# Numerical Stress Analysis of Artificial Femur Bone

**Sujoy Kumar Dey, Vikash Mainali, B.B. Pradhan and Sutanu Samanta**

**Abstract** Femur bone is one of the strongest bones of the human body, and it bears a maximum weight of the body with the different types of daily life activities. In the present study, we are trying to use semi-crystalline polymer such as polyetheretherketone (PEEK) and its composites such as hydroxyapatite-polyetheretherketone (HA–PEEK) as a substitute for bone implant. First a solid cylinder was designed of human bone, PEEK, and HA–PEEK, and the effect of compressive loading was analyzed using directional deformation and Von-mises stress, respectively, in the ANSYS. In the second analysis, a human femur bone was designed using software and analysis was made using ANSYS for the compressive loading. From the analysis, it can be seen that both PEEK and HA–PEEK have shown nearer Von-mises stress and directional deformation as compared to that of a natural bone. HA–PEEK had more close value as compared to the pure PEEK.

**Keywords** Femur bone · HA–PEEK · PEEK · ANSYS

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# 1 Introduction

In this modern era, lot of research has been going on in the field of orthopedic implants and lots of materials have been tried as a bone replacement. But none of materials behaved like natural bone. Once the material have been implanted, there are always chances of revision surgery, and this is due to the *stress shielding* which makes the bone weaker and has to be replaced in due course of time. Revision surgery at an old age is quite risky, and serious problem may occur during surgery. Stress shielding occurs mainly in the metal implants [1].

$$\text{Stress Shielding} = \frac{\{\text{SE (treated)} - \text{SE (reference)}\}}{\text{SE (reference)}} \quad (1)$$

where

$$\text{Strain Energy (SE)} = \frac{\text{Strain Energy Density}}{\text{Apparent Density}}$$

The mentioned Eq. (1) was given by Weinans et al. [2].

To reduce the chances of revision surgery and stress shielding problem, we are trying to find out the polymer which have directional deformation and equivalent stress (Von-mises) closer or nearer to the natural human bone. In this paper, we have taken two polymer materials: one is PEEK, and the other is HA–PEEK. PEEK is a semi-crystalline polymer having excellent mechanical properties and chemically inert to most organic and inorganic chemicals. PEEK is a thermoplastic material which is wear resistant having stability at high temperature [3]. It has a glass transition temperature of 143 °C and a melting point of 335 °C. Some researchers have also described the potential of PEEK in medical applications [4], and it can serve as a replacement of the metal implants in orthopedic surgery [5]. PEEK also remained stable during the process of sterilization process [6] and is biocompatible in both the cases of in vivo and in vitro [7, 8]. It can be modified to increase its bioactivity by surface modification or incorporation of fiber into PEEK matrix [9, 10]. Previously, static analysis has also been done on the artificial femur bone using different materials such as Ti–Al—4 V and structural steel [11]. Analysis has been done for different loading conditions such as walking, standing, running, and jumping [12]. Such analysis helps to know about the stress distribution and from where the facture will occur due to loading.

# 2 Manufacturing

PEEK can be manufactured easily from injection molding, extrusion, conventional plastic processing techniques [13, 14]. HA is the one common material that has been used to increase the bioactivity of the PEEK. Various methods can be used to make a HA–PEEK composite, such as plasma spraying, cold spraying, and spin coating. Plasma spraying method can be used to deposit metallic or nonmetallic material in a molten or semi-molten state onto a different material [15]. High-quality HA coatings can be made using gas plasma sprays [16]. Cold spraying has also been used by some researchers to coat PEEK with the HA. In cold spraying, the particles are accelerated to a very high velocity toward a substrate. The particles to be sprayed are kept below the melting point [17]. Spin coating has also been done for coating HA over PEEK polymer. Zhang et al. [18] have manufactured the HA–PEEK by selective laser sintering process and done the evaluation of the cell attachment. Scaffold development of PEEK and HA has also been done using the laser sintering process [19].

## 3 Modeling and Material Properties

(a) Modeling of Solid Cylinder

1. A circle of diameter 8 mm was drawn using a sketch tool.
2. The circle was extruded to 100 mm length along the normal direction (Figs. 1 and 2).

(b) Model of the Human Femur Bone

The material properties of PEEK [20], PEEK and HA in the ratio of 70:30 [21], and human femur bone [22] are given in Table 1.

