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Design & Fabrication of Manual Wheelchair from Corrugated Cardboard Sheets

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***Abstract*— The present model relates to a recyclable, economical and lightweight manual wheelchair made from corrugated cardboard sheets. Corrugated cardboard boxes which are used in packaging industry proves to be a very promising engineering material as it is lightweight, cheap and easy to recycle. The conventional wheelchair is constructed from a combination of materials such as, steel, plastic, rubber etc. which are not easily reprocessed and are expensive. Four-fifths of the people with disabilities in the world live in low-income countries. Majority of them are poor and do not have access to wheelchair and other rudimentary services. With a hope to narrow the gap between disabled people and the wheelchair affordability, the final model is devised following initial solid modelling, finite element analysis of critical parts and some design changes after numerous trial and error. The model is tested practically by the application of load in static and dynamic conditions.**

Keywords— Wheelchair; Corrugated Cardboard Sheets; Glue; Finite Element Analysis

I. INTRODUCTION

Manual wheelchairs are defined as wheelchairs propelled by the user or pushed by another person. The wheelchair is one of the most commonly used assistive devices which not only enhance personal mobility but also allow user to enjoy their human rights and live with dignity. Due to a deprivation of wheelchair often people with disabilities are isolated and do not have access to the same opportunities as others within their own communities. It assists people with disabilities to participate and become more productive members of their communities. It begins a process of opening up a world of education, work and social life. A wheelchair is appropriate when it: meets the user's needs and environmental conditions, provide proper fit and postural support, is safe and durable, is available locally and can be obtained and maintained at an affordable cost.

Wheelchair users refers to people who already use a wheelchair or who can benefit from using a wheelchair because their ability to work is limited. When we say users, it represents; children, adult and elderly; men and women and girls and boys; people with different neuromusculoskeletal impairments, lifestyle, life roles and socioeconomic status; and people living in different environments, including rural, semi-urban and urban. Users denote a wide range of mobility needs, but the one thing they have in common is the need for a wheelchair to enhance their mobility with dignity.

A. Global Scnario of Wheelchair Users

About 10% of the global population, i.e. about 650 million people, have disabilities. Studies indicate that, of these, some 10% require a wheelchair. It is thus estimated that about 1% of a total population – or 10% of a disabled population – need wheelchairs, i.e. about 65 million people worldwide. In 2003, it was estimated that 20 million of those requiring a wheelchair for mobility did not have one. There is indication that only minority of those in need of wheelchairs have access to them, and of these very few have access to an appropriate wheelchair**.**[4]

B. Challenges for Users

Some 80% of the people with disabilities in the world live in low-income countries. Majority of them are poor and do not have access to basic services, live in small houses with inaccessible surroundings where road systems are poor and the climate and physical terrain are often extreme. Government funding for the provision of a wheelchair is rarely available, leaving the majority of users unable to pay for a wheelchair themselves. In many developing countries, only 3% of people with disabilities who require rehabilitation services have access to them. [4]

II. MATERIAL DESCRIPTION

Corrugated cardboard sheets are inexpensive and lightweight, having a high strength–to–weight and stiffness–to–weight ratios, making the material the best choice for the manufacturing of packages for the transportation of products. Usually the weight of the paper is specified in the terms of grams per square meter (gsm). In the manufacturing and analysis of this model 150 gsm is used. Cardboard are orthotropic in nature with different mechanical properties in

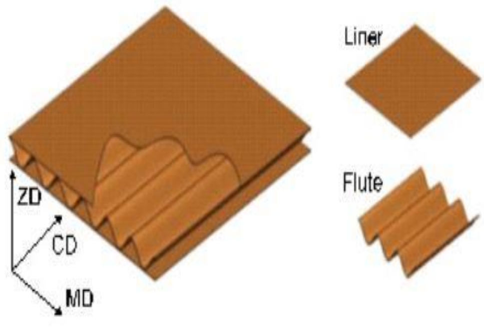

Fig. 1. Corrugated cardboard sheet geometry

the three principal directions consisting of the surface plies known as liners, providing bending stiffness, separated by a lightweight bending core (fluting) that provides shear stiffness. The machine direction (MD) and the cross direction (CD) are the two main directions characterizing this material. MD corresponds to the direction of manufacturing of the material while CD corresponds to the transverse direction. ZD is the direction perpendicular to both the directions and generally known as out of plane direction.

