Design Analysis and Optimization of Cattle Horn – Plastic Composite Chair Seat

Ibrahim Abdullahi, Muhammad Attahir
Department of Mechanical Engineering, Faculty of Engineering,
Bayero University, Kano
Kano, Nigeria.
ibrahimay2k7@gmail.com
sutahirtcc22@yahoo.com

***Abstract*— many researches these days are conducted on new materials development and processing to vital products. These materials include among others mostly composite from renewable materials. This is a major step towards replacing the conventional materials such as metals in daily usage so as to enhance sustainability. This paper presents the design analysis and thickness optimization of cattle horn - plastic composite chair seat. The process involved developing a solid model using solid modelling software (Pro/E), assigning the material properties of the composite to the solid model and then evaluating the performance during operation. The optimum thickness of the chair seat was then evaluated based on load and minimum weight requirements. The maximum stress experienced during loading was evaluated to be 1.148 N/mm^2, the sensitivity study showed that the maximum stress reduces with increase in the thickness of the chair seat. The optimum thickness required to sustain the load during operation was evaluated to be 4.118 mm. Validation of the design analysis was conducted using the optimized model. The validation showed that the maximum operating stress is 30.152 Mpa which is less than 50 % of the flexural strength (65.89 Mpa) of the composite and thus showed that the designed chair seat is safe.**

***Index Terms*—Design, Analysis, optimization, Composite, Validation**

I. Introduction

A composite material is a mixture of two or more materials that differ in form and chemical composition and are essentially insoluble in each other. Composites are mostly produced synthetically by combining various types of particles, fibres or combinations of both particles and fibres with different matrices to increase strength, toughness, and other properties. There are three important types of composite materials; these are polymeric, metallic, or ceramic matrices. Essentially, a composite has two constituents: matrix (continuous phase) and reinforcement (fibres or/and particles), other additions such as surfacants are commonly used to improve on the matrix-particle interactions for better performance.

Agricultural based materials such as natural oils and animal by-products were used in the production of many composites. Guner et al. [1] and Bakare et al [2] have shown that polyurethane as composite matrix can be prepared from non-edible vegetable oils as against the conventional petroleum based oil. The Rubber Seed Oil is non-edible oil from Rubber Tree. Similarly some of the animal by-products such as chicken feather, cow bone and cow horn have been recommended as viable reinforcement material to replace the conventional reinforcements such as glass and kellar. Recent studies on the Animal by-Products demonstrated that they are potential composites reinforcement materials and some of the advantages of the animal by-products as compared to conventional are low cost, renewability, and availability. Their use as composite reinforcement has certain desirable properties that include high thermal insulation properties, excellent acoustic property, lightweight, nonabrasive behavior and excellent hydrophobic properties [3].

A. Chair

A chair is a piece of furniture designed with a raised surface used to sit on, commonly for used by one person. Chairs are most often supported by four legs and have a back; however, a chair can have three legs or could have a different shape. A chair without a back or arm rests is a stool, or when raised up, a bar stool. A chair with arms is an arm-chair and with folding action and inclining footrest, a recliner. A permanently fixed chair in a train or theater is a seat or, in an airplane, airline seat, when riding, it is a saddle and for an automobile, a car seat or infant car seat. With wheels it is a wheelchair and when hung from above, a swing. A chair for more than one person is a couch, sofa, settee, or "loveseat"; or a bench. A separate footrest for a chair is known as an ottoman, hassock or pouffe [4].

B. Composition of Cattle Horn

Abdullahi and Salihi [5] conducted a study on cattle horn to determine among other things the composition and the mechanical properties of the cattle horn. The elemental analysis result of the cattle horn showed that the percentage of sulphur (S) is between (51.10-81.90), Molybdenum (Mo) is between (7.70 -32.0), Calcium (Ca) is between (2.50 - 8.32), Zinc (Zn) is between (1.20 - 2.40), Potassium (K) is between (0.41 - 1.50), Copper (Cu) is between (0.00 - 0.34), Indium (In) is between (0.30 - 1.00), Rhenium (Re) is between (1.70 - 3.20), Aluminum (Al) is between (0.00 - 0.78), Selenium (Se) is between (0.00 - 2.70), and Silicon (Si) is between (0.00-

0.33). In the same work the tensile and flexural test showed that cattle horns can be used in artificial teeth making due to the high percentage of calcium. It can also be used in agriculture due to the high percentage of molybdenum, and the presence of copper and Zinc makes

