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A FINITE ELEMENT APPROACH TO INVESTIGATE THE PERFORMANCE AND RELIABILITY OF AN EXTENSION STAND IN TABLE SAW MACHINES

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Abstract

The extension stand serves as an assistant to the single user on the table saw machine (TSM) without an inbuilt extension. This research developed and simulated an extension stand to estimate its performance reliability during operations. SolidWorks software 2021 was used in designing the stand. Simulation and modeling of the components were performed with SOLIDWORKS 2021 software to generate stress and strain analysis. The extension stand consists of medium wooden members (50 x 50 x 75 mm), having four (4) caster wheels at the upper part of the stand. The designed extension stand was fabricated and evaluated. The simulation analysis shows maximum directional deformation at 3.889e-00 mm, equivalent elastic strain at 2.667e-04, von Mises equivalent stress and yield strength at 6.421e+06 N/m^2 and 3.930e+07 N/m^2 respectively, with the factor of safety at 6.1. The produced extension stand performed optimally with the estimated cost of manufacturing at N17,000.00 (US$38.04) as of 2021. The extension, as evaluated, passed the reliability test; it was strong enough to support the weight of the applied load during the empirical and simulated processes. The stand provides safety; it is affordable and easy to use.

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1. Introduction

Complications involving the prediction of wood and wood-based products behavioural patterns in service have proven a challenging task until recently (Okpala and Okechukwu, 2015). Experts in the field relied on intuition and experience to predict the behaviour of wood (DeCristoforo, 1988). In developed countries, a lot of efforts have been made to develop non-destructive techniques for the prediction and reliability assessment of materials, including wood (Brischke, 2021). Assessments on the capacity of carpentry joints using finite element (FE) models had been investigated, compared to experimental results with acceptable prediction capacity (Massaro et al., 2022). Huber et al. (2022) presented a technique based on X-ray computed tomography scans for recreating the geometry, pith, knots, and local fibre orientations in wood boards. They suggest that in the future, adapting the method for logs could enable analyses of boards before sawing. Nailed connection in wood (Hong and Barrett, 2010), screws (Hu et al., 2022) crack propagation (Qiu et al., 2014), water absorption (Salin, 2008), wood fracture mechanics (2004), and many other behaviours have been presented (Blomqvist et al., 2023). Autengruber et al. (2021) developed a finite-element-based simulation concept to better understand the failure mechanics of wood-based composites and to support a targeted optimization of new cross-section types of I-joist beams. The performance of the modeling approach was reported as providing a very good prediction of stiffness values. Developing countries such as Nigeria are gradually catching up with the trend (Icha and Odey, 2024). Hence, applying this approach to investigate the performance of locally developed products gives the professionals the platform to compete with those around them.

Woodworking machines are dedicated equipment that are designed and used for a variety of wood processing activities (Landscheidt and Kans, 2016; Twede, 2005). Expert woodworkers, who make wood products including furniture, cabinets, doors, windows, and many other wood-based items in woodworking factories and workshops, often employ this equipment (Top et al. 2016; Camci et al. 2018; Kisseloff, 1969; Wacker, 1970). Many pieces of equipment and machinery used for processing wood are divided into categories based on their uses and include sanders, saws, planers, routers, jointers, and lathes, among others. According to Lucisano et al. (2016) and Landscheidt and Kans (2016), these machines are made to carry out specialized operations such as cutting, shaping, drilling, sanding, and polishing wood. Due to the high importation costs, access to this equipment is limited in low-income countries like Nigeria (ITC/ITTO, 2002). Industries and factories employ outdated versions of machinery from advanced nations, while those with little financial resources locally manufacture them for usage (Adewole, 2015; Oteng-Amoako et al. 2008).

One of the advantages of using woodworking machines is that they can increase the speed and accuracy of wood processing tasks (Adewole et al. 2017). For instance, a table saw machine (TSM) can cut wood pieces to the exact measurements required, and a router can shape and create intricate designs on wood pieces that would be difficult to achieve by hand. In addition, using woodworking machines reduces physical stress, making work more efficient and less strenuous (Richards, 1966). Conversely, improper use of woodworking equipment can result in dangers such as injury or damage to the tool or the wood processed (Kminiak et al. 2016; Marinov, 2014: Tomlinson, 1971). Hence, woodworkers must acquire the right training and tools and adhere to machinery safety precautions (Skills Institute Press, 2010).

