CHAPTER 1

INRODUCTION

Electrical energy is one of the most vital form of energy needed for various operations in aircraft. Majority of the subsystems in aircraft such as avionics system, cockpit control system, engine fire system runs on electrical energy. Presently, electrical energy is produced onboard by taking some proportion of power from the turbine of aircraft. During this mechanical extraction there will be loss of energy due to low efficiency of reduction gears. More over due to this extraction it reduces the output of turbine, as it not only gives energy to electrical system but also drives compressor through the shaft. The goal of the power harvesting device is to utilize the energy of a system, which is lost to the surroundings and convert it into feasible energy for the electrical device consumption. Electronics that do not depend on finite power supplies, such as batteries, can be supplied continuous power by utilizing this untapped energy. Here we use piezoelectric materials as potential energy harvesters, which produces electrical energy from mechanical vibrations. A piezoelectric material is proposed which extracts mechanical vibrations and provide electrical output in more efficient, clean and reliable manner.

1.1 FORCES AND VIBRATIONS ACTING ON THE AIRCRAFT

As the aircraft are built with huge structures like wings, vertical stabilizers etc, which are subjected to huge mechanical loading during the flights. Thus, one can utilize the energy produced during the mechanical vibration of aircraft wing. Most of these aircraft wings are built with the laminated composites. The amount of stress that the aircraft structure is subjected to immense as a result of which the aircraft experiences the vibrational loads, utilizing this stress and implementing piezoelectric materials to convert this vibrations and forces into useful electricity.

Vibration of lifting surfaces have significant influence on the airplane dynamic parameters. For example, in the commercial aviation varying aerodynamic forces and moments acting on the airplane as an effect of the structural vibrations, produce variable gravity loads lowering the journey comfort. Those factors worsen concentration of the aircrew and fatigue to passengers.

During flight the loads imposed on the wing structure act as preliminary on skin. On the skin, the loads are transmitted to the ribs and then to the spars. The spar supports distributed loads along concentrated weights such as fuselage, landing gears.

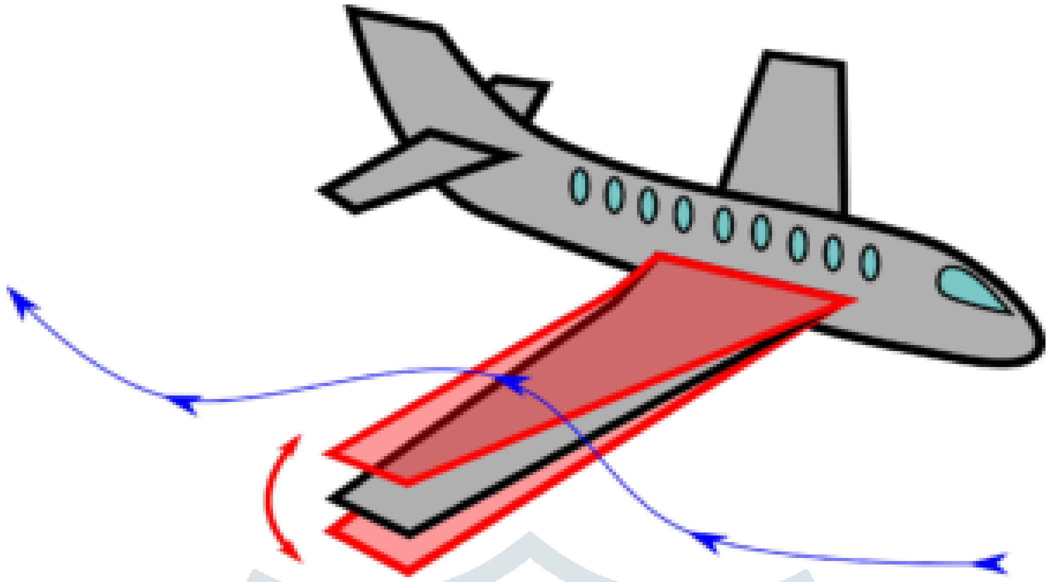

Fig. 1.1. Aircraft wing vibration. [1]

The wing root is fixed to the fuselage, but wing tip can experience twisting at tip due to its cantilever beams. The air flow over the wing creates lift, but also creates a twisting moment. A longest body in a fluid stream wants to position itself perpendicular to the stream, that is why we need the tail assembly of an aircraft. So, the wing would like to position itself perpendicular to free stream the tip is twisted by the stream and stopped by the torsion stiffness of the wing box. The torsion stiffness and the damping needed to be sufficiently high to stop the construction from the over shooting, and then being pulled back and over shooting.

