Jurnal Polimesin
Department of Mechanical Engineering
Lhokseumawe State Polytechnic
http://e-jurnal.pnl.ac.id/polimesin

e-ISSN : 2549-1999	No : 2	Month : August
p-ISSN : 1693-5462	Volume : 20	Year : 2022

Article Info

Received	:	2022-07-02	Accepted	:	2022-07-21
Revised	:	2022-07-21	Available online	:	2022-08-31

Design and stress analysis of adjustable chair on handcycle for persons with disabilities

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Abstract

Handcycle is one of bicycle that used by someone with physical limitations, and this bicycle is operated by hand. Some people who have physical limitations will not be able to ride a bicycle in general, so a handcycle is made using three wheels to be able to maintain the balance of the rider's body. This handcycle is a solution for people with disabilities to be able to go somewhere and also exercise. In this study, an adjustable chair design was made that is suitable for handcycles and has an adjustable function, namely making the handcycle seat move forward or backward to make it easier for a rider to adjust the position of the legs in moving the handcycle. The material used to manufacture the adjustable chair on the handcycle is iron plate, which is an elbow-shaped iron plate with an angle of 90^{o}. The length is 300 mm, width 200 mm and thickness 50 mm. After the design is made, then a stress analysis test with Autodesk Inventor 2016 is carried out on the adjustable chair on the handcycle by analyzing the strength of the chair and also the appropriate body posture when supporting the weight of a person with a disability. The final result of the adjustable chair applied to the handcycle was measured by stress analysis using Autodesk Inventor 2016 software. The material strength (Von Misess) for male users who weighs 70 kg has a maximum value of 1.767 MPa with a maximum displacement of 0.0059. As for female users weighing 60 kg, the maximum value is 1.514 MPa with a maximum displacement of 0.050.

Keywords:
Handcycle, adjustable chair, stress analysis, disabilities

1 Introduction

In Indonesia, 2.45% of the population is comprised of individuals with disabilities. About 10.26% of them have been diagnosed with a lower limb defect [1]. Since 1900, handcycles, which combine wheelchairs and bicycles, have been developed. This is an alternative mode of transportation for those with a lower limb deformity. Since 2004, handcycling has been included among the Paralympic sports [2]. There has been a converge on the hand-bike as a form of flexibility for rehabilitation [3-5].

People with lower limb difficulties rely on modes of assistive devices other than walking for accessibility and physical exercise. Hand-rim wheelchairs are the most prevalent type of wheeled mobility [6-8] when the upper body can still be physically active. The handcycle is an alternative method of outdoor wheeled mobility for longer distances [3, 4]. Handcycles are comes in a multitude of architectures, such as a connectedness to a wheelchair (with or without power assist) or as a stationary tricycle with different physical stances and frequently multiple gear settings. [9]. This is an alternative mode of transportation for those with missing limbs [10].

A handcycle is a type of bicycle whose front riders propel it with a chain and crank-mounted arm. Hand cyclists have relied on the object or design of the handcycle [11]. There are two types of arm cranksets for handcycles: synchronous and asynchronous. In dissimilarity to the asynchronous crank, which duplicated such as a bicycle's crank chase, the synchronic design has synchronized the crank's motion in the same direction. There are three distinct frame geometries: upright, hand cycle attachment, and recumbent [12]. A few formal manufactures do exist and offer both stock and custom solutions. However, many chairs are custom made by the persons themselves or by fabricators commissioned by the persons themselves. Few of these chairs provide the types of postural support ubiquitously found in everyday seating and mobility devices.

To identify the characteristics of individuals with multiple disabilities, it is necessary to recognize anthropometric data [13]. On the justification and comparing of Indonesian anthropometric data, frame design and stress analysis research was conducted to develop a prototype. To enhance handcycling for rehabilitation, daily activities, or sport activities, a balance between the individual, the environment, and the assistive device is required [14, 15]. The purpose of this study is to provide a foundation for current handcycling practice and to provide a foundation for future handcycling research and the current development is designing the shape and size of an adjustable chair that fits on a handcycle and is comfortable to ride for a person with a disability. The design of this adjustable chair has the characteristics of being easy to operate. The theoretical background of this study is comprised of four interconnected models that attempt to represent the state of the art in the scientific literature on handcycling.

