ISSN: 0974-5823 Vol. 7 No. 3 March, 2022

International Journal of Mechanical Engineering

Analysis and optimization of motorized wheelchair dimensions for disabled and elderly

Bobby P Paul

Karunya Institute of Technology and Sciences

S Darius Gnanaraj

Vellore Institute of Technology

P Sam Paul

Karunya Institute of Technology and Sciences

Aaron Mathew John

SAINTGITS College of Engineering

Lawrance G

Karunya Institute of Technology and Sciences

Keshav Manhas

Vellore Institute of Technology

Abstract: Low cost motorized wheel chairs are the need of the day for many disabled and elderly persons. Optimization of a Motorized Wheel chair (MWC) using the Finite Element Method is presented in this paper. ANSYS Work bench analyses of the leg and seat frame of the MWC are carried out to identify the optimum conditions of the thickness, width, and material. Minitab Software using the Taguchi method is used to design the dimensions for optimum cost and weigh based on the 'smaller the better' criterion. The total deformations of the whole-body of MWC made of Mild Steel, Stainless Steel, and Aluminum are compared. The static analysis of the lock subjected to various loads is also presented in the paper. Optimum dimensions of the legs, frame and overall dimensions of the MWC are reported. It is shown that the dimensions of the newly designed MWC conforms with the ISO standards.

Index Terms— Finite Element analysis, DOE, Taguchi Technique, Motorized Wheelchair, Minitab

INTRODUCTION

World health organizations suggest that about 15% or 1 billion of the total world population is differently-abled. Out of this, 650 million people need a wheelchair. The number is estimated to be 80,000 to 160,000 in India [1]. Wheelchairs aid healthcare facilities to improve the mobility of the patient. Motorized wheelchairs assist people with disabilities and injuries. There is a 63.4% rise in the global [2] and a 4.21% rise in the Indian manual wheel chair (MWC) users. People prefer an automated wheelchair because a manual wheelchair needs the assistance of another person [3].

Ever since the development, the Finite Element Method (FEM) is the prevalent and successful technique used for analyzing physical phenomena in the field of structural Solid and fluid mechanics. The physical properties like Force, pressure, fluid flow, etc. can be calculated using FEM [4]. Solidworks is 3D design software which was used for designing the MWC Model. Solidworks reduce the time and improves the speed and quality of the design [4]. Design of Experiment (DOE) is to optimize the minimum Weight and Cost of the MWC. In Taguchi Design, L9 Orthogonal Array sets the DOE with three factors and three levels [5]. The Factors are the thickness of the sheet, width of the Frame, legs, and materials. The DOE delivers results of total deflection, stress, and weight of the MWC. Taguchi DOE aids to identify the markers for the best setting [6]. The analysis also compares the sustainability of the Lock with incremental loads. Minitab optimizes the results obtained through the FEA analysis to identify the best setting.

Literature Review

Structural optimization has become a significant field of research in recent years. The Taguchi Design of Experiments (DOE) optimizes the experiment in fewer steps than other methods. DOE reduces the complexity of the computational effect without changing the output or the results [7]. The most common methodology of DOE is to process some controllable input factors to find the best response. There are many methods to do DOE like One Factor design, where only one element is under investigation. If there is more than one factor, each factor separately considered. The number of experiments increases and becomes a time-consuming, tedious process for optimum results. Factorial Design investigates multiple factors. The full Factorial technique considers all factors. Another method is Fractional Factorial Design which gives importance to factors with fewer runs. Screening experiment method considers all factors, and levels to determine the significant factor. Running a series of Full Factorial experiments and mapping the response comes under Response surface Analysis. [8]. All the factorial methods mentioned above are not applicable to some cases and might consume more time. Out of all the DOE methods, the most effective and secured method is the Taguchi method Developed by Genichi Taguchi. Genichi Taguchi is an Engineering Professor and Advocate who developed this method for quality improvement [9]. The goal of the Taguchi method is to reduce the complexity of the design without affecting the output. The part files are modeled and assembled in Solidworks to create a STEP file for all ANSYS studies. Solidworks also enables easy pre-processing of the model under analysis [11]. The SolidWorks 3D model of all nine experiments analyzed with the Finite Element Method. The identified factors and levels use L9 orthogonal Array to design nine sets of experiments. Unlike the regular Design of Experiments, the Taguchi technique restricts the number of experimental runs to nine [10]. The STEP (STandard for the Exchange of the Product model data) files of models with specified dimensions of the L9 orthogonal Array set conditions for analyzing the total deflections and stress concentrations on each body. Applying the Taguchi optimization technique identifies the best combination with the least Deflection, Cost, and Weight. [12]. Minitab software with inbuilt Taguchi DOE analyses the data to optimize the results [13].