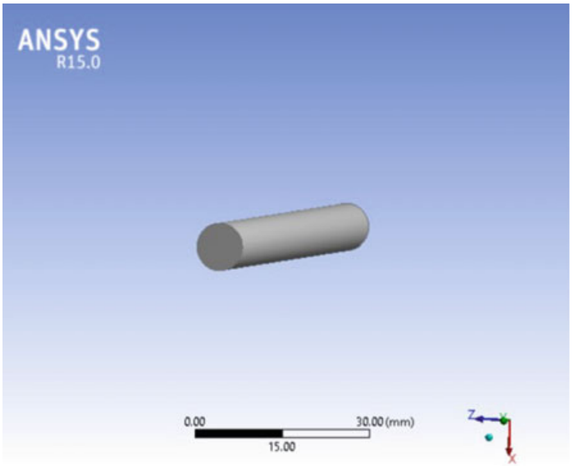


**Fig. 1** Model of solid cylinder

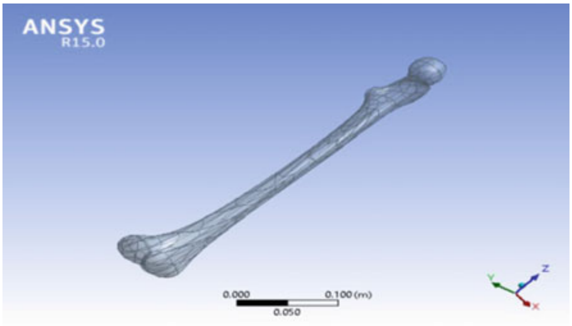


**Fig. 2** Model of human femur bone

**Table 1** Properties of human bone PEEK and PEEK composite

| Properties | Human bone | PEEK | HA–PEEK |
|---|---|---|---|
| Density (g/cm$^3$) | 2 | 1.291 | 1.851 |
| Poisson ratio | 0.3 | 0.42 | 0.38 |
| Young's modulus (Gpa) | 2.13 | 3.2 | 6.8 |

The density of the HA–PEEK is calculated using the formula of density of composite, given by

$$\rho_c = \rho_f v_f + \rho_m v_m$$

where $\rho_c, \rho_f, \rho_m$ is density of the composite, fiber, and matrix, respectively, and $v_m, v_f$ are the volume fraction of the matrix and the fiber.

# 4 Analysis

## *4.1 Analysis of the Solid Cylinder*

Static analysis of the cylinder has been done considering the material to be isotropic and homogenous. Material properties are assigned as given in Table 1.

**Step 1**: Meshing
Meshing was done all over the volume of the cylinder, with 66,722 nodes and 15,496 elements using a mesh tool. Figure 3 shows the meshed model.
**Step 2**: Condition for Analysis
One end of the cylinder has been fixed, and a compressive load of 750 pa [5], which is consider to be a weight of 75 kg person, is applied on the other end of the cylinder. We have taken compressive load as during walking or standing the nature of the load is compressive on the human femur bone. Figures 4 and 5 show the end conditions.

