JIT Journal of Innovation and Technology
e-ISSN: 2721-8562; p-ISSN: 2721-8570
Vol. 5, No. 2, October 2024. Page: 62 – 68

Comparison Study Between the Experimental and Finite Element Analysis (FEA) on a Static Load of Magnesium AZ31B as Biodegradable Bone Plate Material

Mahruri Arif Wicaksono[1], Irza Sukmana[2], Akhmad Riszal[2,*], Yusup Hendronursito[1], Rizal Nazarrudin[2,], and Muhammad Haviz[3]**

1 Mining Technology Research Center - National Research and Innovation Agency (BRIN) Jl. Ir. Sutami Km. 15 Tanjung Bintang, South Lampung 35361, Indonesia
2 Department of Mechanical Engineering, Faculty of Engineering, Universitas Lampung, Gedung H lt. 2, Jl. Prof. Soemantri Brojonegoro No. 1, Bandar Lampung, 35145, Indonesia
3 Chemical Engineering Department, College of Chemical and Materials, King Fahd University Petroleum and Minerals – KFUPM, Dhahran, Kingdom of Saudi Arabia.

Corresponding email: *) akhmad.riszal@eng.unila.ac.id; **) rizalnazar@eng.unila.ac.id

Article history
Received: 29.07.2024
Revised: 22.08.2024
Accepted: 24.09.2024

DOI:10.31629/jit.v5i2.7538

Abstract
Biomaterials is an advanced material engineering technology that is used to help heal bone fractures or fractures. Currently, many biomaterials use materials such as titanium alloy, stainless steel, platinum, and chromium, but these materials cannot be degraded naturally so a second operation must be carried out to remove the installed biomaterial. Biomaterials are temporary in nature so when the bone returns to its original state, the biomaterial must be surgically removed. Research was conducted to obtain a design with a material that can be naturally degraded without causing toxicity. Magnesium AZ31B is a recommended candidate as a base material for degradable bone implants. Magnesium AZ31B material, it is expected to reduce or minimize the surgical removal of implant biomaterials. Bone plate geometry use plate bone dimension 150mm x 15mm x 3mm with variation 10 hole parallel and zigzag as well as with a bolt bone dimensions long 40 mm with pitch 1mm diameter 5mm. Test bending was conducted with ASTM E290-14 showing that on plate bone hole parallel with burden maximum 33,419 KN with a deformation maximum of 30.89 mm whereas for plate bone hole zig zag with the burden maximum 32,863 KN with deformation maximum big as 29.97 mm. From the study experimental that plate bone hole parallel have nature mechanic more tall compared with plate bone hole zig Zag although with the difference which is not significant. Whereas on simulation FEA plate bone hole parallel with burden 33,419 KN get results total deformation as big as 31,481 mm with von Mises stress 15,337 MPa, then for plate bone hole zig Zag with burden 32,863 KN with total deformation 32.466 mm and von Mises stress as big as 33,948 MPa. In testing by experiment and simulation FEA plate bone hole parallel get difference around 0.591 mm or 0.94% whereas for plate bone hole zig Zag in testing by experiment and simulation get difference around 2,893 mm or 4.60%.

Keywords: Magnesium AZ31B, bone plate, three point bending, FEA

1. Introduction

Biomaterials is something ingredient or alloy which originated from natural or synthesis which aim for repair, replace, and regeneration of organs function in the body nor outside body. Room scope very biomaterial large no only something material that used or implanted in the body (implant) but something material that relate with body man, good which implanted, pasted, or just tool help [1]. Biomaterials type metal is ingredient the most often used, there is a number of recommendation material metal which could in Use as ingredient orthopedics like alloy Co-Cr, stainless steel type 316L (SS316L), titanium and alloy titanium [2]. System framework charged various type style which different with so appearance, there is burden which generated by heavy, by gravity, by strength muscle and by strength external. Burden applied in direction which different produce strength which could varied from five type which different like compression, stress, sliding, curvature or torsion [3]. There is a number of methods in to do innovation plate bone like method experiment, system manufacture and modeling math like method finite element analysis (FEA) [4]. With method finite element analysis (FEA) capable predict strength mechanic and nature physique something material without in do experimental like stress, propagation, nature-tired materials, and failure something materials [5] To evaluate the results of FEA (finite element analysis) it is necessary to give a mechanical loading test with various boundary conditions for bone loading [6].

