

ANALYSIS OF CREEP IN FUNCTIONALLY GRADED CYLINDER

A
Thesis Report
submitted in partial fulfillment of the requirement for the award of degree

MASTER OF ENGINEERING IN CAD/CAM & ROBOTICS

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DECLARATION

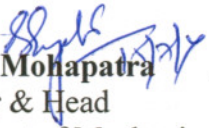
I hereby declare that the work is in this thesis report entitled “**Analyses of Creep In Functionally Graded Cylinder**” in partial fulfillment of requirement for the award of the Master Degree in CAD/CAM & Robotics submitted in the Department of Mechanical Engineering, Thapar University, Patiala, is an authentic record of the work carried out by me under the guidance of **Mr. Kishore Khanna, Assistant Professor, Mechanical Engineering Department, TU, Patiala.**


The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.


Dated: 15/7/10


(Harmandeep Garg)

This is to certify that above declaration made by the student concerned is correct to the best of my knowledge & belief.


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ABSTRACT

Creep is the tendency of a solid material to slowly move or deform permanently under the influence of stresses when subjected to high temperatures for long duration of time. So creep is one of the major considerations while analyzing the materials which are used for high temperature for long durations. Functionally Graded Materials (FGM) is the materials meant for high temperatures. FGM cylinders are used under high temperatures mainly in petroleum industry and nuclear power plants. So creep analysis of FGM cylinders has a wide scope for research.

In this research work the radial and circumferential stress analysis of the FGM cylinders when subjected to internal and external pressures at high temperatures for long durations of time is done with the help of Ansys Software. The validation of the results is proved by matching the results with Jian Jun Chen et al. [16]. Further the effect of increasing internal pressure on the radial and circumferential stresses is seen.

From the results obtained it is clear that they are in accordance with the results obtained by Jian Jun Chen et al. [16]. The results of the stress analysis showed that by increasing the internal pressure the radial and circumferential stresses increases directly proportional to internal pressure.

INDEX

S. No.	Topic	Page No.
	Declaration	i
	Acknowledgement	ii
	Abstract	iii
	Index	iv-v
	List of figures	vi-vii
	List of tables	viii
	Chapter 1	Introduction
	Introduction	
1.1	Creep	1-2
1.2	Stages of creep	2-3
1.3	General creep equation	3-4
1.4	Mechanism of creep deformation	4-6
1.5	Composite materials	7
1.6	Classification of composite materials	8-12
1.7	Advantages of composite over conventional materials	12-13
1.8	Uses of composite materials	13
1.9	Limitations of composite materials	13-14
1.10	Functionally graded materials	14-15
1.11	Applications	15-16
1.12	Cylinder	16
	Chapter 2	Literature review
2.1	Literature review	17-23
2.2	Problem formulation	23-24
	Chapter 3	FEM and Ansys
3.1	Introduction to Finite Element Method	25
3.2	How the Fem works	25-26
3.3	Advantages of Fem	27
3.4	Element types and Discretization	27-28
3.5	Applications of Fem	28
3.6	Ansys	29
3.7	Why Ansys required	29
3.8	Steps to solving any problem in Ansys	29-30
3.9	Analysis which can be done on Ansys	30-32

	Chapter 4	Modeling and Analysis
4.1	Modeling and analysis of FGM cylinder	33-36
	Chapter 5	Results and discussions
5.1	Validation of results for radial stresses when cylinder subjected to internal pressure	37-39
5.2	Validation of results for circumferential stresses	39-40
5.2.1	Validation of time dependent results for circumferential stresses	41-42
5.3	Validation of results for radial stresses when cylinder subjected to internal pressure	42-44
5.4	Variation of stresses by varying of internal pressure for radial stresses	44-46
5.5	Variation of stresses by varying of internal pressure for circumferential stresses	46-49
	Chapter 6	Conclusions and future scope
6.1	Conclusion	50
6.2	Scope for further study	50
	References	51-53