By moving the centre of gravity of the wing closer to the centre of twist and by raising the frequency of the flutter by making the wing stiffer and lighter can also set the maximal allowed airspeed below the speed at that the flutter occurs. It is almost impossible to control the vibration of aircraft wings because of its cantilever structure and environmental turbulence.

1.2 PIEZOELECTRIC MATERIALS

Piezoelectric materials belong to a larger class of materials called ferroelectrics. One of the defining traits of a ferroelectric material is that the molecular structure is oriented such that the material exhibits a local charge separation, known as an electric dipole. They exist in natural form but for our desired properties they are doped with metallic ions to increase its efficiency and sometimes artificial piezoelectric are used as they are manufactured according to the given requirement. The piezoelectric effect exists in two domains, the first is the direct piezoelectric effect that describes the material's ability to transform mechanical strain into electrical charge, the second form is the converse effect, which is the ability to convert an applied electrical potential into mechanical strain energy.

The direct piezoelectric effect is responsible for the material's ability to function as a sensor and the converse piezoelectric effect is accountable for its ability to function as an actuator. A material is deemed piezoelectric when it has this ability to transform electrical energy into mechanical strain energy, and the likewise transform mechanical strain energy into electrical charge.

Table 1.1 Different types of Piezoelectric Material.

S.No	TYPE	MATERIAL
1.	Single Crystals	Quartz Lead Magnesium Niobate
2.	Ceramics	Lead Zirconate Titanate (PZT) Lead Metaniobate (LMN) Lead Titanate (LT)
3.	Polymers	Poly vinylenedifluoride (PVDF)
4.	Composite	Ceramic Polymer Ceramic Glass

1.2.1 PIEZOELECTRICITY/PIEZOELECTRIC EFFECT

The phenomenon of piezoelectricity can be defined as the generation of electrical energy from certain solid material or salts when mechanical stress acts on them. It must be started that the inverse of this concept is also applicable, that is, when electric energy is supplied to any piezoelectric material it results in mechanical strain in that material. This phenomenon was discovered by Pierre and his brother Curie in 1880.

Hence if piezoelectric materials must be implemented to harness electrical energy then the sources of the mechanical vibration and forces must be natural, or they should be produced of any other process. Only this would serve the purpose to generate and harvest clean electrical energy without any substantial losses.

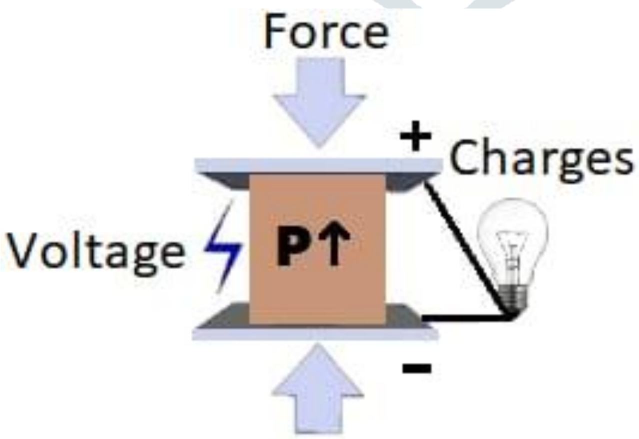

Fig. 1.2. Piezoelectric effect. [3]

The aircraft structure is a source of huge amount of mechanical stresses which would be equal to a lot of energy that just goes to waste, unutilized during every flight. Hence, it would not be a bad idea to try to use the mechanical energy, which is a by-product of the normal flight of the aircraft of the normal flight of the aircraft to activate the piezoelectric material and to utilize the electricity; hence generated to operate the various components of the aircraft that require electricity. Piezoelectric materials are already used in many aircraft to nullify the strain caused on the aircraft structure by the gust load that act on the aircraft. Piezoelectric macro fibre composite under the deformation due to the influence of gust load is activated by supplying electricity to

picture and the macro fibre composites embedded path reduces the deformation.

