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Design and Fabrication of A Multi-Purpose, Portable and Foldable Ladder

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Abstract

This paper is based on the design and fabrication of a multipurpose, portable, compact and foldable ladder that serves multiple purposes, overcoming the limitations of already existing ladder designs in the market. The ladder so formed by the modification proposed by us will not only perform as a simple fixed climbing ladder, but will also provide various utilities such as platform, orchard ladder, step ladder and many more. The whole project involved various methods like conceptualisation, analysis, market survey, simulation, fabrication and testing. Testing was carried out to ensure that the product is functional and can meet the objectives successfully. Analytical calculations were done for safe load and this calculation was used for proposed frame of Multi-Purpose ladder. Further, this design is again optimized using SOLIDWORKS. Final design is fabricated in the Mechanical Workshop of Madan Mohan Malaviya University of Technology, Gorakhpur.

Keywords: Multipurpose, Ladder, Solidworks Simulation, Fabrication, Analytical Calculations.

INTRODUCTION

A ladder is a vertical or inclined set of rungs or steps for climbing up and down. There are two basic types of ladder: Rigid ladder that are self-supporting or that may be leaned against a vertical surface, and Rope ladder, that may be hung from the top. The purpose of using ladders is to ease the different work processes at various industrial as well as residential areas. The ladder available in the market is heavy, requires a lot of space and serves single purpose. Apart from this, they are not stable as they should be which results in lot of accidents across the globe. The vertical members of rigid ladder are called stringers or rails or stiles. Rigid ladders are usually portable, but some types are permanently fixed to a structure or equipment. They are commonly made of metal, wood, fiberglass or tough plastic.

Types of ladders:

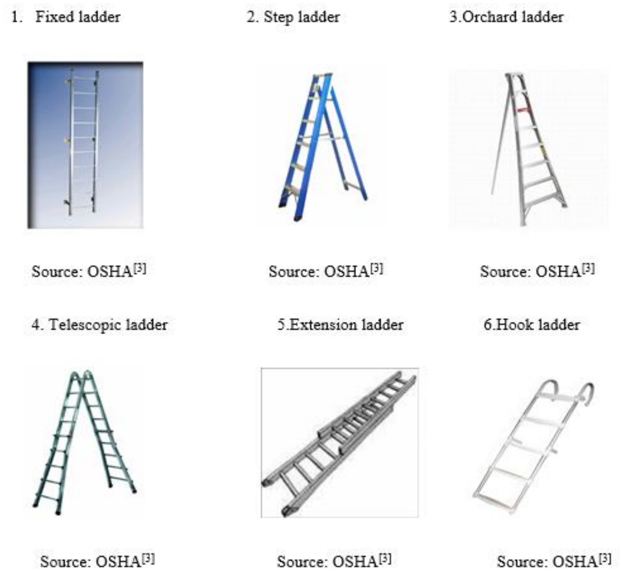

Figure 1. Various Types of existing ladders

Certain requirements which cannot be completely fulfilled by the above mentioned systems:

1. Should be easily foldable.
2. Easy to lift and compact enough to be stored in less area.
3. Minimum coast and affordable price.
4. Higher loading capacity (Around 160 kg).
5. Can be converted into platform for material handling.

PROPOSED DESIGN

The above mentioned requirements can be fulfilled by using a compact, foldable and multipurpose ladder comprising of same sized long stiles (rectangular cross-section) and twelve short rungs (square cross-section) separated by the required distance for developing the ladder. There are two stabilisers attached at extreme end positions with rubber paddings to provide stability to the structure. The entire product is divided into four equal parts; each comprising of two stiles and three rungs; connected by a joint mechanism to make the ladder foldable.

