International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 / https://doi.org/10.14445/22315381/IJETT-V70I9P235

Volume 70 Issue 9, 354-361, September 2022

Original Article

Finite Element Analysis of a Patient Specific Maxillofacial Implant

J. Akshay Kumar[1], Kode Jaya Prakash[2], Yeole Shivraj Narayan[3], B. Satyanarayana[4]

[1,2,3,4] *Department of Mechanical Engineering, VNR Vignana Jyothi Institute of Engineering & Technology, Hyderabad, Telangana, India*

[3]*Corresponding Author : shivrajyeole@vnrvjiet.in*

Received: 17 June 2022 Revised: 06 September 2022 Accepted: 26 September 2022 Published: 30 September 2022

Abstract - *The present study examines the mastication force that the implant can withstand for a patient-specific parameter. As a result, a finite element (FE) analysis is performed on the patient's unique oral maxillofacial implant. The force applied to the implant gradually increases to create a relationship between implant strength and mastication forces. The FE analysis's von Mises stress findings assist in identifying the maximum allowed mastication force. Furthermore, FE analysis facilitates the identification of crucial areas of the implant. There is just one critical area where stress concentration occurs in the implant used for this purpose. The findings of the FE analysis based on mastication forces are utilized to advise the patient on food intake restrictions.*

Keywords - *Computational Tomography, Finite element analysis, Mastication force, Maxillofacial implant, Patient-specific implant.*

1. Introduction

Every human being has a unique facial bone structure. Maxillofacial bones include the jaws, neck, face, and mouth. Any operation to repair the maxillofacial components is always tailored to the individual patient.[1,2] As a result, they are known as patient-specific surgeries (PSI). The uniqueness of the issue involved is reflected in the patient-specific character of these treatments.[3,4] Even expert surgeons have difficulty performing these sorts of operations. Because the implants are patient-specific, the data from a Computational Tomography (CT) scan is utilised to build the implant. If the portion to be replaced is completely injured, the surgeons will leverage the facial symmetry and collect CT scan data from the opposite side of the face. The ideal implant should have biocompatibility and optimal thickness to increase strength while weighing less. Additive Manufacturing (AM) technology is a powerful tool for manufacturing and improving these patient-specific components in this context.[5-7] Design for Additive Manufacturing principles must be addressed for component manufacturing. Ensuring perpendicularity between the printing and loading directions is vital.[29] As the fabricated implants are patient-specific in form and thickness, it is difficult to predict implant strength before placement. Numerical and simulation approaches like the finite element method help in realizing the behaviour of the implant when subjected to a certain load.[9,10] Conventionally made implants yield poor results due to multiple tweaking. 3D imaging and AM technologies have been a boon in maxillofacial reconstruction leading to the production of customized patient-specific implants.

This research aims to model and analyse a patient-specific implant through finite element analysis to determine the amount of mastication force the implant can sustain. The outcome of this research would aid dentistry practitioners during maxillofacial reconstruction and surgeries.

2. Materials and Methods

Bones and living tissues behave like ceramic materials but change their properties over time. An average adult bone is more active than the bone of an older person. Its properties can also be altered by inducing forces on it continuously, which triggers the body to pump more calcium to make it stronger. Bones use internal sources to bind and increase their strength when injured or fractured. Bones can be affected by diseases, reducing their strength and weakening. As a result, this would make the patient life highly uncomfortable. This condition is known as osteoporosis. It is a condition in which the porosity of the bone is higher than the normal one. Proper medication, following a strict regime, and reducing effortful loading can increase its life; however, nothing is better than the original, so utmost care needs to be taken for the prolonged life of the internal bone structure.[11-14] Implants, post replacement, offer similar mobility but with decreased performance as it is an advanced engineered solution to make a patient's life comfortable. The prime goal of this research focused on detecting changes in response due to the application of load on models for seeking insights. Elderly people above 65 years of age need proper care as their bones are fragile. Also, it is difficult for them to recuperate from any surgeries performed due to low immunity. Research has been carried out on a unique model and does not mimic or compare with the commercial products available. The results obtained were for comparison only.

Stresses in the per implant developed due to mastication can be computed through CT scan data, developed implant and building of anatomy of implant location through 3D imaging. It is possible to do surgical procedures with diverse types of implants to be simulated and verify (theoretically) the bone responds to the stresses acted by the surgical procedure and the osseointegration of the implant. It has allowed for evaluating a system suitable for one case and in orthodontics.[15-19]. Simulating correct dental moves is achievable depending on the forces exerted, thereby permitting the assessment of the desired position of an orthodontic element through evaluation at distinct positions. The application of finite elements and 3D printing in other streams like prosthetics is reported. A novel design of prosthetic hand support is proposed for those whose disability is primarily due to neurological disorders. The designed components are analyzed, 3D printed and assembled.[30] A myoelectric prosthetic arm has been revealed through 3D printing.[21] Step-wise process flow adopted is portrayed in Fig. 1.