LIST OF FIGURES

Fig No.	Description	Page No.
1.1	Creep curve showing the three stages of creep	3
1.2	Influence of stress on steady-state creep rate schematic	6
1.3	Classification of Composite Materials	8
1.4	Particles as the reinforcement (Particulate composites)	9
1.5	Flat flakes as the reinforcement (Flake composites)	9
1.6	Continuous fibre (long fibre) reinforced composites	10
1.7	Metal matrix composites	11
1.8	Properties and texture of different materials	15
3.1	Discretized domain	26
3.2	One dimensional elements	27
3.3	Two dimensional elements	27
3.4	Three dimensional elements	28
4.1	Cylinder model	33
4.2	Selecting the type of Analysis	33
4.3	Selecting the type of element	34
4.4	Rectangular section taken from cylindrical section	34
4.5	Modeling of different areas	35
4.6	Meshed area	35
4.7	Load and boundary condition	36
5.1	Graph showing results of Jian Jun Chen [16] for radial stresses	37
5.2	Variation of radial stresses along the radius	38
5.3	Graph for radial stresses along the radius	38
5.4	Graph showing the results of Jian Jun Chen [16] for circumferential stresses	39
5.5	Variation of circumferential stresses along the radius	40
5.6	Graph for circumferential stresses along the radius	40
5.7	Graph showing the results of Jian Jun Chen [16] for circumferential stresses with respect to time	41
5.8	Graph showing the results for circumferential stresses with respect to time	42
5.9	Graph showing results of Jian Jun Chen [16] for radial stresses	43
5.10	Variation of radial stresses along the radius	43
5.11	Graph for radial stresses along the radius	44
5.12	Variation of radial stresses along the radius for pressure 75MPa	44
5.13	Graph for radial stresses along the radius for pressure 75 MPa	45
5.14	Variation of radial stresses along the radius for pressure 100 MPa	45
5.15	Graph for radial stresses along the radius for pressure 100 MPa	46
5.16	Variation of radial stresses along the circumferential for pressure 75 MPa	47

5.17	Graph for circumferential stresses along the radius for pressure 75 MPa	47
5.18	Variation of circumferential stresses along the radius for pressure 100 MPa	48
5.19	Graph for circumferential stresses along the radius for pressure 100 MPa	48

LIST OF TABLES

Table No.	Description	Page No.
4.1	Materials Values	34
5.1	Range of Values for Radial and Circumferential Stresses	49
5.2	Maximum Values for Radial and Circumferential Stresses	49

1.1 CREEP [24]

It is the tendency of a solid material to slowly move or deform permanently under the influence of stresses. It occurs as a result of long term exposure to levels of stress that are below the yield strength of the material. Creep is more severe in materials that are subjected to heat for long periods, and near the melting point. Creep always increases with temperature.

The rate of this deformation is a function of the material properties, exposure time, exposure temperature and the applied structural load. Depending on the magnitude of the applied stress and its duration, the deformation may become so large that a component can no longer perform its function — for example creep of a turbine blade will cause the blade to contact the casing, resulting in the failure of the blade. Creep is usually of concern to engineers and metallurgists when evaluating components that operate under high stresses or high temperatures. Creep is a deformation mechanism that may or may not constitute a failure mode. Moderate creep in concrete is sometimes welcomed because it relieves tensile stresses that might otherwise lead to cracking. Unlike brittle fracture, creep deformation does not occur suddenly upon the application of stress. Instead, strain accumulates as a result of long-term stress. Creep deformation is "time-dependent" deformation.

The temperature range in which creep deformation may occur differs in various materials. For example, Tungsten requires a temperature in the thousands of degrees before creep deformation can occur while ice formations will creep in freezing temperatures. As a rule of thumb, the effects of creep deformation generally become noticeable at approximately 30% of the melting point for metals and 40–50% of melting point for ceramics. Virtually any material will creep upon approaching its melting temperature. Since the minimum temperature is relative to melting point, creep can be seen at relatively low temperatures for some materials. Plastics and low-melting-temperature metals, including many solders, creep at room temperature as can be seen markedly in old lead hot-water pipes. Planetary ice is often at a high temperature relative to its melting point, and creeps.

Creep deformation is important not only in systems where high temperatures are endured such as nuclear power plants, jet engines and heat exchangers, but also in the design of many everyday objects. For example, metal paper clips are stronger than plastic ones because plastics creep at room temperatures. Aging glass windows are often erroneously used as an example of this phenomenon: measurable creep would only occur at temperatures above the glass transition temperature around 500 °C (900 °F). While glass does exhibit creep under the right conditions, apparent sagging in old windows may instead be a consequence of obsolete manufacturing processes, such as that used to create crown glass, which resulted in inconsistent thickness.