TSM is a major wood conversion equipment and comes in many shapes and sizes (Adewole, 2015; Sokolovski and Deliiski, 2009). The ability to make accurate and precise cuts is one of the table saw's key advantages. Users could make bevels, grooves, and other specific cuts because of the blade's ability to adapt to different angles and depths (Cheng et al. 2010; Kminiak et al. 2016). The machine also cuts through thick, dense materials, which makes it the best tool for slicing through hardwoods, plywood, and other difficult materials (Krilec et al. 2014; Orlowski et al. 2020). It is adaptable and can be applied to several woodworking projects. It can generate customized cuts and shapes with the right jigs and fixtures, as well as for ripping, crosscutting, and precision cutting (Capotosto, 1983; De Cristoforo, 1988; Kminiak and Kubs, 2016; Odey and Icha, 2022).

The use of the TSM, as with others, requires safety precautions; otherwise, the implications are fatal. According to the Environmental Health and Safety Office (EHSO, 2017), kickbacks can happen, resulting in significant injury. Other disadvantages of some TSMs include noise and a messy work environment (Chukarin et al. 2017; Meskhi et al. 2014). One such safety measure applied to TSMs is the use of an extension stand when cutting long boards and large panels (Capototos, 1983; De Cristoforo, 1988). The added workspace helps to stabilize the wood and provide additional support, which can help to reduce the risk of kickback or other accidents during the cutting process (De Cristoforo 1988; Hamilton and Nubs, 2015). However, the reliability check for such stands has not been carried out to determine the performance capacity and possible failure modes. The study focuses on the use of the finite element method to simulate and evaluate the performance of the extension stand.

2. Materials and Methods

2.1. Outline

The manuscript considers the mechanical properties of the stand construction made of wood that could be used as an extension part of a TSM. The analysis was carried out using a finite element method. The literature, structural design, manufacturing costs, and mechanical loading acting on the support in real conditions were previously considered. The results of the numerical calculation are presented. Two different scales are presented with the FE-models to portray performance reliability and failure mode.

2.2. Materials

The materials used in this study were solid wood (mahogany) available within the environment of the research area (Calabar - Nigeria). The bolts used in the study were M20 and M4 end-to-end bolts with their hand-fabricated knobs. The screw used in this study was a GB wood screw made of steel. Figure 1 shows the pictorial view of the designed extension stand. A detailed drawing and an exploded view of the stand are shown in Figures 2 and 3, respectively. The specific configurations of the extension stand are also presented.

