J. Disability Stud. 2020, 6(2), 79-82

Review Article

JOURNAL OF DISABILITY STUDIES

Design and Analysis of Polymer Composite based Lightweight Caliper for Locomotor Disabilities

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Received on: May 29, 2020 Accepted on: December 21, 2020

ABSTRACT

Increasing population has led to numerous disabilities and one such disability which should be taken into account is related to human gait. Locomotor patients mainly suffer from this kind of disability due to which their muscles get weakened and they are unable to walk properly. The locomotor disabilities patients require an assistive device with the help of which they can walk without any difficulties and the appliance acts as an aid for the correct positioning of their joints. Recently, developments of high strength aluminum alloy based calipers are used, but still patients urge for better comfort and design. The requirement apart from more strength and stiffness, durability at cost effectiveness, eco friendly along with light weight. Composite materials are one such material which provides less weight to volume ratio, high strength and stiffness with cost effectiveness. The present study is to compare the mechanical properties of presently used aluminum calipers with jute/unsaturated polyester composite based on CAD. The study reveals that unsaturated polyester based matrix materials will provide the generous strength and firmness when compared to presently used aluminum based calipers and model designed on CAD tools. Hence, the usage of the composite material will understand the researchers to design modified orthotic calipers which will have higher strength at a lower weight and low cost.

Keywords: Locomotor disabilities, Assistive technology, CAD model, Simulation.

INTRODUCTION

The mobility of many locomotor disable patients is limited and most identify walking as a high priority for rehabilitation and assistive technology. The majority of muscular dystrophy (Allartab,2012), polio (Chih-Hsuan, 2016), cerebral palsy (Polack, 2018) and paraplegia (Karimi, 2016) based locomotor disable patients exhibit motor dysfunction that affects their ability to movement. Their gait patterns are often very different from normal humans (Radzak, 2017). The differences include abnormal joint motion, altered muscle timing and disturbed temporal-distance characteristics (Shiu-LingChiu, 2015). While changes in step length (Delcour, 2018), duration of stance (Park, 2018), midstance (Harandi, 2020) and swing phases. Due to locomotor disabilities patient's muscles become weak and they find difficulties in normal walking from one place to another, sitting and standing.

Caliper based orthosis are clinical devices designed to minimize gait deviations and to improve walking ability in the absence of adequate natural substitutive patterns (Ji-hyun Lee, 2015). It was observed by some of the researchers that rural locomotor patients are using self designed premitive braces or calipers made up of wooden pieces which supported their weakened muscles when brought together (Skaaret, 2019). Later for strength and durability reasens the wood was replaced with common ferrous materials. The ferrous material was found to be heaviest so it did not help the patients with their comfort level so they moved on to the non-ferrous materials such as aluminum (Santos, 2015). The calipers aid in treatment of locomotor disabilities, provide support to the weakened muscles and help the locomotor disable patients from risks and fractures. The calipers holds the legs tight with the help of the leather straps and provides all the benefits due to which locomotor disable patients doesn't feel as if they are having weakened muscles and require anybody's support.

The calipers presently are made up of aluminum alloy which has strength greater when compared to stainless steels. The aluminum was chosen as a material because of its inherent mechanical properties such as they are easily fabricated, cost effectiveness when compared to most of the metals especially ferrous materials (Hernández, 2018). Aluminum is also corrosion resistant and has very small shrinkage property (Convery, 2004). The rehabilitation professionals thought of aluminum as a material for calipers for locomotor disable patients few decades ago but still there are some issues which are still to be taken into consideration like the cost, lower weight-to-volume ratio, strength and stiffness. As calipers

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Cite as: Lerma, P., & Chen, R. K. (2020). Adults with Learning Disabilities in Postsecondary Education and the Workforce. *Journal of Disability Studies. 6*(2), 79-82.

 ISSN: 2454-6623 http://pubs.iscience.in/jds

become aged it increases fatigue in case of locomotor disable patients so they require a much lighter weight with low cost. The general locomotor disable patients still cannot afford calipers due to its high cost and the other reason is aluminum is not able to provide the required stiffness and firmness due to which there may be a problem of risk while walking, sitting and moving disable patients (Doğan, 2019). As patients are getting aged from childhood, the weight is a factor which has become a problem. Therefore, it is necessary to design more high strength and light weight assistive device which is durable enough. The present developments of engineering polymer composites provide the modern calipers with high strength and optimum stiffness (Hautamäki, 2013).

The engineering polymer composite materials are made by combination of two or more materials having totally different physical and chemical properties (Wan, 2007). They are used in several bioengineering, assistive technology, prosthetics and orthotics industries these days to manufacture high performance assistive devices at an economic advantage (Ramakrishna, 2001). There are various facts of advantages including material, economy, aesthetic etc. in usage of polymer composites for better performance with low cost products.