A few formal manufactures do exist and offer both stock and custom solutions. However, many chairs are custom made by the persons themselves or by fabricators commissioned by the persons themselves. Few of these chairs provide the types of postural support ubiquitously found in everyday seating and mobility devices. Indonesia has never manufactured a handcycle product. On the basis of Indonesian anthropometric data and a comparison to existing anthropometric data, frame design and finite element analysis studies were conducted to create a prototype. This study designed handcycles and created prototypes based on frame design, finite element analysis, and anthropometry. Based on adjustable chair design, and anthropometry, handcycles have been designed and prototyped. Based on adjustable chair design, and anthropometry, handcycles have been designed and prototyped.

Autodesk Inventor is a CAD (Computer Aided Design) program for the visual creation of 3D prototype objects, simulation, drafting, and data documentation. In Inventor, a designer can create a 2D sketch of a creation, model it in 3D, and then create a visual prototype or a simulation that is even more complex. Autodesk is 3D design mechanical CAD software used to create 3D digital prototypes for product design, visualization, and simulation [16, 17]. The frame is a highly calculated component because it has the heaviest mass relative to other components and affects the bicycle's efficiency [18].

In a static trial, anthropometric measurements such as arm length and shoulder width were not calculated. During the dynamic trials, the hand bike config.uration and hand bike user interface were determined. Shoulder and crank heights were derived from arm length and crank center heights. Measuring the distance between the centers of the four markers on the left and right hands determined the width of the handgrip. The crank fore aft position was determined by measuring the distance between arm lengths when the cranks are parallel to the ground and pointing away from the chest of the athlete. The config.uration of the hand bike user interface was then calculated using crank height, crank width, and crank forward position relative to shoulder height, shoulder breadth, and arm length. [19].

The study from Jeang *et., al.* [20] took an acute triangular shape as the original concept for the main frame and use lightweight tubing materials (i.e. with a thickness of ≦ 2 mm). To achieve a lightweight goal, the entire frame was designed with 6061 aluminum alloy tubes. As depicted in Fig. 1, Garrett *et., al.* [21] the base serves to encouragement the seat and grab bar, require a position for acquiring the Highly Adjustable Throwing Chair (HATC) to the throwing surface with tie-downs, and accommodate for varying cushion thickness so that the seat for floor height can be set to a maximum competition height of 75 cm. On a prototype scale, the handcycle's design was developed. It referred to recumbent and synchronous frame geometry types for arm crank set up to conduct finite element analysis studies with Autodesk Fusion 360 software to determine the value of the handcycle frame design's strength. A decent frame at 160 kg loading with a critical value of 330 MPa was designed and served as a benchmark for the handcycle manufacturing process [2].

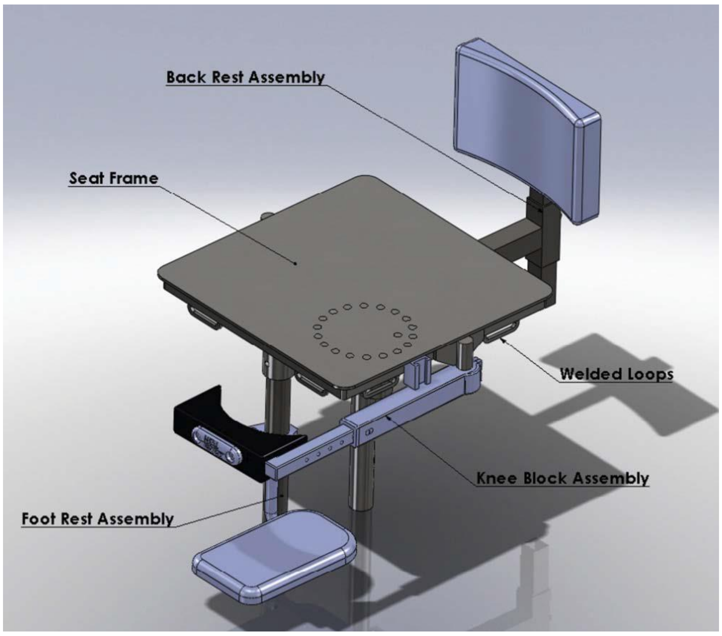

Fig. 1. Highly adjustable throwing chair (HATC) [21]

