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Experimental investigation of flexural strength on Honeycomb composite materials using Python Programming

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Honeycomb structures are often natural or artificial assemblies, which have the similar geometrical shape of a honeycomb and are used to get the expected strength by minimize the amount of used material, reduce the weight and cost of the materials. The advantages of honeycomb sandwich structures when compared to conventional structures are that it provides: very low weight, production cost savings, durability and high stiffness. Acrylic Honeycomb structures are made-up of unique core material that offers advantages such as good impact strength, transparency, resistance to breakage, elasticity, good weatherability, good heat resistance, excellent dimensional stability. Honeycomb sandwich composite fabricated by using Acrylic honeycomb sheet as a core material along with carbon fiber reinforced polymers (CFRP) and glass fiber reinforced polymers (GFRP) as face sheets. The main objective of this paper is to evaluate the Flexural strength of Honeycomb sandwich composite and calculate the values from the Python Libraries such as NumPy and Matplotlib.

Keywords: Honeycomb, Carbon fiber, Glass fiber, Face sheets , Flexural strength, NumPy, Matplotlib.

1. Introduction

Nowadays, Python is one of the mostly used Object Oriented Programming Languages and more libraries are being developed for various purposes. This has edge over other programming languages in such a way that the length or lines code is lesser when compared to its counterparts. For calculating the Flexural strength of Honeycomb composite structures availability of many libraries used. The advantages of honeycomb sandwich structures, when compared to conventional structures, are that it provides: very low weight, production cost savings, durability, and high stiffness. Honeycomb cores find wide applications in sandwich structures where there is primary function is to resist transverse shear loads similar to the web in the I-section beam. Generally, an aluminum honeycomb core is used in applications requiring sandwich construction with Fiber-reinforced composite face sheets. Composite materials, such as glass fiber or carbon fiber reinforced plastics are suited for sandwich construction methods due to their low weight, high stiffness, high strength, dimensional stability, and ease of manufacture. Sandwich panels are used for design and construction of lightweight transportation systems such as satellites, aircraft, missiles, high speed trains and biomedical applications. R Cimrmana et al. [1] have investigated SfePy (Simple finite elements in Python) is a software for solving various kinds of problems described by partial differential equations in one, two or three spatial dimensions by the Finite element method. Borden MJ et al. [2] have worked on a two-scale piezoelastic model is presented, showing both the mathematical definition of the problem and it corresponding code implementation. Bradshaw et al. [3] have implemented the core functionality of the Cython compiler which was similar to that of Python and has written the libraries to support the FEM Analysis. Dipak G. Vamja and G. G. Tejani [4] have selected composite material of Aluminium as skin material and polyethylene as core material for fabricating the composite material. They reported that tensile strength and bending strength with hexagonal composite material is less compared to without hexagonal composite material. F. Ernesto Penado [5] has conducted experiment on composite core and aluminium core as honeycomb and fibers as faces sheet. Finite element analysis also conducted to represent the unit cell. Composite core showed that the transverse shear moduli are always higher than those of aluminum for the same core density. K. Kantha Rao et al. [6] have selected several core shapes such as aluminum, titanium and high tensile steel and material for the construction of sandwich among them, it has been known that the aluminum honeycomb core exhibit excellent mechanical properties with regards to weight savings and fabrication costs. They concluded that the wall thickness of a honeycomb core cell is a critical variable affecting the crushing strength of the sandwich panels subject to lateral pressure loads. Ajinkay R. Bagade and Prashant M. Kulkarni [7] have conducted bending test on the aluminum honeycomb sandwich beam specimen, varying the honeycomb core cell thickness, core cell sizes. They observed that with an increase in the thickness of honeycomb core cell, the start of plastic deformation could be delayed, resulting in increase of ultimate strength. The study reveal that honeycomb panel structural behaviuor is mainly depends on its face sheet thickness and core height & core thickness. By increasing the thickness and core geometry as in a desirable manner, the flexural strength of the honeycomb panel improves. Shaik.Nazeer and Shaik Allabakshu [8] have considered different types of honeycomb core structures like square, hexagonal, pentagonal, tetrahedral, pyramidal etc in this study. They conduct structural and thermal analysis for square and hexagonal honeycomb structures. Structural analysis are being used to determine the effects of loads on the physical structure. Thermal analysis to calculate the temperature distribution and related thermal quantities in the system or component of the composite materials. They concluded that aluminium honeycomb has less deflection and also less weight and cost comparing to other materials like titanium. Pankaj Goswami [9] has selected Aramid honeycombs because of as ultra-lightweight material, good thermal and fire retardant properties Aluminium honeycomb possess highest strength to weight ratio but due to its corrosive nature it cannot be installed in marine application and building insulation. Hexagonal honeycomb structure of aramid fiber filled its core with silica aerogel to make it mechanical, corrosive as well as thermal resistant for building insulation or like other applications. Md. Jabihulla Shariff and R. Satya Meher [10] have selected two different core structures like Hexagonal and Rhombus and aluminium as face sheet. They observed that composite material having hexagonal structure weight is less compared with rhombus structure. The weight difference between two structures is small, but tensile strength and bending strength of hexagonal shaped structure is less compared with rhombus shaped structure. From the thorough literature review, it has been found that Acrylic honeycomb composites and applications of python programming has not yet addressed anywhere. Many researchers concentrate the studies on honeycomb composites, which is made up of Aluminium or Paper as a core material and glass or carbon as face sheet.