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A. Corrugated Cardboard Flute Types

Corrugated Flutes are the S shaped waves/arches of a corrugated box that makes up the board. This is called the boards corrugation. Flutes are essentially the reinforcement that make up the board. They run parallel to the depth of the container and give it its rigidity and crushing/stacking strength. As well as providing stacking strength, flutes also provide insulation that protects products from sudden temperature changes. Larger flutes like A & B profile provide greater strength and cushioning, while smaller flute profiles like D & E provide better printability and foldability. B flutes have 42-50 flutes per foot and are 1/8″ thick. They provide the second highest arch size. B flutes provide good stacking strength and crushing resistance. Ideally used for canned goods and displays. C flutes have 39-43 flutes per foot and are 11/64″ thick which lies in-between A flute and B flute and are very common. C flutes provide good cushioning, stacking and printing properties. Ideally used for glass, furniture and dairy. E flutes have 94 flutes per foot and are 1/16″ thick. E flutes provide the greatest crush resistance and a super printing surface which make it an excellent choice for die-cut custom boxes.

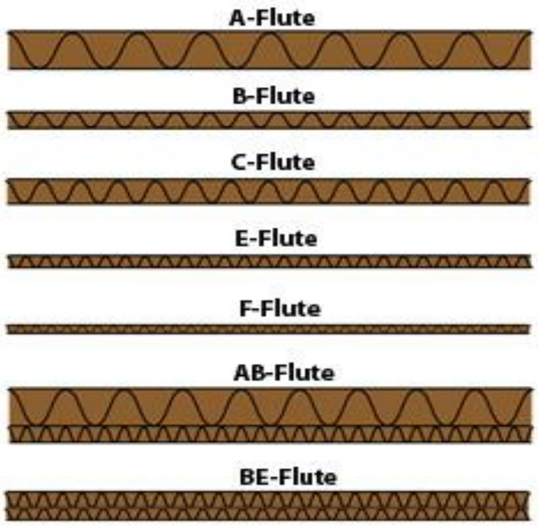

Fig. 2. Corrugated flute types

B. Corrugated Board Strength

Board strength is the factors that defines how strong the box should be. The strength can be determined by two different methods: selection of suitable flute type and using the edge crush test.

The edge crush test is a laboratory test method that is used to measure the cross-direction crushing of a sample of corrugated board. It gives information on the ability of a particular board construction to resist crushing. It provides some relationship with the peak top-to-bottom compression strength of empty single walls regular slotted containers in laboratory conditions.

The edge crush resistance *R*, expressed in kilonewtons per meter (kN/m) is calculated by the equation:

$$R = 0.01 \times Fmax \qquad (1)$$

where Fmax is the mean value of the maximum force and measured in newtons.

Corrugated fiberboard can be evaluated by many material test methods including an edge crush test. There have been efforts to estimate the compression strength of a box (usually empty, regular single wall slotted containers, top-to bottom) based on various board properties. Some have involved finite element analysis. One of the commonly referenced empirical estimations was published by McKee in 1963. This used the board ECT, the MD and CD flexural stiffness, the box perimeter, and the box depth. Simplifications have used a formula involving the board ECT, the board thickness, and the box perimeter. Most estimations do not relate well to other box orientations, box styles, or to filled boxes. In order to calculate the value of BCT (Box compression test), the formula of McKee would be the easiest but also the most inaccurate. The ratio of height to the circumference must be greater than 1:7; even then, there are many reservations.

