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Research paper



Effect of Ring Material and Diameter on Orthopedic Implant Stability: External Fixation in Femur Bone

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Abstract

Axial stiffness is the most important factor in stability. It is known that any changes in the diameter of any components of the frame will either increase or decrease the axial stiffness of the fixation. The model of implant and bone will be variety as the variables changes. Current studies states that ring stability are one of the most important factors in ensuring fractured bones to have a successful re-union. In circular external fixation, the stability of the pin-bone interaction is influenced by the stability of the fixation frame where the major component is the rings. The objective is to study the finite element analysis (FEA) of the external fixator assembled in human diaphysis under compression force with different materials of the exoskeleton which are stainless steel, titanium alloy, magnesium alloy and carbon fiber. The results obtained show the mechanical strength of each material where it will be used to compare the value of von-Mises stress, stiffness and total deformation to acquire the best suitable ring diameter and material. Based on the result, as the diameter of the ring increases, the stiffness of the ring will be decreased.

Keywords: *External Fixation, Stiffness, Structural Analysis*.

1. Introduction

Human body contains 206 bones that can be divided into two categories which are axial skeleton and appendicular skeleton. Femur bone is the most important part of leg for human to walk but most of bone fracture will occur at femur bone especially for elder people. Fracture happens when the bone cannot withstand the external impact or stress exerted upon them [1]. Fracture can be divided into two types which are open fracture or closed fracture. Open fractured usually happens when a high-force blow hits the thigh bone that caused by a collision with an object for example, a car accident. In order to heal the fractured site, an external fixator is used because it can create a mechanical environment to help heal the bone fractures typically by the secondary bone healing in suitable patients [2]. External fixator is known as an exoskeleton applied to a broken endoskeleton where any changes in exoskeleton effects the endoskeleton [3]. It is used to maximize the stability of a broken bone where pins and screws are attached to the frame outside the skin. The advantage of using this kind of fixation are that it makes less interruption of blood supply to fracture fragments, decrease the length of surgery where sometimes surgeon left the fixation at patient until fracture is fully healed and decreasing the blood loss [4]. As a result, stability can be conceived as the sum of distribution from both endo- and exoskeleton. However, fixation failure can lead to a few complications that will be experienced by the patient such as pin loosening that can directly increase pain. Therefore it will lead to the usage of excessive pain medication and delayed in the mobilization. According to Pommer et al, [5] the early occurrence of pin loosening is due to mechanical reason where the main reason of the failure of the implant is the stability. Each of the components of the system is directly influence the stability of external fixator. Frame is one of the components that directly influence the stability where the ring properties give a huge impact towards it [6]. According to Zhang and Oyadiji [7], the stiffness of circular fixator effect by the properties of the rings. In order to prevent these circumstances, a newly designed external fixator has been introduced by Hospital Universiti Kebangsaan Malaysia (HUKM) and Universiti Malaysia Perlis (UniMAP) as a universal fixator for bone fracture treatments was used for this study. Investigation for identifying and measuring strength or weakness of the performance of fixator is needed before apply to human body. Therefore, in order to prevent failure of the implant, the understanding of the effect of ring diameter on the mechanical performance of the external fixator is paramount to avoid. Thus, delay the process of osseointegration and bone remodelling.

2. Materials and Methods

Figure 1(a) shows the fixator that was designed in SolidWork and all the finite element analysis were conducted by using ANSYS Workbench. The bone is attached to four half pins and two half ring to give support to the bone. The rings have the diameter of 150 mm, 180 mm, 200 mm and 240 mm where these diameters are the standard size of existing rings in clinical use where a constant standard radial thickness of 12 mm and axial thickness of 5 mm were applied. The half pins used are also the standard size half pins where they have the diameter of 4 mm and it is attached 2

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mm over the cortical bone where it usually applied in the medical procedure. An axial load of 1000 N was applied to the femoral neck where these load covers the range of physiological loads [7]. The ring that placed closely to the femoral head was defined as the first level while the ring after is considered as the second level.