Procedure

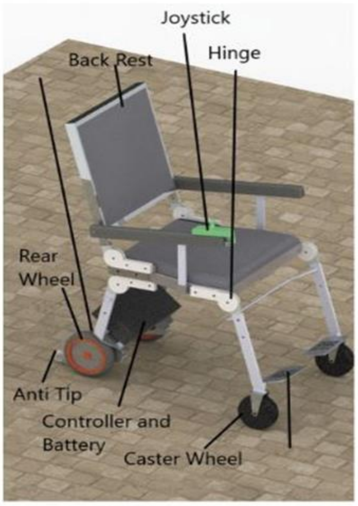


Fig.1 Wheelchair

Finite Element Analysis and Design of Experiments

Much literature show that the results between computational Finite Element Method and real-time Mechanical experiments are very close to each other [13]. ANSYS FEM analyses the MWC in Fig.1 to identify optimal settings to increase the strength and reduce cost and weight. The Design of Experiment is the design of specific tasks to explain the variation of information under different conditions. DOE applies where situations with more than one input factor influence the output. Steps involved in DOE are, define the problem(s), determine objective(s), brainstorm, design experiments, conduct experiments, collect data, analyze data, interpret results and verify predicted results.

Factorial experiment, Quasi-experiment, Six Sigma, Fractional factorial design, and Response surface methodology are some of the other DOE techniques other than the Taguchi method. Because of the simplicity and less time consumption, Taguchi is selected for the analysis.

ANSYS Analysis and Taguchi Technique of Optimization

Genichi Taguchi developed the statistical technique which uses a unique set of arrays called orthogonal arrays as shown in Table 3. These arrays reduce the total number of experiments compared to other Design of Experiment methods. Factors are the inputs of the research, and levels are the conditions of the input data which controls the test. Table 1 & 2 show the levels and factors for Taguchi optimization. Taguchi DOE optimizes the MWC's legs and seat frame for strength, low weight and low cost.

TABLE 1: FACTORS AND LEVELS OF LEG

Factor	Level 1	Level 2	Level 3
A-Thickness of the hollow square pipe of the leg (mm)	0.912	1.214	1.519
B-Width of the square pipe of the leg (mm)	25	27	29
C- Material	Mild steel	Stainless Steel	Aluminum Alloy

TABLE 2: FACTORS AND LEVELS OF FRAME

Factor	Level 1	Level 2	Level 3
A-Thickness hollow square pipe of the seat (mm)	0.912	1.214	1.519
B-Width of the hollow square pipe of the seat (mm)	25	26	27
C- Material	Mild steel	Stainless steel	Aluminum alloy

TABLE 3: ORTHOGONAL ARRAY

Exp No.	1	2	3
1	A1	B1	C1
2	A1	B2	C2
3	A1	B3	C3
4	A2	B1	C2
5	A2	B2	C3
6	A2	B3	C1
7	A3	B1	C3
8	A3	B2	C1
9	A3	B3	C2

Table 1 & 2 show nine experimental settings to analyze in ANSYS Workbench. The STEP file of leg and seat frame meshed are shown in Figs. 2 & 3. Increasing the number of meshes improves the results substantially. The maximum mesh size gives the best results.