Simplified McKee formula:

$$B\,C\,T = 5.876 \times E\,C\,T \times (U \times d\,)^{1/2} \qquad (2)$$

Where,
BCT = Box compression test in Pounds

U = box outline in inch

d = thickness of corrugated board in inch

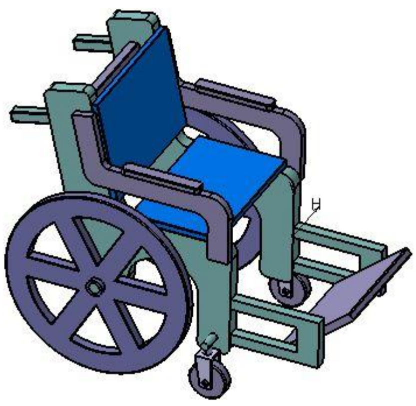

Fig. 3. 3D CATIA V5 model

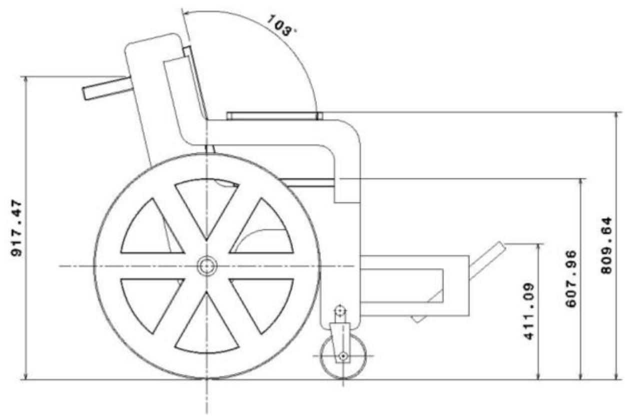

Fig. 4. Wheelchair dimensions

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III. DESIGNING OF MODEL

Firstly, 3D model of the manual wheelchair is prepared using CATIA V5 software considering ergonomics of sitting which is shown in Fig. 3. The dimensions of wheelchair are given in Fig 4.

A. Finite Element Analysis

It is always desirable to do FEA before actual manufacturing as it gives information about the stresses induced due to loading, indicates probable region of failure, saves cost and time, and represents approximate system behaviour on application of various boundary conditions. FEA of critical parts like: wheel, frame and seat is carried out in ANSYS workbench 16.0.

The properties of corrugated cardboard sheets vary according to the manufacturing quality. Therefore, actual results may not be obtained using FEA. For this model, FEA of critical components is carried out by using the properties given in the Table I [2]. In order to have general idea about the stresses and probable failure region, actual loading and boundary conditions are found by trial and error.

TABLE I. MEASURED VALUES OF ELASTIC STIFFNESS PARAMETERS IN TENSILE LOADING FOR SOME MACHINEMADE PAPERS.

Parameters	**Value**
Density, kg/m^3	780
MD modulus E_x, MPa	7440
CD modulus E_y, MPa	3470
ZD modulus E_z, MPa	40
Poisson ratio ν_{xy}	0.15
Poisson ratio ν_{xz}	0.008
Poisson ratio ν_{yz}	0.021
Shear modulus G_{xy}, MPa	2040
Shear modulus G_{xz}, MPa	137
Shear modulus G_{yz}, MPa	99

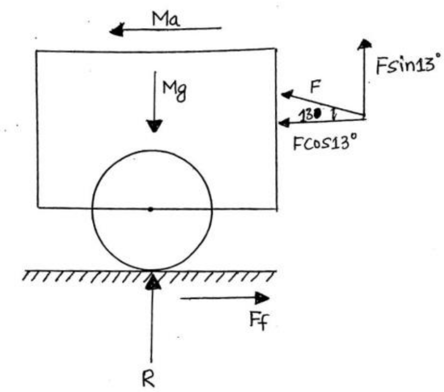

Fig. 5. Simple model of wheelchair

Calculation for boundary conditions

Let's model the wheelchair as shown in Fig. 5. for simplicity neglecting front wheel.