Figure 1: Pictorial view of the designed extension stand

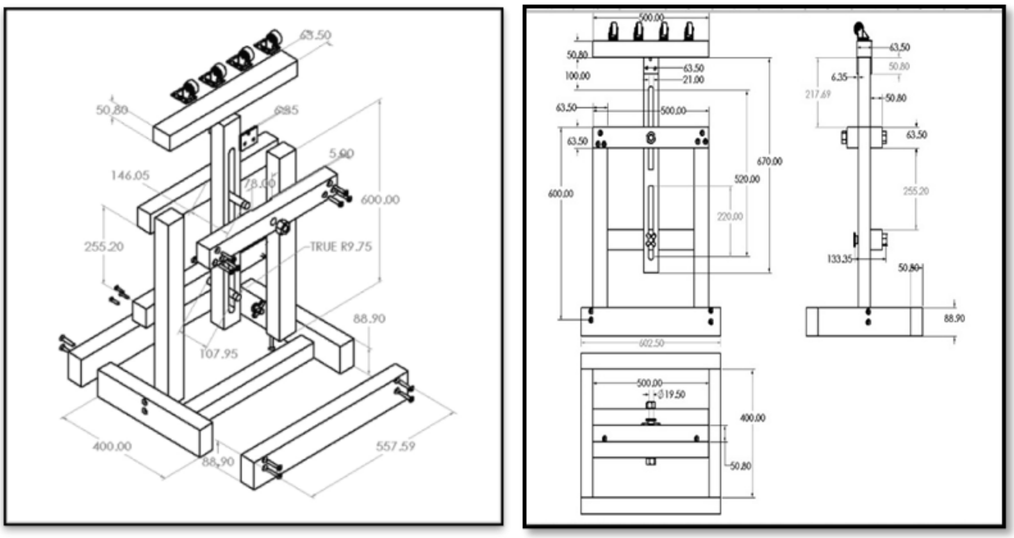
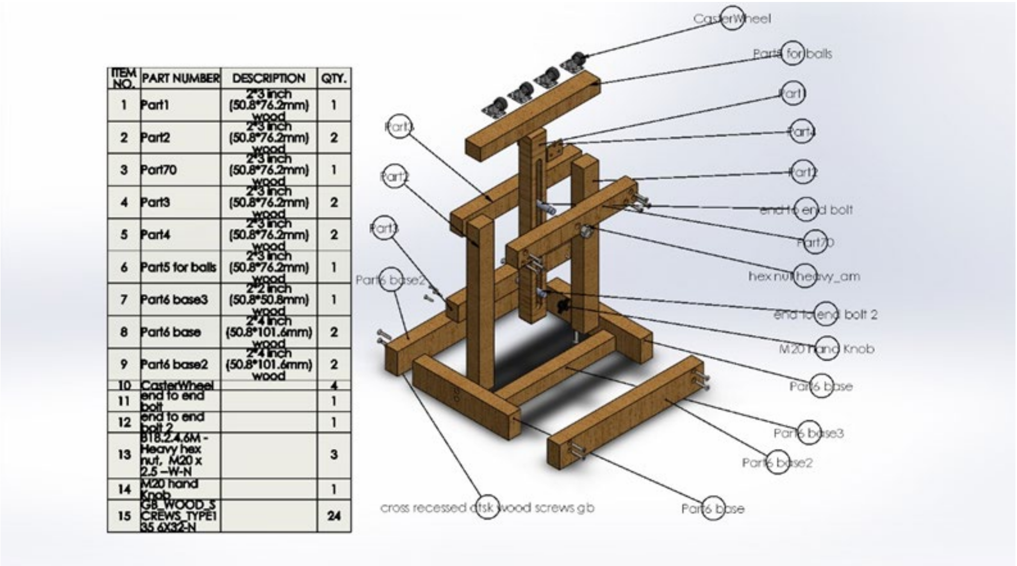


Figure 2: Detailed drawing of the designed extension stand



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Part1	2*3 inch (50.8*76.2mm) wood	1
2	Part2	2*3 inch (50.8*76.2mm) wood	2
3	Part70	2*3 inch (50.8*76.2mm) wood	1
4	Part3	2*3 inch (50.8*76.2mm) wood	2
5	Part4	2*3 inch (50.8*76.2mm) wood	2
6	Part5 for balls	2*3 inch (50.8*76.2mm) wood	1
7	Part6 base3	2*2 inch (50.8*50.8mm) wood	1
8	Part6 base	2*4 inch (50.8*101.6mm) wood	2
9	Part6 base2	2*4 inch (50.8*101.6mm) wood	2
10	CasterWheel		4
11	end to end bolt		1
12	end to end bolt 2		1
13	B18.2.4.6M - Heavy hex nut, M20 x 2.5 --W-N		3
14	M20 hand Knob		1
15	GB_WOOD_SCREWS_TYPE1 35 6X32-N		24

Figure 3: Exploded view of the designed extension stand

2.3. Design Considerations

The design of extension stand took into account estimates for the fasteners' resistance, screw-holding ability, and loading capacity. The fastener design processes outlined in Forest Products Laboratory's General Technical Report from 2021 were adhered to.

2.3.1. Bolts

The shear and bearing capacity under the bolt were computed using the formula of Seward (2014).

Shear capacity,

$$F_{v,\,Rd} = \frac{0.6\, f_{ub} A}{\gamma_{M2}} \tag{1}$$

Bearing capacity

$$F_{b,\,Rd} = \frac{f_{ub} d t}{\gamma_{M2}} \tag{2}$$

Where; f_{ub}= ultimate tensile strength of bolt, A = bolt tension area/full area, γM2 = partial safety factor = 1.25, d = nominal bolt diameter, t = plate thickness

2.3.2. Screws

Screws were commonly used in areas where withdrawal strength was important (Hu et al. 2022). Care was taken when tightening screws in the wood to avoid stripping the threads. The maximum amount of torque that was applied to a screw before the threads in the wood were stripped is given by

$$T = 3.16+0.0069X \text{ (Khurmi and Gupta, 2005)} \quad (3)$$

Where. T is torque (N–m) and X is the density of the board (kg m^{-3}).

