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Research Article

Analysis of safety factors in wheelchair frames for stroke sufferers

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Abstract

This research aims to analyze the safety factors of wheelchair frames explicitly designed for stroke patients to provide a therapeutic tool. Five participants voluntarily took part in the study, selected based on variations in loading conditions applied to the wheelchair frame, with weights ranging from 60 to 100 kg. The wheelchair was designed using SolidWorks 2019 software, and the frame material consists of strum iron with a diameter of ¾ inch and a thickness of 3 mm. The manufacturing processes involved in the design include bending, cutting, and welding. The data were analyzed using an engineering design application with Inventor software for stress analysis. The test results revealed that the maximum and minimum stress values were observed at loadings of 980 Newtons, producing 12.75 MPa and 588 Newtons, resulting in 7.99 MPa. The Von Mises stress simulation indicated that as the load on the wheelchair frame increased, the corresponding Von Mises stress values also increased. This demonstrated that higher loads result in greater forces and moments acting on the wheelchair frame. In conclusion, the wheelchair design was highly safe for stroke patients weighing up to 100 kg. The wheelchair is intended to assist with mobility and facilitate therapeutic activities for stroke patients seated.

***Keywords*:** Stroke; Therapy; Wheelchairs; Inventor analysis

1. Introduction

Stroke is a very worrying health condition and is reported to be the second leading cause of death in the world (Mohanan et al., 2023), which often results in disability and death for sufferers (Gujjar et al., 2018). Stroke can cause changes in body shape and disruption of spatial, motor and sensory relationships, which has an impact on reducing the sufferer's quality of life (Bienkiewicz et al., 2015; Bosma et al., 2019; Stralen et al., 2017). Then, stroke sufferers usually experience impaired postural control, which has the potential to affect balance and walking function (Hyndman et al., 2006).

Much rehabilitation must improve post-stroke recovery (Ferrarello et al., 2015; Stinear & Byblow, 2014). It focuses on improving postural control, balance, and gait function for their independence in daily activities (Bang et al., 2013). However, this long-term care and rehabilitation is expensive (Bushnell et al., 2018; Zhang et al., 2020). In this case, light to moderate physical activity is the primary treatment. The physical exercise provided must be individual and specific, of sufficient frequency, and sufferers must do it to the limit of their abilities (Pollock et al., 2014; Veerbeek et al., 2014). Physical activity is carried out to improve muscle strength, functional capacity, ability to carry out daily activities, gait, balance, and cardiorespiration, and restore quality of life (Arnando et al., 2023; Chaeroni et al., 2021; Haris et al., 2023; Irawan et al., 2024; Liza et al., 2024; Padli et al., 2020). There is increasing interest in this in rehabilitation clinics, namely combining conventional sports training with games and virtual reality to motivate their patients' involvement (Palmcrantz et al., 2017).

Stroke sufferers with low physical activity have a 91% risk of experiencing secondary complications (for example, disability, decubitus ulcers, pneumonia, and heart problems). Usually, this physical activity is less than four hours per week (Feigin et al., 2014). Low physical activity or sedentary behaviour also risks complications from diabetes mellitus, recurrent strokes and even death (Saunders et al., 2021; Young et al., 2016). Therefore, when the post-stroke condition is stable, sufferers are advised to carry out physical activity with a regular program and focus on using walking methods to train cardiorespiration, balance and motor control. Physical exercise can also be done using a bicycle ergometer, which has kinematic similarities to walking (Kim & Bae, 2010). However, the cost is an obstacle for most sufferers, so they spend hours daily sitting in a manual wheelchair (hands placed in the lap or on the armrests) (Jette et al., 2005).