2. Materials and Methods

A-hot-rolled Magnesium AZ31B plate with size geometry 100 mm x 200 mm x 3 mm was used in this study. The design plate bone was using Solidworks™ as well as Inventor, Catia, Autodesk power shape [7]. AZ31B magnesium material bought on company manufacture Xi'an Yuechen Metal Products Co., Ltd, use technology production in accordance with standard international with product specification SGS BV number models AZ31B-H24 special for production use standard ASTM B107/B107M-13. Test Pull [8] and testing Three Point Bending ASTM E290-14 use machine Computer Universal Testing Machine conducted in Laboratory BRIN-BPTM Cape Star for knowing Ultimate Tensile Strength and Young's modulus, to do simulation FEA Three Point Bending plate bone (Total Deformation, Von-Mises stress, Linearized von Mises stress).

2.1 Materials

Magnesium AZ31B refers to on making with process processing rolling then in tempering. AZ31B magnesium material which used produced by Xi'an Yuechen Metal Products Co., Ltd, use technology production in accordance standard international with product specification SGS BV number models AZ31B-H24 special for production use standard ASTM B107/B107M-13. Study this use AZ31B magnesium material shaped plate with long 200 mm x wide 100 mm x thick 3 mm with process temperature 230 - 425°C and temperature annealing 345°C. As for nature mechanic AZ31B magnesium material which used as on Table 1.

Table 1: Mechanical properties Mg AZ31B and bone cortical.

NO	MATERIAL	PARAMETER	
1	Mg AZ31B	Yield Strength	153.15 MPa
		Young's modulus	44.28 GPa
		Density	1.77 g/cm ^{3}
		Poisson Ratio	0.35
		Ultimate	258.44 MPa
		Shear modulus	17 GPa
		Shear strength	160 MPa
		Thermal Conductivity	96.0 W/mK

2.2 FEA Method

In the process of engineering the AZ31B magnesium bone plate, there are several stages to obtain results from experiments and simulations with FEA. Bone plates are produced to meet the needs of the healing process of bone damage, especially for fracture healing. The bone plate production process is carried out in various stages such as determining the mechanical properties of the material, bone plate design, bone plate analysis and bone plate manufacturing. In mechanical testing, three points bending with ASTM E290-14 standard. In the FEA analysis, the total deformation, von Mises stress and linearized von Mises stress were obtained. The method used in conducting the analysis using Ansys software is illustrated on the figure 1.

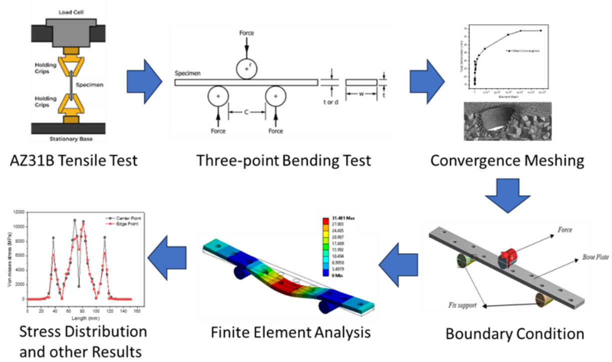


Figure 1 : Research Illustration

3. Result and Discussion

The results and discussion of the research that has been carried out are through several stages such as CAD design. The results of the research are as follows, In the research conducted, several research parameters were obtained such as tensile testing, bending testing and FEA simulations in the form of bending simulations on parallel and zig-zag holes bone plates. The results of this study will be presented afterwards.

3.1 Bending Test

Bending tests were carried out for bone plate specimens with parallel holes and zigzag holes with dimensions of length 150 mm x 15 mm x 3 mm. This design is different from the previous design which is 175 mm x 15 mm x 4.5 mm [9], 135 mm x 14 mm x 5 mm [10] , 150 mm x 15 mm x 3 mm [11], 80 mm x 10 mm x 5 mm with Ti6Al4V [12], and 8 bone plate holes with 96 mm x 12 mm x 3.6 mm hole diameter 5 mm [13]. The standard three point bending test uses test specifications according to the ASTM E290-14 for the parallel as well as zigzag hole plates as presented on figure 2.