Equation (T) is for 8-gauge screws with a depth of penetration of 15.9 mm. The maximum torque is fairly constant for lead holes: 0% to 90% of the root diameter of the screw.

Ultimate withdrawal loads P (N) of screws from wood was predicted by the equation given in Forest Products Laboratory's General Technical Report from 2010.

$$P = KD^{1/2} (L-D/3)^{3/4} G2 \quad (4)$$

Where. D = shank diameter of the screw (mm, in.), L = depth of embedment of the threaded portion of the screw (mm), and G = specific gravity of the board based on oven-dry weight and volume at current moisture content. K = 41.1 for withdrawals from the face of the board, and K = 31.8 for withdrawals from the edge. Other screw withdrawal load resistance considerations were following Hu et al. (2022).

2.4. Costing of Production

The materials used for the fabrication of the extension stand were estimated based on the list produced by the design software (Figure 3). Table 1 shows the cost of fabricating the extension stand. The stand cost a total of seventeen thousand, one hundred naira (N17,000) an equivalent of US$38 as of 2021. This shows that workshops within the town can afford the extension stand with the interest of fabricating the table saw machine.

Table 1: Material cost analysis of extension stand

Description of Item	**Qty**	**Unit**	**Rate**	**Amount (N)**
50mmx50mm wood	3	Pieces	400	1,200
Medium-size top bond glue	1	Jar	800	800
Bolt	2	Pieces	500	1,000
Knob	2	Pieces	100	200
50mmx75mm wood	1	Pieces	600	600
Screws	1	Pound	600	600
Washer	4	Pieces	100	400
Caster wheel	2	Pair	2600	5,200
Transportation				2,000
Workmanship				5,000
TOTAL				**17,000**

2.5. Fabrication of Extension Stand

Materials for the fabrication of the extension stand were sourced from the local wood market within the research location and taken to the University Wood Products Engineering workshop for the fabrication process. Full-lengths of mahogany wood with dimensions of 50 x 50 x 1200mm were first processed and cut into dimensions as specified in the design (Figure 2). Holes for bolts and knobs were drilled as detailed. Finally, the stand was assembled using an electric driver. Screws were driven into the blocks perpendicular to the face to ensure the screw threads were fully inserted into samples.

2.6. Experimental Evaluation

Figure 4 illustrates the setup of the extension stand on the table saw machine. The extension stand was placed on the floor perpendicular to the table saw machine. A full-length plywood board of 18 x 2240 × 1220 mm was used to perform the reliability test of the extension stand on the table saw machine using visual observations and on-the-job assessment methods. The worker was also observed for signs of difficulty during the operation. All observations were recorded.