2 Research Methods

2.1 Anthropometry and flowchart of design

The design of the handcycle is based on anthropometry data. Table 1 and 2 lists the characteristics of anthropometry data from the Indonesian National Standards for People with Disabilities [22]. The geometry of the frame was based on a recumbent model that allows the foot position to be straightened. The handcycle was designed to incorporate all of the vehicle's subsystems. A CAD Model was created in Autodesk Inventor to facilitate the incorporation of the design.

Table 1. Anthropometry people with disabilities

No	Measurement	Male Avg.(mm)	Female Avg.(mm)
1	Sitting shoulder height position	569.0	499.4
2	Elbow height sitting position	216.7	124.9
3	Popliteal depth	485.5	452.4
4	Popliteal height	430.3	331.3
5	Shoulder breadth	460.6	410.0
6	Hip breadth	328.9	313.2
7	Elbow breadth	455.5	442.8

Table 2. Anthropometry data for Indonesian people (all dimensions in cm, body weight in kg)

No	Dimension	Male	Female
1	Vertical grip reach (standing)	206	186
2	Vertical grip reach (sitting)	122	113
3	Forward grip reach	73	67
4	Body weight	63	53
5	Stature	172	159

The flow chart in the Fig. 2 is the stages and stress analysis of the design process adjustable chair on the handcycle. Starting from preparing the model and size to design an adjustable chair, then applying the image and size in the Autodesk Inventor software. The next stage is to realize the results of the design into a real form, then analyze the data needed for the perfection of making adjustable chairs on handcycles.

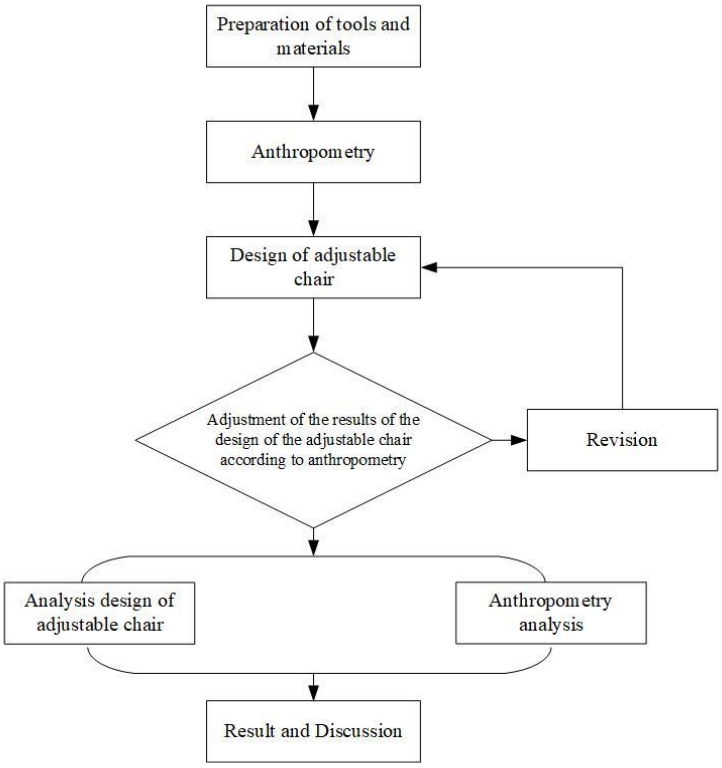

Fig. 2. Flowchart diagram adjustable chair on handcycle

2.2 Material selection of the design

The frame of the adjustable chair on the handcycle was constructed from readily available, safe, dependable, and easily welded material [23, 24]. The material used to manufacture the adjustable chair on the handcycle is iron plate, which is an elbow-shaped iron plate with an angle of 90^o. The length is 300 mm, width 200 mm and thickness 50 mm. In the simulation, mechanical strengthen with the properties listed in Table 2 was utilized.