Today, the balance between weight and energy storage is a compromise between the conflicting requirements of making the vehicle more energy efficient and having a long range. One path towards reducing the weight of the aircraft while storing the same amount of energy is to exchange the vehicle structure with structural batteries. Structural batteries are the material that store electrical energy while being a part of load carrying structure itself.

In order to fulfil the requirement of low weight and energy store at the same time all different parts of the structural battery must work together. It has been previously found that that the carbon fibre are good material ads a component, since the fibre perform very well at carrying load and at the same time can intercalate the lithium ions as the same way as negative electrode in a commercial lithium ion battery.

1.3 CARBON FIBRE IN AIRCRAFT

Reducing weight of the aircraft has become a priority in the aircraft industry seeks greater fuel efficiency, the biggest weight reduction in the aircraft across the board has been the use of the composite materials such as carbon fibre polymers.

Fig. 1.3. Carbon fibre in aircraft as structure.

The versality of the carbon fibre materials offers an ideal opportunity to develop multifunctional composites which can store electrical energy required to power the systems, while meeting the demands of the mechanical loadings. Carbon fibres are particularly attractive as they are commonly used as both electrode and high performances structural reinforcement.

1.4 CARBON FIBRE AS STRUCTURAL BATTERY

Batteries use control redox reaction to convert stored chemical energy into electrical energy. A battery has three major parts they are as an anode, a cathode and electrolyte. In lithium ion battery the active ion is intercalated and extracted from the electrode during charge and discharge. The electrolyte is an ion conductive medium of polymer and salt. During discharge, ions are transported through the electrolyte, from anode to the cathode. Electrons are transported from the electrodes via an outer circuit. It is a common practice to manufacture thin electrode and electrolytes in aircraft batteries.

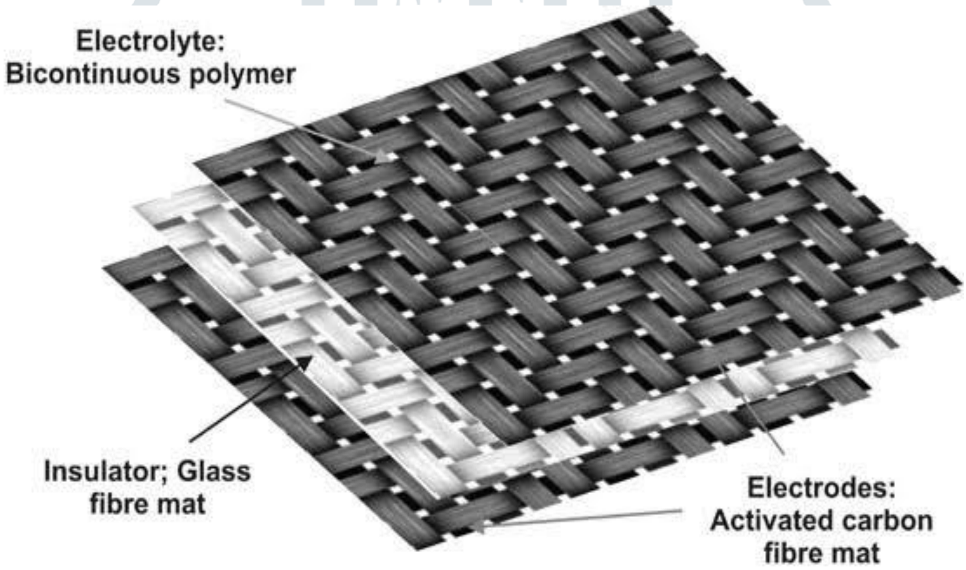

Fig. 1.4. Carbon fibre structural battery.

Hence, to create a carbon fibre based structural battery a solid polymer electrolyte should be combined with the carbon fibres to form a composite material. The solid polymer electrolyte should be designed to perform two functions namely, to transfer the mechanical load to reinforcing fibre and to enable ion transfer between negative and positive electrodes during the charging or discharging of the structural battery.

