# Aircraft Turbine Blades and Expected Advancement in Technology Using Carbon Nanotubes

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*Abstract*— Gas turbines are of prime importance to aircrafts. The turbo machinery is a complex aspect of designing. Efficiency of turbo machinery is closely proportional to material selection and its performance. Each section of a turbo machinery deserves or has a different criteria of temperature dependency. As per this dependency turbine blades, nozzles and wheels are designed using different types of materials- alloys, which are highly resistant to temperature and light weight. This will lead to aircrafts which are very light and highly efficient. These materials are alloys which are very costly. And this high cost are making them difficult to be used abundantly. All these problems has made researchers to look around for material which is light, comparatively cheap and highly efficient as per turbine needs. This paper throws light on the existing materials used in turbine blades and a new compound which is a carbon allotrope which is capable of meeting all above needs perfectly.

***Keywords**:* Aircraft, turbine blades, carbon Nanotubes (CNT)

## I. INTRODUCTION

Gas turbines are used in aeronautical fields widely because of their versatility. Gas turbines use gases as working fluid. These are small as compared to steam turbines in power plants. This is the reason why gas turbines are the choice in aircrafts. The mechanical output is obtained through three vital steps: compression, combustion and expansion. Turbines come to work after combustion process and hence are supposed to be in a high temperature environment and bear too much heat. These requirements are not easily fulfilled by normal metals like steel, aluminum etc and hence alloys were developed to bear this amount of heat.

In gas turbines the compressor and turbine are coupled to form a spool. This means the compressor is run by the turbine. So the power input will be utilized in turning the compressor hence to increase the power combustion is provided in between these two. Combustion increases the pressure and hence thrust increases.[1]

Taking these considerations many alloys were developed like Inconel, GTD111 etc. The composition and materials used in gas turbines are listed in Table1.1. [2]

But as everything is not perfect the alloys are gradually getting outdated due to their high cost and weight.

Scientists have discovered a new compound or an allotrope of carbon called carbon Nanotubes or CNT. The CNT are light weight, have high tensile strength and high melting point which makes them suitable for use in turbine blades. These are of low cost as compared to other alloys. These are of two types SWNT (Single Wall carbon Nanotubes) and MWNT (Multiwall carbon Nanotubes). Both have different properties at different states.

| Component | Cr | Ni | Co | Fe | W | Mo | Ti | Al | Cb | V | C | B | Ta |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Turbine Blades | | | | | | | | | | | | | |
| U500 | 18.5 | BAL | 18.5 | – | – | 4 | 3 | 3 | – | – | 0.07 | 0.006 | – |
| RENE 77 (U700) | 15 | BAL | 17 | – | – | 5.3 | 3.35 | 4.25 | – | – | 0.07 | 0.02 | – |
| IN738 | 16 | BAL | 8.3 | 0.2 | 2.6 | 1.75 | 3.4 | 3.4 | 0.9 | – | 0.10 | 0.001 | 1.75 |
| GTD111 | 14 | BAL | 9.5 | – | 3.8 | 1.5 | 4.9 | 3.0 | – | – | 0.10 | 0.01 | 2.8 |
| Turbine Nozzles | | | | | | | | | | | | | |
| X40 | 25 | 10 | BAL | 1 | 8 | – | – | – | – | – | 0.50 | 0.01 | – |
| X45 | 25 | 10 | BAL | 1 | 8 | – | – | – | – | – | 0.25 | 0.01 | – |
| FSX414 | 28 | 10 | BAL | 1 | 7 | – | – | – | – | – | 0.25 | 0.01 | – |
| N155 | 21 | 20 | 20 | BAL | 2.5 | 3 | – | – | – | – | 0.20 | – | – |
| GTD-222 | 22.5 | BAL | 19 | – | 2.0 | 2.3 | 1.2 | 0.8 | – | 0.10 | 0.008 | 1.00 | – |
| Combustors | | | | | | | | | | | | | |
| SS309 | 23 | 13 | – | BAL | – | – | – | – | – | – | 0.10 | – | – |
| HAST X | 22 | BAL | 1.5 | 1.9 | 0.7 | 9 | – | – | – | – | 0.07 | 0.005 | – |
| N-263 | 20 | BAL | 20 | 0.4 | – | 6 | 2.1 | 0.4 | – | – | 0.06 | – | – |
| HA-188 | 22 | 22 | BAL | 1.5 | 14.0 | – | – | – | – | – | 0.05 | 0.01 | – |
| Turbine Wheels | | | | | | | | | | | | | |
| Alloy 718 | 19 | BAL | – | 18.5 | – | 3.0 | 0.9 | 0.5 | 5.1 | – | 0.03 | – | – |
| Alloy 706 | 16 | BAL | – | 37.0 | – | – | 1.8 | – | 2.9 | – | 0.03 | – | – |
| Cr-Mo-V | 1 | 0.5 | – | BAL | – | 1.25 | – | – | – | 0.25 | 0.30 | – | – |
| A286 | 15 | 25 | – | BAL | – | 1.2 | 2 | 0.3 | – | 0.25 | 0.08 | 0.006 | – |
| M152 | 12 | 2.5 | – | BAL | – | 1.7 | – | – | – | 0.3 | 0.12 | – | – |
| Compressor Blades | | | | | | | | | | | | | |
| AISI 403 | 12 | – | – | BAL | – | – | – | – | – | – | 0.11 | – | – |
| AISI 403 + Cb | 12 | – | – | BAL | – | – | – | – | 0.2 | – | 0.15 | – | – |
| GTD-450 | 15.5 | 6.3 | – | BAL | – | 0.8 | – | – | – | – | 0.03 | – | – |

