Mechanical Behavior of Coronary Stent for Flexibility of Ring Made of Magnesium Alloy AZ31 using Finite Element Method (FEM)

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Abstract. Cases of death caused by cardiovascular disease are commonly coronary heart disease. The most well-known way to treat it is by installing a stent. Several studies related to the development of stents have been done. Continues in the materials used, one of which is the development of biodegradable materials so that the stent will dissolve in the body over time. In addition, when installed, the stent should be able to adjust its shape to the blood vessel and have a minimum tension so that it will not injure the vessel wall. This study investigated a bare metal stent with magnesium alloy AZ31 material using a strut mirror design (S><). The study used two stent conditions, namely crimped and expanded stent, to obtain changes in angle and maximum stress on the bending moment when simulated. The bending moment test simulates the finite element method (FEM) on Abaqus 6.14 software. The study results showed that to get the highest flexibility in crimped stent conditions, the best flexibility using von Mises stress in the safety limit is 0.011 N.mm bending moment and 50 µm thickness, with a curvature index of 0.0519 mm.

Keywords: Flexibility, Cardiac stent, Stent design, Curvature index.

1 Introduction

Cases of death caused by cardiovascular disease are commonly coronary heart disease. According to t WHO data, there are 7.4 million people who die in the world due to coronary heart disease, which is 31% of the total number of deaths in the world [6]. The total demand for stents in 2012 in 3 hospitals, namely Harapan Kita Hospital, Sardjito Hospital in Jogjakarta, and Sutomo Hospital in Surabaya, reached 4,472 units and still increasing year by year [2][4].

It is necessary to use the Finite Element Method (FEM) to correctly identify the condition and interaction of the stent with the artery [7]. For the type of stent made from biodegradable metal [8], research has been performed on evaluating the stent design based on magnesium alloy using the FEM method. This study used three types of stent models with different geometries.

Data were collected using the finite element method (FEM). This numerical method solves a problem by dividing the object of analysis into small parts. The small part will then be analyzed and recombined to get the solution [12], and it can identify the characteristics of the stent, artery, and the interaction of the two [12]. FEM proved more efficient and inexpensive when used as an optimization technique. The data from simulation results using Abaqus 6.14 software [15].

The flexibility of a stent is the ability to accommodate the curvature and angle of the blood vessels [3]. Based on numerical methods, especially the Finite Element Method (FEM), a comparison of the flexibility between two types of 316L stainless steel stent models was carried out by providing bending moments at both ends of the stent [7]. Flexibility testing on the stent unit and the whole stent stainless steel material 316L in expanded configuration [14]. Measurement of flexibility by applying a multipoint constraint (MPC) element in the Finite Element Method so that the given moment can be applied uniformly and gives fixed results [12].

In this research, a simulation of bending moment on stent design made of Magnesium Alloy AZ31 obtained the best flexibility for stents with a diameter of 1.171 mm and a length of 2 mm in crimped or expanded configurations with different thicknesses of 50 μm, 60 μm and also 70 μm. Stents used are stents with balloon catheter development technique. The study's results were a reference to the development of stents made from metal stents, especially Magnesium Alloy AZ31.

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2 Research Methods

Stent design in 2D view and 3D perspective. For simulation needs, only a pair of stents reduce computational time. This pair of struts is sufficient to represent the entire length of the stent [7].

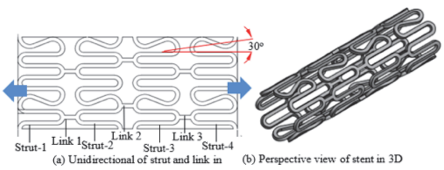


Fig. 1. Stent Design S><: (a). 2D perspective. (b) 3D perspective.

The finite element method is a numerical method used to discover solutions to problems in engineering. In general, for structural problems involving complex geometries, boundary conditions, and loadings, it will be difficult to find a solution analytically, because the differential equations are difficult to know [1]. So, a numerical approach is needed to obtain the solution. The finite element method can solve various problems regarding structural analysis, heat transfer, fluid flow, electromagnetic potential, and applications in bioengineering [14]. The finite element method solves structural problems that have complex geometries through a discrete or discretization approach. Discretization is dividing part of the geometric model into simple elements. At each end of the element there are corner points or nodes that are connected to other element nodes, as shown in Fig. 2.

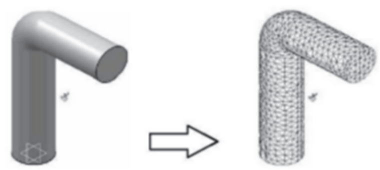


Fig. 2. Object modeling with finite element method [10]

By using FEM, the reliability and accuracy of designing a product will be faster and easier to achieve. Some examples of applications for FEM are Abaqus, ANSYS, Nastran, SAP2000, Solidworks, and others. There are three stages carried out in FEM [13]. Simulations and experiments were conducted to determine the change in angle after being given a pressure load of 0.01-0.11 MPa. Meanwhile, for flexibility, only in simulations carried out using the ABAQUS 6.14 software [5].

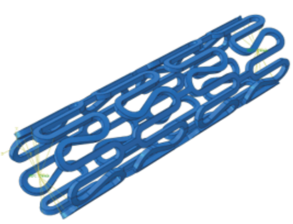


Fig. 3. Multi Point Constraints (MPC) modeled on ABAQUS

Fig. 3 Multi Point Constraints (MPC) in the simulation of elements used is Quadratic Tetrahedral C3D10 with the number of elements 50.932. While the constraint is mounted on the longitudinal axis and the moment load is set to the entire surface of the stent tip [11].