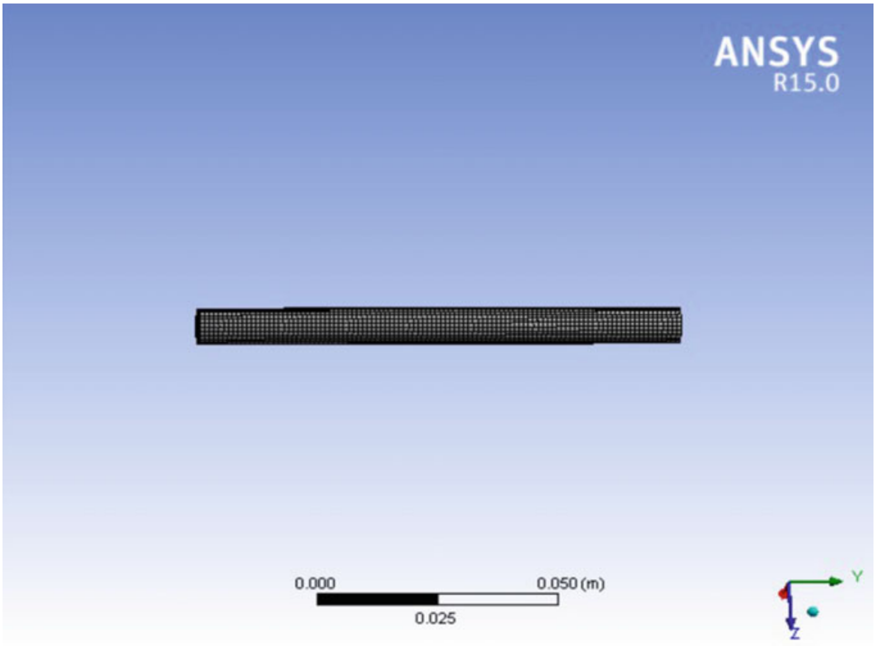


**Fig. 3** Meshed model

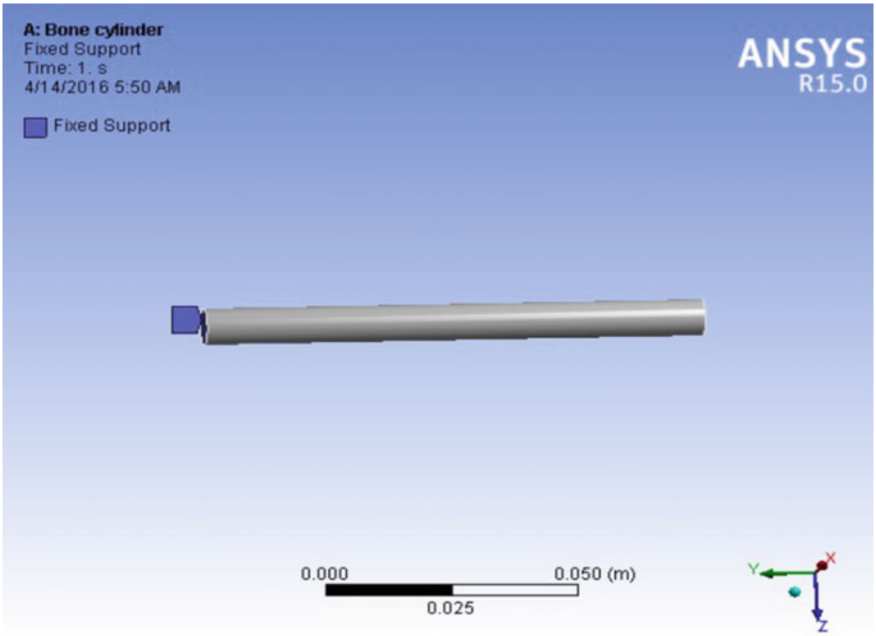


**Fig. 4** Fixed support

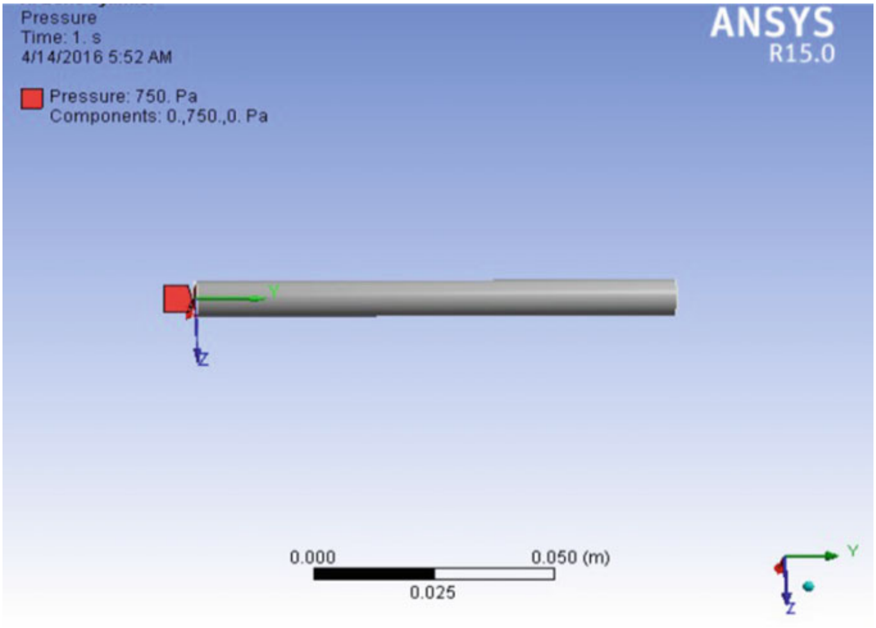


**Fig. 5** Load application

**Step 3**: Results and Discussion
On the basis of the static structural analysis done in the ANSYS and considering the results based on the Von-mises stress and directional deformation, Figs. 6 and 7 show the directional deformation and equivalent stress in all the three materials: bone, PEEK, and HA–PEEK.

As per the static analysis of the natural bone, we find the value of the directional deformation is $3.513 \times 10^{-8}$ m and the stress is equal to 1026.9 pa (maximum) and 373.87 pa (minimum) (Figs. 8 and 9).

As per the static analysis of the PEEK cylinder, we find the value of the directional deformation is $2.332 \times 10^{-8}$ m and the stress is equal to 1175.1 pa (maximum) and 179.38 pa (minimum) (Figs. 10 and 11).

As per the static analysis of the HA–PEEK cylinder, we find the value of the directional deformation is $1.099 \times 10^{-8}$ m and the stress is equal to 1120.4 pa (maximum) and 250.12 pa (minimum).

The above results are given in Table 2 for the comparison of the directional deformation and equivalent stress.

From the analysis, it can been seen that HA–PEEK has closer properties as compared to the natural bone and even its directional deformation is less than both the bone and PEEK, so it can act as a substitute in orthopedic implants.