In this regard, special attention must be paid to considering the equipment used, modifying it, and the safety and security of the sufferer (Billinger et al., 2014). Providing adaptive equipment to stroke survivors is an effective way to reduce their burden. Adaptive equipment will help them carry out daily activities to maintain health and autonomy and live the best life possible (World Health Organization, 2004), such as showering or moving to another place (Gelderblom & Witte, 2002). Experts have designed these

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various pieces of equipment to help stroke sufferers carry out physical therapy to speed up their recovery. For example, Umar et al. (2023) designed wheelchairs as a tool for recovery for mild-severe stroke sufferers. (Hakim et al., 2023) designing and analyzing a stationary bicycle as a physical therapy exercise for post-stroke patients (upper and lower body). Then, Batan et al. (2019) also designed a tricycle for physical therapy in stroke sufferers. Unfortunately, the effectiveness in terms of the maximum weight of the user (stroke sufferer) for using the designed equipment has not been investigated with certainty (Umar et al., 2023).

Therefore, this study aims to analyze the safety factors in wheelchair frames designed for stroke sufferers, with the hope that they can be helpful as therapeutic tools to speed up the recovery of sufferers. This research is essential because using a wheelchair for rehabilitation can help sufferers sit comfortably and serve as a means of transportation (Umar et al., 2023). Additionally, stroke survivors often use manual wheelchairs during inpatient rehabilitation for seating and transportation due to initial difficulties with balance and walking (Barker et al., 2004).

2. Materials and Methods

A total of 5 participants volunteered to participate in this study, each weighing 60 to 100 kg. Recruitment of participants was based on testing variations in loading on the wheelchair frame. The wheelchair was designed using the 2019 version of the Solidwork application. The wheelchair frame has been designed to suit the needs of stroke sufferers, namely a pedal system for leg muscle therapy and a swing arm mechanism for hand muscle training (Umar et al., 2023). Stroke sufferers have limited ability to pedal, so this wheelchair is also equipped with a servo motor to make pedalling easier. As a therapy and mobility tool, the motor rotation system can be adapted to the needs of stroke sufferers. The load on the pedals is also adjusted according to the ability and severity of the sufferer (Umar et al., 2023).

The design material for the wheelchair frame is strum iron with a diameter of ¾ inches and a thickness of 3 mm (Figure 1). The material selection is adjusted to the estimated user weight (60 to 100 kg), and the frame design is carried out using several manufacturing processes, such as bending, cutting, and welding.

a) b) c)

Fig. 1. a) Materials for designing a wheelchair frame, b) design process, and c) sketch of the final shape of a wheelchair for stroke sufferers

The design of the wheelchair frame prioritized both functionality and aesthetics. Various load indicators were used to perform a systematic analysis of safety factors to ensure durability and reliability. The results of the descriptive analysis of the wheelchair design are outlined in Table 1. Following this, the data was analyzed using Inventor, an engineering design application, to assess the structural integrity and performance of the frame further.

Table 1
Design description of wheelchairs

Mass	14.2146 kg
Area	1473460 mm^2
Volume	1810770 mm^3
Center of gravity	X = -62.0017 mm
	Y = 321.617 mm
	Z = 495.011 mm

3. Result

Table 2 and Figure 2 analyze safety factors on wheelchair frames with varying loads. The highest stress value was obtained at 980 Newtons with 12.75 MPa loading, and the lowest was obtained at a loading of 588 Newtons with 7.99 MPa (Table 2). The simulation results of the Von Mises Stress value using inventor analysis show that an increase in the load given to the wheelchair frame is accompanied by a high value of Von Mises Stress (Figure 3. a).

Table 2
Tabulation of data for analysis of safety factors on wheelchair frames

Test	Loading (Newtons)	Gravity	Reaction Force (Newtons)	Reaction Moment (Newtons)	Von Mises Stress (MPa)	Displacement (mm)	Safety Factor (ul)
1	588	9810.000 mm/s^2	430.407	148.365	7.99	0.05726	15
2	686	9810.000 mm/s^2	479.784	167.332	7.86	0.06583	15
3	784	9810.000 mm/s^2	528.961	185.822	10.30	0.07436	15
4	882	9810.000 mm/s^2	578.138	204.914	11.57	0.08292	15
5	980	9810.000 mm/s^2	627.315	223.841	12.75	0.09146	15

Note- 9.8 Newtons is equal to 1 kg.