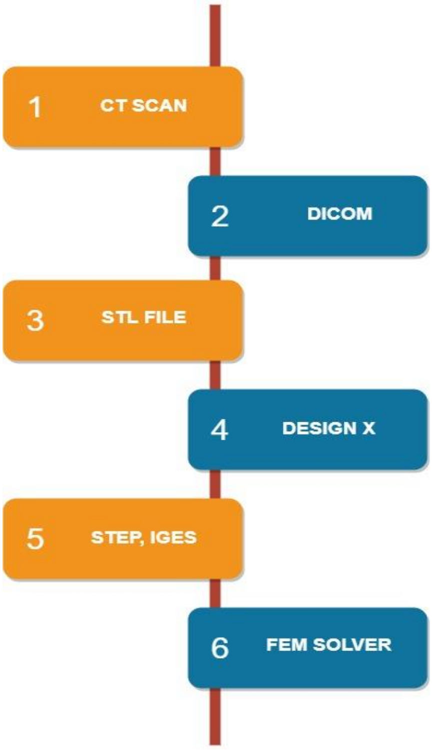


Fig. 1 Step-wise process flow

Casestudy presented here is about a patient whose left submandibular and submental areas have been injured in an accident and require repair, as depicted in Fig. 2. The following contains information about modelling and material choices.

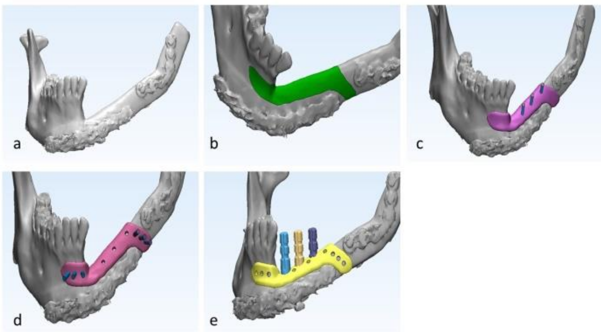


Fig. 2 Repair of the damaged mandible. (a) Damaged mandible (left side). (b) Implant location on the damaged portion. (c) Repairing stage 1. (d) Repairing stage 2. (e) Implant fixation on the damaged portion

2.1. Modelling

Because the patient's left submandibular and submental area is completely injured, the right-side section is utilised to create the implant. Figure 2 (e) depicts the intended implant. The CT scan data of the right-side area is collected and mirrored to construct the implant. The implant is modelled using the commercial blackbox programme "Materialize." In medical imaging, a CT scan is prominently used. The data is saved in DICOM (.dcm) format.[23-27] DICOM data are initially stacked using appropriate tools. It is followed by segmentation for generating .stl file. This format is the default format needed in CAD softwares which will be beneficial in additive manufacturing and finite element analysis.

2.2. Material Data

The implant material is Ti-64, and its parameters are shown in Table 1. Because the component is evaluated for load-bearing capability within elastic limitations, the materials' characteristics – Youngs' Modulus and Poissons' ratio, are carefully considered. Based on this information, other parameters like shear and bulk modulus are computed.

Table 1. Material Characteristics

Property	**Value**
Density	8000 kg/m^3
Youngs' modulus	200 GPa
Poissons' Ratio	0.29

2.3. FE Analysis

In ANSYS 19.2, the automatic mesh generation algorithm is used for meshing. The element type utilised for meshing is tetrahedral. A fine mesh is utilised to prevent convergence concerns, as seen in Fig. 3. The final mesh has 792035 nodes and 462686 elements. As seen in Fig. 4, the down section of the implant attached to the jaw is fixed, and distributed loading is provided to the middle region of the implant, which experiences the most mastication force. To investigate the implant's durability, several loading circumstances with escalating magnitudes of force are evaluated. Because there is no dynamic strain on the implant, static structural analysis is performed.