This brings challenging in manufacturing, material selection and material characterisation. The load carrying batteries are evaluated regarding both their mechanical stiffness and electrical characteristics. Since the batteries are to be used as multifunctional composite the properties are not par with the single functional composites.

CHAPTER 2

METHOD AND METHODOLOGY

The purpose of this project is to show that piezoelectric materials, if applied in a proper way on an aircraft structure can be used to generate electricity that would be available from the vibration of the components of the aircraft. That could be stored in the carbon fibre battery fabricated using the multifunctional composite materials, separator, and gel electrolyte.

Aim: The main aim of this project is to investigate the performance of piezoelectric materials under vibrations and try to implement them for the purpose of the electricity harvesting in aircraft by storing in structural battery made from carbon fibre composite material.

2.1 MANUFACTURING PROCESS

Both the piezoelectric polymer composite and the carbon fibre structural batteries were manufacture under required conditions as mentioned below.

2.1.1 FABRICATION OF PIEZOELECTRIC COMPOSITE

The specimen is prepared by embedding the piezoelectric material in the polymer as per the requirements, then the testing is carried out to find the amount of power generated with PFC-W14.

MATERIAL USED

The following materials will be used for the fabrication of piezoelectric fibre embedded in composite construction

a) Piezoelectric fibres: PFC-W14
b) Glass fibre: Structural glass fibre
c) Epoxy: -

Resin: Araldite CY230-1, Hardener: Aradur HY 951

FABRICATION PROCESS

The fabrication of the piezoelectric composite is carried out using vacuum assisted resin transfer technique

a) Select required mould as per the specimen that has to be fabricated.
b) Clean the mould using acetone or any cleaning agent.
c) Place the peel ply on the mould so that the proper release of the mould can occur.
d) Stack the glass fibre layer by layer with epoxy and to place the piezo.
e) Wax the surface with PVA then clean with cotton.
f) Tape the edges with sealant tape for all sides.
g) Place the peel ply mesh on top of the glass fibre.
h) As the dimension of the specimen place caul plate or silicon rubber.

i) Place the vacuum line with spiral then place the breather so has to have a continuous vacuum passage, then place the breather and vacuum bagging is done.

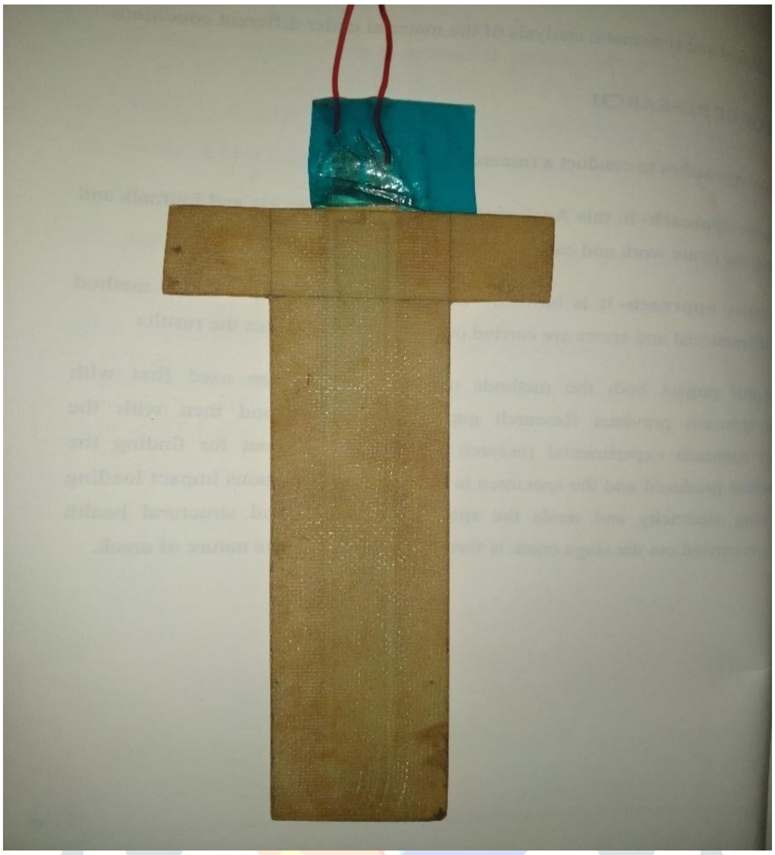

Fig. 2.1 Fabricated piezoelectric material.

