CASE STUDY ON BLOOD FLOW OVER NFRPC BONE ATTACHED PLATE USING COMPUTATIONAL FLUID DYNAMICS

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Abstract— In this research thermal stress analysis using Computational Fluid Dynamics [CFD] has been carried out on (Sisal (Agave sisalana) and Roselle (Hibiscus sabdariffa) hybrid plate material and the values compared with manual calculation found to be good in agreement. This invention focuses thermal properties of natural fibers that are used for bone grafting substitutes which are now becoming a great challenge for biomedical engineers. This paper proposed suggestions of using Natural fiber reinforced polymer composite [NFRPC] as a plate material which uses pure natural fibers that are rich in medicinal properties like Sisal and Roselle fiber. The most important thing that the researchers have to take into account is that these step taken now, will help the mankind to develop and to have a more pleasant life.  
Keywords- Thermal stress analysis, CFD, Agave sisalana, Hibiscus sabdariffa.

I INTRODUCTION

This project work concentrates on the biomaterials progress in the field of orthopedics. An effort to utilize the advantages offered by renewable resources for the development of biocomposite materials based on biopolymers and natural fibers, in this research work natural fiber particle reinforced materials such as (Sisal (Agave sisalana), Banana (Musa sepientum) and Roselle (Hibiscus sabdariffa) reinforced polymer composite plate material with bio epoxy resin Grade 3554A and Hardener 3554B were used for bone grafting substitutes.

The basic governing equations for a viscous, heat conducting fluid have been derived for NFRPC material. It is a vector equation obtained by applying Newton's Law of Motion to a fluid element and is also called the momentum equation. It is supplemented by the mass conservation equation, also called continuity equation and the energy equation. Usually, the term Navier-Stokes equations are used to refer to all of these equations.

In this research thermal stress analysis using CFD has been carried out on NFRPC plate material and the values compared with manual calculation found to be good in agreement. This invention focuses thermal properties of natural fibers that are used for bone grafting substitutes which are now becoming a great challenge for biomedical engineers. This project emphasis the enhanced property of natural fiber as bone implants. It is a challenge to the creation of better materials for the improvement of life quality. This project proposed suggestions of using Natural fiber reinforced composite as a plate material which uses pure natural fibers that are rich in medicinal properties like Sisal, Banana & Roselle (hybrid) fiber. The most important thing that the researchers have to take into account is that these step taken now, will help the mankind to develop and to have a more pleasant life.
II MATERIALS AND METHODS

TABLE I. Properties of Materials

<table>
<thead>
<tr>
<th>Materials</th>
<th>Young’s Modulus (N/mm²)</th>
<th>Density Kg/mm³</th>
<th>Poisson ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roselle and sisal (hybrid)</strong></td>
<td>18857.075</td>
<td>1.450×10⁶</td>
<td>0.33</td>
</tr>
<tr>
<td><strong>Roselle and banana (hybrid)</strong></td>
<td>22061.9593</td>
<td>1.5×10⁶</td>
<td>0.32</td>
</tr>
<tr>
<td><strong>Sisal and banana (hybrid)</strong></td>
<td>25779.2532</td>
<td>1.350×10⁶</td>
<td>0.30</td>
</tr>
</tbody>
</table>

**Compiled from References. [2 and 3]**

A. COMPUTATIONAL DETAILS OF PRESENT WORK

Manual Calculation

Assumptions Made

- Buoyancy effects are negligible
- Radiation effects are negligible
- The flow is adiabatic (there is no heat transfer between the flow and the surroundings).

Plate Dimensions

Length of plate = 0.106 m  
Breadth of the plate = 0.01 m  
Thickness of the plate = 0.003 m  
Thermal conductivity = 0.543 W/m-K  
C.O.P of blood = 3594 kJ/kg-K

Domain Dimensions

Diameter of domain = 0.16 m  
Length of the domain = 0.5 m  

BORDER CONDITIONS

Inlet velocity = 0.5 m/s  
Inlet Temperature = 305 k  
Outlet pressure = 0 Pa

Bone Dimensions

Length of bone = 0.191 m

Solution

Nusselt number

\[ Nu = \frac{h D}{k} \]

\[ h D / k = 0.023 \times (Re)^{0.8} \times (Pr)^{1/3} \]

Where,

\( Nu \) - Nusselt number  
\( h \) - Heat transfer coefficient (W/m²-K)  
\( D \) - Diameter of Domain (m)  
\( K \) - Thermal conductivity (W/m-K)  
\( Re \) - Reynolds number  
If \( Re > 2300 \) (Flow is Turbulent)