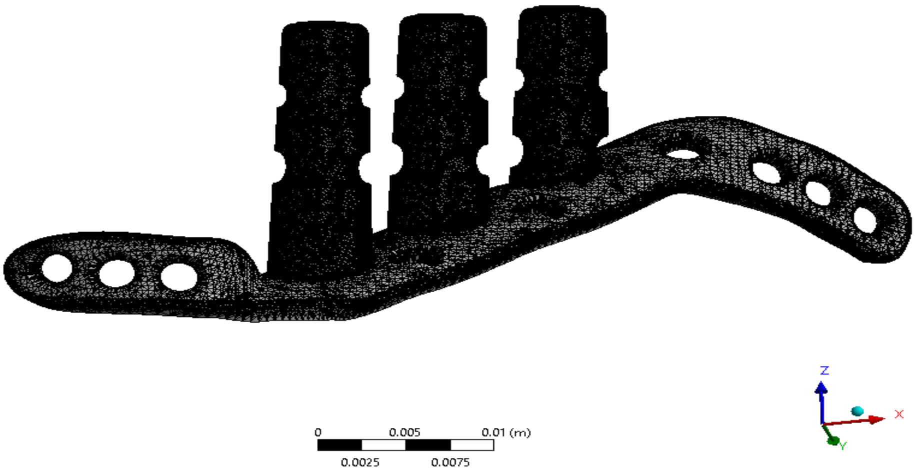


Fig. 3 Meshing of the CAD model

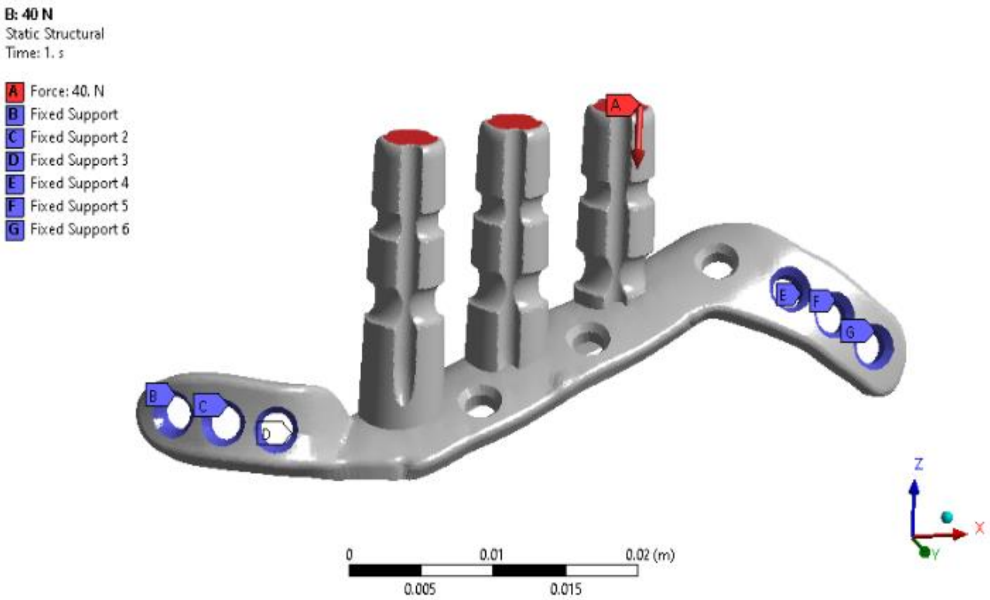


Fig. 4 Description of loading and boundary conditions

3. Analysis of Results

Deformation and equivalent stresses for loads applied from 40 N to 160 N are exhibited in Fig. 5. It is observed that maximum stress for all the applied loads is located in the same area.

Fig. 6 depicts a graph plot between the applied load and the stress generated. Linear correlation is obtained between the stresses and applied loads. However, a slight drop in the slope is noticed beyond the load of 120 N. Ti-64 has the highest permissible stress at 620 MPa. As a result, the maximum load that the component may withstand is 160 N by considering a factor of safety of 1.7.