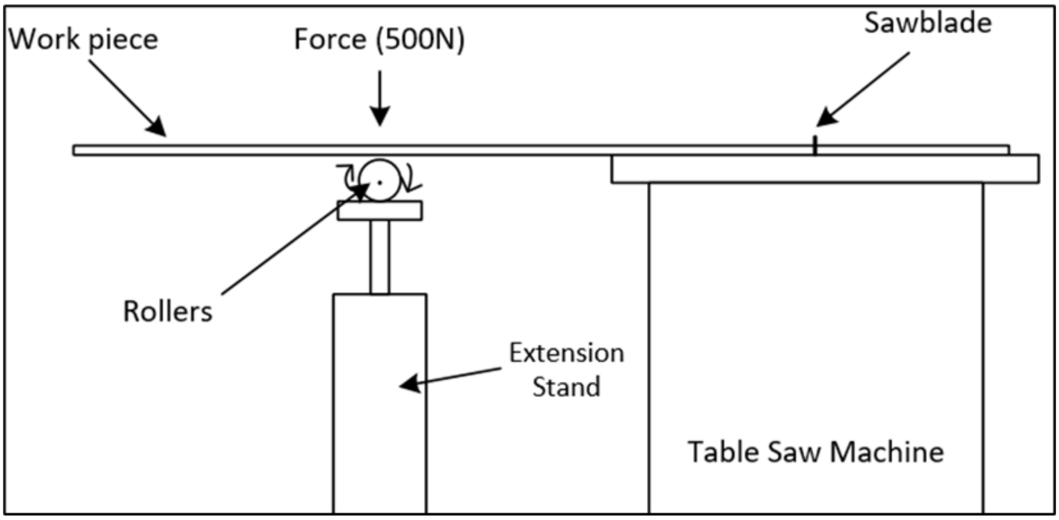


Figure 4: Experimental setup of the extension stand on the table saw machine

2.7. Finite Element Modelling

Finite element modelling (FEM) was employed in this study to simulate the extension stand performance in a TSM, closely resembling the real conditions of the experimental evaluation. The 3D finite element model (FE model) geometry is depicted in Figure 5. The simulations were conducted using the FE SolidWorks (2021) software interface. The mesh density of the wood-based sample was set at approximately 1.2 mm, ensuring adequate representation of the material's structural properties. The mechanical properties of solid wood, as detailed in Table 2 (NCP 1973), were specified within the FE model. The model used tetrahedral elements (Silid186) with degrees of freedom (d.o.f) per node, allowing for translations in the x, y, and z directions. For the extension stand connection, bolts and nuts were modelled as illustrated in Figure 3. Contact interactions were simulated using surface-to-surface elements with a friction coefficient of 0.33, as derived from the literature (Massaro et al., 2023). Finite sliding was assumed to accurately replicate the contact behavior between the rollers and the workpiece. Both linear and non-linear finite element analysis (FEA) were considered in this study. Non-linear analysis accounted for material and geometric non-linearities, reflecting the real-world behavior of the wood under loading conditions. The stress-strain behavior of the wood, essential for capturing the non-linear response, was defined based on experimental data (Figure 7), ensuring an accurate representation of material properties within the model. The base in the yz-plane was assigned as a fixed support geometry, anchoring the model to replicate the experimental setup shown in Figure 5. A displacement load (500N) was applied in the direction of the rollers, perpendicular to the TSM, until the maximum magnitude was reached (Figure 4). A mesh convergence study was conducted to ensure the accuracy of the FE model. Several mesh densities were tested, with the final mesh chosen based on achieving less than 1% change in the von Mises stress and reaction force outputs between successive refinements. The final mesh configuration provided an optimal balance between computational efficiency and solution accuracy. Two FE models were developed in this study: one representing the true scale of deformation and the other at a scaled factor of 23,6896 to highlight failure modes. The von Mises equivalent stress and the maximum reaction force at the reference point of the applied load were the primary outputs analysed. The FE model's accuracy was validated against experimental results, with a deviation of less than 19% in the key performance metrics, indicating high reliability of the simulations.

Table 2: Mechanical properties of wood used in the study

Property	Value	Units
Elastic modulus	9800	N/m^2
Poisson's Ratio	0.032	N/A
Tensile strength	2.04	N/mm^2
Compressive strength	6.9	N/mm^2
Yield strength	39.3	N/m^2
Mass density	600	kg/m^3
Shear modulus	3 x 10^8	N/m^2

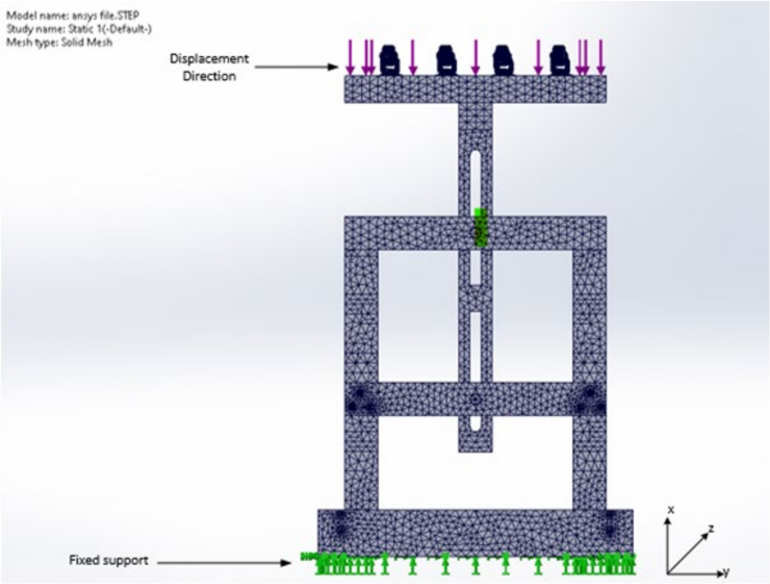


Figure 5: Mesh and boundary conditions in the numerical model

3. Results and Discussion

3.1. Fabrication and Evaluation of Extension Stand

The extension stand, as shown in Figure 6, was easy to fabricate using simple and portable tools. It is observed that using fabrication methods according to DeCristoforo (1988) and Capototos (1983) produced satisfactory results. For easy screwing, an improvised method was used to fabricate the knobs for the bolts. The evaluation process was done in the university departmental workshop using the table saw machine examined during the design process. Figure 7 shows the finished extension stand that is ready for use with the table saw. The extension stand was tested with a standard-length plywood board (Figure 7). The stand was observed to support the user adequately and satisfactorily after the evaluation process. There was no risk of not fixing the stand to the floor as the rollers allowed the boards to slide through the stand.