Table 3. Material properties [2]

No	Measurement	Dimension
1	Density	$7.8 \times 10^{-6}\ kg/mm^3$
2	Young's modulus	200 GPa
3	Poisson's ratio	0.26
4	Yield strength	248.2 MPa
5	Ultimate tensile strength	475.7 MPa

2.3 Adjustable chair design

The design of the adjustable chair, seat slide and rail frame that shown in Fig. 2 and 3 below follows the anthropometric size and standard of disability chairs in general. For the design of the seat slide, the size adjusts to the size of the rail frame where the length of the seat slide is not the same as the rail frame so that the function of the seat slide can be used as it should.

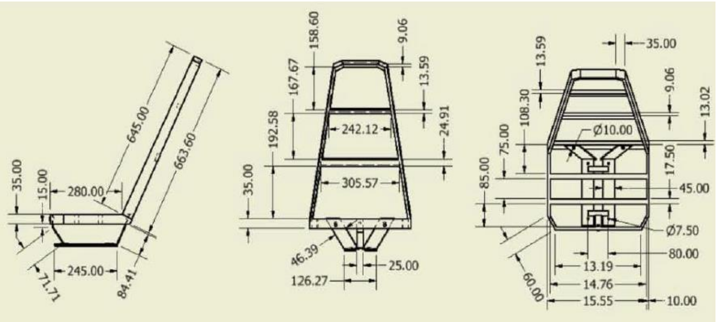

Fig. 3. Design and dimension of seat slide and adjustable chair

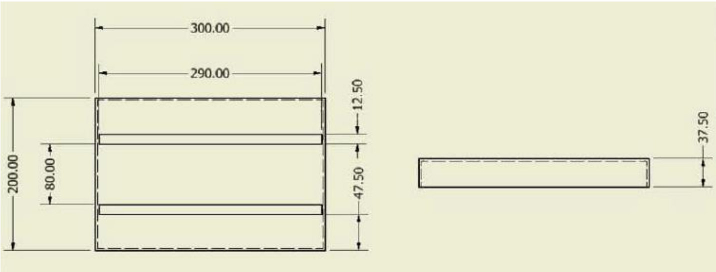

Fig. 4. Design of rail frame

The rail frame design concept, as shown in Fig. 3 above, follows the length of the main frame on the handcycle. The length of the rail is 290 mm and the movement of the adjustable seat is only able to move a maximum distance of 50 mm with the width of the rail frame following the balance for the pedestal of the seat of 200 mm.

3 Result and Discussion

3.1 Stress analysis adjustable chair in Software Autodesk Inventor

Recently, research on anthropometry becomes more essential, and yet, it is critical due to its implication and contribution to product and system design about handcycle especially in adjustable chair. Since it deals with human capability and limitation on physical activities, its role becomes more important, especially, when it comes to the needs for special populations.

The design of the adjustable chair on the handcycle has the characteristics of being easy to operate which is mounted on the frame slide. The slide mechanism consists of a rail frame mounted at the bottom of the adjustable chair to allow for the sliding motion on its axis

The study of anthropometry in humans will provide an explanation of the differences in the human body. By having the right anthropometric data, a product designer such as an adjustable chair on this handcycle will be able to adjust the shape and size of body parts which will later operate the product efficiently, effectively and comfortably.

Von mises states that yielding will occur when the invariance of the two deviators exceeds a certain critical price limit. In other words, yielding will occur when the distortion energy or shear strain energy of the material reaches a certain critical

The outcomes of the stress analysis indicated that the frame design of the adjustable handcycle seat did not fail under constant load. The maximum value stress Von Mises for female users in 70 kg from Fig. 5 is 1.514 MPa. Fig. 6 depicts the maximum displacement as 0.05 mm, which was still within safe limits and did not affect the functionality of the handcycle. In general, frame design possessed a 15-safety factor value (Fig. 7).