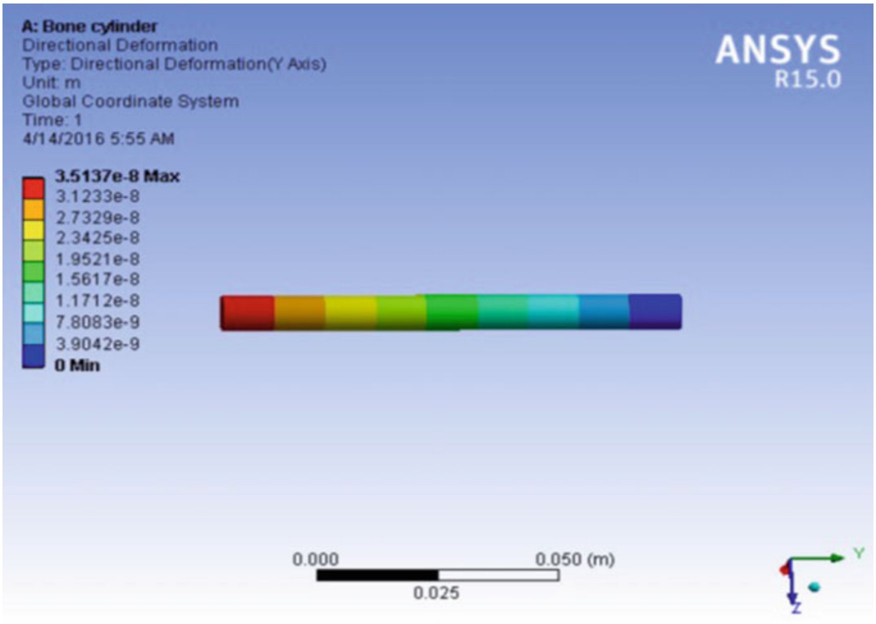


**Fig. 6** Directional deformation of bone cylinder

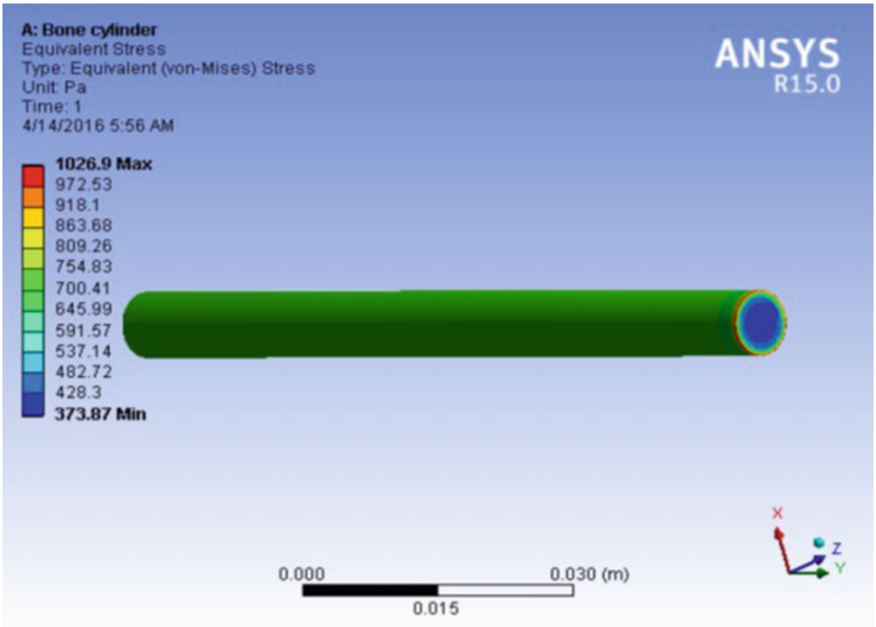


**Fig. 7** Equivalent stress in bone cylinder

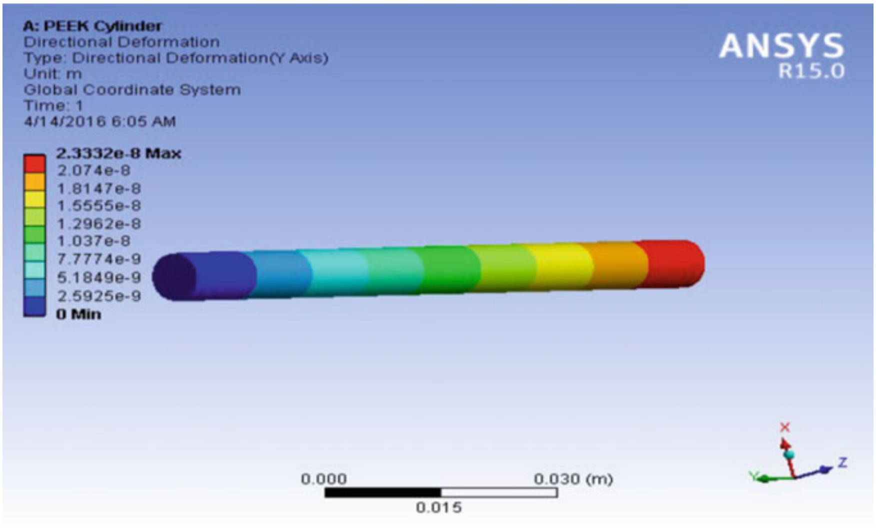


**Fig. 8** Directional deformation of PEEK cylinder

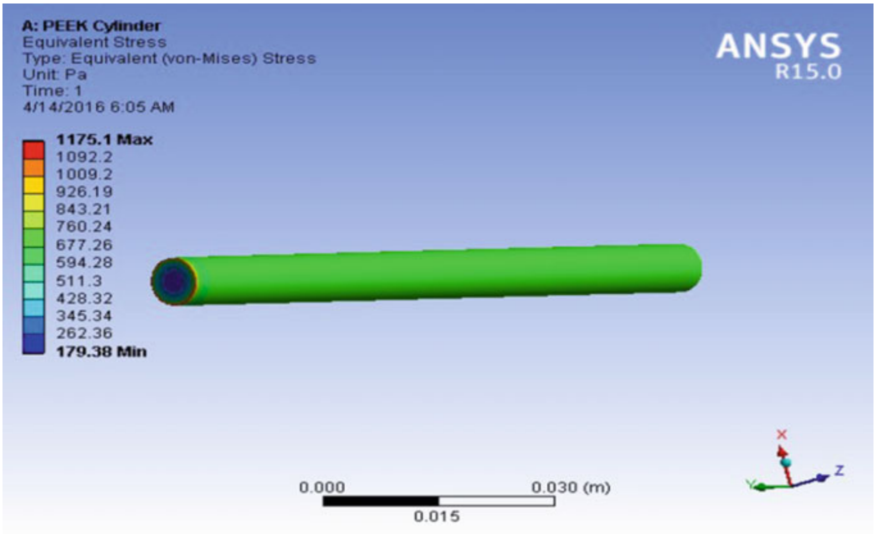


**Fig. 9** Equivalent stress in PEEK cylinder

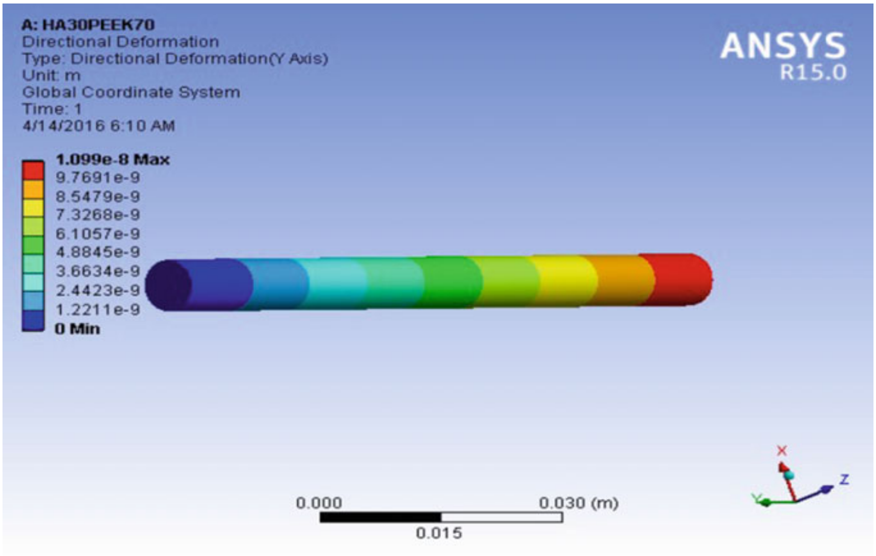


**Fig. 10** Directional deformation in the HA–PEEK cylinder

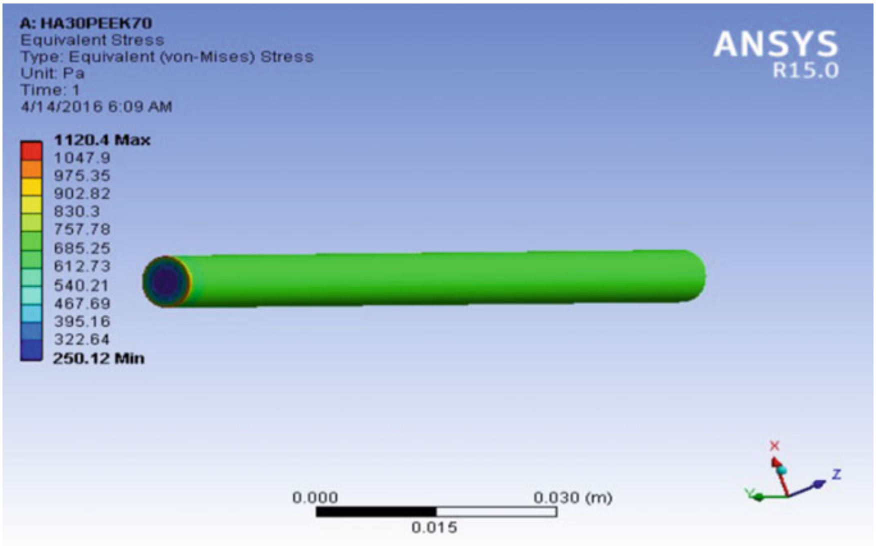


**Fig. 11** Equivalent stress in HA–PEEK cylinder

**Table 2** Results of the analysis

| | Bone | PEEK | HA–PEEK |