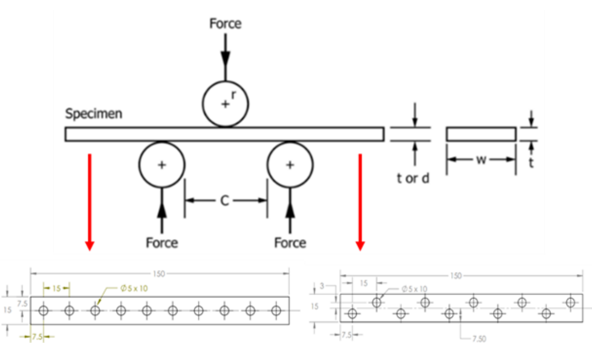
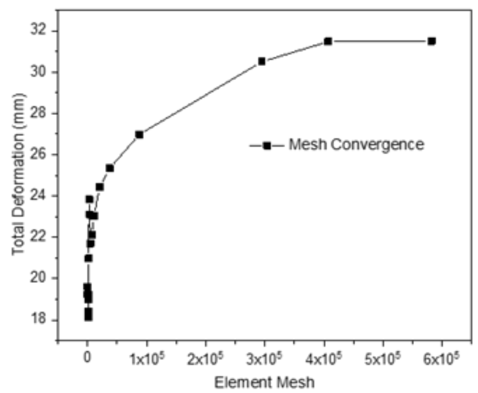


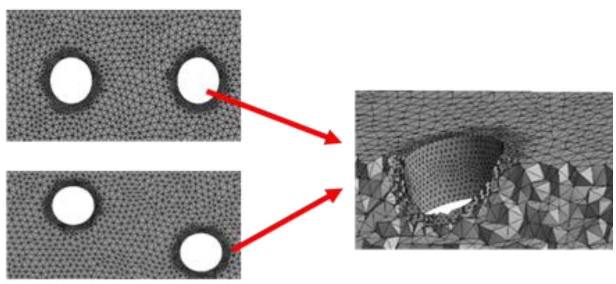
Figure 2: Three-point Bending Test for Parallel and Zigzag Hole of Bone Plates

3.2 Convergence Meshing

In the FEA simulation test, first the mesh convergence with the manual method is used to determine the optimal mesh element. The design carried out by [12] with dimensions of 80 mm x 10 mm x 5 mm with Ti6Al4V material has a meshing element of 162143 elements [12]. Model development with LCP bone plate (locking compression plate) with the number of meshing elements 163485 [14] while on the long plate 96 mm with 76000 elements in 5 holes and 99600 in 8 holes [15], in order to have the convergence meshing as presented on figure 3(a), while its illustration is on figure 3(b).



(a) Convergence Meshing Curve



(b) Illustration of the Meshing Condition

Figure 3: The convergence meshing for more accurate finite element analysis results

From the calculation, it can be defined that for the parallel hole bone plate, the total elements are 581,920; with total deformation and Von Mises stress consecutively were 32,466 mm and 16,984 MPa. While for Zigzag hole bone plate

DOI:10.31629/jit.v5i2.7538

consecutively were 581,920 elements; 31,481 mm and 33,948 MPa.

3.3 The Boundary Condition

The boundary conditions was carried out for the FEA simulation for both parallel as well as zigzag hole bone plates using three boundary conditions, as follows: the load given to the top pressing pedestal with a force load of 33,419 KN then place the support on the pedestal in the direction of X:0 mm; Y:0 mm and Z:0 mm, therefore the pedestal assumed not move in the three axis directions.

3.4 Bending Test

Bending test was carried out to determine the strength of the mechanical properties of the bone plate against the load perpendicular to the given plate. The bending test was carried out at the BRIN-BPTM Tanjung Bintang Laboratory with bone plate specimens of parallel holes and zigzag holes and then analysed with FEA to determine the accuracy between the experimental and the simulation. The standard three-point bending test uses test specifications in accordance with the ASTM E290-14 standard and each testing was conducted there-times. The bending test results was presented on Table 2.

Table 2: ASTM E290-14 standard for experimental bending test

Mg Specimen AZ31B	*Load* (KN)	*deformation* (mm)
Parallel hole plate test-1	33.92	31.33
Parallel hole plate test-2	34,572	32.43
Parallel hole plate test-3	33,769	30.69
Average	33,419	30.89
Zigzag hole plate test-1	32,267	29,49
Zigzag hole plate test-2	31,565	29,16
Zigzag hole plate test-3	32,231	29,35
Average	32,863	29,97