Stent flexibility is represented by the curvature index, defined as the ratio between the angle changes that occur compared to the standard conditions and the length of the stent. The following is the equation of curvature index (CI) [7]

$$X = \frac{\Delta\emptyset}{L} \qquad (1)$$

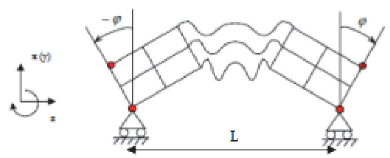


Fig. 4. Angle change in stent due to bending moment

Von Mises stress or equivalent stress is a type of stress that causes failure in the structure of the material, which von Mises discovered.

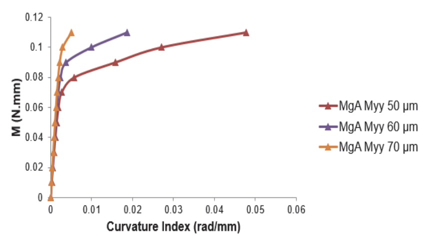
$$\sigma' = \left\{\frac{[\sigma_1-\sigma_2]+[\sigma_2-\sigma_3]+[\sigma_3-\sigma_1]}{2}\right\}^{1/2} \qquad (2)$$

Table 1. Material's mechanical properties of Magnesium Alloy AZ31[15]

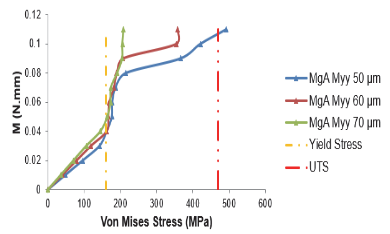
Mechanical Properties	Material: MA AZ31
Yield Stress (σ_y), MPa	130
Ultimate Tensile Strength (σ_u), MPa	414
Young's Modulus (E), GPa	43.5
Poisson's Ratio (υ)	0.35
Density (ρ), g/cm^3	1.77

3 Result and Discussion

The effect of changes in the stent angle in crimped conditions on the magnitude of the curvature index with von Mises stress can be observed on the figure below.



5a



5b

Fig. 5. 5a. Simulation results of curvature index with crimped stent using Magnesium Alloy AZ31 with

thickness of 50, 60 and 70 μm and 5b. Simulation results of von Mises with crimped stent using Magnesium Alloy AZ31 with thickness of 50, 60 and 70 μm.

Fig. 5 shows that when the stent angle changes, the curvature index flexibility occurs at a thickness of 50, 60, and 70 μm with curvature index values of 0.0519, 0.00862, and 0.00353, as seen from the lower crimped stent design with 50 μm thickness. From the results of the study [9], the curvature index value in the crimped configuration of the 50 μm stent is the curvature index value of 0.0064 N.mm, and it can be seen that the curvature index value from the results of this research was more significant in the change in the angle of the stent with magnesium alloy AZ31 material compared to CoCr L605 material.

From Fig. 5, if the stent stress angle changes, von Mises flexibility occurs at a thickness of 50, 60, and 70 μm, with von Mises values of 470, 211, and 201 seen from the crimped stent design under the highest stress angle occurs in a stent with a thickness of 50 μm. From the study's results [10], the von Mises value in the crimped configuration of the 50 μm stent is 432 MPa. The von Mises value from the results of this research is greater than the change in stent pressure with magnesium alloy AZ31 material compared to Material CoCr L605.

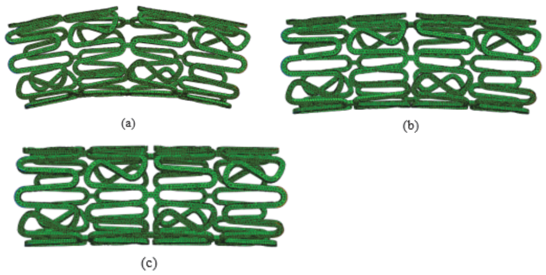
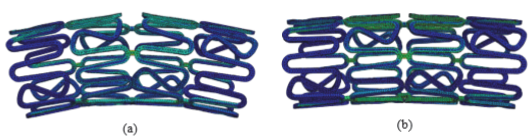


Fig. 6. Crimped stent simulation results curvature index changes: (a). 50µm, (b). 60µm, (c). 70µm

Fig. 6 shows the simulation results of Abaqus 6.14 with a thickness of 50, 60, and 70 μm by looking at the results of the simulation on crimped stents that the curvature index of flexibility is best in the condition of the crimped stent of 50 μm because the thicker the stent used, the lower the curvature index of flexibility and the lower the thickness, the highest the curvature index flexibility. From the research [9] results, the value of flexibility in the crimped configuration on a 50 μm stent is 0.0297 N.mm, and the flexibility value from the results of this research is 0.0519 N.mm with magnesium alloy material AZ31 compared with CoCr L605 material.



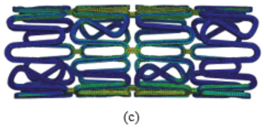


Fig. 7. Crimped stent simulation results on Mises stress change: (a). 50 μm, (b). 60 μm, (c). 70 μm

Fig. 7 shows the results of von Mises stress and stent deformation with a thickness of 50, 60 and 70 μm. It shows that the highest stress level is located at a thickness of 50 μm with an impact on high von Mises stresses.

4 Conclusion

Based on the stent design of the AZ31 magnesium alloy material using the finite element method with crimped stents, the stent design has the highest flexibility value in crimped conditions of 0.0519 mm using a bending moment of 0.011 N.mm with a thickness of 50 μm and von Mises of 470 MPa. Further research can be done to change the strut design or link design to know the correlation of stent and link designs with the resulting flexibility value.

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