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ORTHOPEDIC CALF CAST USING ANTIOXIDATIVE FS3200PA NYLON 3D PRINTING: DESIGN AND OPTIMIZATION

Mohamed Saiful Firdaus Hussin[1], Mohammad Rafi Omar[1], Khairul Azri Azlan[1], Arman Hadi Azahar[2], Zulkefli Ismail[3] and Fatin Farhana Rosli[4]
[1]Faculty of Mechanical and Manufacturing Engineering Technology, Malaysia
[2]Faculty of Electrical and Electronic Engineering Technology, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
[3]Amsteel Mills Sdn. Bhd., Lot, Jalan Waja, Bukit Raja Industrial Estate, Klang, Selangor, Malaysia
[4]School of Ocean Engineering, Universiti Malaysia Terengganu, Kuala Terengganu, Terengganu, Malaysia
E-Mail: mohamed.saiful@utem.edu.my

ABSTRACT

Current cast designs such as heavy plaster cast come up with many disadvantages to patient like discomfort and itchy skin. Most of the hospitals in Malaysia are still using traditional custom made cast which is made by paris and mold that cannot be recycled. The objectives of this project were to design custom fit orthopedic cast and to optimize the weight of cast that used material of FS3200PA Nylon powder that has generally good anti-oxidative properties and not harmful to health. Computer Aided Design (CAD) software and Finite Element Analysis (FEA) computer software were used to design and optimize the shape and geometry of calf cast. T-Scan LV system is used for scanning process. The load applied for simulation are 981 N, 784.8 N, and 588.6 and the thickness varies between 1 mm, 2 mm and 3 mm. Safety factor of $1.0 \leq s.f \leq 3.0$ is considered in selecting the acceptable combination. Fabrication of the cast had been made by used the Farsoon SS 402P laser sintering system. Through optimization and analysis, three combinations of the models are proven to be a safe-to-use model.

Keywords: Orthopedic calf Cast, 3D scanning, 3D printing, finite element analysis.

INTRODUCTION

The current orthopedic plaster cast in Malaysia is traditionally done by manual methods. This cast is widely used in medical field for its function and effectiveness to heal the fractured joint. Fractures mostly happen because of sports injuries, car accidents, and falls [1]. However, conventional casts have many disadvantages and shortcomings. Plaster casts are heavy and restricting the movement, especially for a child. There is a very small amount of air circulation in the cast as shown by Figure-1. Besides, it was not a good moisture absorber and can trap the perspiration. This material also creates a medium for the growth of bacteria and unpleasant odour [2]. Plaster of Paris casts can result in complications including infections, rashes, itching, burns, and allergic contact dermatitis, which may also be due to the presence of formaldehyde within the plaster bandages. The plaster cast should also regularly be broken up, for swelling or off-swelling of the fractured joint part [3]. According to the problems, design improvements and an optimization should be made to the plaster cast [4]. The 3D scanning and 3D printing are used widely in a variety of fields such as engineering, medicine, biology and other fields. The 3D laser scanners using optical triangulation technique, which are leading the current market because of their better accuracy, higher scanning rate and better precision [5]. 3D printing process provides a great variety of materials that could be used, for instances, plastics, metals, combination of metals, and polymers, and combinations of metals and ceramics [6-8]. 3D CAD modeling software is typical in a reverse engineering environment. However, user needs specific skills that are not that diffuse among clinicians and orthopedic technicians [9]. A finite element analysis (FEA) computer software Altair Inspire is applied in redesigning a component to reduce its mass. It was used optimization process in that software to get best shape design by reducing mass as shown in Figure-2. In Altair Inspire software also can assess the safety of design by factor of safety analysis. It needed value of material strength and maximum stress applied on the design when force applied, to measure the safety factor.

Figure-1. Plaster Cast.

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Figure-2. Optimized Shape Design.