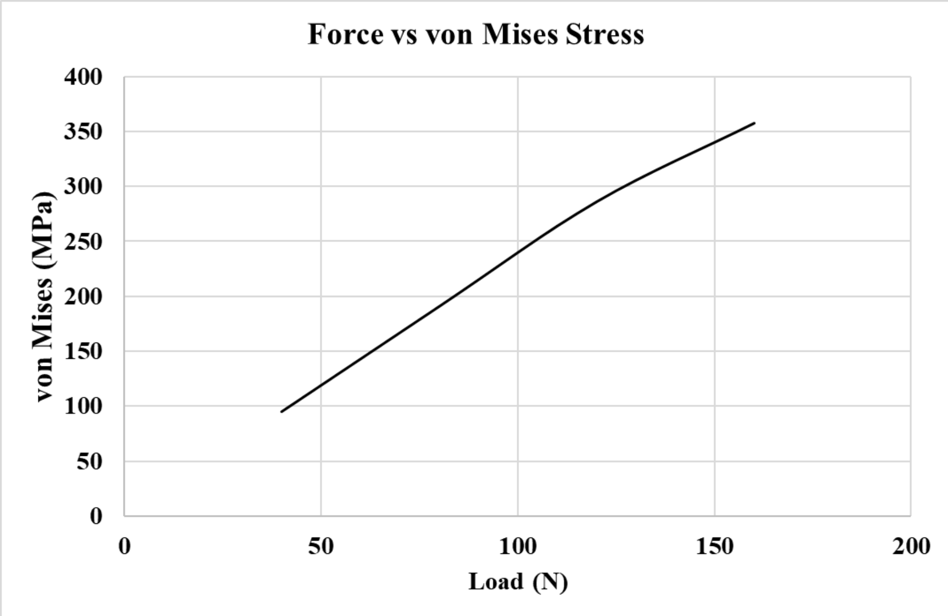


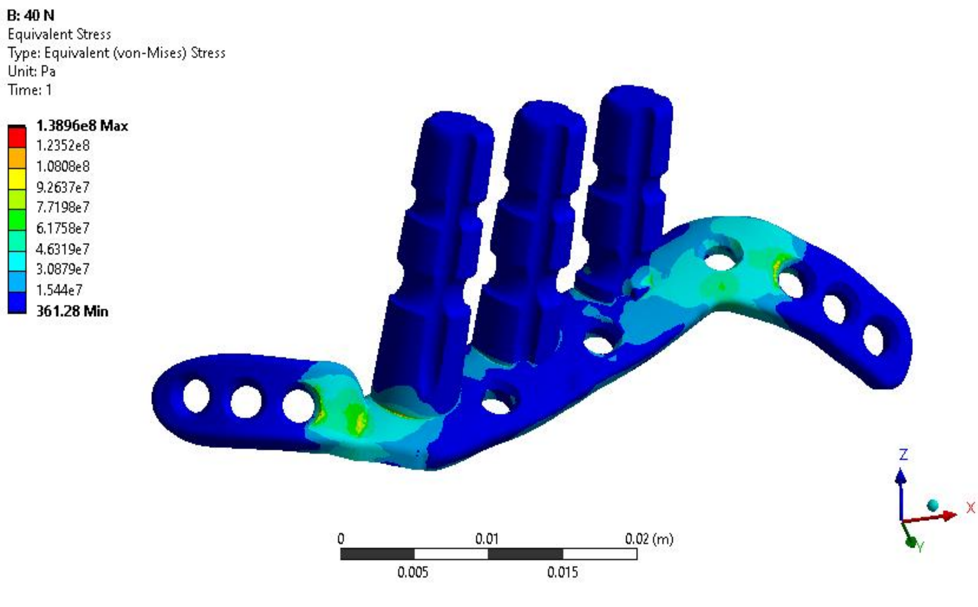
Fig. 6 Force vs von Mises stress

4. Conclusion

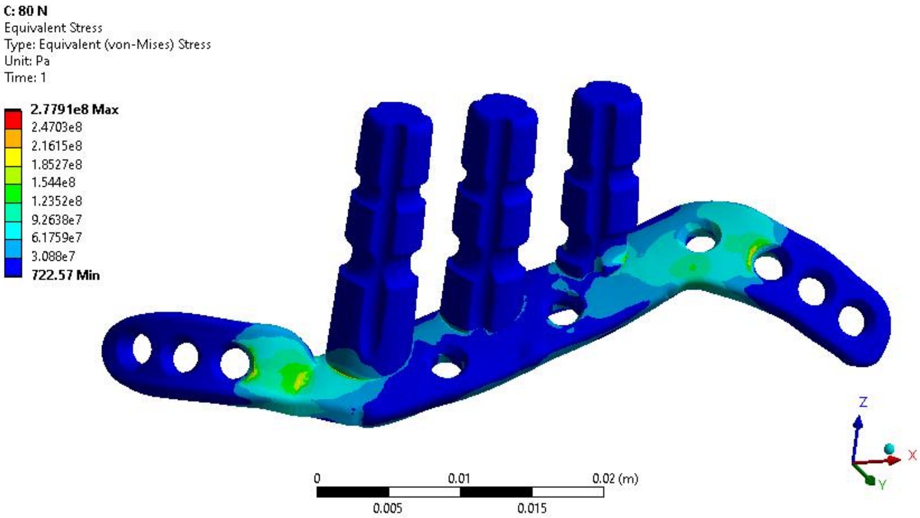
Research presented a case study on the applicability of a patient-specific maxillofacial implant in a patient whose submandibular and submental area has been injured. A patient-specific implant was developed to repair it, and finite element analysis for various loading parameters was performed better to understand the restrictions and constraints on implant loading. It can be concluded that FE analysis is a decision qualification for determining strength in patient-specific implants before they are fabricated. FE results indicate that the developed implant can sustain loads up to 160 N. Dentists can use these data to suggest their food intake limits to patients.