Table 1.1 High Temperature Alloys used in different components of Gas Turbine

Table 1.1

 

## II. MATERIAL SCIENCE INVOLVED IN TURBINE BLADES

Turbine blades are the most vital parts of gas turbines. They are subjected to high temperature of nearly $1400^0$C to $1500^0$C at the turbine inlet which makes the working conditions even worst. In addition the blades are subjected to the following: [3]

(1) Oxidation ( Severe )
(2) Thermal Fatigue (Severe)
(3) Hot corrosion ( Moderate )
(4) Interdiffusion (Severe )

To ensure that the matal or alloy is good or not the following key factors should be taken into account:

(1) High stiffness and tensile strength to ensure accurate blade location and resistance to over speed burst failure.
(2) High fatigue strength and resistance to crack propagation to prevent crack initiation and subsequent growth during repeated engine cycling.
(3) Creep strength to avoid distortion and growth at high temperature regions of the disc.
(4) Resistance to high temperature oxidation and hot corrosion attack and the ability to withstand fretting damage at mechanical fixings.

In addition to all these gas bending stresses and rotational stresses are developed in them and hence needs to be made of advanced material as shown in Table 1.1. These advanced materials are alloys and super alloys having a composition of more than ten elements. They have a simple microstructure like stones stacked in a rectangular array binded by cement. Here titanium works as the cement. Titanium gives high temperature resistance and improved oxidation property. [4]

The most interesting replacement took place when titanium was replaced by nickel (with high level of tungsten and rhenium). Alignment of alloy grain in single crystal blade has contributed to improved vibrational tendencies. After all this chromium addition was done to increase strength. But this led to reduced ductility and also reduced corrosion resistance. This is where coatings started to arrive. But these coatings lead to additional strain which generally lead to fatigue failure of the blades.[5] So continuous research is going on for the development of better and efficient turbine blades. Scientists are working on Nickel based alloys and Carbon Nanotubes (CNT). Stress variation for some materials is shown in figure1.

Based on experiments CNTs are found to have better properties than Inconel718 and GTD111. Still research is going on carbon Nanotubes to produce it quite effectively. Carbon Nanotubes are cheap but it's production cost is not up to expectations. So better processes of producing CNTs are being researched nowadays.

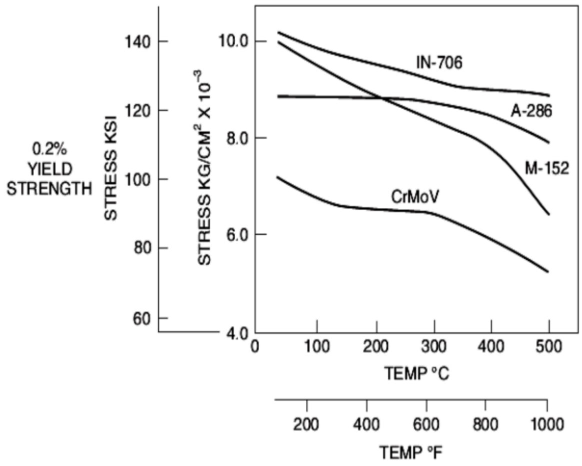


Fig. 1: Variation of stress with temperature change [6]

## III. CARBON NANOTUBES AND EXPECTED USE IN TURBINE BLADES

Carbon Nanotubes are allotropes of carbon of fullerene family. Fullerene are of sheet form, but when these sheets are rolled up to cylindrical shapes , these are termed as carbon Nanotubes.