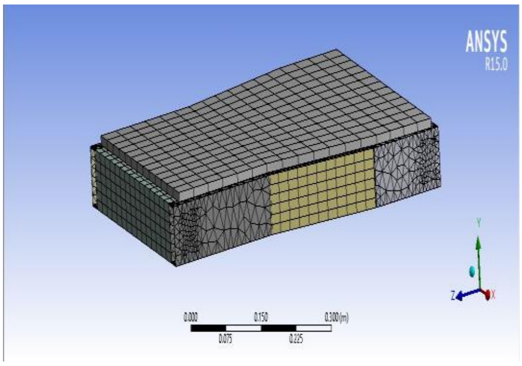


Fig. 2 Meshed image of frame

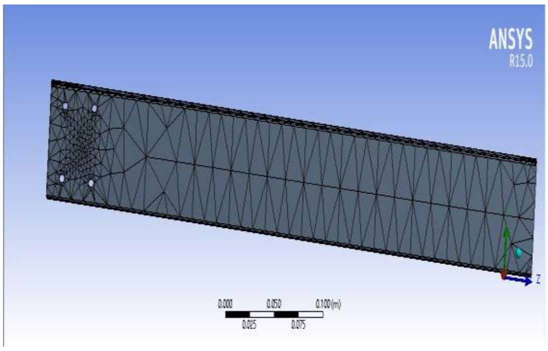


Fig. 3 Meshed image of leg

Boundary Conditions of loaded and fixed ends were specified before conducting the computational static analysis. Figures 4, 6, 8 & 10 show various constraints for the analysis with ANSYS Work Bench. Figures 5, 7, 9 & 11 show the deformations along with the magnitudes of deflections in descending order from red to blue.

Total deformations of leg

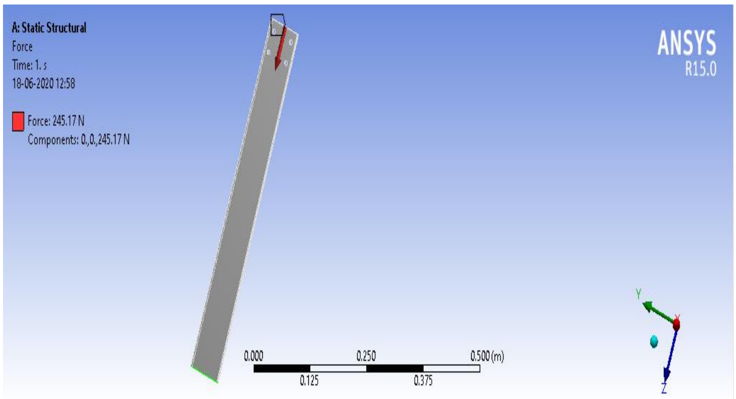


Fig. 4 Constraints of leg

Fig. 5 shows the boundary conditions of one leg. Red arrow indicates the the direction of the force. The lower green line shows the fixed side to process the ANSYS analysis.

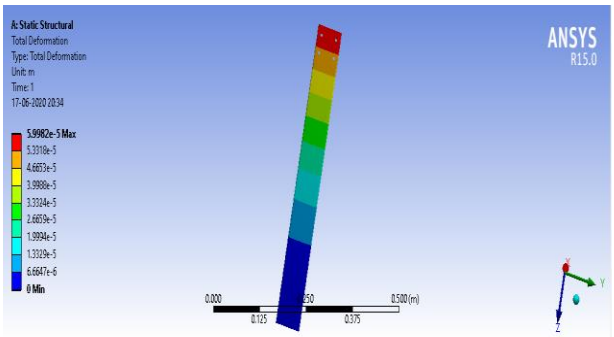


Fig. 5 Total deformation of 0.912 mm thick and 25 mm wide mild steel leg

Fig. 5 shows the results of the first experiment of the Orthogonal Array in Table 3. The Leg with 0.912 mm thickness, 25 mm width, made of mild steel subjected to a Load of 250 N. All nine combinations of experiments were analyzed, and the values obtained are shown in Table 4.