Figure 6. Extension stand ready for use with the table saw machine

Figure 7. Evaluation process of the extension stand on table saw machine

3.2. Simulation Analysis of the Extension Stand

Table 3 presents the data from the simulation analysis carried out on the modelled extension stand when a force of 500 N is applied. The directional deformation, elastic strain equivalent, and equivalent static stress are presented at minimum and maximum levels. The yield strength and safety factor are also presented in the table. The directional deformation values of the extension stand, which indicate the amount by which the object deforms or changes shape in a particular direction, range from a minimum of 1.000 x 10^{-30} mm to a maximum of 3.889 mm. The equivalent elastic strain values of the extension stand measure the ratio of deformation to the original length of the stand and provide an indication of its elasticity range from a minimum of 0 to a maximum of 2.667 x 10^{-4}. The stress experienced values of the extension stand, which indicate the internal forces acting on the stand resulting from external loads or deformation, range from a minimum of 0 N/m^2 to a maximum of 6.421 x 10^6. The yield strength of the extension stand, which is the maximum stress it can withstand without permanent deformation or failure, is 3.930 x 10^{07} N/m^2. The factor of safety associated with the extension stand is given as 6.1.

Table 3: Simulation results: maximum and minimum load values

Object Name	Directional Deformation	Equivalent Elastic Strain	Equivalent Stress	Yield Strength	Factor of Safety
Minimum	1.000e-30 mm	0.000e+00	0.000e+00 N/m^2	3.930e+07 N/m^2	6.1
Maximum	3.889mm	2.667e-04	6.421e+06 N/m^2		

3.2.1. Stress Distribution

Figure 8(a) shows the von Mises stress distribution around the simulated FE model of the extension stand when exposed to external loading of 500N. The stress distribution can be read by corresponding values on the legend. The stresses are observed to be highest at the base of the stand and around the braced neck region. Other areas were observed to have minimal stress distribution. To observe a physical deformation on the FE model ES, von Mises stress was scaled to 23,6896 (Figure 8b). A sway away from the central—axis is observed.

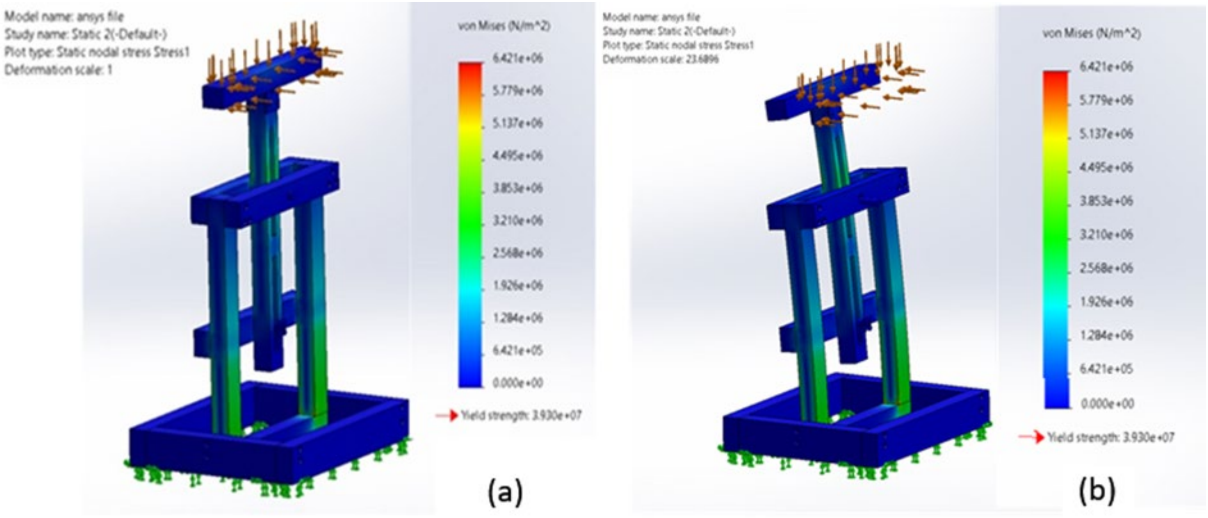


Figure 8. von Mises stress distribution of ES at deformation scale of 1(a) and 23,6896(b)