Reynolds number

\[ Re = \frac{\rho V D}{\mu} \]

\[ = (1060 \times 0.5 \times 0.16) / 0.004 \]

\[ = 2.12 \times 10^4 \], hence flow is turbulent

Where,

\( \rho \) - Density of blood (kg/m³)  
\( V \) - velocity of blood (m/s)
μ - Dynamic viscosity (kg/m-s)
Prandtl number
\[ Pr = \frac{\mu}{C_p/k} = 0.004 \times 3594 / 0.543 \]
\[ Pr = 26.48 \]
Where,
Cp - coefficient of performance (kJ/kg-K)
\[
\frac{h \times 0.16}{0.543} = 0.023 \times (2.12 \times 10^4)^{0.8} \times (26.48)^{1/3}
\]
\[ h = 655.27 \text{ W/m}^2\text{-K} \]

B. CFD analysis of bone attached plate material

A 3D model of bone attached flat plate is used in our analysis. CATIA v5 R18 is used for creating the model.
Figure 2.3 Surface Mesh Model

Figure 2.4 surface mesh models with bone plate

Figure 2.4 shows surface mesh of bone attached plate material. It consists of 36936 elements for bone and plate consists of 6048 elements.
Figure 2.5 Mesh Cut plane of Bone With plate

The figure 2.5 indicates the mesh cut plane of the volume mesh of bone and plate. It consists of unstructured tetrahedral elements.

Figure 2.6 Volume Mesh Model

The figure 2.6 indicates the volume mesh of bone, plate and the domain. It consists of unstructured tetrahedral elements of 906079 and nodes of 165456.
Figure 2.7 Domains in CFX

The Figure 2.7 shows the domain model of bone with plate in CFX. Domain created on the basis of the conditions inlet velocity 0.5 m/s, inlet temperature 305K, outlet pressure 0 Pa. Image indicates only the inlet and outlet directions of blood flow in the domain.

III. RESULTS AND DISCUSSIONS

A. CFD result for wall heat transfer coefficient

Figure 3.1 Result Image of Wall Heat Transfer Co-efficient

The figure 3.1 indicates the wall heat transfer value of bone attached plate material in which maximum and minimum values are 1857 W/m²K, 0.000001 W/m²K respectively.
**B. Temperature contour of bone plate**

The fig 3.2 indicates the temperature contour value at maximum and minimum range. The values are 305.5K, 305K respectively. This result indicates temperature variation is less in nature after the plate attached with bone.

![Temperature Contour of Bone Plate](image1)

**C. CFD model of velocity contour**

The velocity contour of the bone plate material has been shown in Figure 3.3 based on inlet velocity of 0.5m/s.

![CFD model of velocity contour](image2)
C. CFD model of velocity vector

The velocity vector of the bone plate material has been shown in Figure 3.4 based on inlet velocity of 0.5m/s.

![Figure 3.4 Velocity Vector](image1)

The figure 3.4 shows the velocity vector for inlet velocity of 0.05m/s in which maximum and minimum values 0.679m/s and 0m/s. this image shows velocity around the plate material is less and its negligible which does not affect the blood flow. Vectors show the direction of blood flow.

![Figure 3.5 Solution convergence graph](image2)

The above Figure 3.5 indicates the convergence. Final convergence is decided based on maximum residuals of the order of $10^{-4}$ in mass, momentum etc. The computations were carried out on Microsoft windows XP professional 32 bit Edition using Pentium dual core processor of 4 GB Ram. Convergence is reached in about 115 iterations, which took about 3 to 4 hours for the given condition.
D. Temperature variation along axial direction of plate material

The Figure 3.6 shows the temperature Vs distance which is obtained for the inlet temperature of 305K. The starting line indicates the wall temperature value of plate material. This graphical result clearly shows temperature variation around plate material is very less.

D. Velocity variation along axial direction of plate material

The above Figure 3.7 shows the distance Vs velocity which shows velocity variation along axial direction of plate material for the input velocity of 0.5m/s. The ideal line indicates the exact position of plate material. Velocity value is at the layer of plate material is zero.
E. Wall adjacent temperature variation along axial direction of plate material

The above Figure 3.8 shows the distance Vs Wall adjacent temperature which shows Wall adjacent temperature variation along axial direction of plate material for the input velocity of 0.5m/s, inlet temperature of 305K. The ideal line indicates the exact position of plate material. Temperature value is at the layer of plate material is 305K.

TABLE II. Comparisons of Results

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>MANUAL Heat Transfer Co-efficient (h) w/m²-k</th>
<th>CFD Heat Transfer Co-efficient (h) w/m²-k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sisal and Roselle (hybrid) Particle reinforced composite</td>
<td>655.27</td>
<td>695.75</td>
</tr>
</tbody>
</table>
CONCLUSION

In this research Sisal and Roselle fiber particle reinforced composite plate material’s Thermal Heat transfer coefficient has been calculated manually (655.27 w/m²–k) and CFD (695.75 w/m²–k) both the results are found to be good in agreement.

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REFERENCES

Journals


Books


External Links

[1] CFD Tutorial Many examples and images, with references to robotic fish.
[2] CFD-Wiki
[3] Course: Introduction to CFD – Dmitri Kuzmin (Dortmund University of Technology)