|---|---|---|---|
| Directional deformation (m) | $3.513 \times 10^{-8}$ | $2.332 \times 10^{-8}$ | $1.099 \times 10^{-8}$ |
| Equivalent stress (Pa) max. | 1026.9 | 1175.1 | 1120.4 |
| Equivalent stress (Pa) min. | 373.87 | 179.38 | 250.12 |

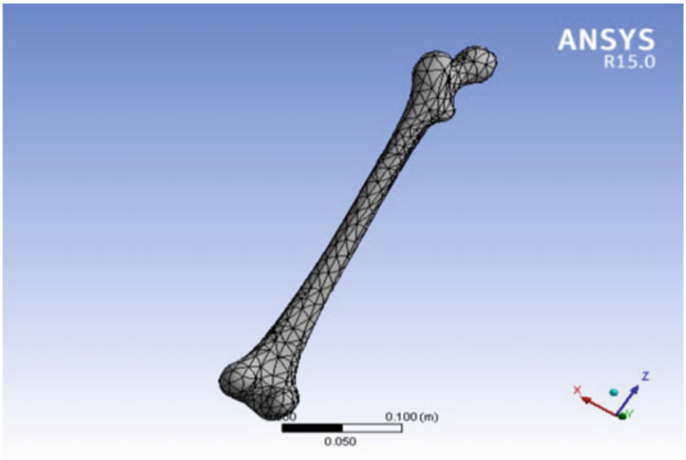


**Fig. 12** Meshed geometry

## *4.2 Analysis of Human Femur Bone*

The static analysis has been on the model considering it to the isotropic and homogenous material though the human femur bone is heterogeneous. Material properties have been assigned as given in Table 1.