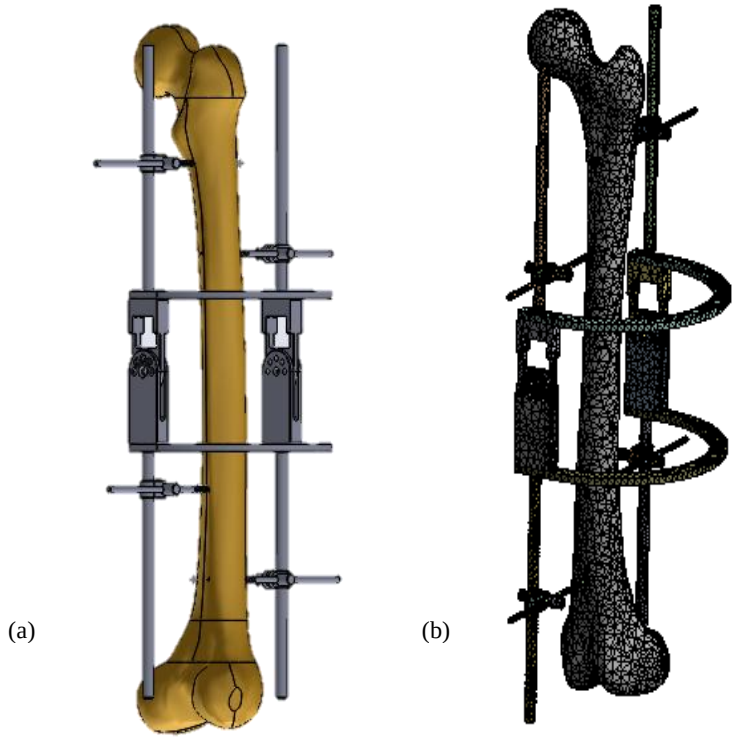

Fig. 1: (a) External fixator with two half rings assembled with femur bone (b) Meshing scheme for uniaxial fixator-femur cortical bone model

Each components of the system were modelled as a few types of materials which are titanium alloy, stainless steel, carbon fiber and the newest material, magnesium alloy. The finite element analysis was meshed using appropriate setting and values in order to have an optimum element size and number model on proximities and curvatures. Table 1 tabulated the material properties of each of the materials considered. Five sets of configuration were designed with different value of ring diameter. As a result, 109073 tetrahedral elements were used for the model.

Table 1: Material properties

Material	Young's modulus (GPa)	Poisson's ratio
Femur Bone	17.00	0.33
Titanium Alloy (Ti-6Al-4V)	120.0	0.32
Stainless Steel 316L	193.0	0.31
Carbon Fiber	113.0	0.32
Magnesium Alloy	45.00	0.32

3. Results and Discussion

Figure 2(a) shows that the relationship between displacement and axial load is linear proportional. Both displacement and stiffness between titanium alloy and carbon fiber are almost similar, where the differences to each other are 1.76% and 3.02%, respectively. Figure 2(b) shows the stiffness values of fixation with 150 mm rings. It can be seen that titanium alloy shows the highest stiffness followed by carbon fiber, stainless steel and magnesium alloy.
From Figure 3(a), it can be seen that magnesium alloy has the highest displacement where it starting to have different trend from the previous configuration. Here, the displacement of titanium alloy and carbon fiber seems to be equal with only 1.40% difference. The stiffness from Figure 3(b) shows that carbon fiber still have the highest stiffness compared to the other three.

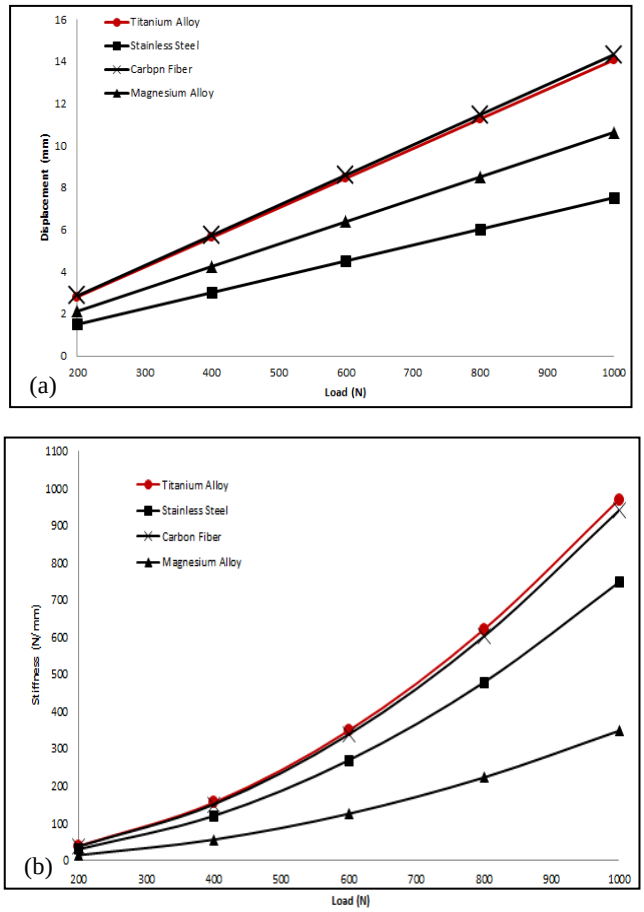

Fig 2: (a) Relationship between displacment and axial load and (b) stiffness characteristics of external fixator of 150 mm ring diameter