Total Deformation of Seat Frame

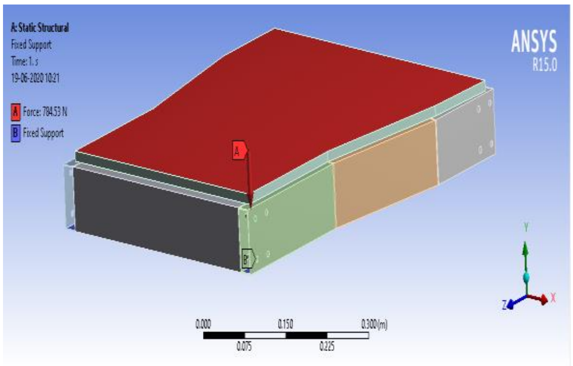


Fig. 6 Constraints of seat frame

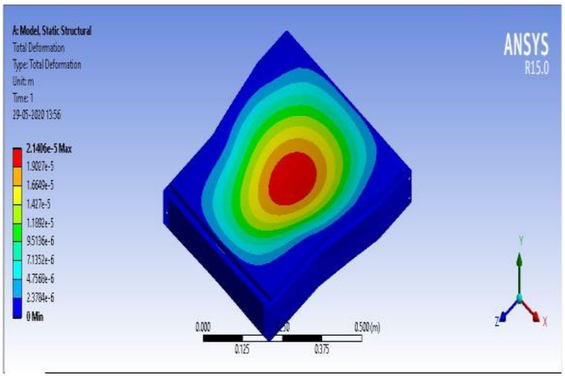


Fig. 7 .Mild Steel seat frame 0.912 mm thick and 25 mm wide

Fig 6 & 7 shows the results of the first set of conditions as per the Table 6 of seat frame. As shown in Fig 6, the fixed constraints are assigned on the bolt-holes of the seat frame. A load of 800 N is applied on the top surface of the seat Frame. The results showing the total deformations for all nine experiments along with its cost and weight are tabulated in Table 6. Table 7 shows the S/N ratios of the corresponding results.

Lock of the Motorized Wheel chair

The Hinge Lock plays a vital role in folding the wheelchair. At the same time, lock should sustain the Weight of the MWC user. The foldable ladders use the lock provided in the MWC. Fig 8 shows the constraints applied on the lock and also shows the experimental set up planned to test on the universal testing machine (UTM). Figure 9 shows the ANSYS analysis of the lock with mild steel as the material. Graph 1 shows the load vs deflection of the lock. It is seen that the lock can sustain oads up to 1500 N with negligible total deformation. The graph shows that from 250 to 1500 N Load is within elastic limits.

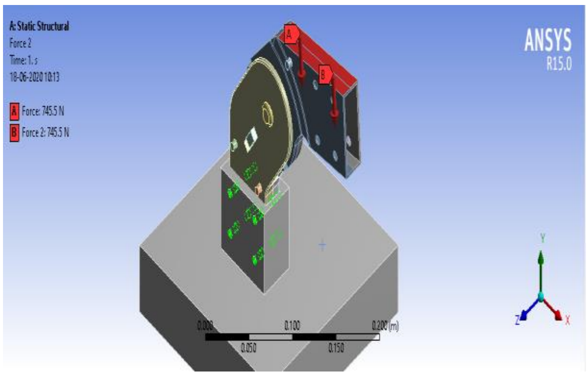


Fig. 8 Constraints of lock

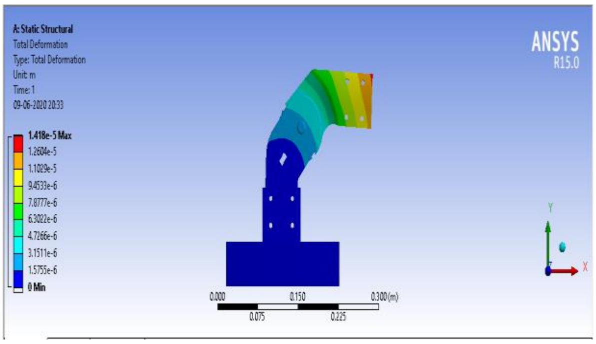
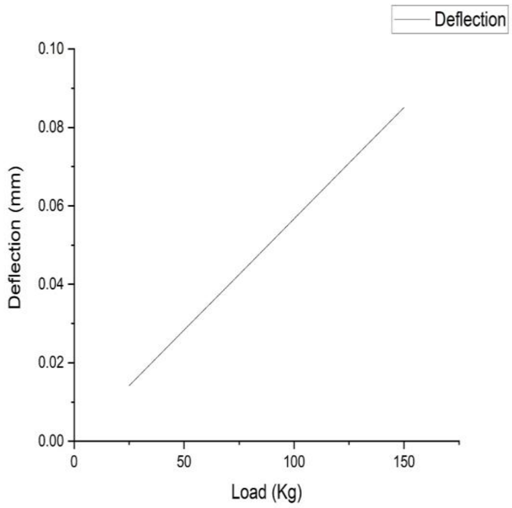