Therefore, in the present study on the Flexural Properties an Acrylic polymer is selected as hexagonal shaped honeycomb material, which act as a core material and glass/carbon fibers as a face sheets for fabricating the honeycomb composite. Flexural Test conducted on Universal Testing Machine and Structural analysis has been carried out to determine the effects of loads on physical structure using NumPy and Matplotlib libraries from Python. The results of such an analysis are supposed to be including forces, stresses, stiffness matrix and displacements.

2. Materials

2.1 Acrylic Sheet

Acrylic sheet is a combustible thermoplastic material. It observes the fire precautions appropriate for comparable forms of wood and paper products. The features that are making it most preferred in the industry of the composite materials are: excellent appearance, easy repair and simple processing technique.

Fig 1. Acrylic Sheet

2.2 Glass Fiber

The composites used today in the industry are made of glass fibers. Fiber glass composite materials exhibit significant reduction in the weight than the conventional materials like steel. Fiber glass may be a lightweight, extremely strong, and robust material. The fiber glass materials are usually less brittle and more elongation and also less cost compared to other fibers. Its bulk strength and weight properties also are very favourable compared to metals, and it is easy to fabricate by using moulding processes. Common applications of fiber glass include high performance aircrafts, boats, automobiles, water tanks, roofing and pipes etc.

Fig 2. Glass Fiber Reinforced Polymers

2.3 Carbon Fiber

The atoms of carbon are bonded together in microscopic crystals that are more or less aligned parallel to the long axis of the fibers. The crystal alignment makes the fiber sheet very strong based on its size. Several carbon fibers are twisted together to form a yarn, which may be used by itself or woven into a fabric. Carbon fiber has many different weave patterns and can be combined with a plastic resin moulded to form composite materials such as carbon fiber reinforced polymer to provide a high strength to weight ratio material. The density of carbon fiber is additionally considerable less than the density of steel, making it ideal for applications requiring low weight. The cost of the carbon fibers is more compared to other fibers like glass. The properties of carbon fiber like high strength , low weight, and low thermal expansion make it very fashionable in aerospace, electronics, military, packaging, sports, construction and automotive industries.

Fig 3. Carbon Fiber Reinforced Polymers

2.4 Resin and Hardener

Epoxy resin is used to give great bonding properties between the fiber layers to form the matrix. The Epoxy resin used at room temperature is LY 556. The epoxy is chosen as the polymer matrix amidst other matrices because of its good mechanical strength, chemical resistance and service temperature requirements. Hardener (HY 951) is employed to improve the interfacial adhesion and impart strength to the composite. Here the resin and hardener mixture of 10:1 is used to obtain optimum matrix composition.

Fig 4. Epoxy Resin and Hardener

3. Fabrication Procedure for specimens

The Acrylic Honeycomb structure (figure 6) is manufactured on CNC machine by cutting the Acrylic Sheet of 2 mm thickness with the Hexagonal shapes of 10 mm size and 3.1 mm of wall thickness as shown in figure 5.

