Six Hole Fracture Fixation Plates: Comparative Mechanical Properties Study

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Abstract – This paper presents an experimental comparative study between 6 holes implant produced by Metal Injection Moulding (MIM) process with the commercially available plates manufactured via machining process. MIM implant has been compared with four commercially available 6 holes stainless steel implants. The study data variables are the ultimate tensile strength, hardness, Young's modulus and elongation. Methods employed in this experiment are Tensile Test using Series IX Automated Material Testing System 8.33.00, Vickers Hardness Equipment and Scanning Electron Microscope. The results showed that the mechanical properties of MIM implant were as good as the commercially available machining implants. The most encouraging result was that the MIM plates had the highest Young's Modulus and elongation among the specimens. This demonstrates that MIM samples are the least susceptible to implant failure as it can withhold more stress before it fractures.

Keywords: Metal Injection Moulding, fracture plates, mechanical properties, machining.

1. INTRODUCTION

Six holes metal implants has been used as internal fixation in case of bone fractures for years now. Currently, the commercially available implants are made of stainless steel 316L and majority is manufactured overseas while only a single product made locally in Malaysia. The fabrication of stainless steel for six holes implant has been in the manner of machining process. It comprises several material-working processes in which power driven machine tools, such as lathes, milling machines and drill presses are used with a sharp cutting tool to mechanically cut the material to achieve the desired geometry or design.

However, researchers are now looking for fabrication of stainless steel which would be more advantages in term of biomechanics and biocompatibility. Other perspectives that possible to be venture is more design options and cost saving. In view of these factors, fabrication of six holes stainless steel implant via metal injection moulding (MIM) looks promising for replacing the current commercially available implant. The manufacturing cost is cheap, faster, and it is available locally too. In addition to that, with the current global environmental challenges, this technology uses waste of palm product as the binder agent in one of the processes.

The purpose of this research is to focus on the biomechanics properties of MIM implants and to compare with the currently available implants (4 different brand) in the market. Metal injection moulding holds a promising future from Malaysia's surgical and economical perspectives and should be explored with much enthusiasm. It is prudent that this field be explored extensively for the possibility of becoming an alternative, replacing the commercially available implants, produced through machining method.

2. MATERIALS AND METHOD

2.1 Materials

The biomechanics properties of 6 holes metal implants are determined by comparing the ultimate tensile strength, density, hardness, Young's modulus and elongation of standard narrow compression plate, 6 holes with length of 103 mm. Our specimen of interest is the fabricated stainless steel MIM 6 holes implant (Patent No: PI 20050182) made via metal injection moulding technique. This specimen will be compared with four commercially available 6 holes stainless steel implants, which are A, B, C and D. Currently, all the four commercially available implants were fabricated via machining techniques. Thus our aim is to compare the differences of biomechanics between these two techniques. The testing software would produce detail parameters about the test such as ultimate tensile strength (UTS), Young's modulus, displacement at maximum load, maximum strain, displacement at ultimate and load at ultimate

2.2 Ultimate Tensile Strength & Young's Modulus

Each specimens were marked and measured its dimensions; width, length and thickness. The study instruments used for this investigation is Series IX Automated Material Testing System 8.33.00. The method chosen was the Grab Test Method. This method is engineered for the determination of tensile strength only, of force and extension characteristics of the specimen for a given rate of displacement. The principle of this test is that specimen is supported by clamping a test piece in stationary jaws so that its longitudinal axis passes through the center of the front edge of each jaw and is perpendicular to the edges of the jaws. Testing software was used to input specimen details, set the desired test control, automatically calculate the desired results and statistics and produce a test report in accordance with the standard. The testing machine mode was set at a crosshead speed 5 mm/min. Tensile stress is imposed on the sample until fracture occurs.

2.3 Microstructure Analysis using Scanning Electron Microscope

The fracture surface of the specimens is cut into appropriate size to fit in the specimen chamber and is mounted rigidly on a specimen holder called a specimen stub. Usually, any conventional imaging in the SEM requires that the specimen to be electrically conductive, at least at the surface, and electrically grounded to prevent the accumulation of electrostatic charges at the surface. As for metal specimen, like in this research, it requires no extra preparation except for cleaning and mounting on a specimen stub.