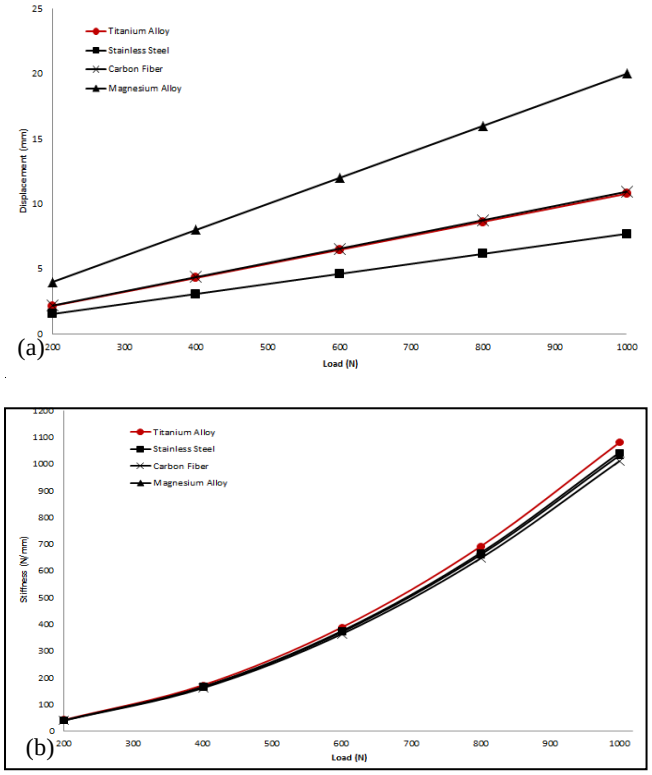

Fig 3: (a) Relationship between displacment and axial load and (b) stiffness characteristics of external fixator of 180 mm ring diameter

Figure 4(a) shows similar trend between displacement and the axial load applied. There are a huge gap between the displacement of magnesium alloy and the displacement of carbon fiber which is 65.5% from each other. From Figure 4(b) the position of the stiffness seems to change compared to previous ring diameter stiffness graph where the magnesium alloy increases to be the highest stiffness value.

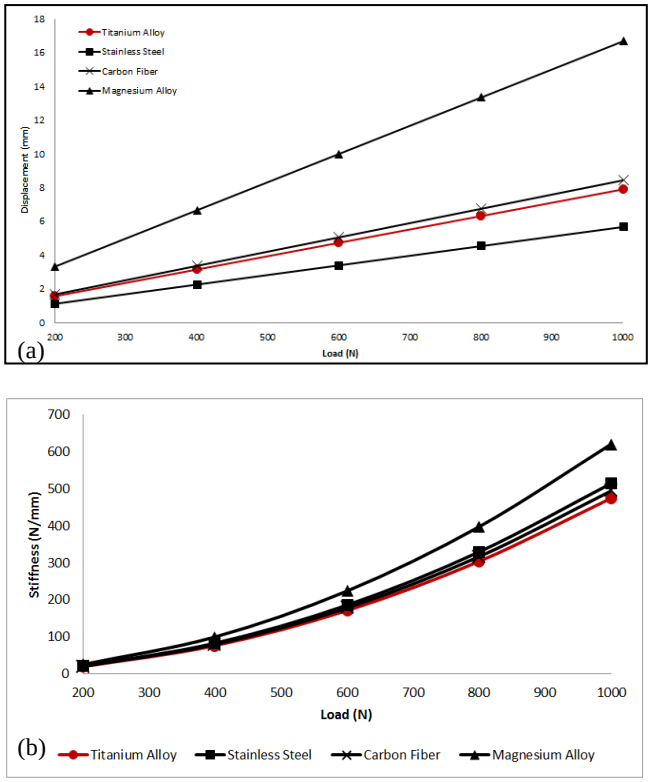

Fig 4: (a) Relationship between displacment and axial load and (b) stiffness characteristics of external fixator of 200 mm ring diameter

