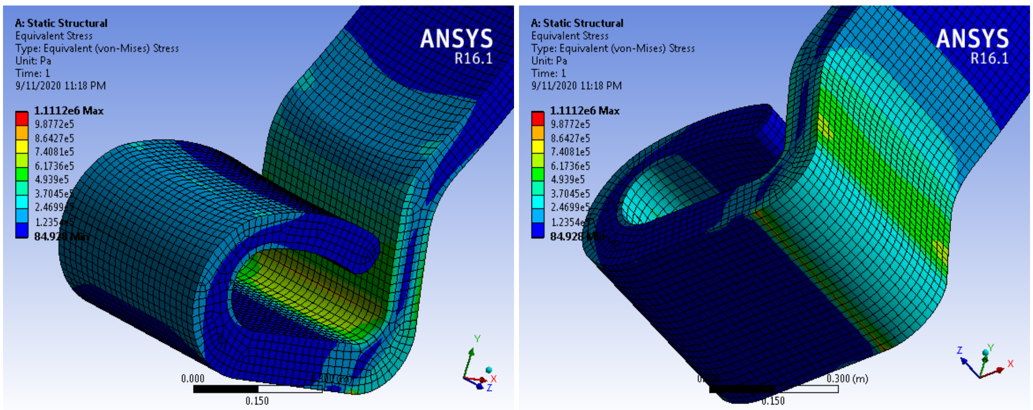

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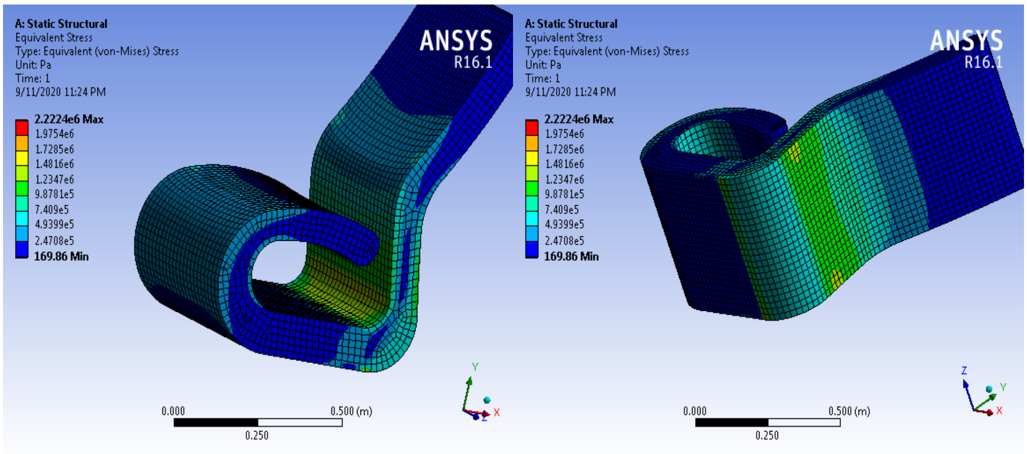

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Fig. 6. The Equivalent von Mises stress in the chair is based on the flexural strength properties of the material at different loading. a) 500 N, b) 1000 N, c) 2000 N.