Where,
R = Normal Reaction (N)
Ff = Frictional force (N)
F = Force applied at handle (N)

Mass of person (M1) = 70 kg

Mass of wheelchair (M2) = 12 kg

Total mass (M) = M1+M2 = 82 kg

Design Mass = M + 10% of M = 90 kg

Total Weight (W) = 90* g =882.9 N

Average Velocity of wheelchair in straight path= 0.8 m/s

Average acceleration of wheelchair in straight path= 0.8 m/s^2

Let's assume rolling resistance coefficient of wheelchair tire to be same as rolling resistance coefficient of bicycle tire on concrete. Therefore, μ = 0.002

R = Mg – Fsin13 = 882.9 – Fsin13

Ff = μR = 0.002*(882.9 – Fsin13)

Under Equilibrium,

Ma = Ff – Fcos13 = 0.002*(882.9 – Fsin13) – Fcos13

90*0.8 = 0.002*(882.9 – Fsin13) – Fcos13

F = -72.05 N

Therefore,

Fsin13 = 16.21 N

Fcos13 = 70.20 N

Boundary conditions for rear wheel:

Static load = 882.9 N

Forward Torque = Fcos13 * d1 = 43.89 N-m

Rolling Torque = Fsin13 *d2 = 1.38 N-m

Boundary conditions for frame:

Rear tyre reaction = 866.69 N

Front tyre reaction = 425.24 N

Horizontal force at handle = 70.2 N

Vertical force at handle = 16.2 N

Boundary conditions for seat:

Pressure = F/A = 882.9/0.1925 = 4586.49 Pa

Equivalent stress and total deformation plot of rear wheel, frame and seat are shown below:

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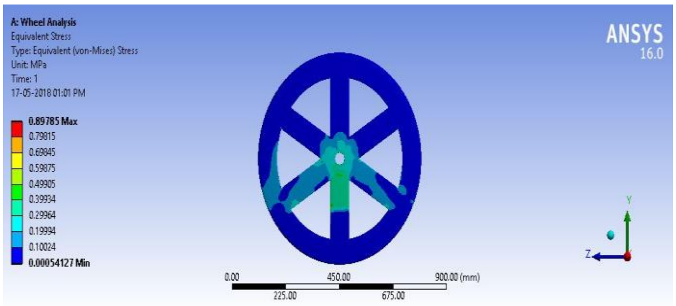