3.2.2. Strain Distribution

Figure 9(a) depicts the elastic strain distribution around the simulated FE model. The strain distribution follows a similar pattern to the stress distribution around the extension stand when subjected to external loading. The strain distribution on the extension stand covers larger areas than those seen on the stress diagram, spreading along the brace on the base post and down the neck post to the middle brace point. Other areas were observed to be in the minimal levels of strains, especially the base. To project physical deformation on the FE model ES, strain was scaled to 23,6896 (Figure 9b) showing a sway away from the central —axis.

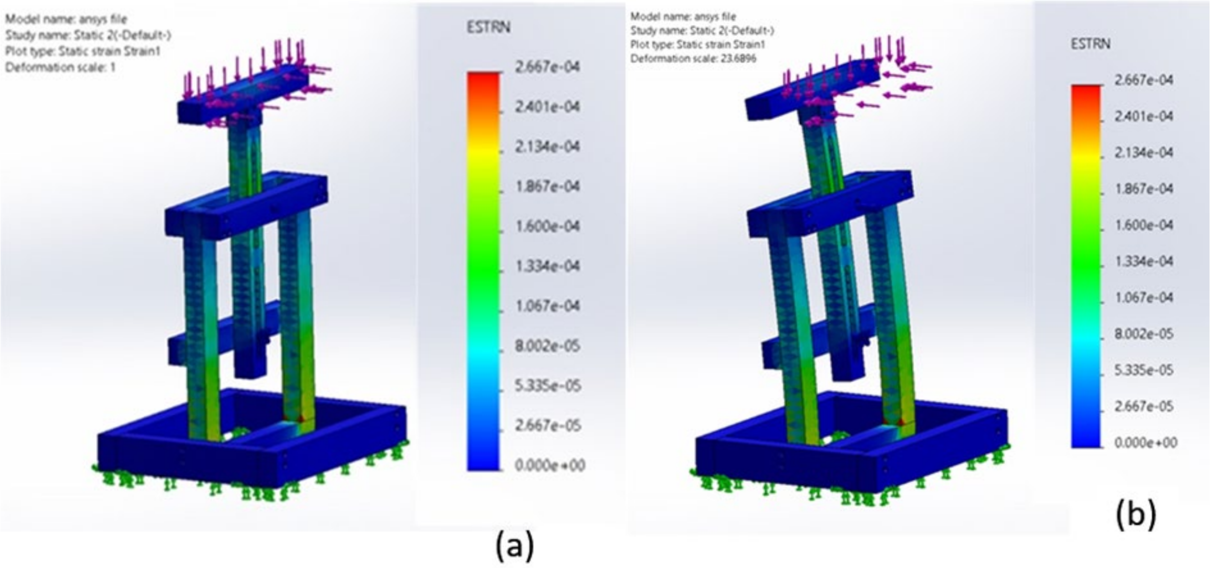


Figure 9. Strain distribution of ES at deformation scale of 1(a) and 23,6896(b)

3.2.3. Displacement Distribution

Figure 10(a) shows the displacement distribution analysis on the simulated ES FE model when an external load is acting on it. The distribution is observed to be highest at the top where the caster wheel is situated, spreading down toward the base but ending just about midway. From there downward is observed to be at the minimal levels of displacement, and no visual distortion is observed on the platform. To project physical deformation on the FE model ES, displacement was scaled to 23,6896 (Figure 10b) showing a sway away from the central —axis.