C. Mechanical Properties of Cattle Horn

Experimental research conducted showed that the Young modulus and tensile strength increase from 850 MPa and 40 MPa at 19% water content to 2.3 GPa and 154 MPa at 0% water content, respectively. The Poisson's ratio of the horn sheath was about 0.38. The critical stress intensity factor was about 4.76 MPa at an intermediate hydration (8 % water content), greater than that at 0 % water content (3.86 MPa) and 19 % water content (2.56 MPa). The mean flexural moduli is 6.26 GPa, 5.93 GPa and 4.98 GPa, whereas the mean yield strength was about 152.4 MPa, in the middle (135.7 MPa) and proximal parts (116.4 MPa) [5].

D. Application of Natural Fibres

Natural fiber composites could be used to manufacture various products. All of these products require relatively easy manufacturing methods and are suitable for production in developing and rural societies, examples of these include among others: boats, roofing sheets, containers, etc. [6].

E. Resins

There has been increase in interest in using bio-based thermosetting polymers as matrix in natural fibre composites over the years, not only because they are from renewable sources but also that they have comparable mechanical properties like other conventional thermosetting polymers.

The effects of bone particle on the properties and microstructure of polypropylene / bone ash particulate composite was investigated by Asuke through experimental analysis. The result of the study revealed that carbonized bone particulates produced superior properties than un-carbonized bone particle composite [7].

F. Synthetic Resin

Synthetic resins are materials with a property of interest that is similar to natural plant resins: they are viscous liquids and are capable of hardening permanently. Chemically they are different from the various resinous compounds secreted by plants [8]. Examples include: Oxy-polymerized Oils, polyesters, polyurethanes (Urethane Oils), polyamides, acrylic resins, epoxy resins, polyester amides.

Abdullahi and Attahir [9] conducted a research work to study the feasibility of developing a composite using cattle horn as the reinforcement and polyester resin as the matrix. To achieve this, the matrix and reinforcement were mixed in various proportions and samples produced from them. The physical and mechanical properties of the developed samples were determined in order to evaluate the composite's performance, which include compression strength, flexural strength, tensile strength, moisture content, water absorption and the wet and dry densities. Based on the flexural strength of the samples, a composite with reinforcement to matrix ratio of 4:11 was selected. Compression strength, flexural strength, tensile modulus, percentage moisture content, percentage water absorption, dry densities and ultimate tensile strength of the chosen formulation was obtained as: 34.25 Mpa, 65.89 Mpa, 22.69 Mpa, 1.248 %, 0.44 %, 1184 kg/m^3 and 0.98 N/mm^2 respectively. Based on the properties of the developed composite, the composite was found to be suitable for used in industrial particle board applications. This work involves using the developed cattle horn – plastic composite to design a chair seat and conduct all the required design analysis and optimization analysis using virtual techniques.

II. MATERIALS AND METODS

A. Materials

The materials used to carry out this work are basically computer system, software such as Pro/E and Pro/Mechanica.

B. Methods

The methods used to conduct this work are essentially virtual modelling, virtual simulation and analysis, optimization and validation. The detail of the procedure is presented in the design analysis (which consists of virtual modelling of the chair seat and simulation and analysis), optimsation and validation sections.

Design Analysis

The design analysis basically involved developing the virtual chair seat model and then subjecting the virtual model to operating conditions (that is to load it, to mimic and adult sitting on it) with a view of assessing its load carrying capacity.

Static Stress Analysis

The chair seat (length = 400 mm, width 405 mm and a initial thickness of 30 mm) was modelled virtually using Pro/E and the analysis was conducted using Pro/Mechanica. The virtual modelling involved developing a virtual solid view of the chair seat using Pro/E which is a parametric solid modelling software. The basic procedure of the stress analysis involved assigning cattle horn – plastic composite properties to the chair seat virtual model. The properties assigned are: Compression strength of 34.25 Mpa; flexural strength of 65.89 Mpa; tensile modulus of 22.69 Mpa; density of 1184 Kg/m^3; and ultimate tensile strength of 0.98 kg/m^3. The constraints and loads (784.8 N) are then applied on the model. The static stress analysis was then run and the results obtained (Fig 1).

Thickness sensitivity study

This aspect of the work involved investigating the effect of varying the thickness of the chair seat on the stress generated or stress profile operating on the chair seat due to the effect of applied load using the ''study'' tool of the software. The procedure involved simulating the load on the material while varying the thicknesses of the chair seat with a view to evaluating the effect (Fig 2).