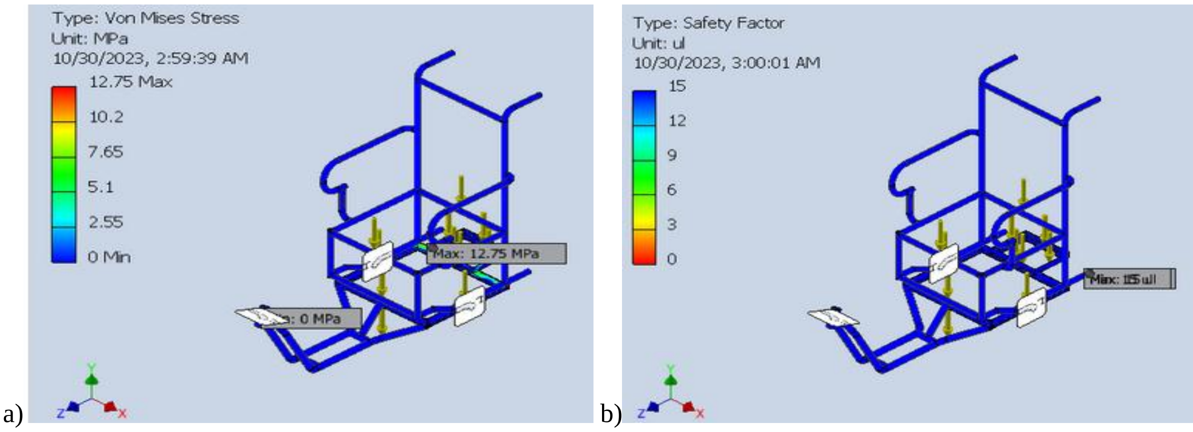


Fig. 2. a) Von Mises Stress analysis, and b) analysis of safety factors in wheelchair frames

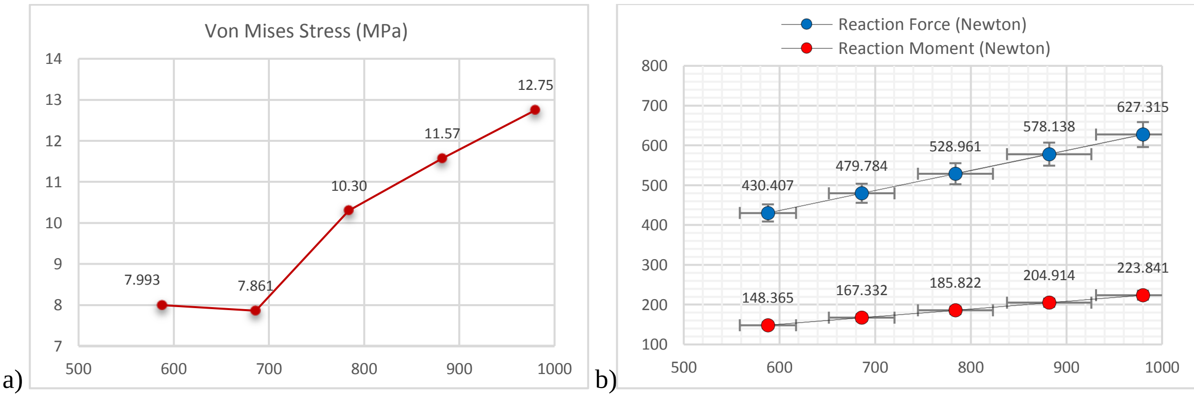


Fig. 3. a) Increase in Von Mises Stress value according to increasing loading, b) force and moment reactions in the wheelchair frame

Loading variations in this simulation were carried out with five indicators: weights of 60, 70, 80, 90, and 100 kg. The simulation results show that the higher the loading, the higher the force and moment reactions in the frame (Figure 3. b). Table 3 presents the value of safety factor analysis on wheelchair frames for stroke sufferers.