Figure 5(a) shows the displacement of the highest ring configuration that is 240 mm ring. The displacement does not have any different from the displacement for 200 mm ring diameter as shown in Figure 4(a). Magnesium alloy starts to have large displacement since the beginning of the load of 200 N. However, the value of stiffness for both configuration have differences where magnesium alloy have the lowest stiffness among others. Carbon fiber and titanium alloy seems to have similar stiffness due to the elastic modulus for both of the materials does not have much different. Each graph of the stiffness of the fixator shows the same behaviour obtained by a two-ring circular fixator by Zhang et al. [7]. It can be seen that the external fixator performed the stiffest when stainless steel was used as the frame. Carbon fiber rings are lighter compared to the other material that will gives more comfort to patients and the composite is radiotransparent where the visualization of the osteotomy site is possible [8].

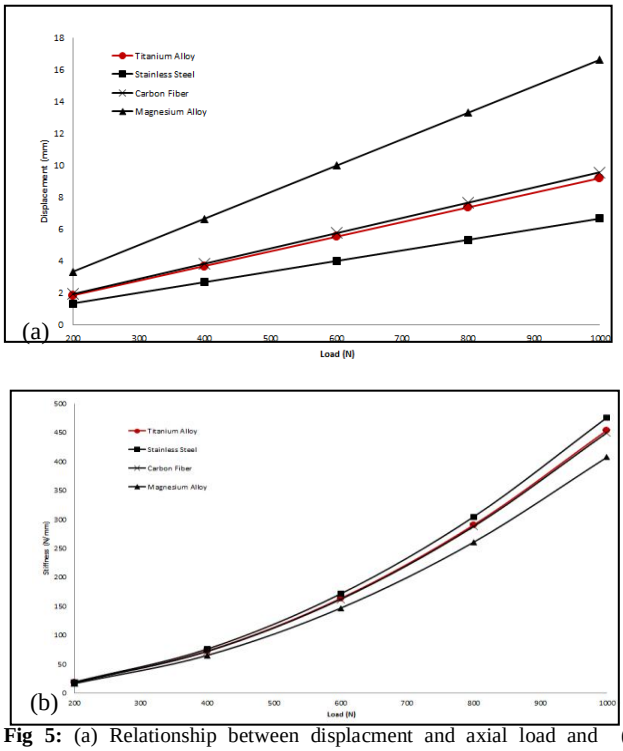

Fig 5: (a) Relationship between displacment and axial load and (b) stiffness characteristics of external fixator of 240 mm ring diameter

Figure 6 shows the stress contour of the fixation's ring. The maximum stress constantly occur at the hole where the ring will be connected to the frame for each of the diameter and materials. Eventhough the configurations are different, the highest stress occurred at the interaction between the rod and the ring as the force flow from half pin to rod and lastly being transferred to the rings.