Optimisation of the thickness of the chair seat

The optimisation procedure involved determining the optimum thickness required to sustain the applied load under minimum weight. The optimisation was conducted using 'optimisation' tool of Pro/Mechanica using a safety factor of 2.

Validation analysis.

The optimum thickness for the chair seat was evaluated automatically by the software based on the stresses generated by the load along with a goal of minimising the weight (Table 1).

III. RESULTS AND DISCUSSION

The results and discussion of the results obtained from various analyses conducted in this work is presented in this section.

A. Results

Stress static analysis of the chair seat

The results of the stress analysis of the chair seat is shown in Fig 1.

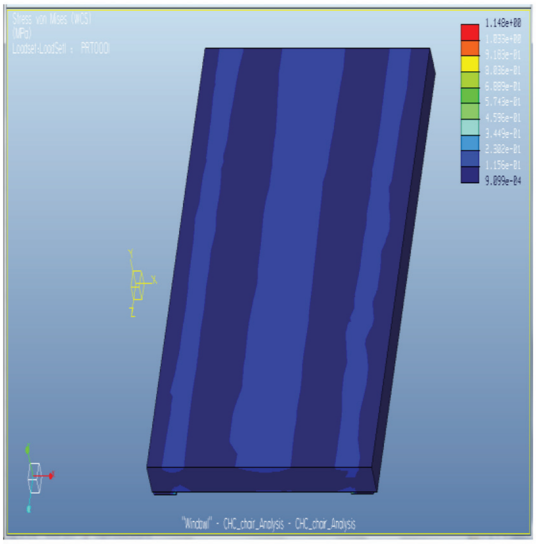

Fig 1: Stress plot of cattle horn – plastic composite chair seat

Thickness sensitivity study Results

The results of the thickness sensitivity study is shown in Fig 2.

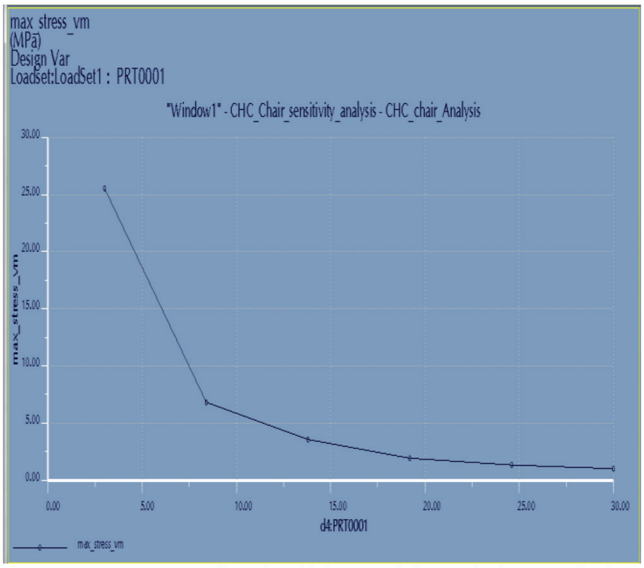

Fig 2: Stress (Mpa) against the thickness of the cattle horn – plastic composite chair seat.

Optimisation of the thickness of the chair seat

The results obtained from the chair seat thickness optimisation evaluation is shown in table 1.

Table 1: Results of Optimisation study

S/No	Thickness (mm)	Stress (Mpa)
1	1.00000	2.9145×10^2
2	1.76545	1.0904×10^2
3	3.02482	5.2822×10^1
4	4.17929	3.2221×10^1

The optimum thickness was evaluated to be 4.11843 mm.

Validation analysis Results

The results obtained from the validation analysis conducted is shown in Fig 3.