Table 3
Safety factor analysis values for wheelchair frames

Loading (Newtons)	Von Mises Stress (MPa)	Displacement (mm)	Safety Factor (ul)	Information
588	7.99	0.05726	15	Safe
686	7.86	0.06583	15	Safe
784	10.30	0.07436	15	Safe
882	11.57	0.08292	15	Safe
980	12.75	0.09146	15	Safe

Note- 9.8 Newtons is equal to 1 kg.

While the small sample size presents challenges in terms of statistical validity, the insights gained from this preliminary investigation can inform future studies and design enhancements. The following table summarizes the participant data and their experiences with the wheelchair's features:

Table 4
Descriptive Statistics of Participants

Statistic	Weight (kg)	Height (cm)	Pedaling Ability (Scale 1-5)
Number of Participants	5	5	5
Mean	82	170	3
Median	85	170	3
Standard Deviation (SD)	0,68125	07.07	01.58
Minimum	60	160	1
Maximum	100	180	5
Range	40	20	4

Table 5
Participant Characteristics Data

Participant	Weight (kg)	Height (cm)	Pedaling Ability (Scale 1-5)	Motor Assistance Needed	Age (years)
Participant 1	60	165	3	Yes	45
Participant 2	75	170	2	Yes	50
Participant 3	85	180	4	No	60
Participant 4	90	175	1	Yes	55
Participant 5	100	160	5	No	40

Table 6
Kruskal-Wallis Test Results for Pedaling Ability

Test	Chi-Square Value	Degrees of Freedom	P-Value	Conclusion
Kruskal-Wallis	06.43	4	00.17	No significant difference

Table 7
Summary Statistics by Motor Assistance Nee

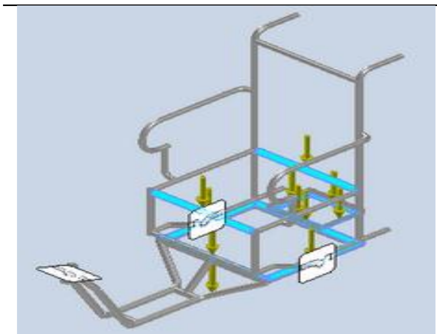
Motor Assistance Needed	Average Weight (kg)	Average Height (cm)	Average Pedaling Ability (Scale 1-5)
Yes	75	170	0,12986111
No	92.05.00	170	04.05

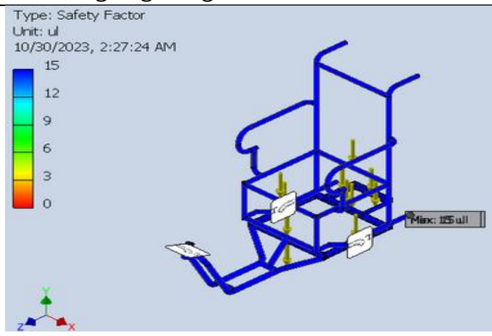
4. Discussion

Based on the results of the analysis of the wheelchair frame, the wheelchair design is very safe for use by stroke sufferers with a maximum weight of 100 kg. From the results of the wheelchair frame simulation analysis, the Von Mises Stress value is below the safety factor value (see Table 4). This proves that the load given to the frame will not damage the frame construction, so it can be concluded that this frame is safe to use. In use, the patient will sit in a wheelchair and carry out therapy activities. Apart from that, this wheelchair also functions as mobility for sufferers. This wheelchair has a servo motor, making it easier and lighter to carry out therapy. A study from Hakim et al. (2023) reported that frame testing on a static bicycle was designed to be safe for stroke sufferers weighing 100 kg. The maximum load test results on the frame from this study are the same as the findings. However, the equipment design differs.