3.5 Finite Element Analysis (FEA)

In this study, we compared the results between the experimental testing and FEA method for both parallel as well as zigzag hole bone plates. The experimental and FEA simulation with the same load of 33,419 KN for parallel hole results the total deformation for the experiment is 30.82 mm while the FEA simulation is 31.481 mm. In experimental and simulation tests, the difference is about 0.591 mm or 0.94%. The FEA simulation results in the form of von Mises stress and total deformation with a loading of 32.863 KN based on the experimental. In the FEA simulation, the total maximum deformation is 32.466 mm, which is higher than the total deformation of the parallel hole bone plate, which is 31.481 mm, this is due to the influence of the geometry of the bone plate design. Whereas in von Mises the stress on the zig-zag hole bone plate is 33948 MPa (33.948 GPa) while in the parallel hole bone plate it is 38706 MPa (38.706 GPa). The comparison between FEA results for the parallel and zigzag hole bone plate with respect to the experimental and simulation is shown in Figure 4.

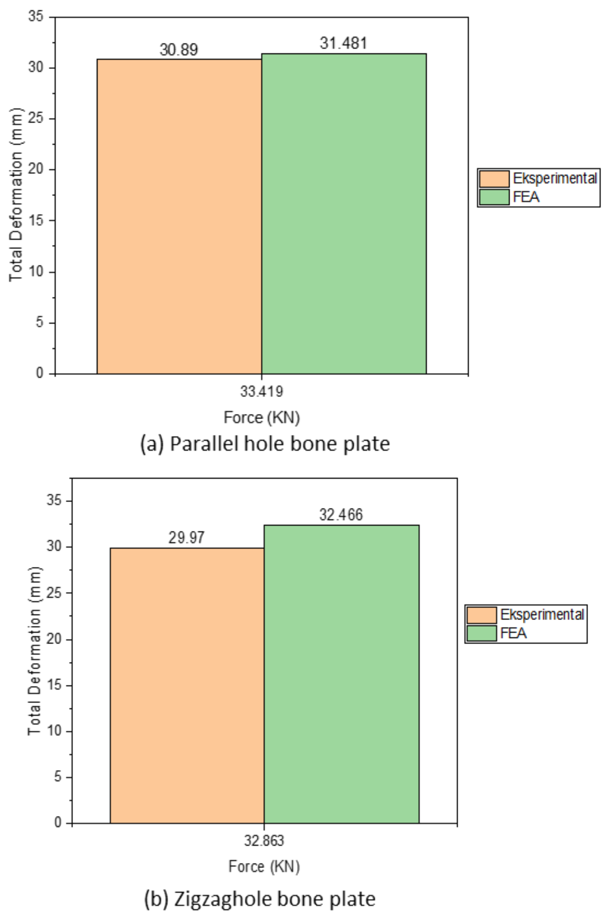
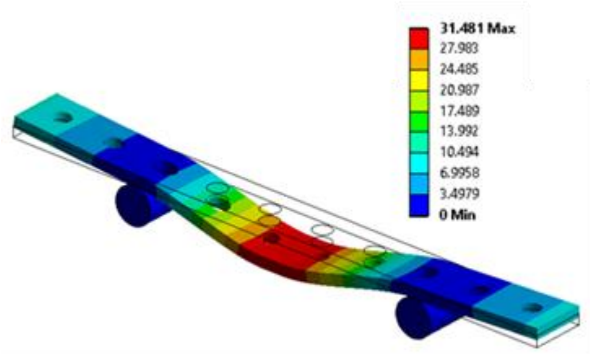


Figure 4: Comparison chart between the experimental bending test and FEA for parallel and zigzag hole bone plates

When compare this study to the previously carried out for Ti6Al4V material with a load of 32.50 KN and maximum deformation of 1.8 mm [16] and for Magnesium ZM21 simulation with a load of

79.44 N and maximum deformation of 1.34 mm [17], both studies found that the FEA simulation results that the largest deformation position occurs in the red colour part, while the minimum was in the blue colour one and in the good agreement to this study. The total deformation of the parallel hole and zigzag hole from FEA simulation is presented on figure 5.