METHODOLOGY

The methodology that had been used in this research is shown in Figure-3. The chosen material for fabricating the lightweight orthopedic calf cast is material FS3200PA nylon powder with bulk density 0.4 g/cm3 [10]. Sintergy FS3200PA delivers these benefits such as a durable part for functional testing or low volume production as a very low cost, to a wide range of industries including aerospace, automotive, medical consumer products and electronics. Since selective laser sintering uses no support structures to build parts, the designers have nearly infinite possibilities to create unique designs. it has a low melting temperature, making it especially easy to use in injection molding manufacturing processes or 3D printing and very simple to machine and it is a good antioxidant. Survey has been conducted for patients that experienced fracture joint before [11]. The material, clearance consideration and current prototype had been studied. Then, the process of reverse engineering stage had been done which are 3D scanning, editing cloud data and redesigning using CATIA software. T-Scan LV, the hand-held laser scanner, is lightweight and balanced, making capturing data possible, even in difficult or hard-to-reach areas [12]. The T-Scan is capable to capture data at the rate of 210,000 points per second. T-Track LV provides free, full-surface measurement of complex objects in a wide range of sizes. The measurement volume of the system is 35 m^3. For editing process, three workbenches that will be used to produce surface from cloud data which are Digitize shape editor (DSE), Quick surface regeneration (QSR) and Generative shape design (GSD). At first, the point cloud data need to import in Digitize shape editor (DSE) workbench to modify the shapes from 3D Scanner. Then, the quality of cloud was refined and convert to mesh. Next, choose the Quick surface regeneration (QSR) for converting mesh into curves and then use commands for creating surfaces. Lastly, use Generative shape design (GSD) to create wire frames. The design models were optimized to get desired mass. Altair Inspire software was chosen to collect important datas for this 3D model. It provides load prediction, stress analysis, and fatigue prediction using stress-life or strain-life methods. Later changes in the design cycle to respond to test results are expensive and create production delays and system risks. Fourth, the optimized models were going through analysis to assess their safety to user. Three parameters were involved in the analysis: displacement, von Mises stress and factor of safety.

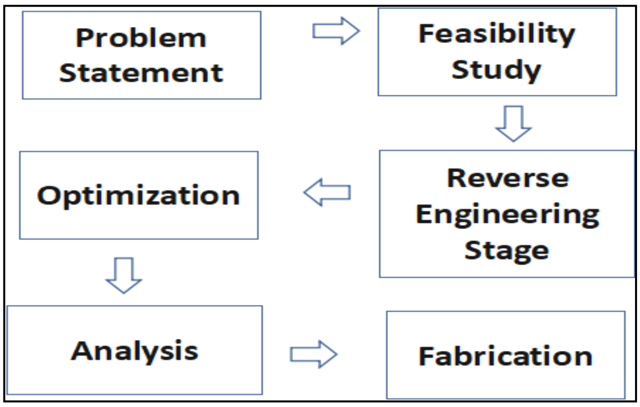

Figure-3. Research Flowchart.

RESULTS AND DISCUSSIONS

A hundred respondents have been given survey questionnaire in order to collect important data that will be used later to classify customers needs. Among the complaints voiced by respondents when wearing the plaster cement are discomfort (27%), heavy (42%) and itchy (31%). Respondents were also asked about the preferred features that a calf cast should have. Most of the respondents voted for lightweight (31%), followed by waterproof (25%), good air ventilation (24%), and color variety (20%). Using the new cast, rspondents were asked on their satisfactory level, where 98% of them agreed that the new cast design will be better than the tradisional plaster design. Respondents were also asked about the acceptable range price for them to buy the calf cast. 78% agreed that the pruce must below MYR 800 while the other are willing to pay more than MYR 900 in order to own a calf cast. Using Hyperworks V14 software, topology optimization process was carried out to reduce weight while maintaining the stiffness of calf cast. The given force onto the calf cast is 981 N, 784.8 N, and 588.6 N. These forces were applied to cast with thickness of 1 mm, 2 mm, and 3 mm for both original and optimized mass.

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Table-1. Toplogy Optimization of Calf Cast.

Parameter	Actual mass of cast (kg) based on thickness			Optimized mass of cast (kg) based on thickness		
Force applied (N)	1mm	2mm	3mm	1mm	2mm	3mm
981.0	0.35643	0.71286	1.0693	0.19052	0.42799	0.67975
784.8	0.35643	0.71286	1.0693	0.19695	0.41730	0.67796
588.6	0.35643	0.71286	1.0693	0.19575	0.43139	0.67265

Table-2. Optimization by Analytical Solution.