MATHEMATICAL FORMULATION

In order to decide proper shape of the structures, a comparative study of polar moment of inertia of various sections were done, and the most suited section is selected amongst all to design the prototype model

Selection of cross section on the basis of strength:-Material used- **Al Alloy 5052-O**

Details of material property-

$\rho = 2.70\ g/cm^3$

$s_{yt} = 500\ Mpa$

$s_{ut} = 570 Mpa$

$\mu = 0.33$

Comparing section modulus for various sections-Assuming unit mass for our calculation

m= 1 unit

m= $\rho \times v$

1=$\rho \times v$

Volume of one rung per unit mass

$v = 1/\rho = 0.3703\ cm^3/g$

Length of rungs = 30.2 cm

$v = A \times l$

Cross-sectional area of rungs

$A = v/l = 0.01226\ cm^2/g$

For square:

A = a^2 = 0.01226 cm^2/g

$a = 0.11072\ cm$

Table 1. Comparative study of section modulus and shape factor of different geometry

Shape	Edge(cm)	Section modulus(cm^3)	Shape factor
Square	a=0.1107	Z =0.0002823	1.5
Rectangular	a =0.123 b=0.8a =0.099	Z =0.0002715	1.4
Circular	d =0.1249	Z =0.0003822	1.7

According to above study

$z_{circular} > z_{square} > z_{rectangular}$

Since, human safety is of utmost importance, due to less friction available in circular cross section, square will be preferred.

<u>Preferred cross section:</u>

Square > circular > rectangular

For same mass, weight carrying capacity of hollow section is more as compared to solid section.

For hollow square section:-

Moment of inertia = $\frac{1}{12}(A^4 - a^4)$

$= \frac{1}{12}(2.8^4 - 2.4^4)$

= 2.3573 cm^4

Area of cross section = 2.08 cm^2

For solid square section:-

Moment of inertia =$\frac{1}{12}(2.8^4)$

= 5.12 cm^4

Area of cross section = 7.84 cm^2

On the basis of above study, a conclusion can be drawn that for the same cross sectional area, the moment of inertia is more for hollow cross section as compared to solid cross section. Thus, in order to reduce the material cost, light weight and high strength, we prefer hollow section.

SOLUTION METHODOLOGY

The computer aided design software SOLIDWORKS 2016 is used to make the detailed design for

analysing the strength of product and its safety features before actual manufacturing.

The result and discussions include-

i) Stress distribution result(based on von mises criteria)

ii) Factor of safety

iii) Displacement (static deformation) result

Stress distribution result:

(A)Fixed ladder form:

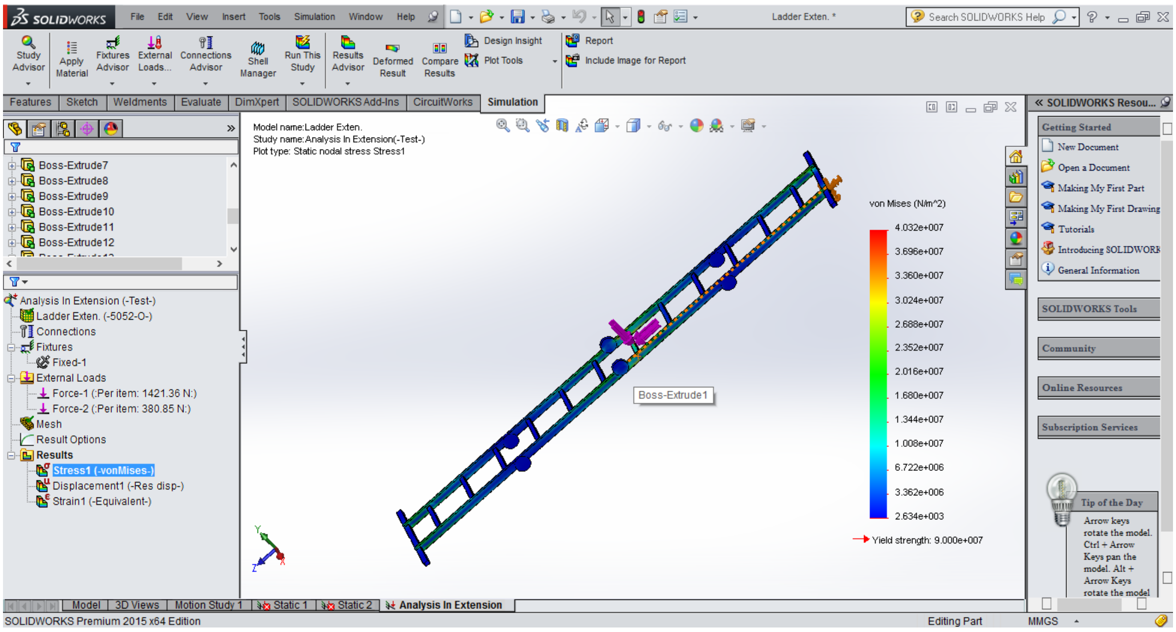

Figure 2. Stress distribution report of fixed ladder in SOLIDWORKS

The above study show that the maximum static nodal stress at various rungs are:

Rung-1(from top): 37.44 Mpa

Rung-2(from top): 39.01 Mpa

Rung-3(from top): 37.83 Mpa

Rung-4(from top):40.50 Mpa

Rung-5(from top): 40.71 Mpa

Rung-6(from top): 40.32 Mpa

Rung-7(from top): 39.55 Mpa

Rung-8(from top): 40.52 Mpa

Rung-9(from top): 40.08 Mpa

Rung-10(from top): 38.48 Mpa

Rung-11(from top): 38.98 Mpa

Rung-12(from top): 36.65 Mpa

The critical value of equivalent stress = 40.71 Mpa (at Rung-5 from top)

Yield strength of material AL alloy 5052-O = 90.00 Mpa

Thus, the value of Factor of safety = $\frac{\text{yield strength}}{\text{actual stress applied}}$

= 90/40.71 = 2.21

(B)Step ladder form:

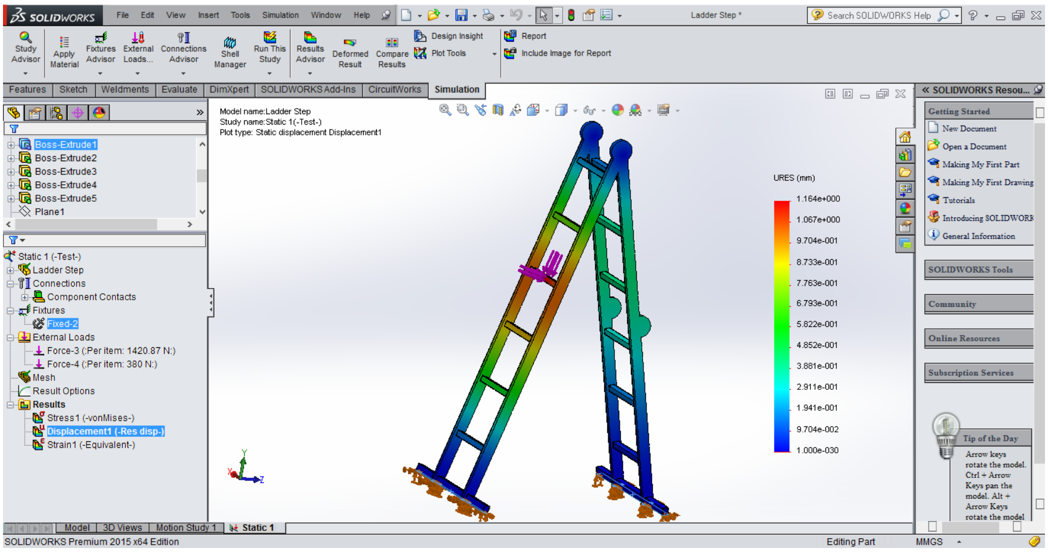

Figure 3. Stress distribution report of step ladder in SOLIDWORKS

The above study show that the maximum static nodal stress at various rungs are:

Rung-1(from top): 47.02 Mpa

Rung-2(from top): 46.68 Mpa

Rung-3(from top): 46.13 Mpa

Rung-4(from top): 46.02 Mpa Rung-5(from top): 44.40 Mpa

The critical value of equivalent stress = 47.02 Mpa (at Rung-1 from top)

Yield strength of material AL alloy 5052-O = 90.00 Mpa

Thus, the value of Factor of safety = $\frac{\text{yield strength}}{\text{actual stress applied}}$

= 90/47.02 = 1.914

Static Deformation Result:

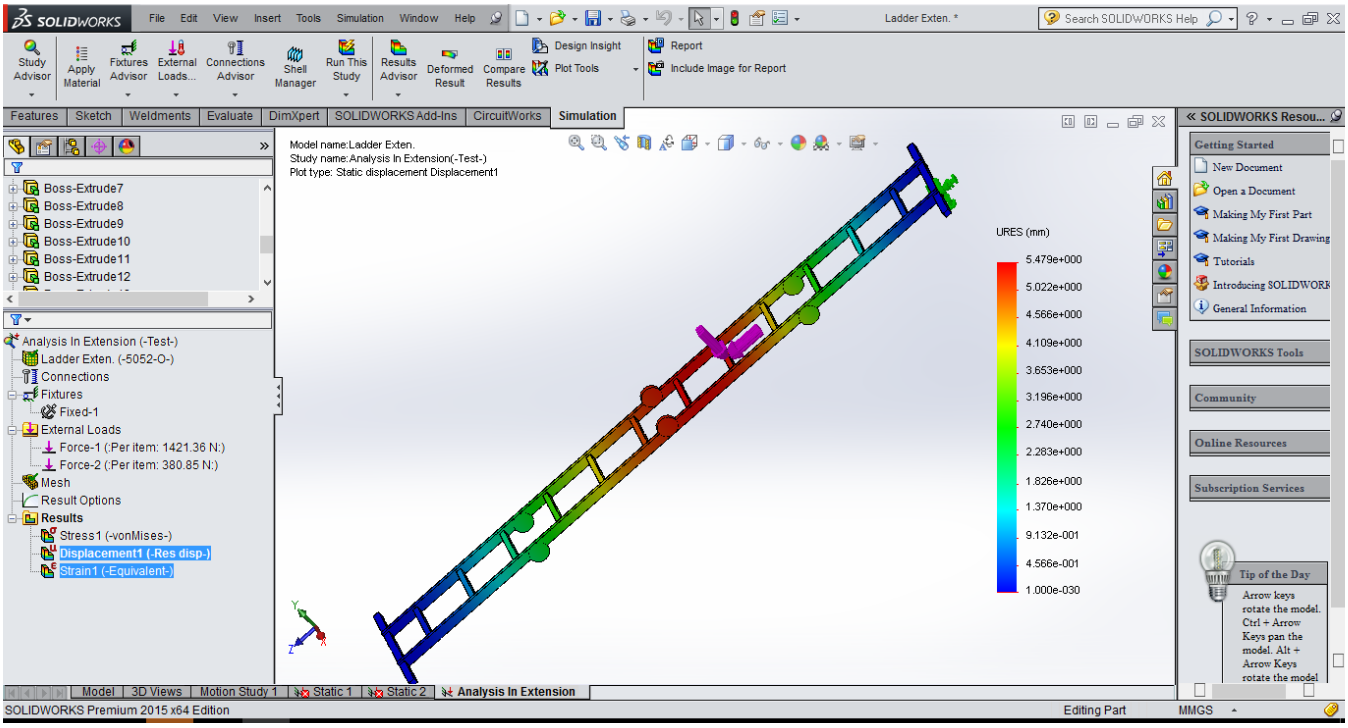

Figure 4. Stress deformation result carried out in SOLIDWORKS

The above study show that the maximum static deformation at various rungs are:

Rung-1(from top): 0.0341 mm

Rung-2(from top): 0.1430 mm

Rung-3(from top): 0.2883 mm

Rung-4(from top): 0.4340 mm

Rung-5(from top): 0.5473 mm

Rung-6(from top): 0.6102 mm

Rung-7(from top): 0.6063 mm

Rung-8(from top): 0.5382 mm

Rung-9(from top): 0.4210 mm

Rung-10(from top): 0.2717 mm

Rung-11(from top): 0.2431 mm

Rung-12(from top): 0.1282 mm

The critical value of maximum deflection = 0.6102 (at Rung-6 from top)

The calculated value of deflection in a fixed beam is:

$$y = Wa^3b^3/3L^2EI \quad (1)$$

Values of Young's Modulus

Table 2. Values of material property for Aluminium Alloy 5052-O

Material	Young Modulus(E) GPa	Shear Modulus(G) GPa	Poisson's Ratio(μ)
Al alloy 5052-0	70	26	0.33

Assuming load to be applied at the centre of the rung, such that a=b,

Maximum deflection= $WL^4/192EI$

Load,W = 150 kg

Length of rung, L = 302 mm

Young modulus, E= 70 N/mm^2

Polar moment of inertia (for square cross section),I = $(A_o^4 - A_i^4)/6$

Where, A_o = outer dimension of the square tube

A_i = inner dimension of the square tube

On solving, we get y_{max} = 0.902 mm (> 0.6102 mm)

Thus, the selected material is suitable for designing ladder.