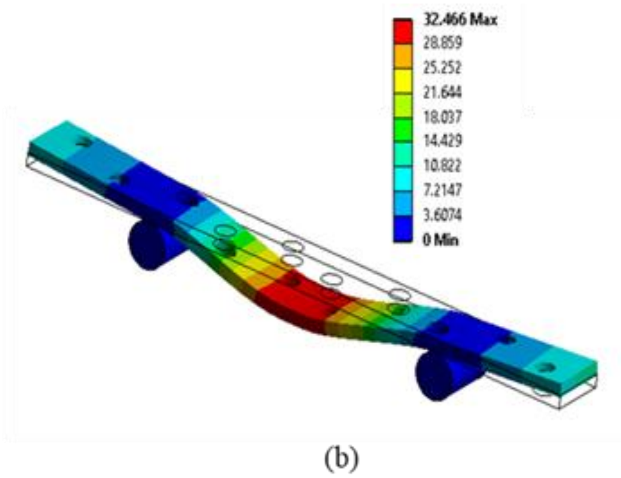
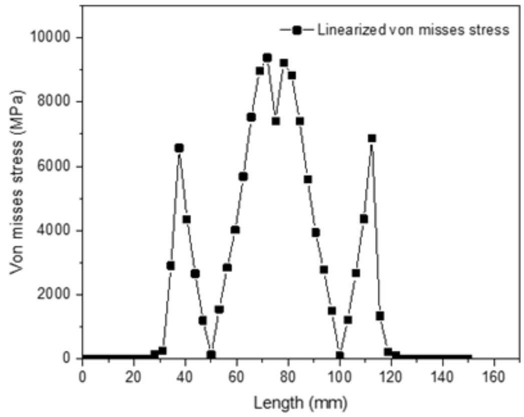


Figure 5: (a). FEA simulation for total deformation of parallel and (b) of zigzag hole bone plate model

Furthermore, the figure results simulation FEA from linearized equivalent von Mises stress of the parallel and zigzag hole bone plates is presented on figure 6. Schematic show location part from plate bone which accept stress highest still same with von Mises stress but in linearized von Mises stress will knowing quantity stress to long plate bone whereas von Mises stress only knowing distribution stress to time.



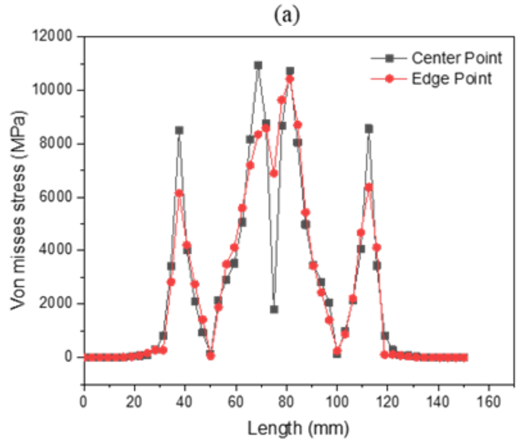


Figure 6: Linearized equivalent stress plate bone parallel hole (a) as well as for zigzag hole mode (b)

Simulation FEA conducted on plate bone hole parallel with long plate 150 mm. Simulation with burden 33,419 KN with deformation total 31,481 mm then simulation FEA linearized von Mises stress with distance 3.125 mm stress 2.3993e-003 MPa then up on distance 31.25 mm 252.56 MPa, distance 37.5 mm have stress as big as 6572.1 MPa because on distance the location point focus so that result in stress Becomes tall, then distance 53.125 mm experience drop stress Becomes 1553.1 MPa, distance 71,875 mm Becomes location stress highest that is 9377.5 MPa because on point the location suppressor , whereas stainless steel material 361L linearized von Mises stress 1352 MPa [18]. Then distance 75 mm experience drop stress that causes because part the is part from pre bending so that Becomes 7411.1 MPa and stress next until to distance 150 mm.

The final comparison between the experimental bending test results and FEA simulation for the parallel and zigzag hole bone plate type is presented on Table 3.

Table 3: Experimental bending test results data and FEA

No	Specimen (Plate)	Bone Plate Size	Force (KN)	*Bending Test*		
				Experiment	FEA	
				Total Deformation (mm)	Total Deformation (mm)	Von Mises Stress (MPa)
1	Mg AZ31B Parallel Hole	Length: 150 mm Width: 15mm Thickness: 3mm	33,419	30.89	31,481	15,337
2	Mg AZ31B Zigzag Hole	Length: 150 mm Width: 15mm Thickness: 3mm	32,863	29.97	32.466	33,948

4. Conclusion

From the experimental research, the parallel hole bone plate has higher mechanical properties than the zigzag hole bone plate because it is influenced by the dimensions of the distance between the holes. In experimental and simulated FEA testing, parallel hole bone plates got a difference of about 0.591 mm or 0.94%, while in the zigzag hole bone plate the test was carried out experimentally and FEA simulation got a difference of about 2.893 mm or 4.60%. In this study, it can be seen that the parallel hole bone plate has higher mechanical properties than the zigzag hole bone plate, this is influenced by the dimensions of the arrangement of the bolt holes.