The CNTs are few nanometers in diameters and have high tensile strength of nearly 63GPa and young's modulus of nearly 1TPa. Carbon Nanotubes can be single walled (SWNTs), multi walled (MWNTs) and also nanobuds. The Carbon Nanotubes are shown in figure 1.1.

Qian D. et al. (2002) quoted some important points about CNTs which are listed below[7]

(1) CNT is 100 times stronger than stainless steel and six times lighter.
(2) CNT is as hard as diamond and its thermal capacity is twice that of pure diamond.
(3) CNT's current-carrying capacity is 1000 times higher than that of copper.
(4) CNT is thermally stable up to 4000K .
(5) CNT can be metallic or semiconducting, depending on their diameter and chirality.

### A. *Classification*

(1) SWNTs
(2) MWNTs
(3) Nanobuds
(4) Polymerized SWNTs

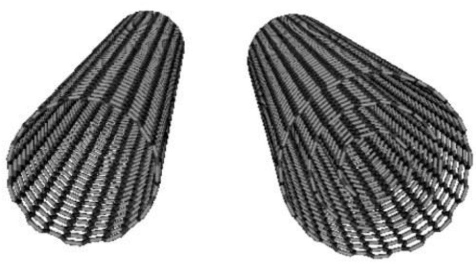

Fig. 1.1: schematics showing SWNTs , MWNTs and Carbon Nanotubes

The amazing mechanical and electronic properties of the Nanotubes stem in their quasi-one dimensional (1D) structure and the graphite-like arrangement of the carbon atoms in the shells. Thus, the Nanotubes have high Young's modulus and tensile strength, which makes them preferable for composite materials with improved mechanical properties. The Nanotubes can be metallic or semiconducting depending on their structural parameters. This opens the way for making it a central element in electronic devices specially FET (Field Effect Transistors).

*B. Properties Of CNTs Which Make It Suitable For Use In Aircraft Turbine Blades*

As discussed earlier turbine blades are supposed to be in a condition of high temperature atmosphere of around 1500$^0$C. So, any material which has to be used in place of turbine should be first of all high temperature resistant. CNTs have a melting point ranging from 2000$^0$C to 4000$^0$C. The SWNTs have has the lower range whereas MWNTs have the higher range of temperature. This property is suitable for design of turbine blades.

CNTs are high tensile materials. As discussed earlier tensile strength of CNTs are around 63GPa and young's modulus of 1TPa. Since the turbine blades are subjected to high torsional and gas bending stresses this material is appropriate.

The best thing about CNTs is that they are thermally stable in high temperature. That means that they can be stable upto 4000K .

An aircraft can be made better by reducing its weight significantly. Carbon Nanotubes are allotropes of carbon and tubular in structure. This tubular structure makes them suitable for being light weight. In practical life they are 100 times lighter than normal steel. This means that CNTs are lighter than the present materials used in turbine blades i.e. Inconel718 , GTD111 etc (mentioned in table 1.1). This makes CNTs of great importance in turbo machinery.

The thermal conductivity of CNTs is much high than expected. It is around three times that of normal steel and two fold of Inconel718.Recently, the thermal conductivity of an individual MWNT was measured using a micro fabricated suspended device . The observed thermal conductivity was more than
3000 W/mK at room temperature. This means it is better than the present materials used.[8]