Parameter	Actual mass of cast (kg) based on thickness			Optimized mass of cast (kg) based on thickness		
Force applied	1mm	2mm	3mm	1mm	2mm	3mm
981.0 N	0.35643	0.71286	1.0693	0.19603	0.39207	0.58811
784.8 N	0.35643	0.71286	1.0693	0.19603	0.39207	0.58811
588.6 N	0.35643	0.71286	1.0693	0.19603	0.39207	0.58811

Table-3. Calf Cast Displacement.

Parameter	Maximum displacement, m			Minimum displacement, m		
Force applied (N)	Thickness 1mm	Thickness 2mm	Thickness 3mm	Thickness 1mm	Thickness 2mm	Thickness 3mm
981.0	3.868×10^{-3}m	1.448×10^{-3} m	6.934×10^{-4}m	1.492×10^{-4}m	5.532×10^{-5} m	2.761×10^{-5}m
784.8	2.448×10^{-3}m	1.158×10^{-3} m	5.029×10^{-4}m	1.006×10^{-4}m	4.425×10^{-5} m	1.667×10^{-5}m
588.6	6.287×10^{-4}m	8.685×10^{-4} m	3.2×10^{-4}m	2.085×10^{-5}m	3.319×10^{-5} m	1.048×10^{-5}m

Table-4. Factor of Safety.

Parameter		Allowable stress of product (Pa), σ			Factor of Safety		
Force applied (N)	Material strength (Pa), σ	1mm	2mm	3mm	1mm	2mm	3mm
981.0	48.1×10^6	5.859×10^7	2.063×10^7	1.065×10^7	0.82	2.33	4.52
784.8	48.1×10^6	4.496×10^7	1.650×10^7	8.816×10^6	1.07	2.92	5.46
588.6	48.1×10^6	1.102×10^7	1.237×10^7	4.997×10^6	4.36	3.89	9.63

In comparison with the value ontained from hyperworks software, the value from analysitcal solution only shows small differences.For example, as the thickness is 1 mm, the differences is less than 3%. Besides, displacement analysis was also done to observe the strength of the calf cast from the force applied. Forces of 981 N, 788.8 N, and 588 N were applied on the calf cast vertically downward as shown by Figure-4. Thicker model with smaller force will results in minimum displacement. However all the displacement is still considerably acceptable as shown by Table 3. Other than that, factor of safety of the design was also considered. It was calculated by using material strength divided by allowable stress of the product. By using 2 mm thickness, the results shows that minimum factor of safety is equal to 2.33. This value is considered as safe. The best design is when the safety factor is in range 1.0 ≤ s.f ≤ 3.0 [13].

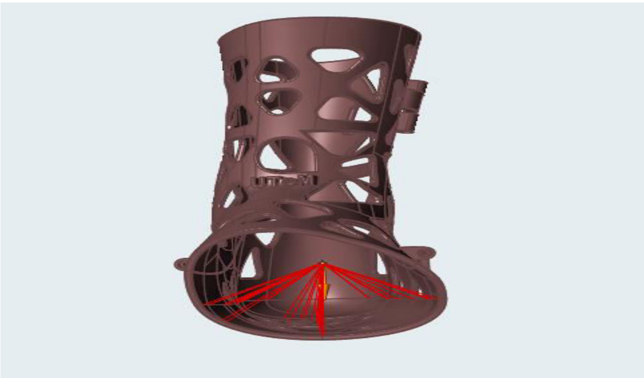

Figure-4. Calf Cast with Applied Force.