Table 4
Results of analysis of safety factors on wheelchair frames using various loading variations

Testing 1: User weighing 60 kg

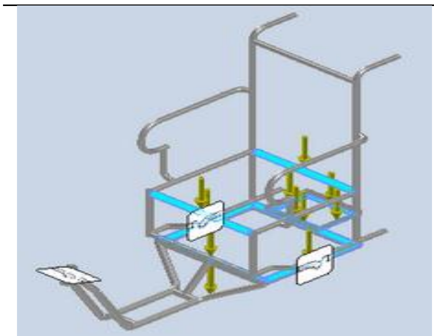


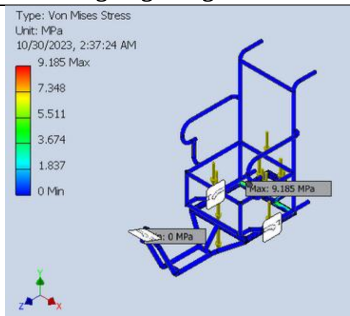


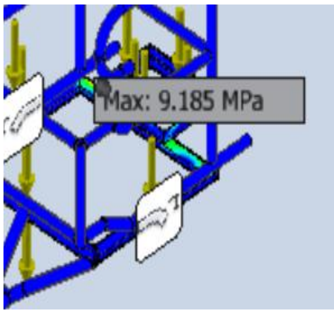
Users weighing 60 kg indicate that the condition of the material on the wheelchair frame has remained unchanged. The turquoise colour in the image shows the dominant loading area.

The results of the safety factor analysis show that the material design has not changed colour. This means the material's ability to withstand loading is still at its maximum capacity, and the stresses in the frame components are still within its tolerance limits.

Testing 2: User weighing 70 kg



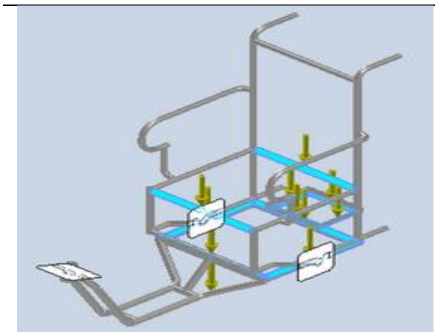


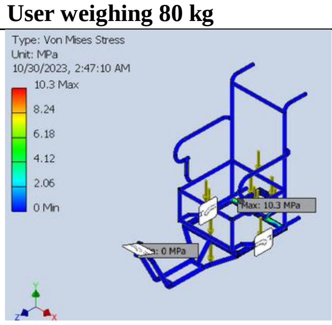


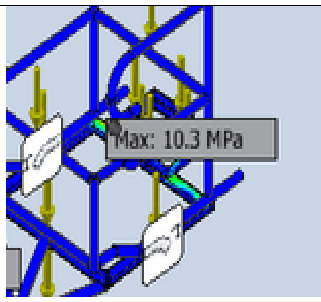
Users weighing 70 kg indicate that the condition of the material on the wheelchair frame has remained unchanged. The turquoise colour in the image shows the dominant loading area.

The results of the safety factor analysis show a change in colour in the material design. This means that the material's ability to withstand loading begins to experience structural changes but is still within the tolerance limit. This is because the colour shown is still green. The part that experiences colour change is the bottom. This is also caused by the positioning of the battery in that part. Thus, the user's and battery's weight cause these components to experience structural changes due to stress. The maximum pressure on the component is 9.185 Mpa.

Testing 3: User weighing 80 kg



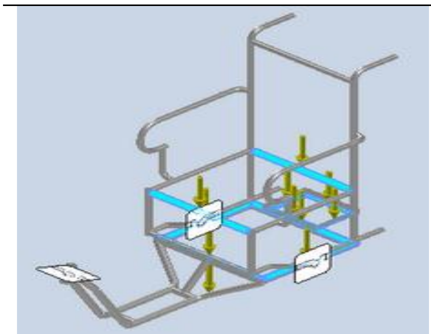


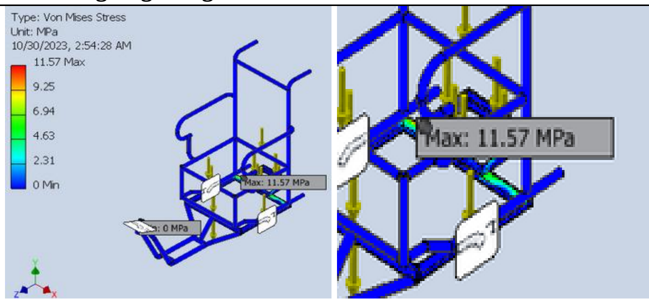


Users weighing 80 kg indicate that the condition of the material on the wheelchair frame has remained unchanged. The turquoise colour in the image shows the dominant loading area.