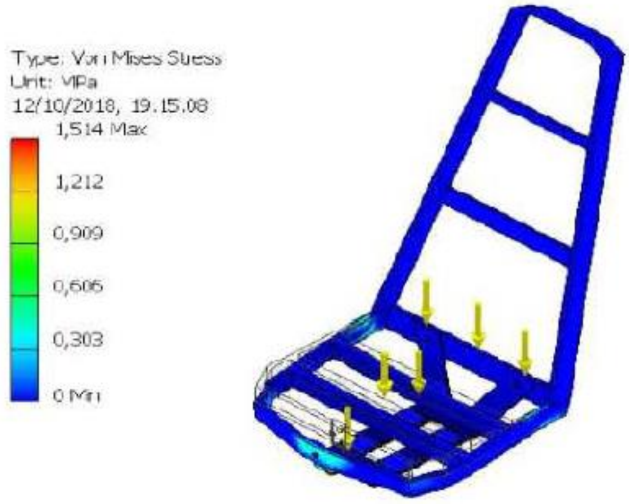

Fig. 5. Stress analysis Von Misses result for female

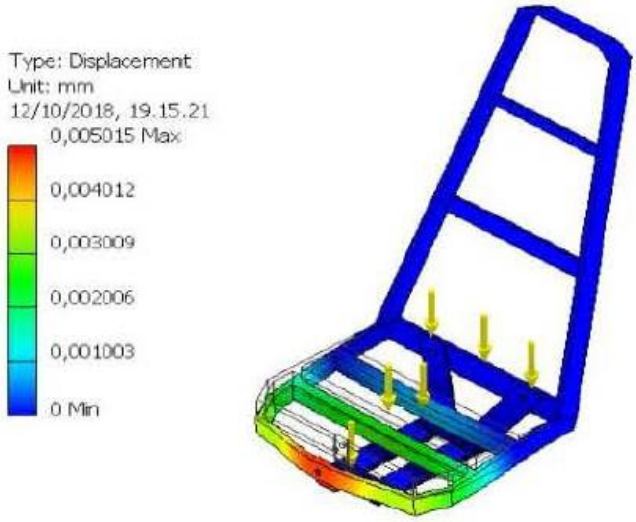

Fig. 6. Displacement result for female

The strength of the material in the Von Misses on an adjustable seat for a male handcycle driver weighing 70 kg has a maximum value of 1.767 MPa that shown in Fig. 7 below.

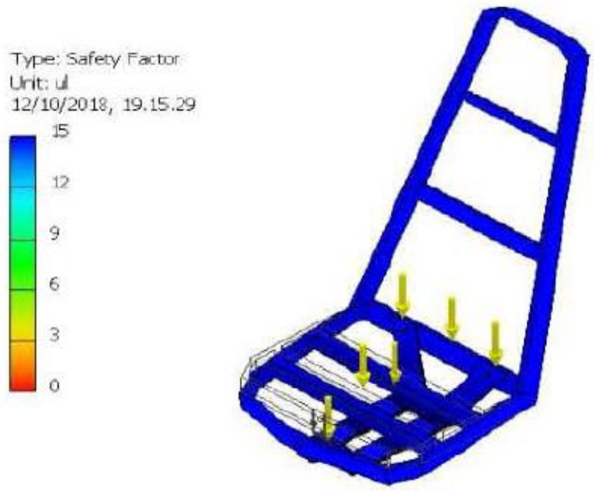

Fig. 7. Safety factor result for female

The strength of the material in the Von Misses on an adjustable seat for a male handcycle driver weighing 70 kg has a maximum value of 1.767 MPa that shown in Fig. 8 below. Fig. 9 depicts the maximum displacement as 0.0059 mm, which was still within safe limits and did not affect the functionality of the handcycle. In general, the safety factor for frame design was 15, as shown in Fig. 10.