Acknowledgements

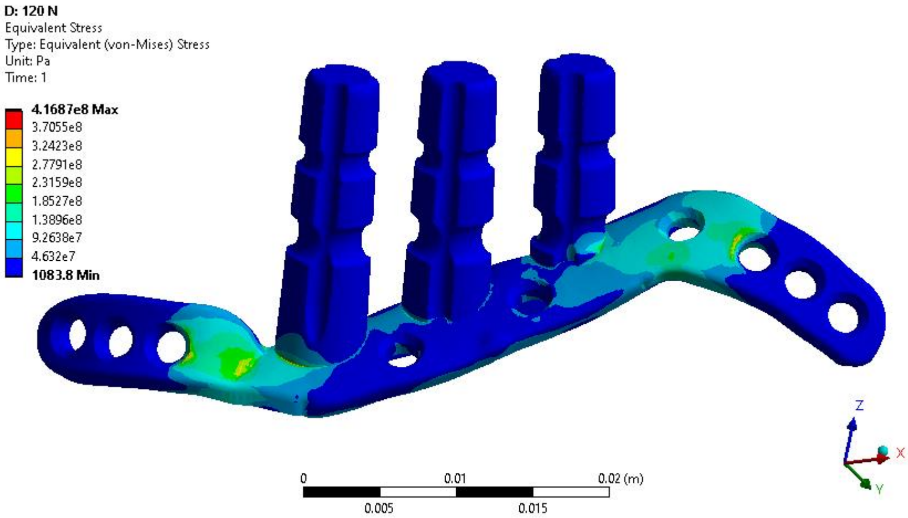
The authors sincerely thank Dr. Arvind UD, Oral and Maxillofacial Surgeon & Dr. Arvind's Dental and Maxillofacial Clinic team members, Hyderabad, for generously helping us while modelling the implant, sharing complete details pertaining to the patient's mandible and also for giving valuable inputs throughout the work. The authors express special thanks to Er. K. Rakesh, Senior Faculty & Head (I/c), Design and Prototyping Centre & Mechanical Division, Engineering Staff College of India, Hyderabad, for giving valuable inputs while performing FE analysis.