Fig. 9 Analysis for total deformation of lock



GRAPH 1. The Load vs Deflection of Lock

Analysis of the Whole Wheel chair

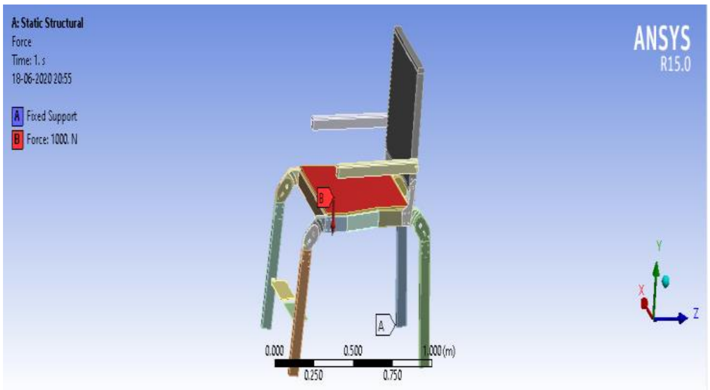


Fig.10 Constraints on the Wheel chair Frame

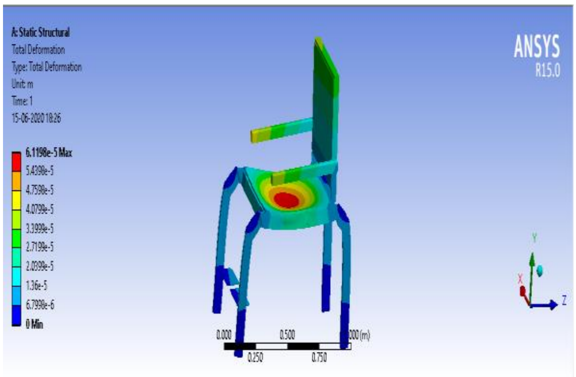
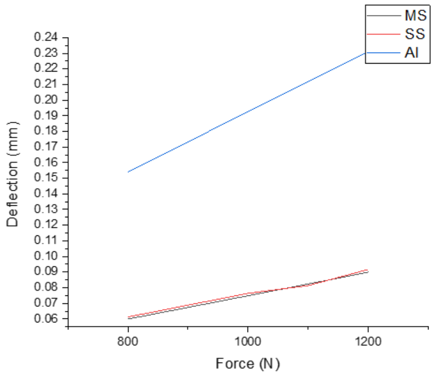


Fig.11 Analysis of the total deformation of the wheelchair

Fig 10 shows various constraints on MWC. The bottom of four Legs fixed and Loads of 800N to 1200N applied on the seat surface to study the total deformation [16]. Fig 11 shows the analysis of whole MWC with materials Mild Steel, Stainless Steel, and Aluminum Alloys. Graph 2 shows that the maximum Deflection is experienced by Aluminum and minimum deflection is experienced by both Mild Steel and Stainless Steel.



GRAPH 2. Load vs Total Deflection of Wheelchair

RESULT & DISCUSSION

The Orthogonal Array in Tables 4 & 6 show the results of the deflection and weight of leg and seat frame from ANSYS Workbench. The cost is calculated based on the weight and current market value of the metals. Table 5 & 7 give the S/N Ratio (deflection and weight) with the criteria 'Smaller the Better'. The graphs are plotted to find the minimum weight and cost. Graph 3 shows the best set of conditions if minimum weight is the desired output. The best setting is 0.912 mm sheet thickness, the leg width of 27 mm or 29 mm, and material Aluminium. For the minimum cost, Graph-4 shows the best set of conditions, which is 0.912 mm sheet thickness, 27 or 29 leg width, and the material mild Steel. Aluminium is having a moderate cost and stainless steel is expensive.