**Step 1**: Meshing
The geometry is meshed using a meshing tool into 34,362 nodes and 23,531 elements. Figure 12 shows the meshed geometry of human femur bone.

**Step 2**: Analysis Conditions
Human bone is inflexible so we had fixed lower end of the femur bone. A compressive load of 750 Pa [22] which is considered to be a weight of 75 kg person is applied on the upper end. The changes in the equivalent stress and directional deformation have been compared between natural bone and bone made of PEEK, HA–PEEK. Figures 13 and 14 show the fixed and compressive loading conditions in human bone.

**Step 3**: Results and Discussion
On the analysis made on the ANSYS workbench using static structural following results were produced (Figs. 15 and 16).

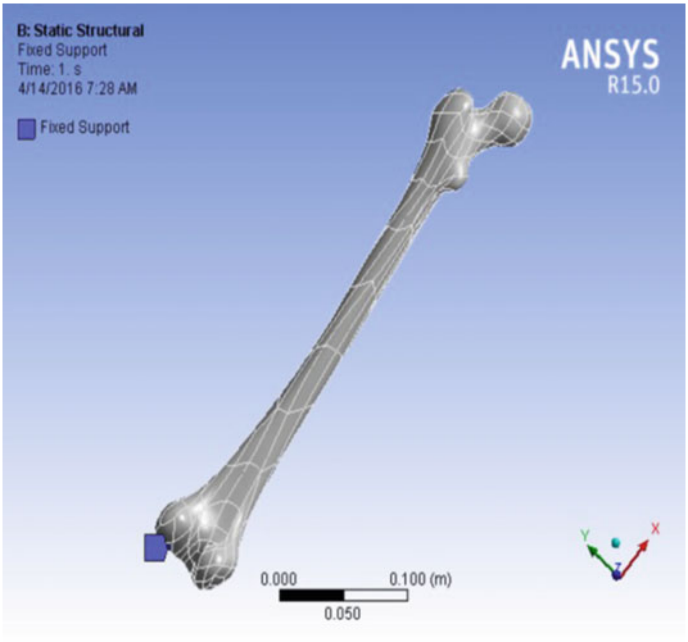


**Fig. 13** Fixed condition

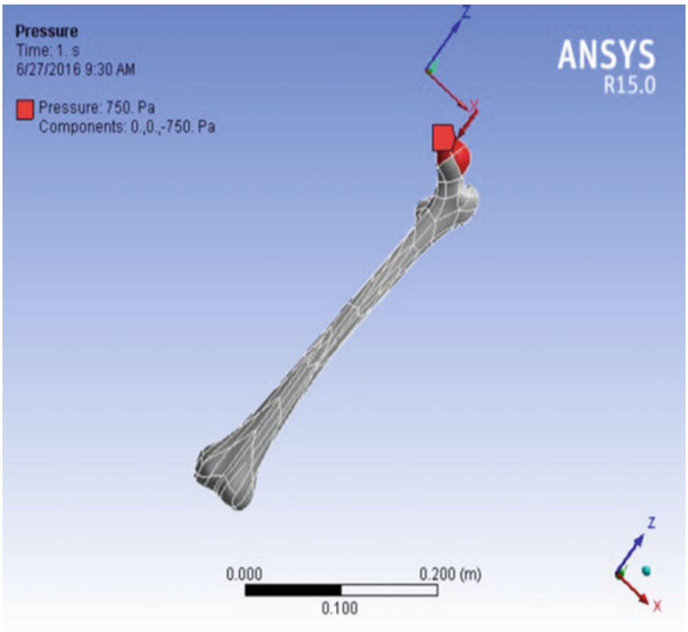