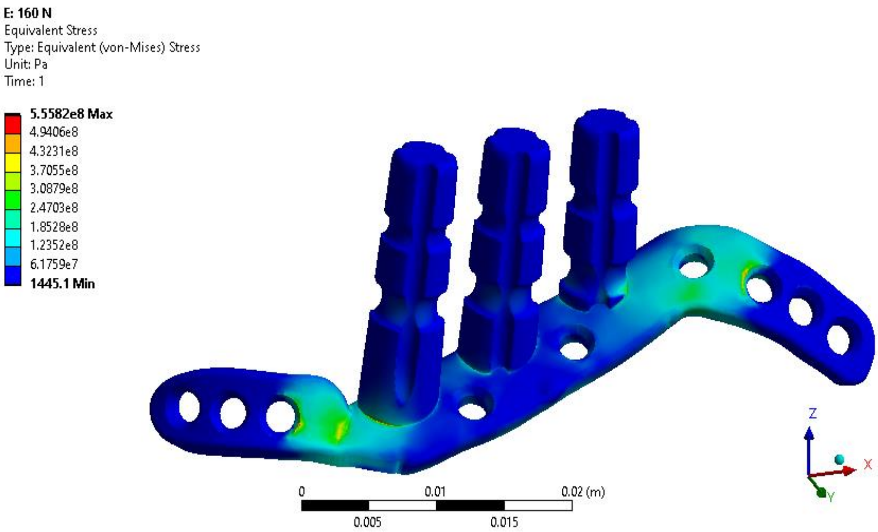
Equivalent Stress for 40 N



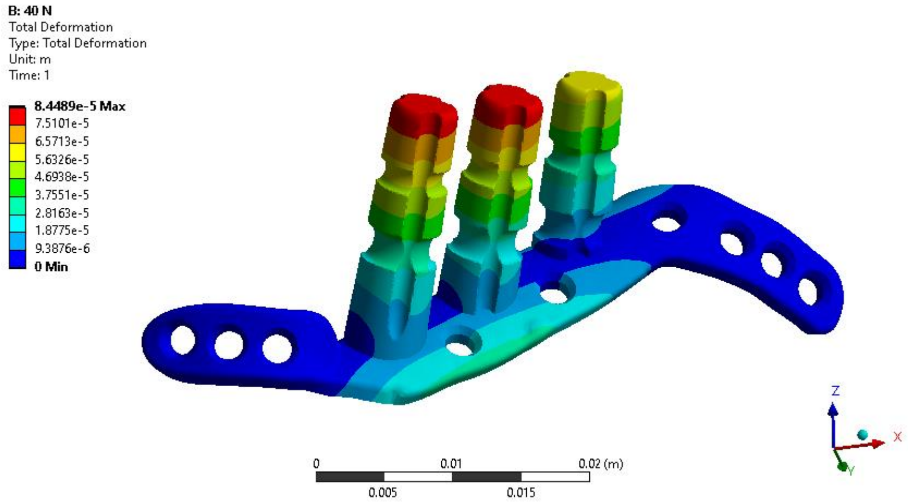
Equivalent Stress for 80 N



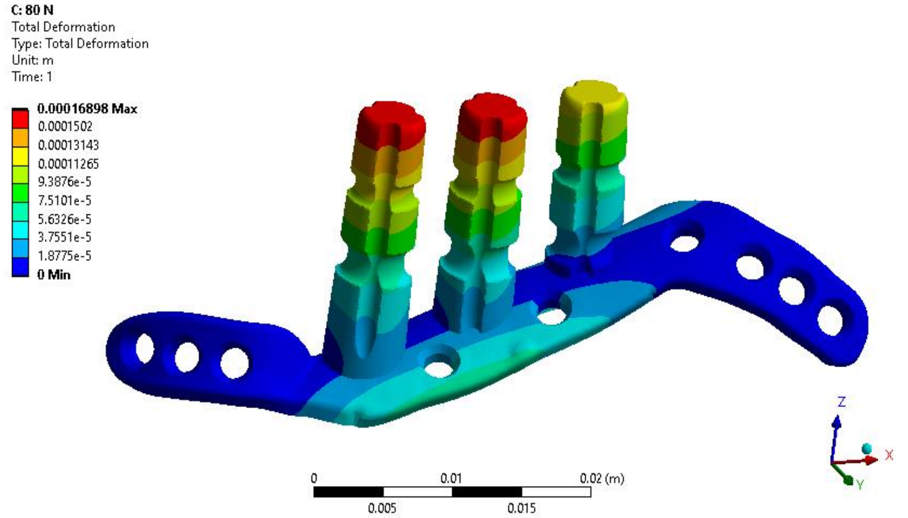
Equivalent Stress for 120 N



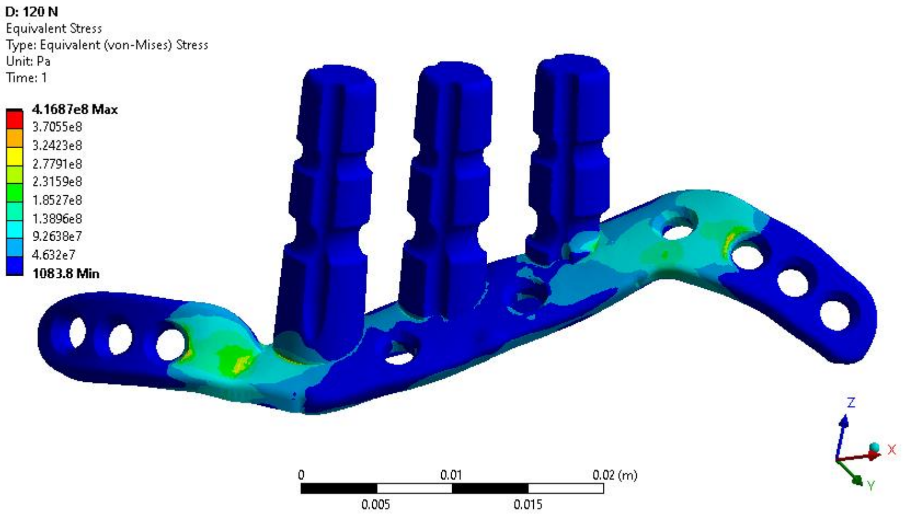
Equivalent Stress for 160 N



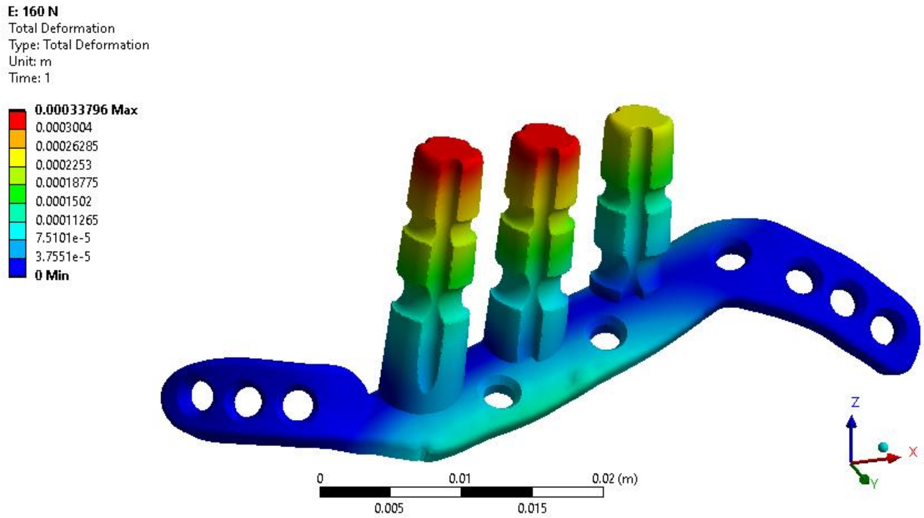
Total Deformation for 40 N



Total Deformation for 80 N



Total Deformation for 120 N



Total Deformation for 160 N

Fig. 5 Maximum stress and total deformation

References

[1] M. Colombo, C. Mangano, E. Mijiritsky, M. Krebs, U. Hauschild, T. Fortin, "Clinical Applications and Effectiveness of Guided Implant Surgery: A Critical Review Based on Randomized Controlled Trials," *BMC Oral Health*, vol. 17, pp. 1-9, 2017. Https://Doi.Org/10.1186/S12903-017-0441-Y.