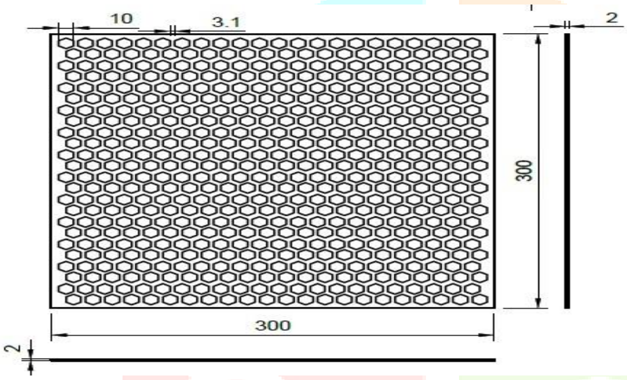


Figure :5 Honey comb structure specifications

Figure : 6 Honey comb structure

The CNC machining process should be carried at an optimum temperature so that the Acrylic material doesn't melt during the cutting procedure. Material should be removed properly from the Acrylic sheet so that the edges of the hexagonal shape are not disturbed and are intact with the expected thickness and size. The Acrylic Honeycomb structure prepared in CNC machine as shown in figure 7.

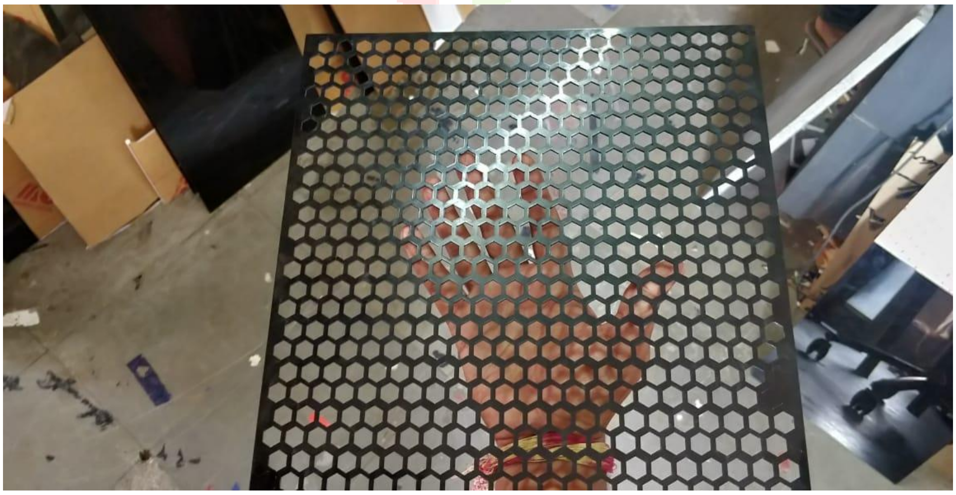


Figure :7 Honeycomb structure prepared in CNC machine

The composite material is fabricated by using hand layup technique with a mixing ratio of resin (epoxy) and hardener is 10:1. The mould surface is cleaned with Acetone and thereafter the releasing agent (wax) is applied. A thin layer of epoxy resin that is selected for the manufacturing process is applied on the mould. The glass fiber sheets and carbon fiber sheets have an aerial density of 420 G.S.M. The glass fiber reinforced polymer sheets are then completely filled with epoxy resin and rolled to squeeze the entrapped air and to uniformly spread the mixture. In this way the layers of glass fiber reinforced polymer sheets are placed one over the other to obtain the required thickness of the glass fiber face sheet. Now place the Acrylic honeycomb structure on the glass fiber sheet formed. Now on top of the Acrylic honeycomb, the carbon fiber reinforced polymer sheets are placed similar to the glass fiber face sheet. Now a load of around 10 kilograms is applied for a curing period of 9-10 hours on the mould. This gives the required composite laminates which can be made to required size by cutting the sides. Sandwich with honeycomb structure with CFRP on one side and GFRP on other side of size 300 x 300 x 4 mm are manufactured by using hand lay-up technique as shown in figure 8.

Figure : 8 The Honeycomb CFRP –Acrylic - GFRP Composite laminate

4. Python Libraries

Python is an object oriented Programming Language that can be used to calculate and plot the Mechanical Properties of composites in a very easy manner with the use of many libraries that are available. Here mentioned some of the libraries that are most widely used in the industry standards.

NumPy: NumPy arrays are the primary data structure used and provide the basic vector and matrix manipulation operations.