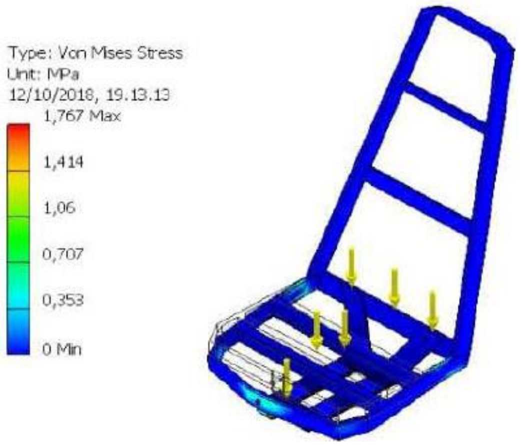

Fig. 8. Stress analysis Von Misses result for male

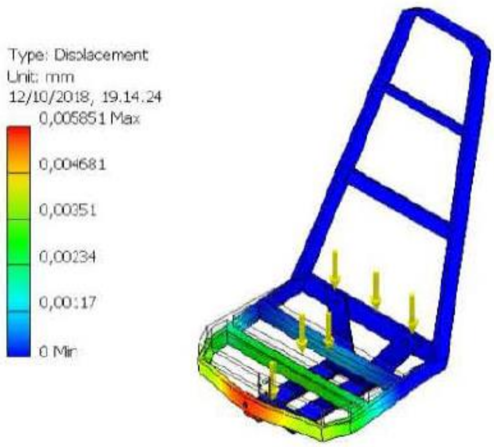

Fig. 9. Displacement result for male

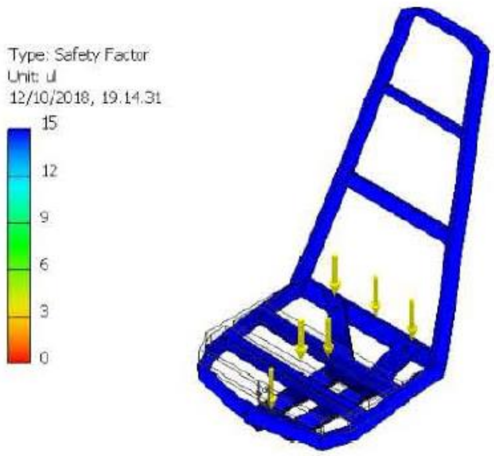

Fig. 10. Safety factor result for male

3.2 Assembly design adjustable chair on handcycle

Fig. 11 depicts the final handcycle manufacturing design, which included an adjustable seat for adjusting the distance between the driver and the crank. This design served as a production guide for the handcycle. The results of the analysis showed that frame design was safe and did not fail to static loading.

Comparing the maximum stress simulation results to the yield strength value yields the safety factor. The analysis factor of safety that produces a similar result to the original without exceeding the yield strength value is selected. In addition, the safety factor takes into account a semi-probabilistic safety format based on boundary state and a partial safety factor applied to the load and strength of the material. As a result, the displacement that occurs in the red region, involving a component of the adjustable chair, has no effect on the handcycle's critical components, and the displacement is therefore of no concern. Assembly design adjustable chair on handcycle.