1.2 STAGES OF CREEP

Curve A in the fig.1.1 illustrates the idealized shape of the creep curve. The slope of this curve ($d\epsilon/dt$) is referred to as the creep rate. A typical creep curve exhibits three stages which are readily distinguishable and depend strongly on the applied stress and temperature.

The first stage of the creep, known as primary creep, represents a region of decreasing creep rate. Primary creep is a period of predominantly transient creep in which the resistance of the material increases by virtue of its own deformation. Primary creep occurs at low temperature and low stress levels.

The second stage of creep, known also as secondary creep, is a period of nearly constant creep rate which result from a balance between the competing processes of strain hardening and recovery. For this reason, secondary creep is usually referred to as **Steady State Creep**. The average value of the creep rate during secondary creep is called the minimum creep rate.

Third stage or tertiary creep mainly occurs in constant load creep tests at high stresses and high temperature. Tertiary creep occurs when there is an effective reduction in cross-sectional area either because of necking or internal void formation. Third stage creep is often associated with metallurgical changes such as coarsening of precipitate particles, recrystallization or diffusional changes in the phases present.

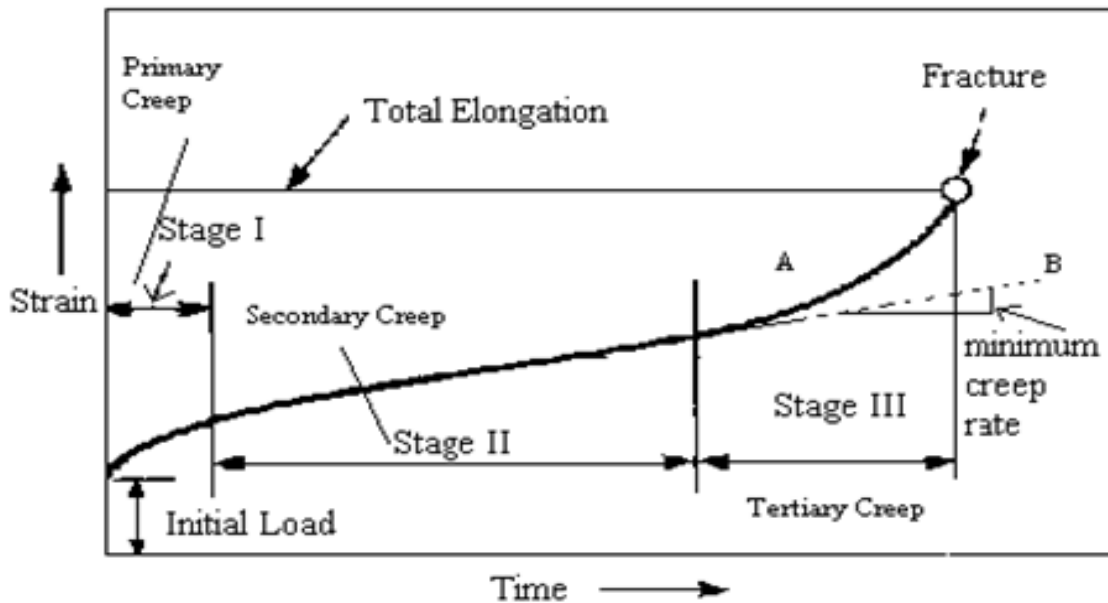


Fig 1.1 Creep curve showing the three stages of creep [24]

(Curve A- Constant load curve, Curve B- Constant stress test).

The dashed line (Curve B) in fig.1.1 shows the shape of a constant-stress creep curve. In engineering situations, it is usually the load, not the stress that is maintained constant, so a constant load creep test is more important

Garofalo has proposed that the creep curve can be represented by the following equation for a limited number of materials.

$$\varepsilon = \varepsilon_0 + \varepsilon_t(1 - e^{-rt}) + \varepsilon'$$

Where ε is total strain, ε_0 is the instantaneous strain loading, ε_t is the limit for transient creep, r is the ratio of transient creep rate to the transient creep strain, and ε' is the steady state creep rate [23].