References

[1] I. Sukmana, "Ilmu dan Teknologi Biomaterial," *Edisi Pertama. Teknosain: Yogyakarta*, 2017.

[2] N. S. Manam *et al.*, "Study of corrosion in biocompatible metals for implants: A review," *J Alloys Compd*, vol. 701, pp. 698–715, 2017.

[3] A. D. P. Bankoff, *Morfologia e cinesiologia: aplicada ao movimento humano*. Guanabara Koogan, 2007. [Online]. Available: https://books.google.co.id/books?id=FOtkOgAACAAJ

[4] N.-H. Kim, B. V Sankar, and A. V Kumar, *Introduction to finite element analysis and design*. John Wiley & Sons, 2018.

[5] V. Kumhar and A. Sarda, "Finite element analysis of implant design used in elbow arthroplasty process," *International Journal of Computer Aided Engineering and Technology*, vol. 11, no. 1, pp. 87–110, 2019.

[6] A. Geier, M. Kebbach, E. Soodmand, C. Woernle, D. Kluess, and R. Bader, "Neuro-musculoskeletal flexible multibody simulation yields a framework for efficient bone failure risk assessment," *Sci Rep*, vol. 9, no. 1, p. 6928, 2019.

[7] T. Asmaria *et al.*, "The 3D printing in material research and medical physics education and its accuracy study," *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, vol. 6, no. 2, pp. 227–236, 2020.

[8] "ASTM_B107_B107M_13_2021 Standard Specification for Magnesium-Alloy Extruded Bars, Rods, Profiles, Tubes, And Wire.," Dec. 01, 2021, *ASTM International, West Conshohocken, PA*. doi: 10.1520/B0107_B0107M-13R21.

[9] "ASTM-B557-10 Standard Test Methods for Tension Testing Wrought and Cast Aluminum-And Magnesium-Alloy Products.".

[10] "ASTM_E290_14 Standard Test Methods for Bend Testing of Material for Ductility.", doi: 10.1520/E0290-1.

[11] O. Subasi, A. Oral, and I. Lazoglu, "A novel adjustable locking plate (ALP) for segmental bone fracture treatment," *Injury*, vol. 50, no. 10, pp. 1612–1619, 2019.

[12] S. Baharnezhad, H. Farhangi, and A. A. Allahyari, "Influence of geometry and design parameters on flexural behavior of dynamic compression plates (DCP): experiment and finite element analysis," *J Mech Med Biol*, vol. 13, no. 03, p. 1350032, 2013.

[13] P. S. R. S. Maharaj, R. Maheswaran, and A. Vasanthanathan, "Numerical analysis of fractured femur bone with prosthetic bone

plates," *Procedia Eng*, vol. 64, pp. 1242–1251, 2013.

[14] T. Asmaria *et al.*, "Finite element analysis of patient specific bone plate with Ti6Al4V material selection," *Jurnal Penelitian Fisika dan Aplikasinya (JPFA)*, vol. 11, no. 1, pp. 83–93, 2021.

[15] A. R. MacLeod, A. H. R. W. Simpson, and P. Pankaj, "Reasons why dynamic compression plates are inferior to locking plates in osteoporotic bone: a finite element explanation," *Comput Methods Biomech Biomed Engin*, vol. 18, no. 16, pp. 1818–1825, 2015.

[16] I. V. Antoniac *et al.*, "Failure analysis of a humeral shaft locking compression plate—Surface investigation and simulation by finite element method," *Materials*, vol. 12, no. 7, p. 1128, 2019.

[17] X. Feng, W. Qi, C. Wang, F. Leung, and B. Chen, "Effect of the screw tightening sequence on the stress distribution of a dynamic compression plate: A pilot finite element study," *Journal of Orthopaedic Surgery*, vol. 27, no. 3, p. 2309499019876073, 2019.

[18] A. Shirurkar, A. Tamboli, P. N. Jagtap, S. Dondapati, and J. D. Davidson, "Mechanical behavior of ZM21 magnesium alloy locking plates–an experimental and finite element study," *Mater Today Proc*, vol. 4, no. 6, pp. 6728–6736, 2017.