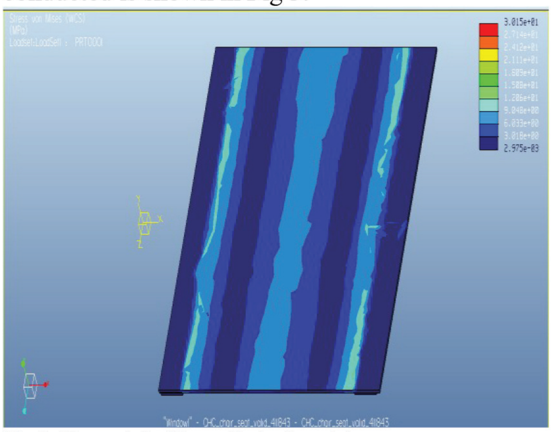

Fig 3: Stress plot of the optimized model

B. Discussion

Static stress analysis of the chair seat

The results of the analysis showed that the maximum stress experienced by the chair seat due to the load applied and under the operating conditions was 1.184 N/mm^2 and the minimum stress was 9.099^{-04} N/mm^2. The stresses obtained are based on the loading condition as well as the chair seat geometry.

Thickness sensitivity study

The result of the simulation (Fig. 2) showed that the stress reduces with increase in the thickness of the chair seat. Therefore the load carrying capacity of the chair seat could increase by increasing the thickness of the chair seat. However, increasing the thickness would bring about increase in weight as well as increase in cost which are actually expected to be minimised as much as possible in any engineering design. In the light of this, it is pertinent to determine the optimum thickness of the chair seat that could carry the applied load while minimising weight as much as possible.

Optimisation of the thickness of the chair seat

The results of the chair seat thickness optimisation showed that the chair seat could be designed to carry the required load with relatively small thickness of 4mm.

Validation analysis

This analysis was conducted in order to evaluate the correctness of the values obtained in the stress analysis and also the values obtained from the chair seat thickness optimisation analysis.

The maximum stress operating on the model is 30.152 MPa while the minimum stress is 0.00298 MPa. Thus the maximum stress operating due to the loading condition is below the strength of the material of the chair seat which is 65.89 MPa.

Plate 1: Chair manufactured using the developed composite

IV. CONCLUSION

In this work design analysis and optimization study of cattle horn – plastic composite chair seat was conducted using virtual simulation approach. The results of the analysis and optimization have shown that virtual simulation could be effectively used to design and analyze products like the chair seat considered. It also showed that it is feasible to use the composite to produce chair seat using indigenous technology. This method of design and prototyping is faster and more economical than the conventional method of physical prototyping.

REFERENCES

[1] C. Guner, B. George, W. Junior, F. Alonso, A. Dickson, and B. Rekha, “A comparative study on tensile behaviour of plant and animal fibre reinforce composite,” International Journal of Innovation and Applied Studies, Vol. 2, No. 2, pp. 645-648, 2006.

[2] I. Bakare, F. Okieimen, C. Pavithran, H. Abdul, Khallil, and M. Brahamkuma, “Mechanical and thermal properties of sisal fiber-reinforced rubber seed oil-based polyurethane composite,” Journal of Material and Design, Vol.10, pp. 1 – 5, 2010.

[3] C. Uzun, D. Montana, O David, L. Samuel, M. Lawrence, and A. Mandy, “Mechanical behaviour of reinforced polymeric composites,” International scientific Journal, Vol. 52, pp. 82-86, 2000.

[4] R. Gentile, “The effect of water absorption on mechanical properties of plastic composite hybrid,” Material sciences and Application, Vol. 3, pp. 317-325, 2000.

[5] U. Abdullahi and A. Salihi, “Characterization and potential application of Kano cattle horn,” Journal of Engineering and Technology, Vol. 6, No. 1 & 2 pp. 32 – 40, 2007.

[6] R. Fleming, K. Lawrence, A. Chanrase, V. Samuel, N. Thirupathi, K. Syed, “Performance evaluation of natural fibre reinforced polymer composite,” International Journal of mechanical Engineering and robotic research, Vol. 3, No.1, pp. 273-284, 1995.

[7] F. Asuke, V. S. Aigbodion, M. Abdulwahab, O. S. I. Fayomi, A. P. I. Popoola, C. I. Nwoyi, and B. Garba “Effects of bone particle on the properties and microstructure of polypropylene/bone ash particulate composite,” Results in Physics, Vol. 2, pp. 135 - 141, 2012.

[8] N. Fritz. (1997). Thermoplastic Coatings and Division Jiantian Institute for research and development.

[9] I. Abdullahi and M. Attahir (2014). Development and Evaluation of the Physical and Mechanical Properties of Cattle Horn – Plastic Composite for Particle Board Manufacturing. Proceedings of the National Conference of the Faculty of Engineering, Bayero University, Kano on Bridging the Gap between Academia and Industry (ACIcon2014), pp. 364 – 376, Kano, 9th – 11th December, 2014.