2.1.2 PREPARATION OF CARBON FIBRE STRUCTURAL BATTERY

In the preparation of carbon fibre structural battery, here we are using carbon fibre weave as anode material, a separator made from glass fibre weave which has a microporosity property and aluminium fibre coated with $LiFePO_4$.

MATERIAL USED

The layered structure of the batteries consisted of three parts. An anode, made from carbon fibre weave with copper collector, a separator and $LiFePO_4$ coated onto aluminium fibre weave used as a collector. Polymer gel electrolyte were prepared. The gel electrolyte was made from polymethylmethacrylate and dimethyl carbonate are used.

FABRICATION PROCESS

a) Carbon fibre weaves, aluminium fibre weave, separator, copper foil cut into required dimensions.

b) To produce the gel electrolyte polymethylmethacrylate and dimethyl carbonate along with poly vinylidene fluoride are mixed in 1:1 ratio in atmospheric temperature.

c) Carbon fibre weave is connected to the copper collector which act as anode in structural battery.

d) Aluminium weave coated with $LiFePO_4$ in the absence of water content and other impurities, which act as cathode material.

e) The resin is mixed with the gel electrolyte solution with constant steering, to form a strong binding agent.

f) The separator is placed in between anode and cathode, the gel electrolyte is applied on to the separator to gain strong mechanical property.

g) The batteries manufactured in wooden mould box, in order the protect the chemicals from the water molecules.

h) Heat and pressure were applied to consolidate the composite batteries, also ensuring contact between electrode and electrolyte.

i) After preparation the structural batteries placed in an airtight bag to protect it from atmospheric humidity.

Fig. 2.2 Carbon fibre structural battery.

2.1.3 PRINCIPLE OF OPERATIONS

Vibrations are natural in aircraft in flight and in case of turbulence these vibrations are even more we can’t get rid of them completely. However, what we could do is to make use of these vibrations in positive ways that is by replacing the existing wing panel in aircraft with multifunctional composite materials in particularly replacing the existing carbon fibre in aircraft skin with unique combination of lead free piezoelectric and carbon fibre battery composites.

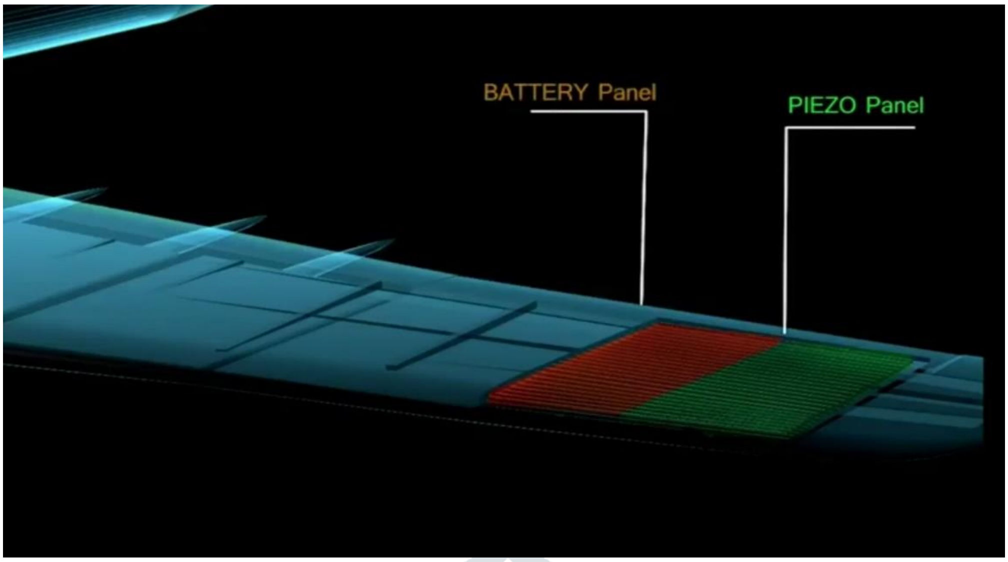

Fig. 2.3 Replacement of present carbon fibre with structural battery and piezo panels.