The results of the safety factor analysis show a change in colour in the material design. This means that the material's ability to withstand loading begins to experience structural changes but is still within the tolerance limit. This is because the colour shown is still green. The part that experiences colour change is the bottom. This is also caused by the positioning of the battery in that part. Thus, the user's and battery's weight cause these components to experience structural changes due to stress. The maximum pressure on the component is 10.30 MPa.

Testing 4: User weighing 90 kg

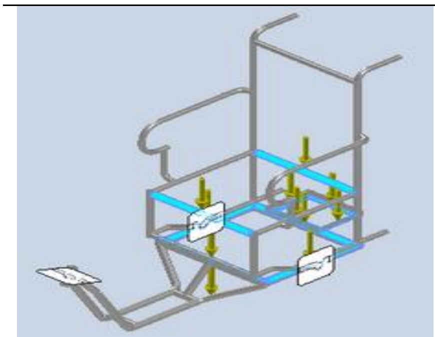


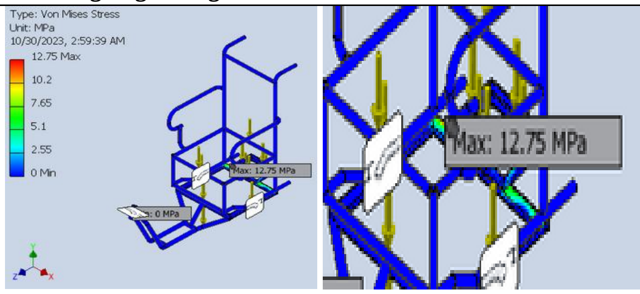


Users weighing 90 kg indicate that the condition of the material on the wheelchair frame has remained unchanged. The turquoise colour in the image shows the dominant loading area.

The results of the safety factor analysis show a change in colour in the material design. This means that the material's ability to withstand loading begins to experience structural changes but is still within the tolerance limit. This is because the colour shown is still green. The part that experiences colour change is the bottom. This is also caused by the positioning of the battery in that part. Thus, the user's and battery's weight cause these components to experience structural changes due to stress. The maximum pressure on the component is 11.57 MPa.

Testing 5: User weighing 100 kg





Users weighing 100 kg indicate that the condition of the material on the wheelchair frame has remained unchanged. The turquoise colour in the image shows the dominant loading area.

The results of the safety factor analysis show that there is a colour change in the material design. This means that the material's ability to withstand loading begins to experience structural changes but is still within the tolerance limit. This is because the colour shown is still green. The part that experiences colour change is the bottom. This is also caused by the positioning of the battery in that part. Thus, the user's and battery's weight cause these components to experience structural changes due to stress. The maximum pressure on the component is 12.75 MPa.

According to (Salminen et al., 2009), intervention from a wheelchair can help sufferers who experience limited mobility to move. This is also an aid for patients who experience paralysis, impaired gait function or whose physical strength begins to weaken (Bang et al., 2013). Also, wheelchairs are the most effective tool for hemiplegic patients with impaired lower body function and difficulty walking (Jung et al., 2015). Wheelchairs increase mobility and prevent and correct the sufferer's disability. A study by (Batan et al., 2019) reported that tricycles could help stroke sufferers recover. However, the maximum patient weight for using the equipment in this study has not been definitively investigated.

One of the limitations reported in this research is that the wheelchair frame has been designed to be safe for users only weighing 100 kg. Then, testing other materials on wheelchairs is very necessary in future research. To prevent accidents in users who weigh more than 100 kg, it is recommended to choose materials that are stronger and resistant to heavier loads, such as mild steel or special aluminium alloys. The frame design must also be strengthened by strengthening parts subjected to high pressure and making necessary structural repairs. Maximum load testing should be done to ensure the frame can safely withstand larger loads. Additionally, installing clear warning labels regarding the maximum safe weight limit is important and informing users of the risks of exceeding those limits. If necessary, consider evaluating and recommending alternative products or equipment suitable for individuals weighing over 100 kg.