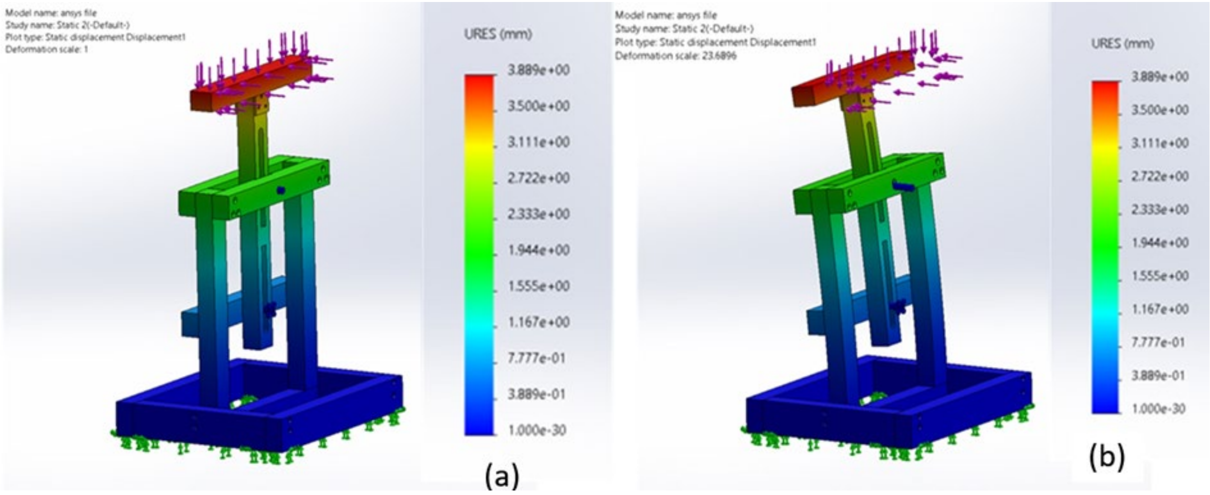


Figure 10. Displacement distribution of ES at deformation scales of 1(a) and 23,6896(b)

3.2.4. Factor of Safety

Figure 11 shows the safety value factor for the extension stand. When subjected to a force of 500N, the design has a minimum factor of safety of 6.1. This means the extension stand is 6.1 times stronger than the force acting on it.

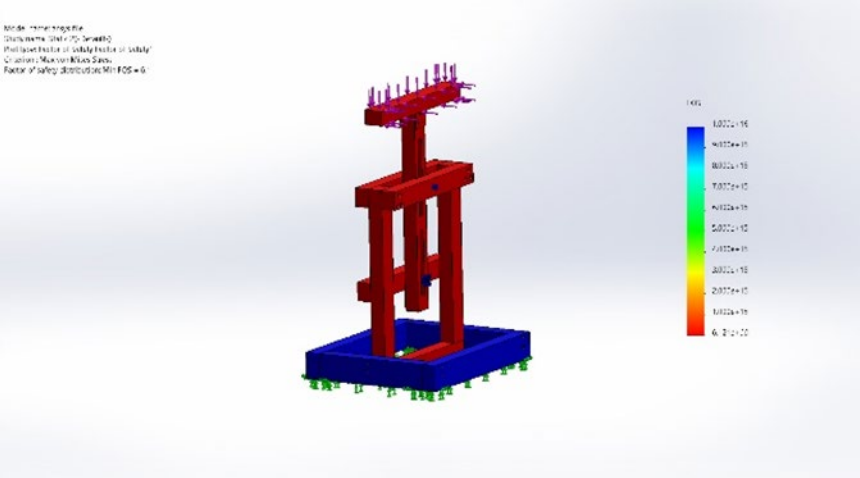


Figure 11: Factor of safety

4. Conclusion

This study successfully employed a FE approach to investigate the performance and reliability of an extension stand for TSMs. The results demonstrate that the ES enhances the usability and safety of the TSMs, which could encourage the development and use of the locally made TSMs. The FE model effectively simulated the behaviour of the ES in wood-based materials, providing insights into stress distributions and predicted potential failure modes, with validation against experimental results showing a deviation of less than 19% in key performance metrics. These insights can guide improvements in the design and reliability of the stand where necessary. The FE analysis serves as a preliminary tool for identifying key areas for enhancement. Future research should integrate optimization techniques to refine the design parameters and improve the stand's performance further. Also modifying and simulating the ES for use with other woodworking machines and on developing additional hardware such as storage compartments or shelves to increase the stand's functionality. The extension stand is affordable, easy to use, safe, and adaptable for educational and research purposes, potentially enhancing economic development. By utilizing this stand, woodworkers can improve their efficiency and precision and create high-quality wood products.

Disclosure Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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