Matplotlib: plotting package, Matplotlib is used to generate custom microstructure visualizations.

SciPy: SciPy's signal processing and numerical linear algebra functions are used to calibrate models and generate synthetic data.

Scikit-learn: Scikit-learn is simple API in order to leverage from Scikit-learn's data pipeling methodology for machine learning and data transformations.

SfePy : Simple Finite Elements in Python, SfePy is used to simulate linear elasticity to create sample response field data.

pyFFTW : FFTW library, python wrapper, PyFFTW is a highly optimized fast Fourier transform library that enhances the efficiency and enables parallel computations.

In this analysis consider numpy and matplotlib for the calculation and plotting the graph for the flexural strength.

5. Testing Results

5.1 Flexural Strength

Flexural tests are conducted to check for composite material properties against the bending forces with rectangular samples according to ASTM D -790 using a universal testing machine (figure 10), fitted with a three-point bending fixture at a cross-head with a speed of 2mm/min. The flexural strength specimen details are shown in figure 9. In this system, a centre loading is utilised on a simply supported beam. The values are taken from an average of 3 specimens for each composite and each composition. The flexural strength braking specimens are shown in figure 11. The average flexural strength of the honeycomb sandwich composite is 201.8 MPa. The average Flexural strength results shown in table 2 and deflection Vs Load graph shown in figure 12.

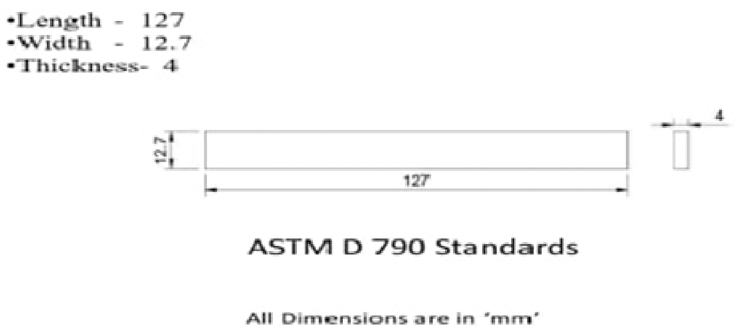


Figure 9: Flexural Strength Specimen

Fig :10 Flexural strength testing machine

Fig :11 Flexural Test Breaking specimens

Table: 2

Flexural Strength Results

Ref. Standard	**ASTM D790**		
Specimen code	**CC-A-GG-01**	**CC-A-GG-02**	**CC-A-GG-03**
Yield Force (N)	487.2154414	393.381	326.673
Yield Deflection (mm)	4.22	3.49	2.75
Max Force (N)	560.9	459.9	409.9
Flexural Strength @ Max (MPa)	243.6931319	191.2591672	170.4612621
Flexural Strain	0.02992156	0.030596161	0.024308097
Flexural Modulus at 1% Strain (MPa)	40874.98	31386.12	27973.13
FLEXURAL MODULUS OF ELASTICITY (N/mm^2)	5183.679797	3910.410106	3360.56505
Average FLEXURAL MODULUS OF ELASTICITY (MPa)	4151.55		
Average Flexural Strength (MPa)	201.8 MPa.		