During the flight of an aircraft, due to turbulence and other factors wing tip vibrations are occurred. These vibrations are converted to electrical potential by the piezoelectric composite materials and store it in adjacent battery composites thus charging it. Then we are proceeded to replace the entire wing panels with such multifunctional composite materials so that we are harvesting and storing the electrical energy within the structure of the aircraft itself.

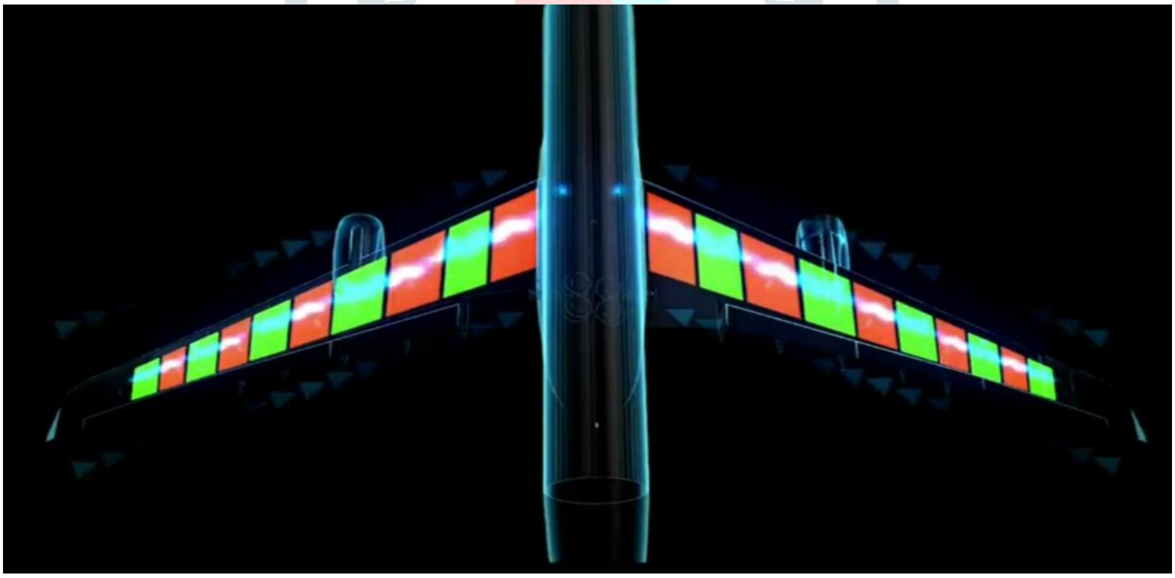

Fig. 2.4 Alternative placing of piezo panel structural battery.

The fuselage of an aircraft behaves as a structural element but here by replacing the same multifunctional composite materials as used in wing panels, so these structural batteries can charge when the aircraft in hanger. By this the entire structure of the aircraft can convert as a giant structural battery storing large amount of the electrical energy which is the major challenge in the aircraft industry.

CHAPTER 3

RESULT AND CONCLUSION

We have successfully fabricated and tested piezoelectric polymer structure, which in terms is producing an electrical energy and the structure with embedded piezo was subjected to impact loading to check the mechanical properties of the structure.

Structural battery composite built from the carbon and aluminium fibre weaves electrode, separated by a glass fibre weave, with a polymer electrolyte as matrix material, have been successfully manufactured the prototype and monitored for their electric potential.

Theoretical result from this analysis suggest that structural batteries with stiffness and in-plane strength comparable to conventional polymer composites can be achieved. Even if the structural batteries do not match the mechanical and electrical properties of the conventional polymer composites, it will contribute to mass saving in structural/energy storage system as the one employed in today's electric vehicles. To improve mechanical properties of the separator layer, the electrolyte mixture was applied onto a glass fibre weave. The result from this study imply that significant mass saving indeed can be achieved.