Increasing environmental awareness has been the driving force behind the renewed interest in the natural fibers. Natural cellulose-based jute fibers are gaining increasing attention for their diversified applications in engineering and their uses (Iannace, 2001). Thermoset based composites has inherent properties such as good strength, flexibility, stiffness, lower-weight to volume ratio and low cost (Scholz, 2011). In addition, very few researches have been performed to design an assistive device based on jute based green polymer composite so far (Singh, 2018). This research therefore proposes a material, which will provide flexibility, robustness and lightness to the locomotor disable patients and by validating the modeling results of the presently used calipers and jute reinforced unsaturated polyester composites.

MODELING AND SIMULATION

SolidWorks® Parametric was used to bring forth the 3D software model of presently used aluminum calipers. The 3D model was drawn with the help of the dimensions being used for designing present calipers as more emphasis is taken on the materials change as material change can only result in providing strength and stiffness to the joints which have become weak.

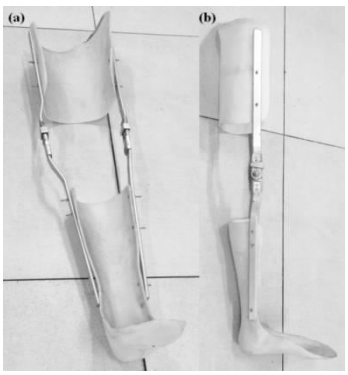

Figure 1. aluminium and polypropylene based calipers (a) front view and (b) left side view.

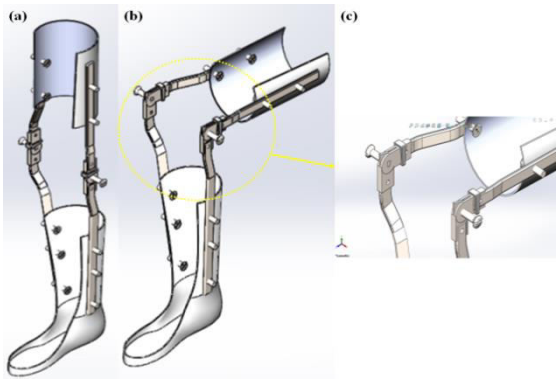

Figure 2. Isometric view of 3D Model of Orthotic Calipers

SolidWorks® was used for the simulation and analysis of the mechanical properties such as total deformation, von-Mises stress and von-Mises Strain with taking into account the axial loading and the transverse loading. Evaluation of the mechanical properties was done only to choose a material which will have more strength and stiffness than the presently used calipers. Another simulation was done using the jute/unsaturated polyester composite to show that thermoset based composites provides generous strength and firmness when compared to the aluminum calipers. The material properties considered to carry out analysis are

Table 1. Mechanical properties of jute fibre cloth.

Property	Value	Units
Young's Modulus	20000	N/mm^2
Poisson's Ratio	0.394	N/A
Mass Density	1400	kg/m^3
Tensile Strength	350	N/mm^2
Yield Strength	100	N/mm^2

In the SolidWorks® 2018 version, it is possible to propose and analyze composite models. In SolidWorks®, it is not needed to define element type explicitly. When a model is meshed, the software generates a mixture of solid, shell, spring and contact elements based on the created geometry and the study settings. For static load and frequency analysis, it allows four types of mesh: solid mesh, shell mesh using mid-surfaces, shell mesh using surfaces and mixed mesh. For the jute/unsaturated polyester composite model, solid mesh was chosen. In the solid mesh, all components in the solids folder that are not suppressed to have shells created on their faces are meshed with tetrahedral 3D solid elements. Tetrahedral elements are suitable for bulky objects. When loads are applied to a body, the body deforms and the effect of loads is transmitted throughout the body. The external loads induce internal forces and reactions to render the body into a state of equilibrium. Linear static analysis calculates displacements, strains, stresses and reaction forces under the effect of applied loads.

RESULTS AND DISCUSSION

Taking into consideration the experimental values boundary conditions (young's modulus, poisons ratio, density. etc.) were provided for the simulation with the help of SolidWorks® Simulation. Figure 3(a-b) shows maximum Equivalent von-

Mises stress and strain to be $7.059e^{+6}$ N/m^2 and $2.808e^{-4}$ mm/mm respectively. Figure 3(c) shows maximum deflection to be $2.357e^{-4}$ mm in case of axial loading. The maximum deflection for the case of transverse loading was found to be $1.550e^{-5}$ mm in Figure 4(c) and equivalent von-Mises stress and strain are $5.744e^{-5}$ N/m^2 and $2.204e^{-5}$ mm/mm respectively as shown in Figure 4(a-b). The observed values are much higher when compared with the results of presently used in aluminum calipers.