Flexural Test Results CC-A-GG

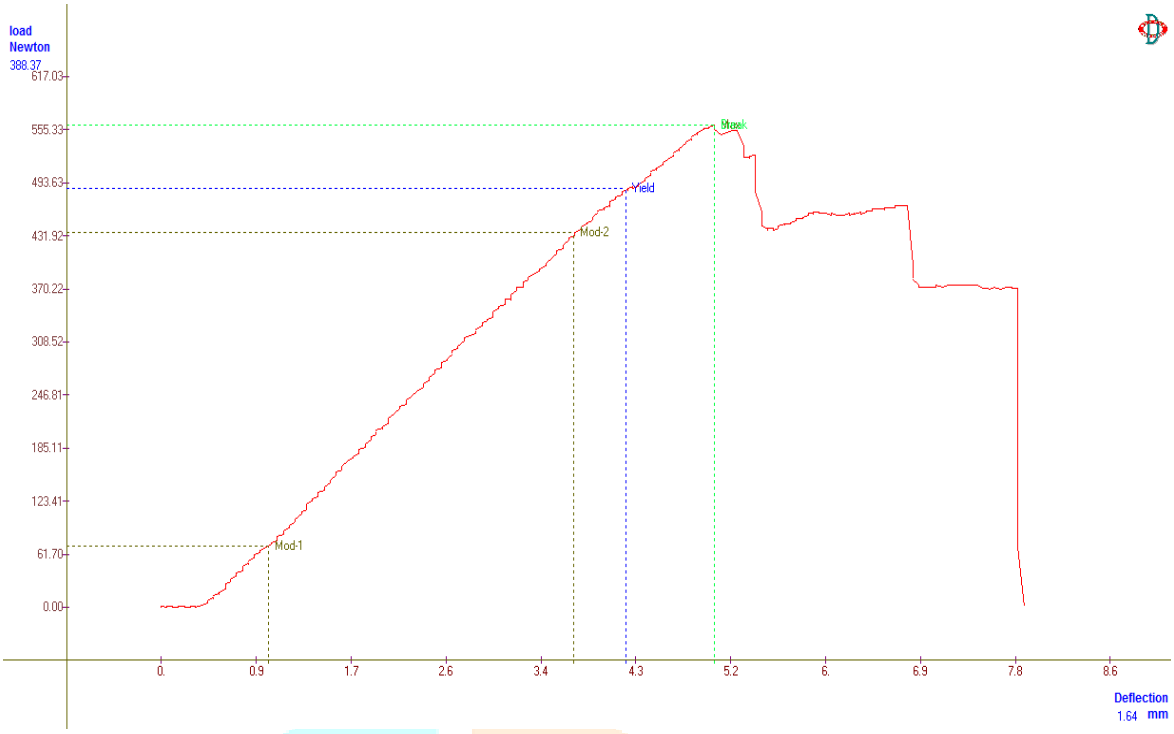


Figure :12 Flexural strength Graph (Deflection –Vs Load)

6. Python Implementation and Calculated Results

In this study NumPy and Matplotlib libraries are used from Python to get the calculation and generate the graph for Flexural tests simulation.

6.1 Algorithm

Step 1. Get the required input data such as length, Force, Modulus of Elasticity, width, depth, slope or gradient at Node1, and Number of Mesh Elements.

Step 2. Calculate the Flexural Modulus of Elasticity using the formulae

$$\mathbf{E_f} = m\,L^3/4bd^3$$

m- slope or gradient at Node1 in N/mm^2

L – length of the beam in mm

B - width of beam in mm

d – thickness or depth of beam in mm

Step 3. Matrix formulation is to be calculated using NumPy methods and save the Force Matrix as txt file

Step 4. Assembly of Stiffness matrix formulation is done using the NumPy Library and save the Stiffness matrix as txt file

Step 5. Boundary calculation using NumPy library for Deflection calculation

Step 6. Plotting the graph for Deflection forces and Length and saving the Graph as .PNG image file.

6.2 Python Program

```
#-------------------------------------------------------------------------------
# Name:        Flexural Test for Calculating Flexural Modulus
# Purpose: To Simulate the Calculation of Flexural Modulus of Elasticity
```

```
# Author:      venug
# Created:     20/07/2020
# Copyright:   (c) venug 2020
#-------------------------------------------------------------------------------
import numpy as np
from matplotlib import pyplot as plt
###########________________Welcome_____________##########
print("\n______________  Analysis of Flexural Tests  ___________\n")
print('\n|            P\n|________________\u2193\n|      L')
############-----------Get Input Data--------##########
L = float(input("\nEnter the Length of the specimen 'L' in mm: "))
P = float(input("Enter the Force 'P' in N: "))
E = float(input("Enter the Modulous of Elasticity 'E' of specimen in N/mm^2 :"))
b = float(input("Enter the width of the Specimen in mm: "))
d = float(input("Enter the depth of the Specimen in mm: "))
m_slope=float(input("Enter the gradient or slope in N/mm - consider the value from the graph at nod1 : "))
mesh = int(input("Enter the number of mesh elements: "))
el = float(L/mesh)
#Flexural Modulus of Elasticity Calculation
n1=L*L*L
n2=n1*m_slope
d1=d*d*d
d2=4*b*d1
E_f=float(n2/d2)
########------------Matrix formulation for the Forces--------##########
Force = np.array([[-P],[0]])
F = np.zeros(2*mesh+2)
F[2*mesh:1+2*mesh] = F[2*mesh:1+2*mesh]+Force[0]
print("\nForce Matrix :")
for i in F:
   print(i)
kb = ((E*b*(d**3))/(12*(el**3)))*np.array([[12,6*el,-12,6*el],
                              [6*el,4*el*el,-6*el,2*el*el],
              [-12,-6*el,12,-6*el],[6*el,2*el*el,-6*el,4*el*el]])
```