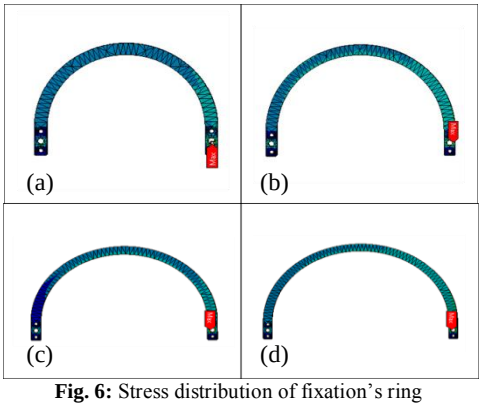

Fig. 6: Stress distribution of fixation's ring

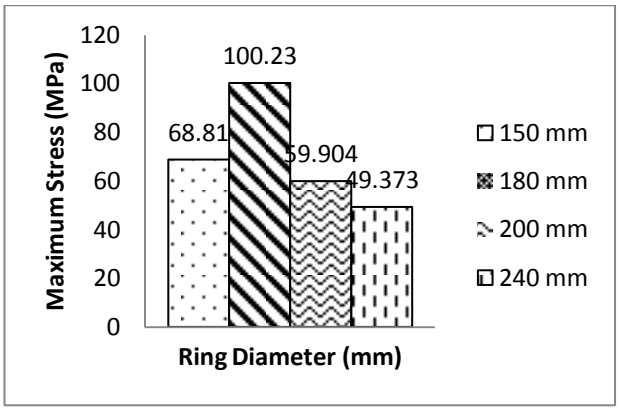

Fig. 7: Maximum stress of titanium alloy

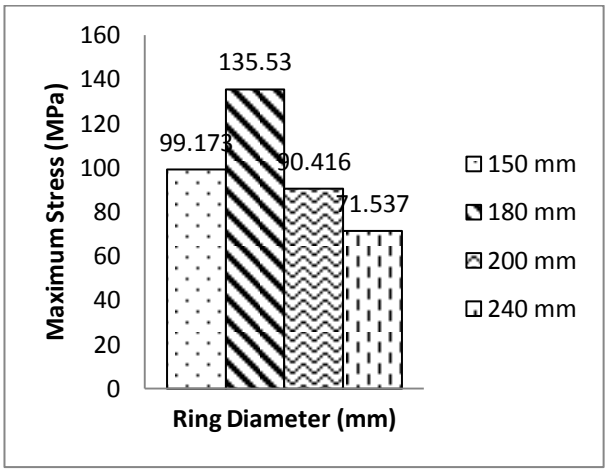

Fig. 8: Maximum stress of stainless steel

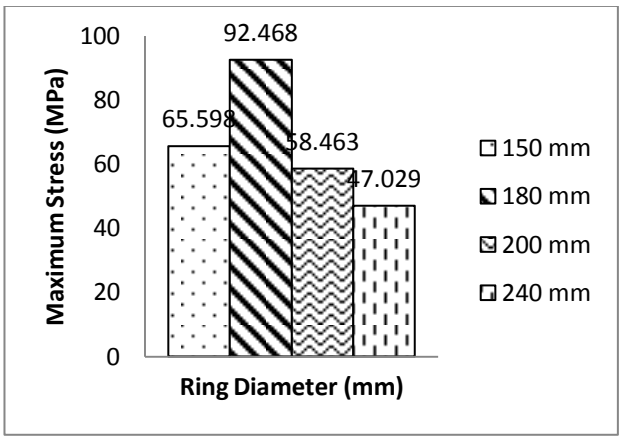

Fig. 9: Maximum stress of carbon fiber

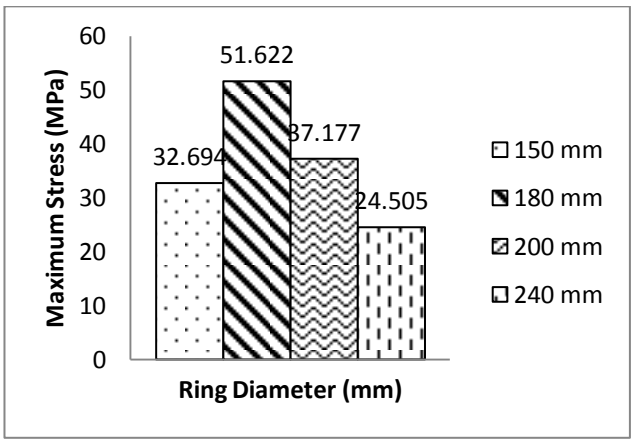

Fig. 10: Maximum stress of magnesium alloy

Figure 7, 8, 9 and 10 shows the maximum stress of each of the material used. From the figures, a similar trend is shown where the ring that have the diameter of 180 mm exerts the largest stress for every of the material. The value of stress seems to decrease as the diameter went bigger. According to Fragomen and Rozbruch [6], when the diameter of the ring decreases, the stability of the system will be increase. However, the reductions of the rings are limited to the size of patient's limb where the distance of the ring and skin surface is approximately 3.5 cm [6, 8].

4. Conclusion

The external fixator contains two rigid half rings. Therefore, it requires less space and weight compared to the common circular external fixator that requires four full rings. In this study, finite element model was analyze to study the displacement responses to various variables of configurations and subjected to axial loading. The result shows that the relationship between the stiffness and the diameter of the rings are nonlinear. It is shown that as the ring diameter increases, the stiffness of the ring decreases where there are 5% of differences between 200 mm and 240 mm diameter rings. Comparing fixator's rings that made of different types of materials, it can be observed that the rings that made of titanium alloy do not have much difference with carbon fiber in each of the comparisons. However, these two materials have different weight that will affect the comfort of the patient. Both of the materials are found stiffer than the other followed by magnesium alloy.

Acknowledgement

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