3. RESULTS AND DISCUSSIONS

3.1 Mechanical Properties

Our investigation reveals in Figure 1 that specimen B has the highest average of UTS among all the specimens. As for MIM implant, its average UTS is 387.157 MPa which is the second highest average of UTS among the specimens. We can conclude that 6 holes stainless steel implant fabricated via MIM has UTS that is within the range of UTS of other commercially available implant fabricated via machining.

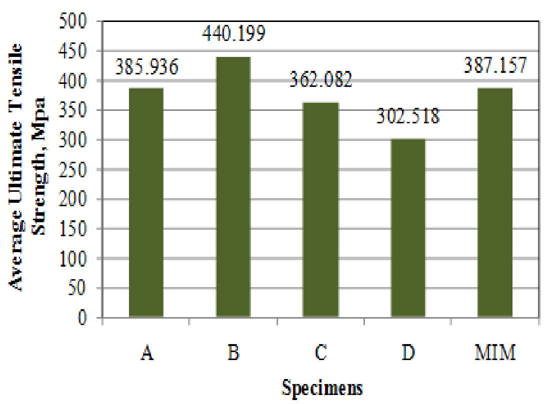


Figure 1: The comparison of ultimate tensile strength (UTS) of the fracture fixation plates

Increased hardness also means that it is more likely to scratch the softer surface, in this case the bone, which would create a film covering the bone's surface thus relative hardness among the different brand of implants may contribute to the behavior of biocompatibility study.

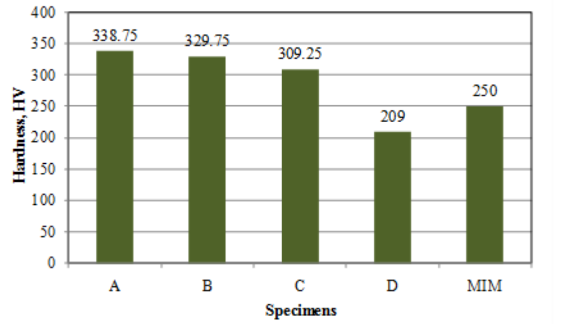


Figure 2: The comparison of hardness of the fracture fixation plates

From the Figure 2, it showed that specimen A has the highest Hardness value (338.75 HV) while MIM has hardness value of 250.00 HV. A material with higher hardness value will also have higher potential to become brittle. Brittle material is not suitable as a biomaterial as the consequences would be so great that include revising the operation and further delay the healing process. Thus, we can concluded that MIM implant has higher prospective to protect the underlying bone's surface and lesser tendency to become brittle compared to other majority commercially available implants.

Young's modulus measures the stiffness of a material. With reference to Table 1, we found that MIM has the highest Young's Modulus among the specimens while specimen C has the lowest.

We can conclude that MIM has the greatest ability to resist deformation when a force is applied. However, during bone healing process, studies found that the fracture ends need to stay in contact and there is also a need for minimal amount of weight loading to enhanced further the bone healing. A internal fixation material should have higher Young's modulus than the bone in order that majority of the weight loading will be transferred down to the implant, giving less weight load to be transferred via the bone.

Table 1 : Young's modulus and Percentage differences of the Young's Modulus of specimens to that of Cortical Bone (17000 MPa)

Specimens	Young's modulus (MPa)	Compared to Young's of Cortical Bone
A	5112	30%
B	4686	28%
C	1883	11%
D	5485	32%
MIM	74733	440%

From data at Table 1, we found that the Young's Modulus of MIM implant is 440% of the Young's Modulus of a cortical bone. With comparing with other specimens, we found that MIM implant has the highest percentage differences compared to Young's Modulus of cortical bone. The significant of this data is that it shows that MIM implant has the highest property of elasticity in which during the application of this implant to a fractured bone, it has the highest and nearest possibility to follow the bone contour and thus giving a good mechanic support for bone fixation and thus, it may lead to shorter bone healing process.