[2] G. Huang, L. Wu, J. Hu, X. Zhou, F. He, L. Wan, and S. Pan, "Main Applications and Recent Research Progresses of Additive Manufacturing in Dentistry," *BioMed Research International.*, vol. 2022, pp. 1-26, 2022. Https://Doi.Org/10.1155/2022/5530188

[3] P. Honigmann, N. Sharma, B. Okolo, U. Popp, B. Msallem, and F. M. Thieringer, "Patient-Specific Surgical Implants Made of 3d Printed Peek: Material, Technology, and Scope of Surgical Application," *BioMed Research International*, vol. 2018, pp. 1-8, 2018. Doi: 10.1155/2018/4520636.

[4] Parthasarathy, Jayanthi, "3d Modeling, Custom Implants and Its Future Perspectives in Craniofacial Surgery," *Annals of Maxillofacial Surgery*., vol. 4, no. 1, pp. 9-18, 2014. Doi:10.4103/2231-0746.133065

[5] K.S.Vepa, N.V.S.S.Sagar, B.Esakki and C.Udayagiri, "Numerical Modeling and Analysis of A Multi-Rotor Uas," *In Innovative Design, Analysis and Development Practices in Aerospace and Automotive Engineering*, pp. 171-179, 2021.

[6] N.V.S.S.Sagar, B.Esakki, C.Udayagiri and K.S.Vepa, "Multistage Mass Optimization of a Quadcopter Frame," *In Innovative Design, Analysis and Development Practices in Aerospace and Automotive Engineering*, pp. 181-188, 2021.

[7] K. S. Vepa, and N. V. S. S. Sagar, "Design, Optimization and Manufacturing of Quad Copter Frame Using Fdm," *International Journal of Engineering Advanced Technology*, vol. 8, no. 5, pp. 1726-1731, 2019.

[8] Suliman Alfarawi, Azeldin El-Sawi, Hossin Omar, "Discontinuous Finite Element Analysis of Counter Flow Heat Exchanger Unit Cell," *SSRG International Journal of Mechanical Engineering*, vol. 8, no. 8, pp. 7-10, 2021. Crossref, https://doi.org/10.14445/23488360/Ijme-V8i8p102.

[9] M. I. Ishak, M. R. A. Kadir, E. Sulaiman, and N. H. A. Kasim, "Finite Element Analysis of Different Surgical Approaches in Various Occlusal Loading Locations for Zygomatic Implant Placement for the Treatment of Atrophic Maxillae," *International Journal of Oral Maxillofacial Surgery.*, vol. 41, pp. 1077–1089, 2012. https://doi.org/10.1016/J.Ijom.2012.04.010.

[10] D. Darvish, S. Khorramymehr, and M. Nikkhoo, "Finite Element Analysis of the Effect of Dental Implants on Jaw Bone under Mechanical and Thermal Loading Conditions," *Mathamatical Problems in Engineering.*, vol. 2021, pp. 1-17, 2021. Https://Doi.Org/10.1155/2021/9281961

[11] J. W. Nicholson, "Titanium Alloys for Dental Implants: A Review," *Prosthesis.*, vol. 2, no. 2, pp. 100-116, 2020.

[12] V. C. Pathade, and S. N. Keche, "Determination of Stresses Induced in the Jawbone After Implant of Tooth Using Finite Element Method," *International Journal Scientific and Engineering Research*, vol. 4, no. 3, pp. 104-107, 2016.

[13] A. Yodrux, N. Yodpijit, and M. Jongprasithporn, "Compressive Stress, Shear Stress, and Displacement Study on Different Structured Dental Implant: 3-Dimensional Finite Element Analysis," *International Journal of Engineering and Research Technology*, vol. 6, no. 7, pp. 427-432, 2017.

[14] L. Zheng, J. Yang, X. Hu, and J. Luo, "Three Dimensional Finite Element Analysis of a Novel Osteointegrated Dental Implant Designed to Reduce Stress Peak of Cortical Bone," *Acta Bioengineering and Biomechnics.*, vol. 16, no. 3, pp. 21-28, 2014.