TABLE 4. Orthogonal Array of leg

Exp No.	1	2	3	Defln. (mm)	Wt. (gms)	Cost (Rs.)
1	0.912	25	MS	0.004	608	**30**
2	0.912	27	SS	0.006	615	148
3	0.912	29	AA	0.011	225	47
4	1.214	25	SS	0.003	797	191
5	1.214	27	AA	0.081	292	61
6	1.214	29	MS	0.003	846	42
7	1.519	25	AA	0.025	993	209
8	1.519	27	MS	0.002	1030	52
9	1.519	29	SS	0.002	1040	250

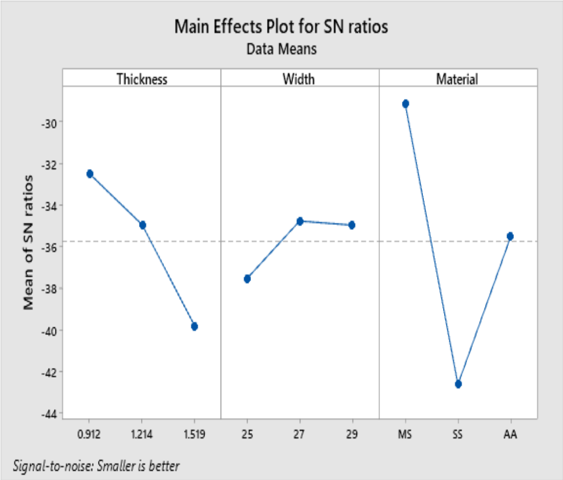
The S/N Ratio for this function:

$$-10log_{10}(\frac{1}{n}\sum_{i=1}^{n} y2i)$$ [13].

GRAPH 3. Mean effects plots for S/N ratio of leg (Weight)

TABLE 5. S/N Ratio of leg

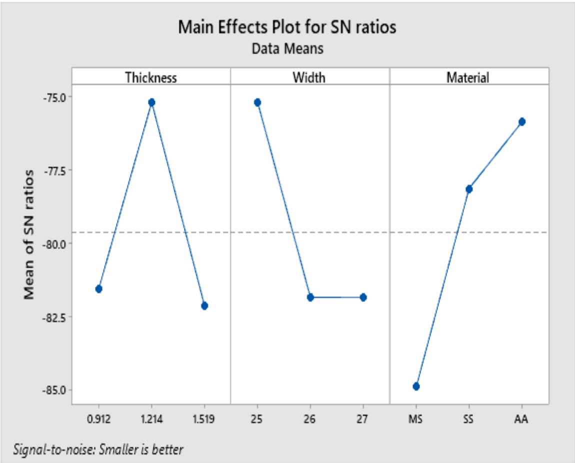
Exp No	S/N Ratio (Deflection)	S/N Ratio (Weight)	S/N Ratio (Cost)
1	48.174	-52.671	-26.651
2	44.440	-52.762	-40.366
3	39.580	-44.023	-30.467
4	50.345	-55.021	-42.624
5	21.862	-46.287	-32.731
6	51.051	-55.533	-29.512
7	32.049	-56.928	-43.372
8	52.767	-57.243	-31.222
9	52.656	-57.330	-44.935



GRAPH 5. S/N ratio of seat frame (Weight)