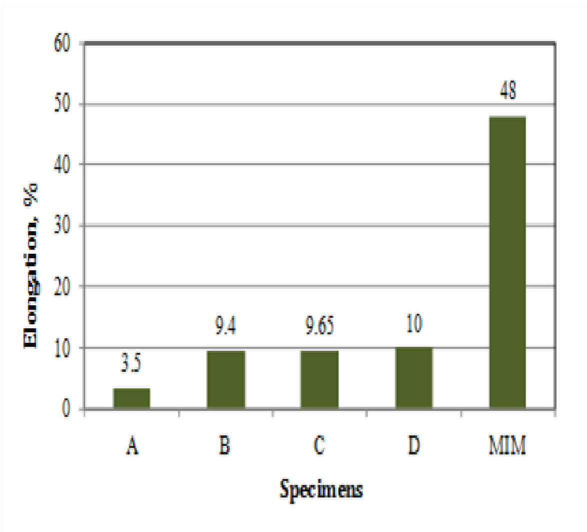


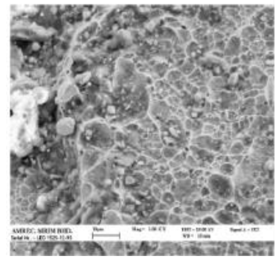
Figure 3: The comparison of elongation of fracture fixation plates

As our result presented on Figure 3, we concluded that MIM has the highest percentage of elongation compared to the others machinery implants. This shows that MIM is the most ductile and having the longest plastic deformation zone. In other words, MIM implant is able to withhold longer against stress before it fractures. In comparison to implant A, it is the least elongated and having at the same time the highest values of hardness which is 338.75 HV.

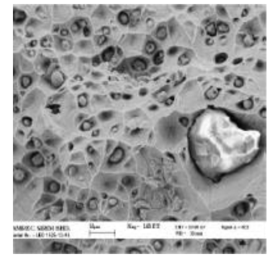
This proves that among all the implants tested; A implant is the most brittle material. When we compared the differences of elongation and the average UTS among the specimens together, we found that MIM implant has the best combination of ductility and tensile strength. This shows that MIM implant has the best potential to follow bone contour during implant installation and able to absorb large amount of strain energy prior to failure.

3.2 SEM Fracture Surface Observations

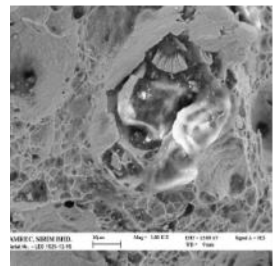
Generally, all the specimens (Figure 4 a,b,c,d,e) have dimple characteristic of ductile fracture which also exhibit transgranular cleavage fracture.



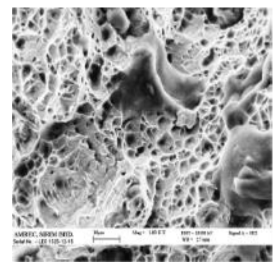
a)Specimen A



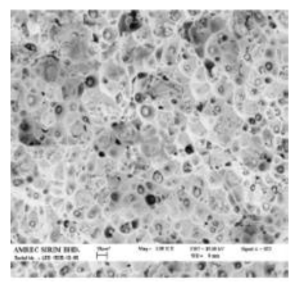
b)Specimen B



c)Specimen C



d) Specimen D



e) Specimen MIM

Figure 4: The fracture surface of the different specimens of fixation plates

This means that the fracture propagation or track runs between the granules, following the granules boundaries. At magnification of 1000x, in term of porosity, specimen D (Figure 4 (d)) is the most porous compared with the others. This explains why specimen D specimen has the lowest average ultimate tensile strength and hardness value. Obvious presence of inclusion was observed in specimen B (Figure 4 (b)) as well as MIM specimen (Figure 4 (e)). The nature of the inclusion which is either metallic or non-metallic in origin can only be known via Energy Dispersive X-ray Spectroscopy, in the future study.

4. CONCLUSION

It was revealed that metal injection moulding process can be used as an alternative manufacturing method to fabricate fracture fixation plates. Majority of mechanical properties of MIM plates fall within range similar to those fabricated via machining process which are now commercially used. As for the Young's modulus, MIM implant has the largest modulus value and 440% more than modulus of cortical bone. This proves that the potentiality of MIM implant in resistance against implant-failure and better function in following the bone contour during the application of the implant, thus leading to better outcome. Research in MIM implant is worth to be continued as this very technology may become the invention of the century in the field of Orthopedics. In addition to that, the result of this research shows that the properties of MIM plates fulfill the terms set by Metal Powder Industries Federation (MPIF) standard 35.

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