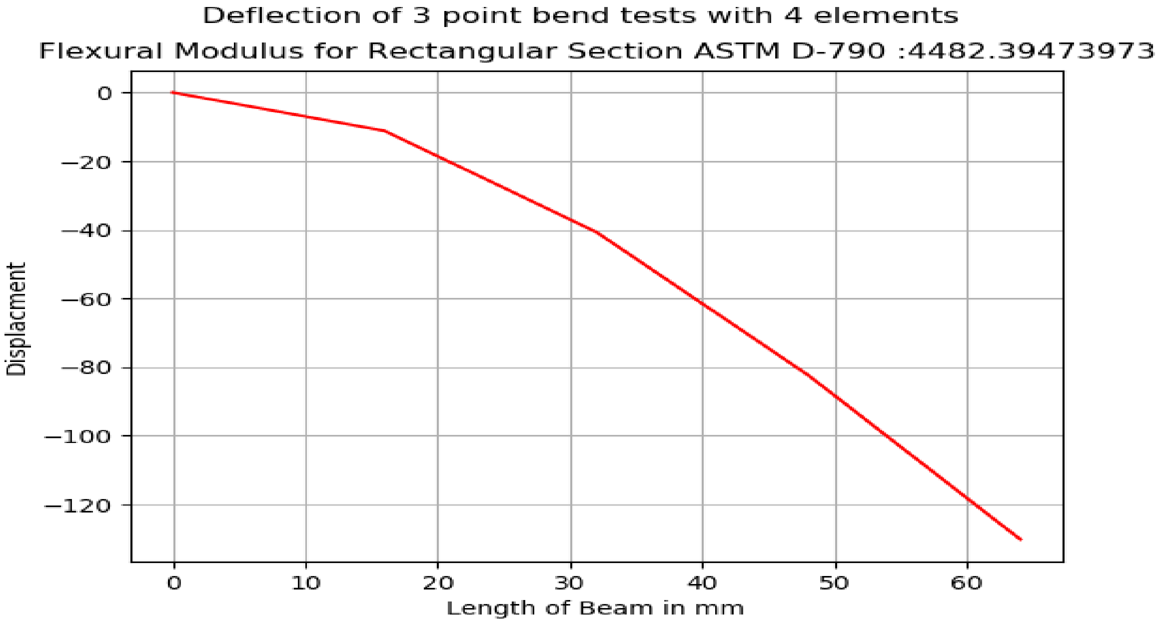
```
print("\nElement stiffness matrix K : \n",kb)
K = np.zeros((2+2*mesh,2+2*mesh))
for i in range(4):
    for j in range(4):
        K[i,j]=kb[i,j]
print(K)
np.savetxt('ForceMatrix.txt',K)
###############-----------Assembly of stiffness matrix-----#########
k=1
while k<=2*mesh-2:
    p=k
    i=1
    while i<=4:
        j=1
        q=k
        while j<=4:
            K[p+1,q+1]=K[p+1,q+1]+kb[i-1,j-1]
            j=j+1
            q=q+1
        i=i+1
        p=p+1
    k=k+2
print(K)
np.savetxt('stiffnessMatrix.txt',K)
###############----------Boundry condition Calculation------------##########
Kinv = np.linalg.inv(K[2:2+2*mesh,2:2+2*mesh])
D = np.zeros((2+2*mesh))
D[2:2+2*mesh] = np.dot(Kinv,F[2:2+2*mesh])
print("\ndisplacement matrix : \n")
for i in D:
    print(i)
#########---------------Ploting the graph-----------$$$$$$$$$$$$%%%%
x = np.arange(0,L+el,el)
y = np.zeros((mesh+1))
p=0
```

```
for i in range(2+2*mesh):
    if i%2==0:
        y[p]=D[i]
        p=p+1
np.savetxt(""+str(mesh)+"Element X.txt",x,delimiter=",")
np.savetxt(""+str(mesh)+"Element Y.txt",y,delimiter=",")
plt.plot(x,y,"-r")
plt.grid()
plt.title("Flexural Modulus for Rectangular Section ASTM D-790 :" +str(E_f))
plt.suptitle("Deflection of 3 point bend tests with "+str(mesh)+" elements")
plt.xlabel("Length of Beam in mm")
plt.ylabel("Displacment")
plt.savefig(""+str(mesh)+" Element.png")
plt.show()
```