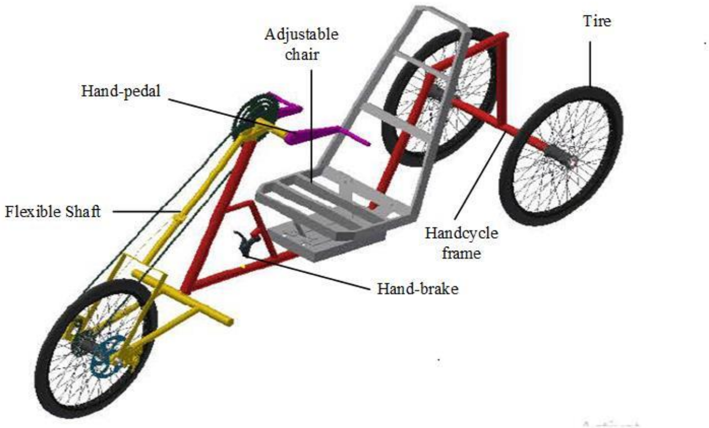

Fig. 11. Assembly design adjustable chair on handcycle

Table 4. Stress analysis main frame on handcycle

Simulation result	Rider weight	
	Male 70 kg	Female 70 kg
Von Misses	1400 MPa	1200 MPa
Displacement	96.63 mm	82.83 mm
Safety factor	15 ul	15 ul

The von misess obtained in the main frame when a male user weighing 70 kg has a maximum value of 1400 MPa while for a female user weighing 70 kg has a value of 1200 MPa. The displacement value for male users is 96.63 mm and for female users it is 82.83 mm. The safety factor value of the handcycle frame has a value of 15 ul.

Handcycles can be designed and manufactured according to the necessary specifications. This design represents the initial phase of handcycle development in Indonesia. There is a need for development to reduce the weight of handcycles and create more dynamic designs.

4 Conclusion

Handcycles can be proposed and manufactured in accordance with the necessary specifications. This design represents the primary phase of handcycle improvement in Indonesia. There is a need for development to decrease the heaviness of handcycles and create further dynamic designs. According to the results of a stress analysis performed in Autodesk Inventor, the portion of the framework that includes the driver's seat experiences the greatest displacement, while the correlation between the seat back and upper frame experiences the greatest equivalent stress. The magnitude of displacement in a bicycle frame is proportional to the amount of force exerted upon it.

References

[1] S. Salsabila and N. C. Apsari, "Aksesibilitas Fasilitas Pelayanan Publik di Beberapa Wilayah dan Implementasi Undang-Undang dalam Memenuhi Hak Penyandang Disabilitas," *Jurnal Penelitian dan Pengabdian Kepada Masyarakat (JPPM)*, vol. 2, no. 2, pp. 180-192, 2021.

[2] R. A. Himarosa, "Design, Frame Analysis and Manufacture of Handcycle Prototype," in *Journal of Physics: Conference Series*, 2020, vol. 1471, no. 1: IOP Publishing, p. 012058.

[3] F. Hettinga, L. Valent, W. Groen, S. Van Drongelen, S. De Groot, and L. Van der Woude, "Hand-cycling: an active form of wheeled mobility, recreation, and sports," *Physical Medicine and Rehabilitation Clinics*, vol. 21, no. 1, pp. 127-140, 2010.

[4] F. J. Hettinga, S. de Groot, F. van Dijk, F. Kerkhof, F. Woldring, and L. van der Woude, "Physical strain during handcycling under daily living conditions," *Medicine And Science In Sports And Exercise*, vol. 42, no. 5, pp. 570-571, 2010.

[5] F. J. Hettinga, M. Hoogwerf, and L. H. van der Woude, "Handcycling: training effects of a specific dose of upper body endurance training in females," *European journal of applied physiology*, vol. 116, no. 7, pp. 1387-1394, 2016.

[6] N. Vignier, J.-F. Ravaud, M. Winance, F.-X. Lepoutre, and I. Ville, "Demographics of wheelchair users in France: Results of national community-based handicaps-incapacités-dépendance surveys," *Journal of rehabilitation medicine*, vol. 40, no. 3, pp. 231-239, 2008.

[7] E. M. Smith, E. M. Giesbrecht, W. B. Mortenson, and W. C. Miller, "Prevalence of wheelchair and scooter use among community-dwelling Canadians," *Physical therapy*, vol. 96, no. 8, pp. 1135-1142, 2016.

[8] M. P. LaPlante and H. S. Kaye, "Demographics and trends in wheeled mobility equipment use and accessibility in the community," *Assistive Technology®*, vol. 22, no. 1, pp. 3-17, 2010.