**Fig. 14** Compresssive loading

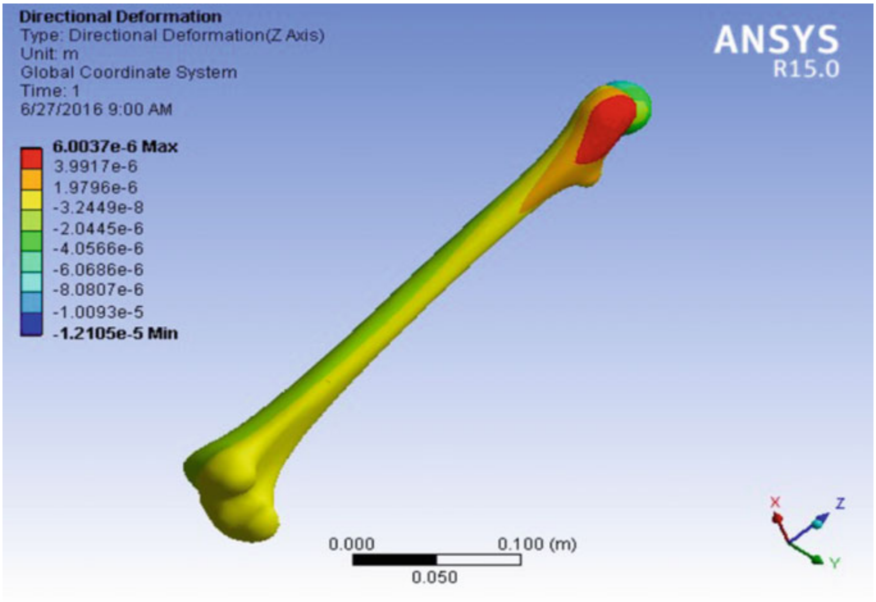


**Fig. 15** Directional deformation of the femur bone

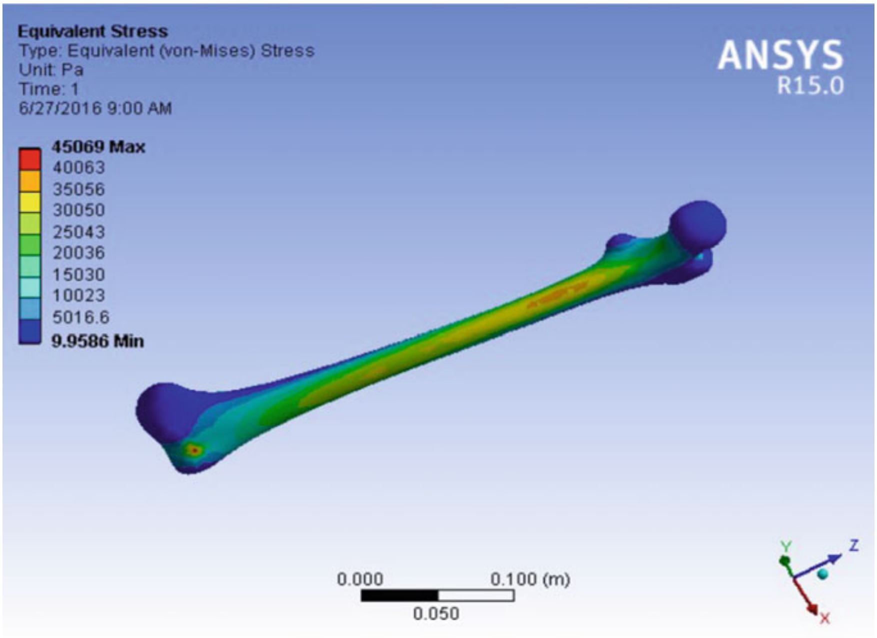


**Fig. 16** Equivalent stress of the femur bone

As per the static analysis, we find the value of the directional deformation is $4.046 \times 10^{-5}$ m and the stress is equal to 45,069 Pa (maximum) and 9.9586 Pa (minimum) in the case of bone (Figs. 17 and 18).

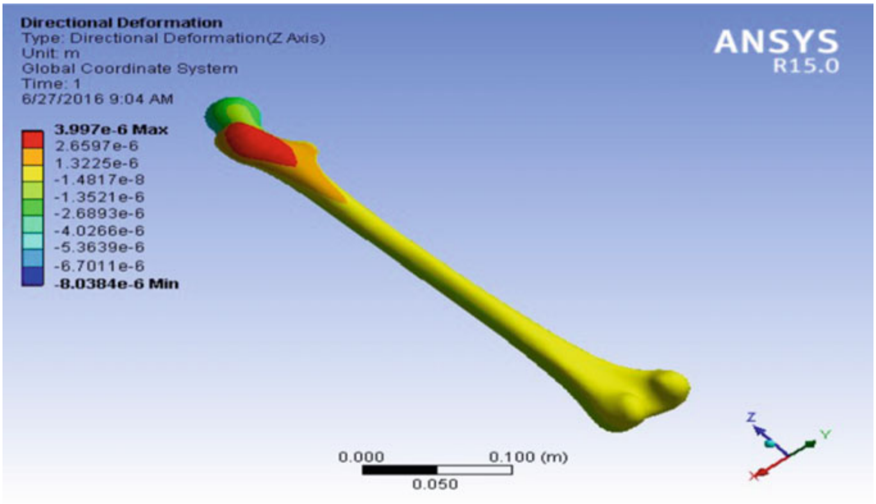


**Fig. 17** Directional deformation of PEEK femur bone

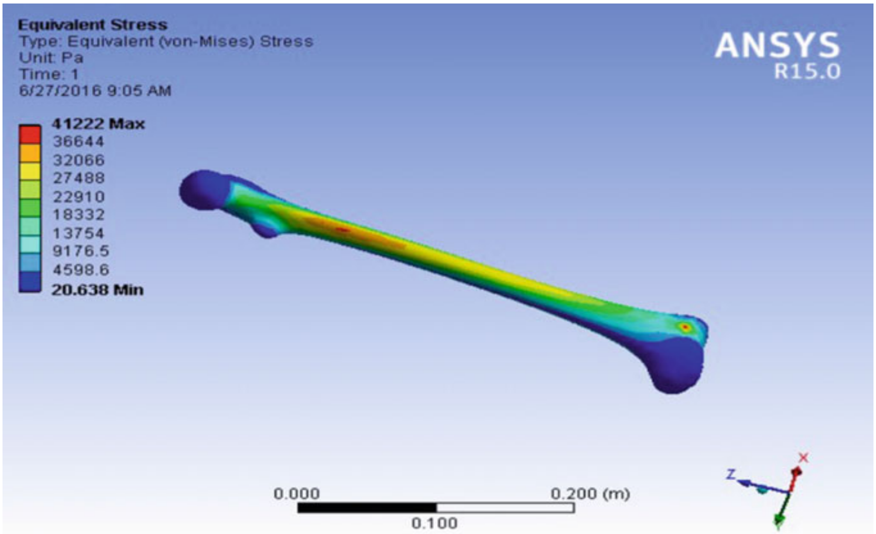


**Fig. 18** Equivalent stress of PEEK femur bone

As per the static analysis, we find the value of the directional deformation is $3.997 \times 10^{-6}$ m and the stress is equal to 41,222 Pa (maximum) and 20.638 Pa (minimum) in the case of PEEK femur bone (Figs. 19 and 20).