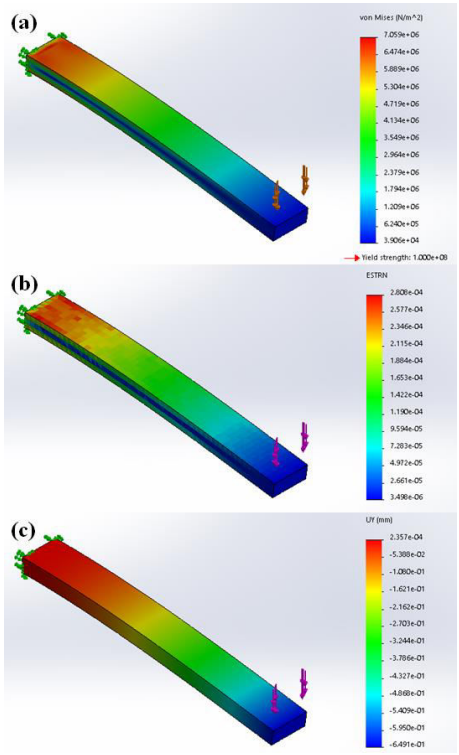

Figure 3. Axial loading conditions for Jute fibre with Polyester (a)Equivalent von-Mises stress; (b) Equivalent von-Mises Strain; (c) Total deformation.

A 3D model of a jute/unsaturated polyester composite is used for FEA to predict the performance of the material. As a result of the static linear analysis, it is concluded that the composite materials can substitute conventional materials. These analyses provide useful insight into caliper performance. Utilization of engineered polymer composite materials will provide many advantages to assistive devices manufacturing industries and also to end users. The major drawback of this analysis is that static loading may not be appropriate for testing assistive devices like caliper owing to the fact that most service failures occur due to repetitive use. On the other hand, the fatigue load model cannot be used for the testing as assistive devices like caliper rarely suffers repetitive loads of consistent intensity. Hence, the use of a more comprehensive load method, i.e. transient dynamic analysis, is necessary to get more accurate results to predict product performance in actual field use. Also, FEA does not eliminate product testing but minimizes the number of tests. Therefore, it is essential to test the assistive devices like caliper base prototypes made up of jute/unsaturated polyester composite materials according to the standard testing.

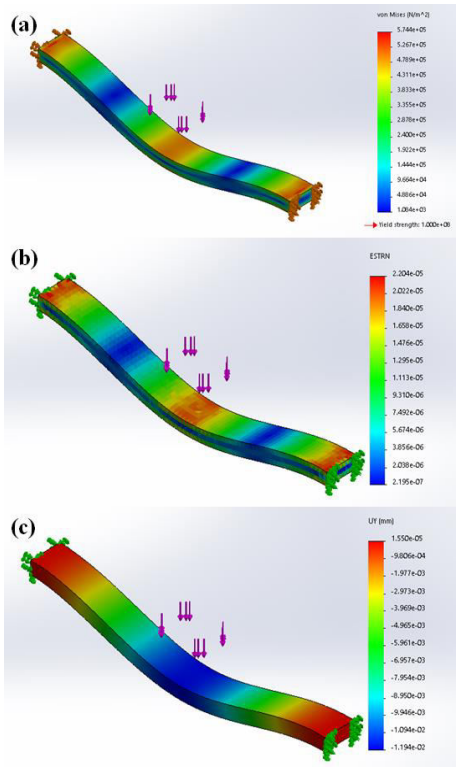

Figure 4 Transverse loading conditions for Jute fibre with Polyester Equivalent von-Mises stress; (b) Equivalent von-Mises Strain; (c) Total deformation.

The above results indicate that the axial and transverse strength of the proposed thermo-set composite is much higher than the currently used aluminium alloy but an experimental validation would be required.

CONCLUSION

After carrying out the above simulation it was observed that the proposed a jute/unsaturated polyester composite provides generous strength and stiffness and lower weight to volume ration when compared with the results of presently used aluminum based calipers (standard values used). Hence with the use of braces manufactured using a jute/unsaturated polyester composite locomotor disable patients can surely get enhanced ease in mobility due to considerable reduction in the weight of the calipers. Since these supports undergo wear and tear and are always subjected to adverse climatic conditions hence tribological testing and dynamic mechanical testing should also be performed. A complete calliper is required to be fabricated and to be clinically tested under actual usage before replacing the aluminium alloy made calipers with jute/unsaturated polyester composite.

ACKNOWLEDGMENTS

The authors are grateful to The Director, National Institute of Locomotor Disability (Divyangjan), Kolkata under the Department of Empowerment of Persons with Disabilities, Ministry of Social Justice and Empowerment, Government of India.

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Source of Funding: None

Conflict of interest: None