[15] A. Merdji, B. Bachir Bouiadjra, T. Achour, B. Serier, B. Ould Chikh, and Z. O. Feng, "Stress Analysis In Dental Prosthesis," *Computational Materials Science*, vol. 49, no. 1, pp. 126-133, 2010. https://doi.org/10.1016/J.Commatsci.2010.04.035.

[16] Abdul Azeez, A. Gopichand, N. V. S. Shankar, and K. Hanumantharao, "A Novel Prosthetic Hand Support for Physically Disabled," *International Engineering Trends and Technology*, vol. 29, no. 6, pp. 295-298, 2015. https://doi.org/10.14445/22315381/Ijett-V29p255.

[17] S. Mahajan, and R. Patil, "Optimizing Dental Implant Model By Comparison of Three Dimensional Finite Element," *International Journal Innovative Research Science, Engineering and Technology.*, vol. 4, no. 11, pp. 11223-11231, 2015. Doi:10.15680/Ijirset.2015.0411067

[18] J. Giannatsis, and V. Dedoussis, "Additive Fabrication Technologies Applied to Medicine and Health Care: A Review," *International Journal of Advanced Manufacturing Technology*, vol. 40, no. 1-2, pp. 116-127, 2009.

[19] H. T. Yau, T. J. Yang, and Y. C. Chen, "Tooth Model Reconstruction Based Upon Data Fusion for Orthodontic Treatment Simulation," *Computers in Biology and Medicine*., vol. 48, pp. 8-16, 2014. Doi: 10.1016/J.Compbiomed.2014.02.001.

[20] Samad Gadiwale, S. A. Kore, "Analysis of Welded Joint Used in Pipeline Support Using Finite Element Method," *SSRG International Journal of Mechanical Engineering*, vol. 7, no. 6, pp. 41-46, 2020. Crossref, https://doi.org/10.14445/23488360/IJME-V7I6P107.

[21] S. Negi, S. Dhiman, and R. K. Sharma, "Basics and Applications of Rapid Prototyping Medical Models," *Rapid Prototyping Journal*, vol. 20, no. 3, pp. 256-267, 2014. https://doi.org/10.1108/Rpj-07-2012-0065

[22] Humaira Tanvir, Jasmeena Tabeen Bhatt, Vikram Kapoor, "Developing Muscular Balance in a Denture"," *SSRG International Journal of Medical Science,* vol. 7, no. 5, pp. 4-6, 2020. Crossref, https://doi.org/10.14445/23939117/IJMS-V7I5P102.

[23] B. Sivasankari, B. Affrudeen, R. Abinaya, B. Harish, and V. Gunaseelan, "Preferment and Intension of the Intellectual 3d Printed Prosthetic Arm Appropriating Emg Signals," *International Journal of Engineering Trends and Technology,* vol. 67, no. 10, pp. 95-99, 2019. https://doi.org/10.14445/22315381/IJETT-V67I10P218.

[24] S. Andrejus, "A Digital Workflow for Modeling of Custom Dental Implants," *3D Printing in Medicine.*, vol. 5, no. 1, pp. 1-11, 2019.

[25] N. Parkhe, U. Hambire, C. Hambire, and S. Gosavi, "Enhancing Dental Implant Model By Evaluation of Three-Dimensional Finite Element Analysis," *International Journal of Engineering and Science Invention.*, vol. 4, no. 12, pp. 26-33, 2015.

[26] G. Laura, J. P. Salcido, T. Guda, and J. L. Ong, "Current Trends In Dental Implants," *Journal of the Korean Association of Oral and Maxillofacial Surgeons*, vol. 40, no. 2, pp. 50-60, 2014. https://doi.org/10.5125/Jkaoms.2014.40.2.50

[27] Z. Mehmet, and S. Aksoy, "Stress Analysis Around Dental Implant in Human Mandible," *Mathematical and Computational. Applicaion*, vol. 3, no. 2, pp. 83-91, 1998.

[28] Yahya Işık, Ecenur Öztürk, "Experimental Analysis of Cutting Forces and Finite Element Simulation in Milling Operations," *SSRG International Journal of Mechanical Engineering*, vol. 8, no. 11, pp. 1-7, 2021. Crossref, https://doi.org/10.14445/23488360/IJME-V8I11P101.

[29] N.V.S.S.Sagar and K.S.Vepa, "Experimental Investigations for Improving the Strength of Parts Manufactured Using Fdm Process," *In Innovative Design, Analysis and Development Practices in Aerospace and Automotive Engineering*, pp. 307-313, 2019.

[30] R. Jain, Supriya, S. Bindra, and K. Gupta, "Recent Trends of 3-D Printing In Dentistry - A Review," *Annals of Prosthodontics and Restorative. Dentistry.*, vol. 2, no. 4, pp. 101-104, 2016.