[9] C. Kraaijenbrink *et al.*, "Biophysical aspects of handcycling performance in rehabilitation, daily life and recreational sports; a narrative review," *Disability and Rehabilitation*, vol. 43, no. 24, pp. 3461-3475, 2021.

[10] G. Legnani, G. Incerti, M. Lancini, and G. Azizpour, "An Identification Procedure for Evaluating the Dynamic Parameters of the Upper Limbs During Handcycling," in *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, 2018, vol. 51807: American Society of Mechanical Engineers, p. V05AT07A056.

[11] S. Litzenberger, F. Mally, and A. Sabo, "Influence of different seating and crank positions on muscular activity in elite handcycling-a case study," *Procedia Engineering*, vol. 112, pp. 355-360, 2015.

[12] E. Zipfel, J. Olson, J. Puhlman, and R. A. Cooper, "Design of a custom racing hand-cycle: review and analysis," *Disability and Rehabilitation: Assistive Technology*, vol. 4, no. 2, pp. 119-128, 2009.

[13] S. Braganca, I. Castellucci, and P. Arezes, "Wheelchair users' anthropometric data: analysis of existent available information," in *Occupational Safety and Hygiene VI*: CRC Press, 2018, pp. 23-27.

[14] G. T. Goodlin, L. Steinbeck, D. Bergfeld, and A. Haselhorst, "Adaptive Cycling: Classification, Adaptations, and Biomechanics," *Physical Medicine and Rehabilitation Clinics*, vol. 33, no. 1, pp. 31-43, 2022.

[15] S. Shore, "The long-term impact of wheelchair delivery on the lives of people with disabilities in three countries of the world," *African Journal of Disability*, vol. 6, no. 1, pp. 1-8, 2017.

[16] S. Fatahul Arifin *et al.*, "Studi analisis simulasi kekuatan beban pada alat bantu pembuatan lubang dengan sudut kemiringan 45 derajat," *Jurnal Polimesin*, vol. 18, no. 2, pp. 116-123, 2020.

[17] Z. F. Emzain, U. S. Amrullah, and A. Mufarrih, "Analisis elemen hingga untuk siklus berjalan pada model prostetik lentur pergelangan kaki," *Jurnal Polimesin*, vol. 18, no. 2, pp. 91-98, 2020.

[18] S. Pardeshi and P. Desle, "Design and Development of Effective Low Weight Racing Bicycle Frame," *International Journal of Innovative Research in Science, Engineering and Technology*, pp. 18215-18221, 2014.

[19] B. Stone, B. S. Mason, M. B. Warner, and V. L. Goosey- Tolfrey, "Shoulder and thorax kinematics contribute to increased power output of competitive handcyclists," *Scandinavian journal of medicine & science in sports*, vol. 29, no. 6, pp. 843-853, 2019.

[20] A. Jeang, F. Liang, and H. F. Huang, "Handcycle design & development process for the disabled," in *Proceedings of the 14th IFToMM World Congress*, 2015, pp. 96-104.

[21] G. G. Grindle, A. J. Deluigi, J. Z. Laferrier, and R. A. Cooper, "Evaluation of highly adjustable throwing chair for people with disabilities," *Assistive Technology*, vol. 24, no. 4, pp. 240-245, 2012.

[22] F. Isharyadi and N. Desinta Rahayu, "Kesesuaian SNI 12-0179-1987 Bagi Penderita Disabilitas di Indonesia," *Jurnal Standardisasi*, vol. 15, no. 3, pp. 230-239, 2013.

[23] A. Wisnujati and R. A. Himarosa, "Analysis the Strength of Mild Steel Material on a Handcycle Bike Frame," *Logic: Jurnal Rancang Bangun dan Teknologi*, vol. 21, no. 2, pp. 80-86, 2021.

[24] A. Wisnujati, M. Yusuf, and A. Hudiatma, "Karakterisasi Pengecoran Poros Berulir (Screw) Dengan Variabel Paduan Unsur Titanium Boron Dan Magnesium," *Jurnal Rekayasa Mesin*, vol. 13, no. 1, pp. 29-36, 2022.