Table 6: Orthogonal Array of seat frame

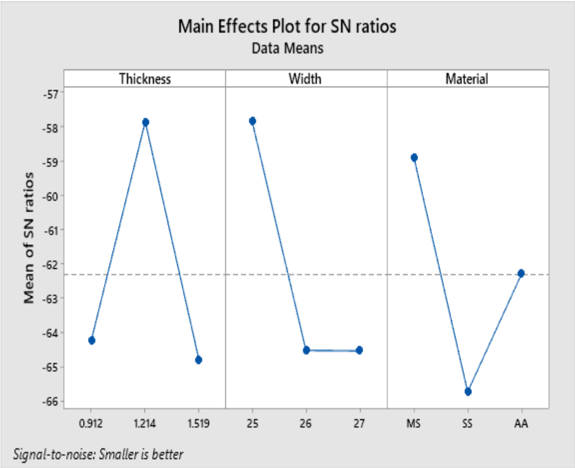
Exp No.	1	2	3	Deflection (mm)	Weight (grams)	Cost (Rs.)
1	0.912	25	MS	0.002	24026	1201
2	0.912	27	SS	0.002	23750	5700
3	0.912	29	AA	0.063	8499	1784
4	1.214	25	SS	0.002	2455	589
5	1.214	27	AA	0.057	8789	1845
6	1.214	29	MS	0.002	24947	1247
7	1.519	25	AA	0.056	9070	1905
8	1.519	27	MS	0.002	25754	1288
9	1.519	29	SS	0.002	25476	6114



GRAPH 4. Mean effects plot for S/N ratio of leg (Cost)

Table 7: S/N ratio values of seat frame

Exp No	S/N Ratio (Deflection)	S/N Ratio (Deflection vs Weight)	S/N Ratio (Deflection vs Cost)
1	53.389	-84.603	-58.583
2	53.265	-84.502	-72.107
3	24.084	-75.577	-62.022
4	52.432	-64.791	-52.395
5	24.827	-75.868	-62.313
6	53.777	-84.930	-58.910
7	25.026	-76.141	-62.586
8	53.793	-85.206	-59.186
9	53.645	-85.112	-72.717



GRAPH 6. S/N ratio of seat frame (Cost)

Graph 5 shows the best conditions for the minimum weight for the seat frame: a thickness of 1.214 mm, a width of 25 mm, and Aluminium (AA) as the material. Mild steel (MS) adds significant weight to the seat frame. Graph 6 shows the best conditions for the cost-effective fabrication: the thickness 1.214 mm, width 25 mm, and MS as material.

Dimensions as Per ISO Standards

The MWC follows ISO standard dimensions [17, 18]. Table 8 compares the ISO standard dimensions to the dimensions of the new design shown in Fig.12. All the dimensions of the MWC stay within the range.

Table 8: ISO Standard Dimensions of MWC vs. the New Design

Motorized Wheelchair Dimensions	**Standards Dimensions (cm)**	**Our dimensions (cm)**
Total Length	110-125	110
Total Breadth	60-70	67
Total Height	90-110	95
Height of Seat	45-50	46.5
Height of Hand Rest	60-70	61.5