The variation of thermal conductivity with temperature is shown on figure 1.2

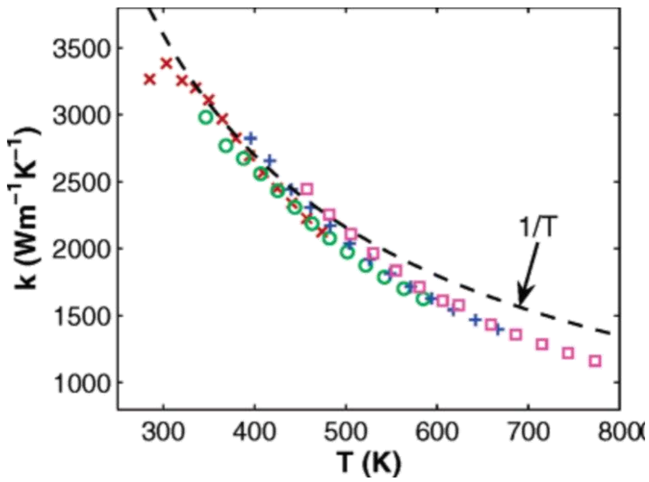


Fig. 1.2: Expected values of thermal conductivity versus standard SWNT temperature

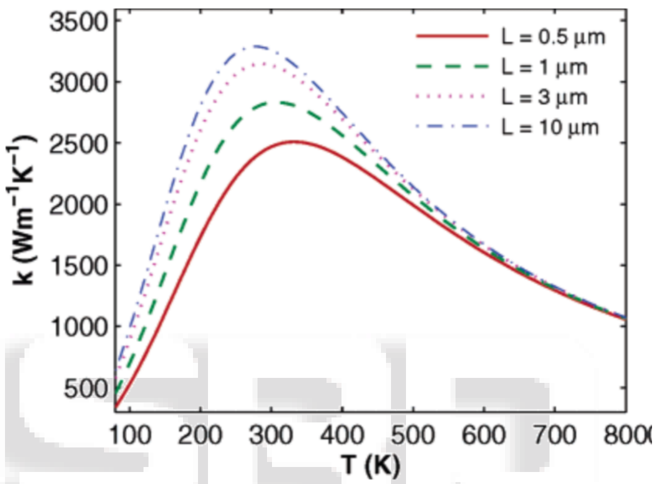


Fig. 1.3: Analytical plot of intrinsic SWNTs

The table 2.1 shows a comparison between SWNTs , MWNTs and stainless steel.

*C. Present Applications of Carbon Nanotubes*

Due to its light weight and high strength CNTs are hot discussion among researchers. These are expected to be everywhere in future. Some of its future aspects are listed below:

(1) NanoNetwork
(2) Nanorobotics
(3) Future nanotech soldiers
(4) Nano armors
(5) Nano space elevator

The above are a small implementations of CNTs. These can be everywhere in use in future.

Although CNTs are good still they have defects which if present in large amount may decrease tensile strength appreciably.

The defect found in CNTs is known as Stone Wales Defect which reduces strength by rearranging the bonds and forming pentagons and heptagons.

Carbon Nanotubes are expected to be very good thermal conductors along the tube, exhibiting a property known as "ballistic conduction," but good insulators laterally to the tube axis.

 

| **Material** | **Young's modulus** | **Tensile strength** | **Elongation in breaking** |
|---|---|---|---|
| SWNTs | E=1 to 5TPa | 13 to 63GPa | 16% |
| MWNTs | E=0.95TPa | 11 to 150GPa | _ |
| Stainless steel | E=0.186 to 0.214TPa | 0.38 to 1.55GPa | 15 o 50% |

Table 2.1

## IV. CONCLUSIONS

As discussed above CNTs are of great importance to science. They are a way better than the normal existing metals and alloys.

As per the table SWNTs and MWNTs surpass stainless steel in all respect. CNTs have better melting point, much higher strength and young's modulus as compared to other metals.

Taking Inconel718 which is widely used in turbine blade materials is a good alloy but cannot beat CNTs in its mechanical and thermal properties.

Inconel718 has a melting point of 1390-1425 $^{0}$C which a CNT easily reaches and it can also attain a temperature up to 4000K . This property makes it outstanding in terms of use in turbine blades of aircrafts. It is cost efficient; only its production technology is costly. Research is still going on it to make the process cheap and handy.

In present stage the use of Carbon Nanotubes is tested on certain aircrafts and it gave outstanding results. The turbine blades and certain chassis of aircraft Boeing 787 was made with SWNTs and also was tested on Airbus A380. The observations shows the weight to reduce by 20% and hence giving a boost to its overall efficiency.

This makes carbon Nanotubes more reliable and effective. Hence future aircrafts are surely to be proposed on the basis of this material and make life more comfortable.

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