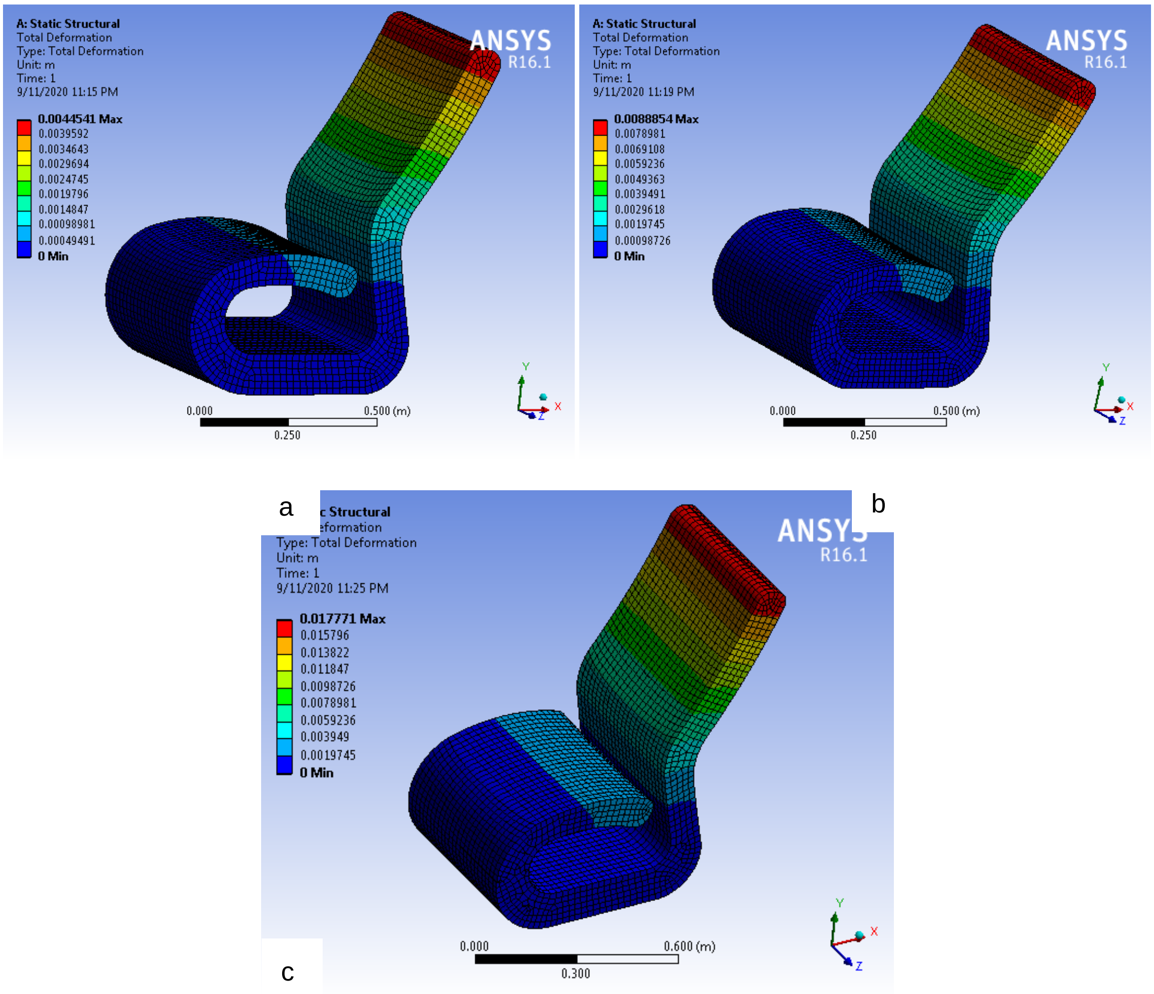

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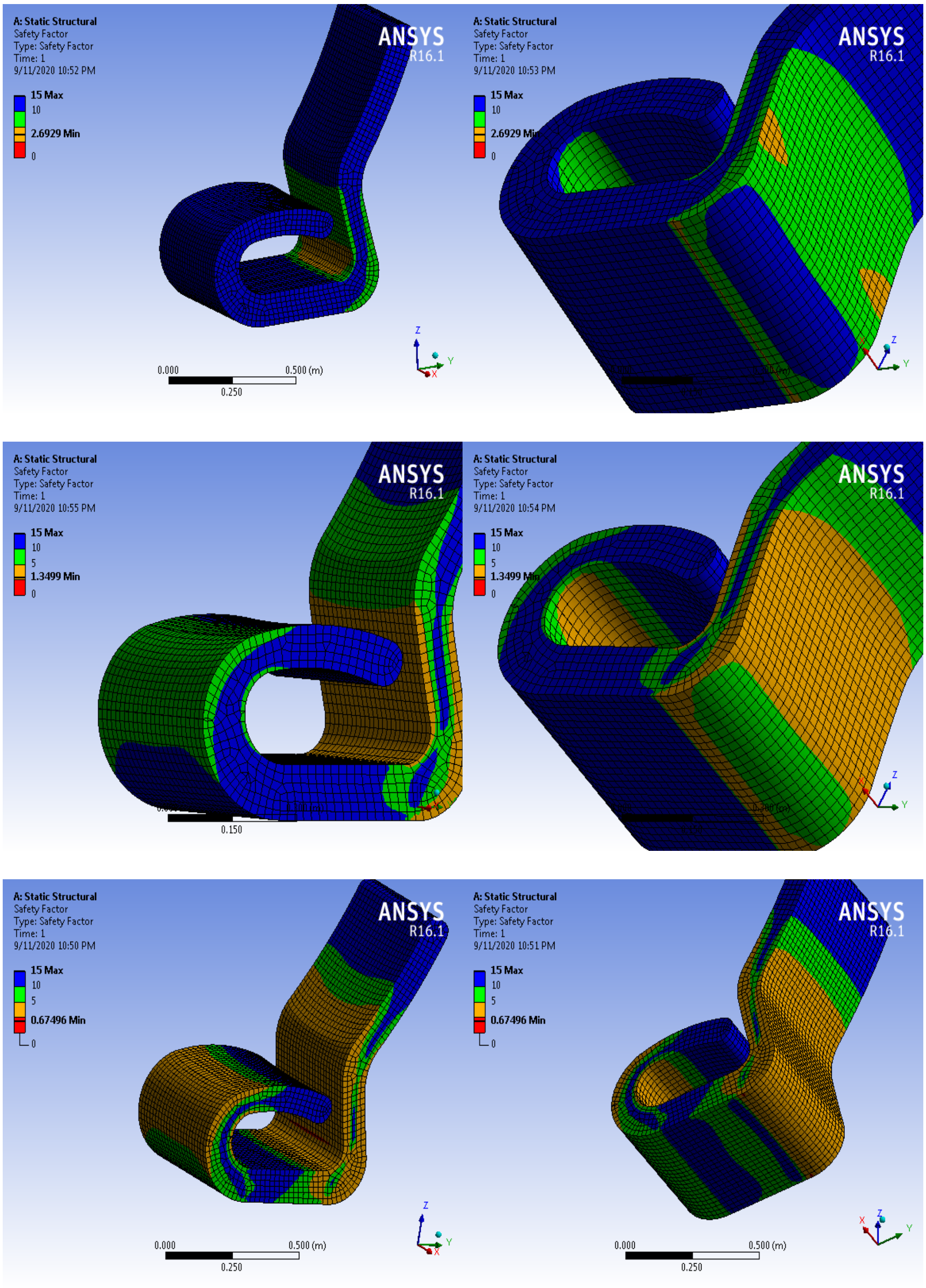
Fig. 7. The total deformation of the chair is based on the flexural strength properties of the material at different loading. a) 500 N, b) 1000 N, c) 2000 N.

The safety factors resulting from the simulation are reduced from the maximum level of 2.69 at low load 500 N to the minimum level of 0.674 in a small spot at the highest load.

Basically, according to the simulation results, a clear decision appeared precisely that the selected design of the chair based on the date palm leaves particleboard mechanical properties can withstand human weight till 2000 N (more than 200 kg). This indicates that it may be possible to fabricate the design of the chair with this type of material. Moreover, the numerical simulation can produce a good predictable strength optimization for any furniture style design through importing the experimental mechanical properties of any employed wood types in the numerical simulation software.



a

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Fig. 8. The safety factor of the chair is based on the tensile strength properties of the material at different loadings. a) 500 N, b) 1000 N, c) 2000 N.

4 CONCLUSIONS

The numerical investigation was presented for a new style chair made of date palm leaves particleboard to detect the optimum strength behaviour. The results show that the chair size has an optimum strength by using ANSYS software by employing the experimental mechanical properties of the selected material. In addition, numerical modeling and simulation can predict the design style of the chair safely based on the materials used before starting fabrication.

5 ACKNOWLEDGEMENT

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