This product stands out compared to similar wheelchairs on the market thanks to several innovative features and customized designs. Unlike conventional wheelchairs, this product is designed specifically for stroke sufferers with a pedal system and swing arm mechanism that supports hand and foot muscle therapy, providing dual benefits as a therapeutic tool and mobility. An additional feature in a servo motor makes the pedalling process more manageable, helping users with limited mobility to perform therapy more efficiently. Frame materials made of strum iron with diameters and thicknesses adjusted to the user's estimated weight to ensure optimal strength and durability while manufacturing processes such as cutting, bending, and welding increase the strength of the structure. Safety is also a priority with Inventor's analysis to assess Von Mises' safety and stress factors, showing that the frame design can withstand loads of up to 100 kg without damage. In addition, the ability of this product to adjust the load on the pedal according to the user's ability increases the effectiveness of therapy based on the severity of the stroke patient. Overall, the product offers a combination of therapeutic and mobility features with safety-optimized materials and designs, something that is often not found in conventional wheelchairs on the market.

The innovative design of these products, including the addition of a servo motor and a specialized therapy system, highlights the significance of fostering innovation that sets the product apart from competitors and addresses a critical gap in the market. Additionally, managers should focus on risk and safety analysis, ensuring that all aspects of the product have been thoroughly tested to mitigate potential issues before launch. Strict supervision of material quality and manufacturing processes is crucial to ensure the final product meets high-quality standards. Effective marketing strategies must be developed to highlight product excellence and reach relevant target markets. Collecting user feedback and analyzing product performance in the field is essential for continuous improvement. The manager must handle various product development aspects, from innovation to marketing and feedback, to ensure user success and satisfaction. The wheelchair is designed to be safe for users weighing up to 100 kg. Testing results indicate that, despite color changes in the material when used by individuals weighing between 70 kg and 100 kg, the material condition remains within tolerance limits. However, these changes suggest that the material is beginning to undergo structural alterations due to the applied load. Based on the analysis, the maximum pressure experienced by the components ranges from 9.185 MPa to 12.75 MPa, indicating that use by individuals over 100 kg could pose risks and requires further testing. Therefore, it is essential to explore other materials to ensure safety for users exceeding this weight limit. To mitigate risks for users surpassing the specified weight, additional research and development of stronger materials, as well as a thorough evaluation of the wheelchair frame design, are necessary.

5. Conclusions

This wheelchair design offers dual therapeutic functionality, featuring a pedal system and swing arm mechanism that allow users to engage in muscle therapy while also serving as a mobility aid. The ability to adjust the load on the pedals based on the user's capabilities enhances personalized therapy, thereby increasing its effectiveness. An innovative addition is the servo motor, which facilitates the pedaling process, making therapy more accessible for individuals with limited mobility. Furthermore, the use of engineering analysis through Inventor software to assess structural integrity and stress factors ensures that this wheelchair is safe for users weighing up to 100 kg without compromising durability.

However, there are several drawbacks to consider. The current design is only safe for users with a maximum weight of 100 kg, which poses risks for individuals exceeding this limit, indicating a need for the development of stronger materials and improved design. The observed color changes in the material during use suggest that, while the structure remains within tolerance, it may begin to experience wear, necessitating monitoring for long-term durability. Additionally, the focus on a specific weight range and therapeutic function may limit the product's applicability for a broader demographic of stroke survivors. Cost is another consideration, as the emphasis on advanced features may render the design expensive for some users or healthcare providers. The requirement for further testing and evaluation for users exceeding the weight limit highlights a continuous commitment to safety, which demands resources and time. Furthermore, effective marketing strategies will be essential to educate potential users and healthcare professionals about the benefits and unique features of this wheelchair, presenting challenges in reaching target markets. Balancing these pros and cons will be crucial for the successful implementation and adoption of this product within the rehabilitation sector.

Conflict of interest

The authors report no potential conflicts of interest.

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