3.1 TEST RESULT OF CARBON FIBRE STRUCTURAL BATTERY

3.1.1 FLEXURAL TEST

Specimen	Flux modulus MPa	Flux strength MPa	Thickness mm	Width mm	Length mm
1.	4050	154	2.35	37.06	40

STATISTICS

Series N=1	Flux Modulus MPa	Flux Strength MPa	Thickness mm	Width mm	Length mm
X	4050	154	2.35	37.06	40

S	-	-	-	-	-
V	-	-	-	-	-

SERIES GRAPH

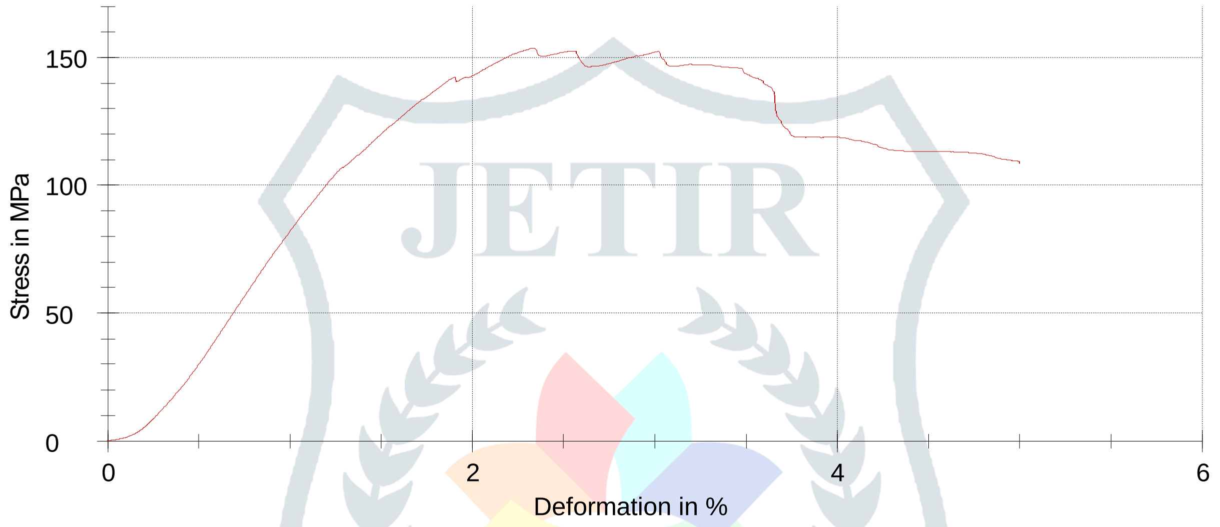

Fig. 3.1 Stress acting per deformation in flexural test

3.1.2 TENSILE TEST

Specimen	F max N	Tensile Modulus MPa	Tensile Strength MPa	Strain at Break %	WIDTH mm	THICKNESS mm
1	16320	416	206	20.9	31.72	2.50

STATISTICS

Series N=1	F max N	Tensile Modulus MPa	Strain at break %	Tensile Strength MPa	Width mm	Thickness mm
X	16320	416	20.9	206	31.72	2.50
S	-	-	-	-	-	-
V	-	-	-	-	-	-