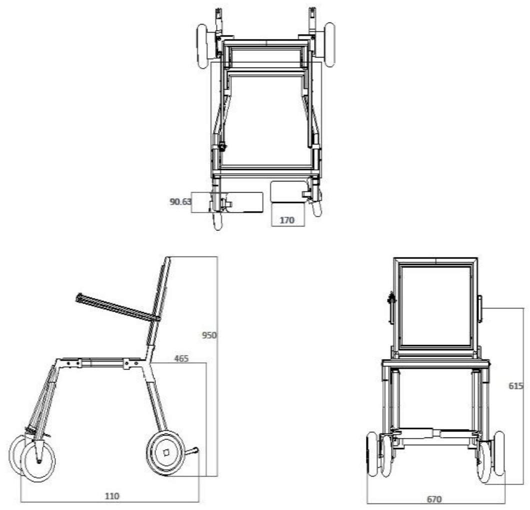


Fig. 12 Dimensions of the wheel chair

CONCLUSION

The objective of this paper is to find the material and optimum thickness of square frames used for fabricating a motorized wheel chair based on the minimum weight and minimum cost. ANSYS Work Bench analyses were conducted for analysing the leg and seat frame. Taguchi Technique was employed to optimize the weight and cost with minimum deflection of Mild Steel, Stainless Steel, and Aluminium based on the ‘smaller the better’ criteria. The Taguchi DOE tool in Minitab analyzes the values and fetch optimum results. For leg, a thickness of 0.912 mm, a width of 27, or 29 mm, and Aluminium (AA) as material are the best conditions to achieve the minimum weight. A thickness of 0.912 mm, a width of 27 or 29mm, and material mild steel are the best conditions for the leg based on the minimum cost. Aluminium (AA) is the next cost-effective material and Stainless Steel (SS) costs the maximum. a thickness of 1.214 mm, a width of 25 mm, and Material Aluminium (AA) are the best conditions for the seat frame based on the minimum weight. For cost-effective fabrication, the best conditions for the seat frane are, a thickness of 1.214 mm, width 25 mm, and MS as material. Load vs. Deflection for the whole motorized wheel chair (MWC) and folding hinge lock remain with elastic limits.

REFERENCES

1. https://www.who.int/disabilities/world_report/2011/report/en/
2. https://www.medicalbuyer.co.in/manual-wheelchair-market-expected-to-reach-usd-4099-1-million-by-2025/
3. https://www.prnewswire.com/in/news-releases/wheelchair-market-rising-at-421-cagr-by-2022--reportsnreports-668461093.html
4. Çolakoğlu, M. H., & Apay, A. C. (2012). “Finite element analysis of wooden chair strength in free drop”. *International Journal of the Physical Sciences*, *7*(7), 1105-1114.
5. Sam, Rosidah, Kamarul Arrifin, and Norlida Buniyamin. "Simulation of pick and place robotics system using Solidworks Softmotion." *2012 International Conference on System Engineering and Technology (ICSET)*. IEEE, 2012.
6. Fisher, R. A. (1960). The design of experiments. *The design of experiments.* (7th Ed).
7. Wen, Z., Jin, X., & Zhang, W. (2005). Contact-impact stress analysis of rail joint region using the dynamic finite element method. *Wear*, *258*(7-8), 1301-1309.
8. Sun, W., Zhu, W. H., Wang, C. K., Sun, A. Y., & Tan, H. B. (2008, April). Warpage simulation and DOE analysis with application in package-on-package development. In *EuroSimE 2008-International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Micro-Systems* (pp. 1-8). IEEE.
9. Kuehl, R. O., & Kuehl, R. O. (2000). Design of experiments: statistical principles of research design and analysis.
10. Patel, T. M., Bhatt, M. G., & Patel, H. K. (2013). Parametric Optimization of Eicher 11.10 Chassis Frame for Weight Reduction Using FEA-DOE Hybrid Modeling. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, *6*(2), 92-100.

11. Nalbant, M., Gökkaya, H., & Sur, G. (2007). Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. *Materials & design*, *28*(4), 1379-1385.

12. Zhang, C., Jiang, Z., Lu, D., & Ren, T. (2006, January). 3D MEMS design method via SolidWorks. In *2006 1st IEEE International Conference on Nano/Micro Engineered and Molecular Systems* (pp. 747-751). IEEE.

13. Kashif, Muhammed, and Prashantha Kumar ST. ""Application of Taguchi Methods and ANOVA in Optimization of Process Parameters for Metal Removal Rate in Electrochemical Machining of Al/5% Sic Composites."

14. Reh, S., Beley, J. D., Mukherjee, S., & Khor, E. H. (2006). Probabilistic finite element analysis using ANSYS. *Structural safety*, *28*(1-2), 17-43.

15. Mishra, S., & Sain, M. (2007). Strength analysis of chair base from wood plastic composites by finite element method. *Materials Research Innovations*, *11*(3), 137-143.

16. Lin, Z. C. (2013). The strength analysis and structure optimization of packer slip based on ANSYS. In *Applied Mechanics and Materials* (Vol. 423, pp. 1967-1971). Trans Tech Publications Ltd.

17. Steinfeld, E., Maisel, J., Feathers, D., & D'Souza, C. (2010). Anthropometry and standards for wheeled mobility: an international comparison. *Assistive Technology®*, *22*(1), 51-67.

18. Axelson, P., Minkel, J., & Chesney, D. (1994). *A guide to wheelchair selection: How to use the ANSI/RESNA wheelchair standards to buy a wheelchair*. Paralyzed Veterans of America.