As per the static analysis, we find the value of the directional deformation is $1.8804 \times 10^{-6}$ m and the stress is equal to 42,769 Pa (maximum) and 16.083 Pa (minimum) in the case of HA–PEEK femur bone.

Comparative results are given in Table 3.

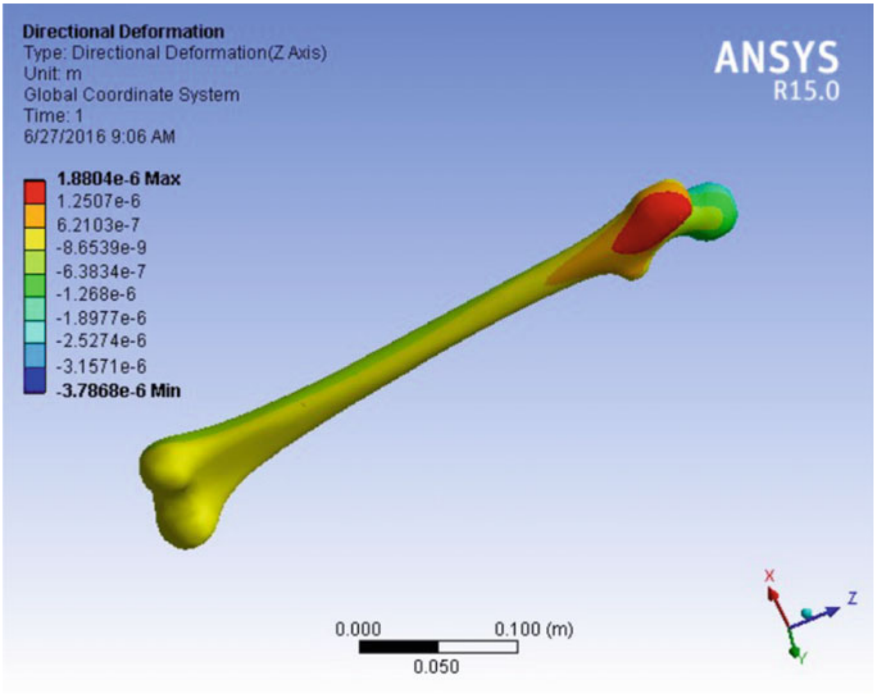


Fig. 19 Directional deformation of HA–PEEK femur bone

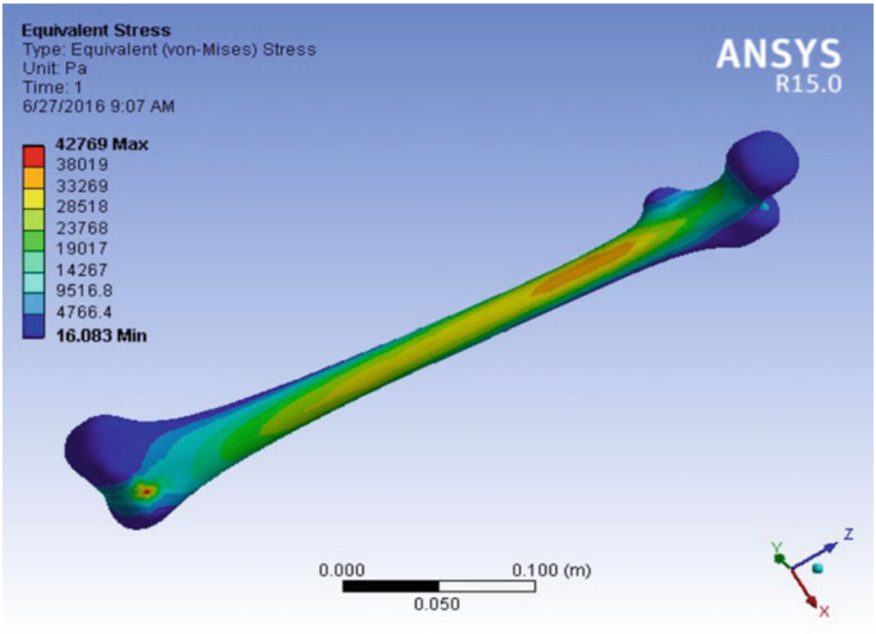


**Fig. 20** Equivalent stress in HA–PEEK femur bone

**Table 3** Results of analysis

| | Human bone | PEEK | HA–PEEK |
|---|---|---|---|
| Directional deformation (m) | $4.046 \times 10^{-5}$ | $3.997 \times 10^{-6}$ | $1.8804 \times 10^{-6}$ |
| Equivalent stress max (Pa) | 45,069 | 41,222 | 42,769 |
| Equivalent stress min (Pa) | 9.9586 | 20.638 | 16.083 |

## 5 Conclusion

- Comparison was done between natural bone, the artificial PEEK, and HA–PEEK bone.
- PEEK and HA–PEEK showed closer properties with natural bone and can act as a material for bone implants.
- HA–PEEK showed closer as results compared to PEEK.

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