SERIES GRAPH

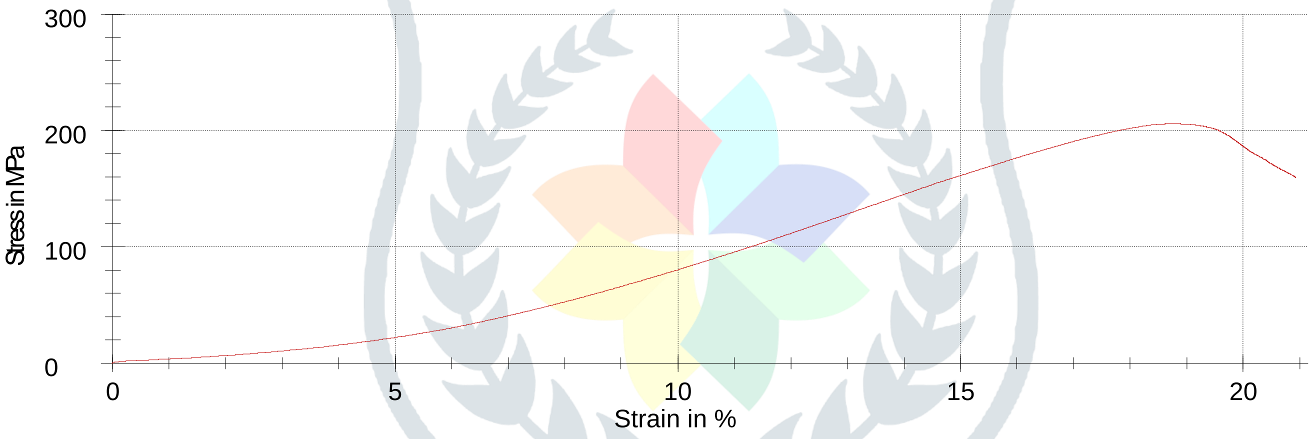

Fig. 3.2 stress vs strain in tensile test.

3.2 VOLATGE OUTPUT DUE TO PIEZOELECTRIC COMPOSITE VIBRATION

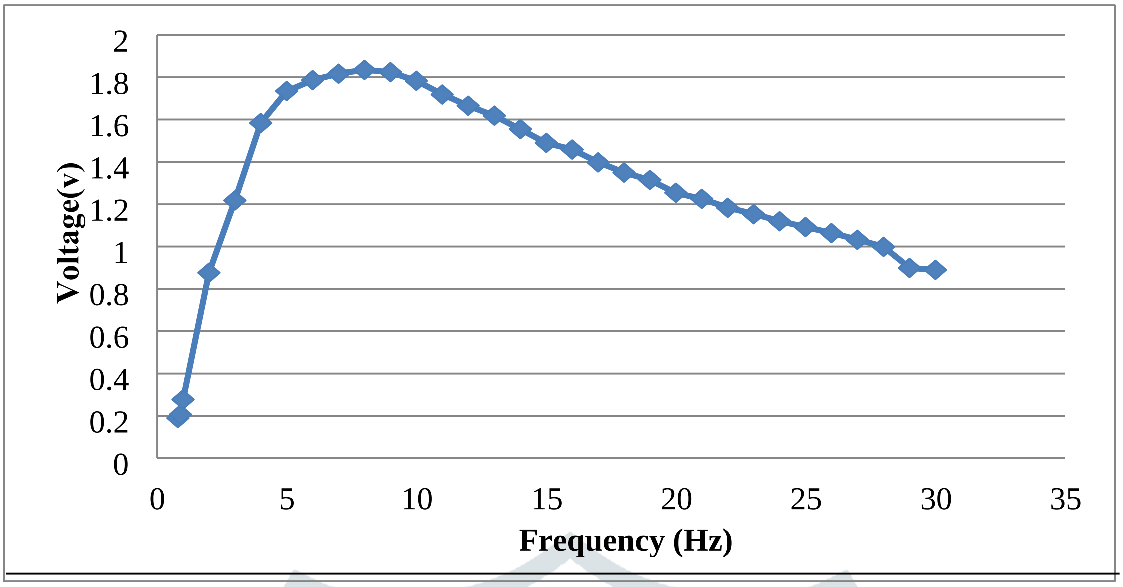

Fig. 3.3 Voltage output per frequency of vibration.

When the specimen was undergone under electrodynamic shaker it was noticed that till 8 Hz the voltage was increasing then it has reached a maximum volt of 1.835 then it started to decrease.

CONCLUSION

From the conducted experiments it has been shown that the vibrational energy from the aircraft can be harvested by converting into useful electrical energy which has been wasted. The piezoelectrical materials are shown to have high load bearing property when embedded composite form and considerable amount of mechanical vibrational energy can be converted into electrical potential energy. This could lead to the harvest of electrical energy in its pure form without any environmental effects, onboard continuous generation of electrical energy could be achieved this has been a potential area of consideration of aviation industry.

Electrification of aircraft is not been implemented due to the problem of storage of electrical energy in huge batteries which will consume vast volume and weight of the aircraft would be increased, so this concept help us to overcome this problem by using carbon fibre structural batteries which acts as a structural component as well as could store huge amount of electrical energy. By this we can achieve electrification of aircraft with low weight having high mechanical strength.

In future by implementing this technology we can eliminate the use of petroleum and its products from aviation industry this could lead to eco-friendly air transportation system and reducing 50% of present aircraft weight.