CONCLUSIONS

The first purpose of this project is to design custom fit orthopedic cast by using CATIA and Altair Inspire Softwaree. In this project, CATIA software were used when editing cloud data from 3D Scanner and used for redesigning the shape of desired cast. CATIA really works in editing cloud data. It helps to modify the shapes from 3D Scanner. Then, the quality of cloud was refined and converted to mesh. It also converting mesh into curves and then use commands for creating surfaces. Lastly, it was created the wire frame of the design shape. After that, it helps in generating the 3D models from the last method of editing cloud. Altair Inspire softwaree was useful in doing optimization and analysis of the design which had been edited in CATIA. This software helped in creating the lightest structure capable of withstanding the applied forces to model. This approach was ideal for maximizing the stiffness of components while trying to achieve a desired mass. The design was optimized topologically in reducing the weight of cast using FS3200PA Nylon powder. This material has a low melting temperature, making it especially easy to use in injection molding manufacturing processes or 3D printing and very simple to machine. FS3200PA Nylon is generally safe as it good antioxidative properties, and there are no known adverse health effects. This material can create accurate and repeatable parts as demanded by manufacturers. This material is good also in recyclability. It is low water absorption and color stable. Nylon uses to produce prototype pieces and end-use parts without tooling. The fabrication of the cast was done by using the 3D Printer machine, Farsoon SS 402P laser sintering system. Farsoon is the main additive manufacturing company in the world capable of creating laser sintering machines and materials at one facility. This combination brings an integrated solution for best in class performance. SS 402P laser sintering system has claimed as quickest scan and boost rates in the industry field. The cast was printed successfully by using Farsoon SS 402P laser sintering system. The cast was ready to fit by patient in mass of 100kg who was experienced fractured joint in calf part. The cast achieved 43% mass reduction from the actual mass.

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REFERENCES

[1] Ploeger M. M., Burger C., and Wimmer M. D. 2016. Acute Fracture (Lower Leg, Ankle, Hindfoot, Midfoot, Forefoot), Foot and Ankle Sports Orthopaedic, Springer.

[2] Lorraine J. R., 1985. Orthopedic Devices, Materials and Methods, Newport News.

[3] Inglis M., McClelland B., Sutherland L. M., and Cundy P. J. 2013. Synthetic Versus Plaster of Paris casts in the Treatment of Fractures of the Forearm in Children. The Bone & Joint Journal, 95-B: 1285-1289.

[4] Eman N.U., Firdaus H.M.S., Halyani, M.Y., Hasan, Z., and Farhana, R.F. 2017. Optimization of Stiffened Square Plate Topographically under Uniform Distributed Pressure. MATEC Web of Conferences, vol. 97, 01071.

[5] Amir Y. M. and Thornberg B. 2017. High Precision Laser Scanning of Metallic Surface. International Journal of Optics. vol. 13.

[6] Kaufui V. W. and Aldo H. 2012. A Review of Additive Manufacturing. ISRN Mechanical Engineering, 10.

[7] Damanhuri A. A. M., Fauadi M. H. F., Hariri A., Alkahari M. R. and Omar M. R. 2019. Emission of Selected Environmental Exposure from Selective Laser Sintering (SLS) Polyamide Nylon (PA12) 3D Printing Process. Journal of Safety. Health and Ergonomics, 1(1): 1-6.

[8] Damanhuri A. A. M., Subki A. S. A., Hariri A., Tee B.T., Fauadi M.H.F., Hussin M.S.F. and Mustafa M. S. S. 2019. Comparative Study of Selected Indoor Concentration from Selective Laser Sintering Process using Virgin and Recycled Polyamide Nylon (PA12). IOP Conference Series: Earth and Environmental Science, 373(1): 012014.

[9] Gabriele B., Sami H., and Alberto S. 2016. A Critical Analysis of a Hand Orthosis Reverse Engineering and 3D Printing Process. Applied Bionics and Biomechanics. vol. 7.

[10] Sordelet D. J., and Akinc M. 1998. Sintering of Monosized, Spherical Yttria Powders. Journal of American Ceramic Society, vol. 71.

[11] Ghorbanhoseini M., Riedel M. D., Gonzalez T., Hafezi P. and Kwon J. Y. 2017. Is it “Fractured” or ”Broken”? A Patient Survey Study to Assess Injury Comprehension after Orthoepaedic Trauma. The Archives of Bone and Joint Surgery, 5(4): 235-242.

[12] Pravdina E. A., and Lepikhina O. J. 2017. Laser Scanner Data Capture Time Management. ARPN Journal of Engineering and Applied Sciences, 12(5): 1649- 1661.

[13] Al-Shadeedi M. B., and Hamdi E.J. 2017. Comparison of the Structural Stability of Gravity Concrete Dams using Usace and USBR Standards. ARPN Journal of Engineering and Applied Sciences, 12(5): 1580-1592.