6.3 Inputs to the Python Program and Corresponding Outputs

Ref. Standard	**ASTM D790**		
Specimen code	**CC-A-GG-01**	**CC-A-GG-02**	**CC-A-GG-03**
Span Length l (mm)	64	64	64
Sample Width b (mm)	13.34	13.34	13.34
Sample Thickness d (mm)	4.07	4.16	4.16
Max Force F (N)	560.9	459.9	409.9
Slope or Gradient (N/mm2)	61.79	50.5	49.19
Number of Mesh Elements	4	4	4
Calculated FLEXURAL MODULUS OF ELASTICITY (MPa)	4482	3889	4049
Average FLEXURAL MODULUS OF ELASTICITY (MPa)	4140		

6.4 Output Result from the Program



7. Conclusions

Carbon fiber Reinforced Polymer (CFRP), Acrylic and Glass fiber Reinforced Polymers (GFRP) honeycomb composite materials are fabricated and tested the mechanical properties like Flexural strength. A Python Program has developed using NumPy and Matplotlib libraries. The Following conclusions are drawn from the test results mentioned below:

- Flexural Tests conducted on the CC-A-GG specimens are exhibiting an average "**Flexural Modulus of Elasticity**" of 4151.55 MPa.
- Flexural Tests Program executed with the inputs from that of the Tests conducted is calculating the average of "**Flexural Modulus of Elasticity**" as 4041.76 MPa.

From the above experimental data and the results from the Python Program, it can be concluded that the Honeycomb composite material formed by Carbon fiber Reinforced Polymer(CFRP) and Glass fiber Reinforced Polymers (GFRP) along with Acrylic Honeycomb shows almost close results for average Flexural Modulus of Elasticity.

REFERENCES

1. R. Cimrmana, V. Lukesb, E. Rohanb , Multi-scale finite element calculations in Python using SfePy, International Journal of Science and Research, Preprint submitted to Advances in Computational Mathematics October 2, 2018

2. Borden MJ, Scott MA, Evans JA, Hughes TJR (2011) Iso-geometric finite element analysis data structures based on Bezier extraction of NURBS. Int J Numer Meth Engng 87:15{47, DOI 10.1002/nme.2968.

3. Bradshaw R, Behnel S, Seljebotn DS, Ewing G, et al. (2018) The Cython compiler . Http://cython.org, Accessed 25 September 2018.

4. Dipak G. Vamja, G. G. Tejani, Experimental Test on Sandwich Panel Composite Material, International Journal of Innovative Research in Science, Engineering and Technology, 2(7), 2013, 3047-3054.

5. F. Ernesto Penado, Effective Elastic Properties of Honeycomb Core with Fiber-Reinforced Composite Cells, Journal of Composite Materials, 3, 2013, 89-96.

6. K.Kantha Rao, K et al. (2012), Strength Analysis on Honeycomb Sandwich Panels of different Materials, submitted at International Journal of Engineering Research and Applications, 2(3), 2012, 365-374.

7. Ajinkay R. Bagade, Prashant M. Kulkarni, Experimental Analysis of Aluminum Honeycomb Sandwich Panel, International Journal for Scientific Research & Development, 6(12), 2019, 226-232.

8. Shaik.Nazeer et al. (2015), Design and Analysis of Honey Comb Structures with Different Cases, published in International Journal of Engineering Development and Research, 3(4), 2015, 144-156.

9. Pankaj Goswami , Thermal Insulation analysis of an Aramid honeycomb Sandwich Structure Filled with Silica Aerogel, International Journal of Engineering Research in Mechanical and Civil Engineering, 3(7), 2018, 1-6.

10. Md. Jabihulla Shariff, R. Satya Meher, Design Modulation of Composite Material Sandwich Panels with Different Inner Polyethylene Core Structures, International Journal of Engineering Research & Technology, 3(11), 2014, 404-408.