MATERIALS AND PROCESSES

On the basis of computer aided design and prototype, fabrication processes were carried out in Mechanical Workshop of Madan Mohan Malaviya University of Technology, Gorakhpur.

Prototype Generation

On the basis of existing product design, certain dimensions were selected and prototype ladder was made using handmade drawings.

Frame generation

Considering the total height of the ladder as 3.4 meters and divided into four sections as discussed previously, four folds were required to serve the purpose. Each section was made 75 cm long and 35 cm in width (including the side rail thickness). Long stiles and stabilisers were made from rectangular hollow aluminium tubes whereas the rungs were made from square hollow aluminium tubes. The rung size was 28×28 mm whereas the distance between two rungs, i.e., rung pitch was kept as 270 mm. when folded; the product has a dimension of 920mm×350 mm×260mm.

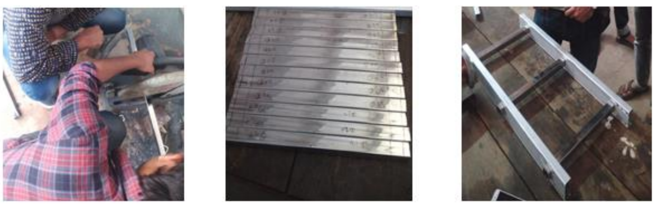

Figure 5. fabrication of ladder frame

Locking system

To make ladder easily foldable at various angles and inclinations, a joint mechanism comprising of two pivotally connected joint members rotatable about a common axis was fabricated between two frames using an interference fit.

Stabilizers

Two long rectangular hollow cross-section aluminium pipes were fabricated at both the ends using fasteners (nuts and bolts). A square notch was cut in the lowermost stiles and stabilizers were fitted in it along with bolts to make it fixed to the product. Width of stabilizer is kept 730mm.

Rubber friction pads

Rubber friction pads (total four) were adhered to the bottom and top of ladder (at the end of stabilizers) to provide it necessary friction against slipping. Synthetic rubber stamps were used to achieve this purpose.

Figure 6. Final ladder fabrication

PROJECT COST

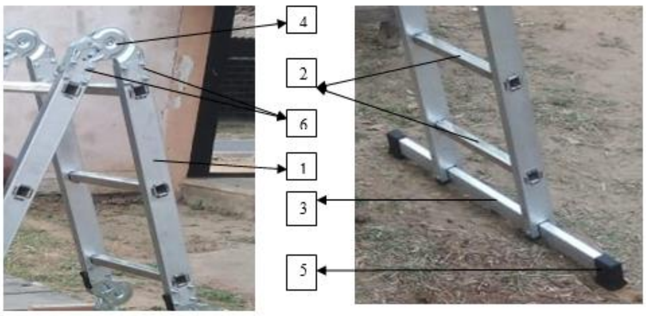

Figure 7. Various parts of ladder

Table 3. Cost report with dimensions

S.NO.	Parts	Material	Dimension (in mm)	No. of pieces	Cost
1.	Long braces (stile)	Al 5052-O	750×22×50	8	1320
2.	Short braces (rungs)	Al 5052-O	350×28×28	12	2100
3.	Stabilizers	Al 5052-O	730×22×45	2	330
4.	Locking system	Mild steel		6	2700
5.	Rubber friction	Synthetic		4	180

	pads	rubber			
6.	Fasteners	Stainless steel	Bolt- 5 Nut- 5	72	150
7.	Miscellaneous				200

CONCLUSION

In a nutshell, final product serves number of purposes despite being simple and easy from design point of view. The fabrication process was performed in university mechanical workshop with limited facilities. Thus, it can be said that its manufacturing will be relatively easy for local Indian manufacturers who normally have very basic machineries. Also, the final product is highly compact and portable. The parts involved are stiles, rungs, friction pads, fasteners, etc. that are easily available in market. The maximum load carrying capacity of product is 150 kg. Minute details had been kept in mind during designing and fabrication. However, changes can also be made in the design depending upon the requirements. Maintainability of Product is also in fabrication.

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