Fig. 6. Stress contour plot of rear wheel

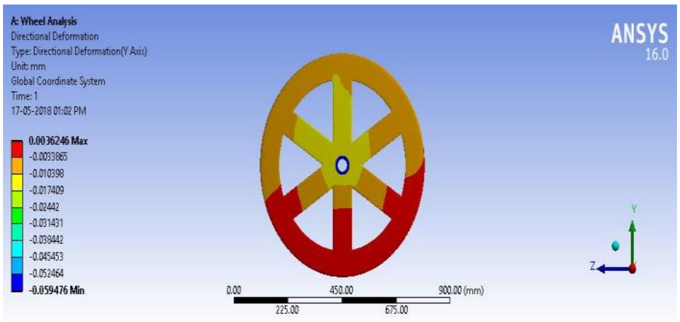

Fig. 7. Displacement contour plot of rear wheel

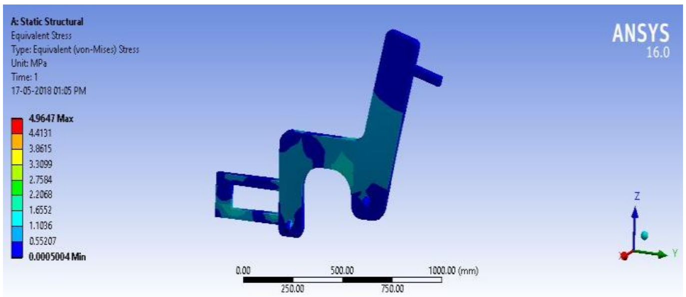

Fig. 8. Stress contour plot of frame

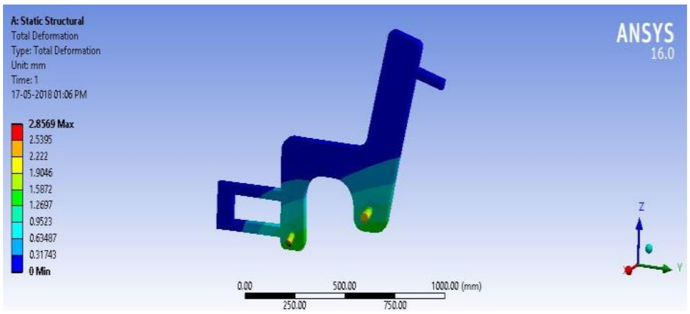

Fig. 9. Displacement contour plot of frame

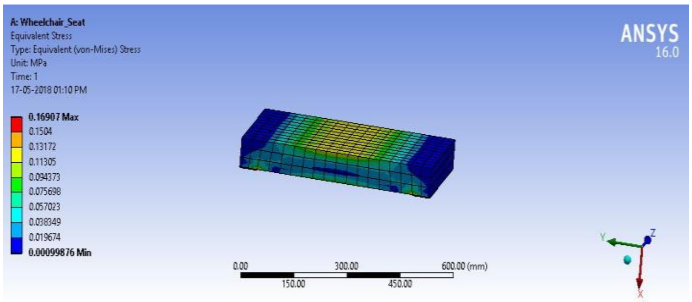

Fig. 10. Stress contour plot of seat

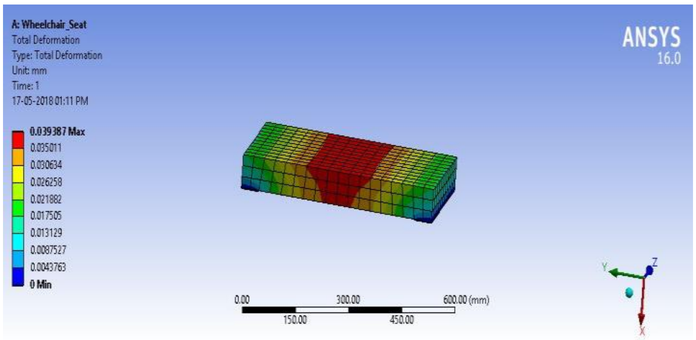

Fig. 11. Displacement contour plot of seat

B. *Manufacturing Process of the Model*

Seven ply, C flute, 150 gsm cardboard sheets are used for fabrication of model. The dimensions are marked on cardboard sheets which is then cut carefully with cardboard cutter. The number of sheets which are cut with appropriate dimensions are stacked with one another with special type of glue. The stacked part is compressed by load upon its top for about 7 hours, to ensure better attachment of all stacked parts and to acquire required strength.

The glue used is dextrin based compound prepared from tapioca starch.

IV. RESULTS AND DISCUSSION

The FEA results viz. maximum equivalent stress and total deformation of components like: wheel, frame and seat obtained suggest that the material used can sustain the load of

Fig. 12. Final manufactured model

70kg which is further verified with trial and error of these components. The maximum equivalent stress and total deformation induced due to loading are below permissible stress and deformation. The final manufactured model is tested by loading with a person having 70kg weight and the model works satisfactorily under static and dynamic conditions. The final manufactured model is shown in Fig. 12 and the specifications of the manufactured model are given in Table II.

TABLE II. SPECIFICATIONS

Type of wheelchair	Manually operated
Maximum load, kg	70
Net weight, kg	12
Estimated cost, Rs	1200
Seat width, m	0.45
Height of arm rest from ground, m	0.81
Seat height from ground, m	0.61
Leg rest height from ground, m	0.41
Height of handle from ground, m	0.92

V. CONCLUSION

Though corrugated cardboard sheets are mostly used for the manufacturing of cartons for the transportation of products, its features like high strength–to–weight and stiffness–to–weight ratios can be employed for manufacturing cheap, lightweight and fully-reusable engineering system and devices. The manual wheelchair fabricated from this material shows promising solution to mitigate the problem of disabled people living below the poverty line mostly in developing countries. The designed model can work satisfactorily if used indoor. Though a resin coating is used to prevent model from water for short period of time, it does not guarantee for long term water proofing. Hence, the better water proofing technique can be used. Also the model can have made more lightweight using different orientations and design. If corrugated cardboard is used in the form of composites with other reusable material, it would increase the durability of wheelchair.

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