1.2 GENERAL CREEP EQUATION

The general creep equation is:

$$\frac{d\varepsilon}{dt} = \frac{c\sigma^m}{d^b} e^{\frac{-Q}{kT}}$$

where ε is the creep strain, C is a constant dependent on the material and the particular creep mechanism, m and b are exponents dependent on the creep mechanism, Q is the activation

energy of the creep mechanism, σ is the applied stress, d is the grain size of the material, k is Boltzmann's constant, and T is the absolute temperature.

To determine the engineering creep curve of a metal, a constant load is applied to a tensile specimen maintained at a constant temperature and the strain (extension) is determined as a function of time.

1.4 MECHANISMS OF CREEP DEFORMATION [23]

A great deal of research has gone into developing mechanisms for creep deformation. The various methods are:

- a) Dislocation glide
- b) Dislocation creep
- c) Diffusion creep
- d) Grain boundary sliding

(a) Dislocation Glide

It involves dislocation moving along slip planes and overcoming barriers by thermal activation. This mechanism occurs at high stress levels $\sigma/G > .01$ which is high relative to those normally considered in creep deformation. The creep rate is established by the ease with which dislocations are impeded by obstacles such as precipitates, solute atoms and other dislocations.

(b) Dislocation Creep

Dislocation creep occurs by dislocation glide aided by vacancy diffusion. The frame work on which the various theories are hung is the idea of Orowan and Bailey that the steady state creep rate represents a balance between the competing factors of rate of strain hardening $h = \partial\sigma/\partial\varepsilon$ and the rate of thermal recovery by rearrangement and annihilation of dislocations $r = -\partial\sigma/\partial t$. A steady-state creep condition occurs when the rate of recovery is fast enough and the rate of strain hardening is slow enough that a balance is reached between these competing factors.

$$\dot{\varepsilon}_s = \frac{r}{h} = -\frac{\partial\sigma/\partial t}{\partial\sigma/\partial\varepsilon}$$

Physical models of dislocation creep must predict the $\dot{\epsilon}$ and n terms. The mechanism proposed by Gittus gives good agreement with experiment. It is based on a model of stress and diffusion-aided movement of dislocations in a three-dimensional network (substructure).

$$\dot{\epsilon}_s = \frac{16\pi^3 c_j D_v G b}{kT} \left(\frac{\sigma}{G}\right)^3$$

Where C_j concentration of jogs

D_v = Bulk or lattice self-diffusion coefficient

G = Shear modulus

b = Burgers vector of the dislocation

σ = Applied stress

k = Boltzmann's constant

T = Temperature absolute scale

The earliest models of dislocation creep were advanced by Weertman based on a mechanism in which dislocation climb plays a major role. At elevated temperature, if a gliding dislocation is held up by an obstacle, a small amount of climb may permit it to surmount the obstacle, allowing it to glide to the next set of obstacles where the process is repeated, the glide step produces almost all of the strain but the climb step controls the velocity. Since dislocation climb requires diffusion of vacancies or interstitials, the rate controlling step is atomic diffusion. This model again predicts an equation for creep rate in which stress is raised to the third power. However, creep experiments with a range of metals show that the exponent on stress varies from 3 to 8, with a value of 5 most common. Thus, for intermediate to high stress levels at temperatures above $0.5T_m$ the steady-state creep rate is described by a power-law relation

$$\dot{\epsilon}_s = \frac{A D_v G b}{kT} \left(\frac{\sigma}{G}\right)^n$$

Where A and n are material constants. Since the diffusion coefficient D_v can be described by

$$D_v = D_0 \exp(-Q/KT)$$

(c) Diffusion Creep

Diffusion creep becomes the controlling mechanism at high temperatures and relatively low stresses. $\sigma/G < .0001$. Naharro and Herring proposed that the creep process was controlled by stress-directed atomic diffusion. Stress changes the chemical potential of the atoms on the surfaces of the grains in a polycrystal in such a way that there is a flow of vacancies from grain boundaries experiencing tensile stresses to those which have compressive stresses. Simultaneously, there is a corresponding flow of atoms in the opposite direction, and this leads to elongation of the grain.

(d) Grain Boundary Sliding

While grain boundary sliding does not contribute significantly to steady state creep, it is important in initiating in intergranular fracture. However it has been shown that grain boundary sliding must be present to maintain grain continuity during diffusional flow mechanism as shown in figure below.

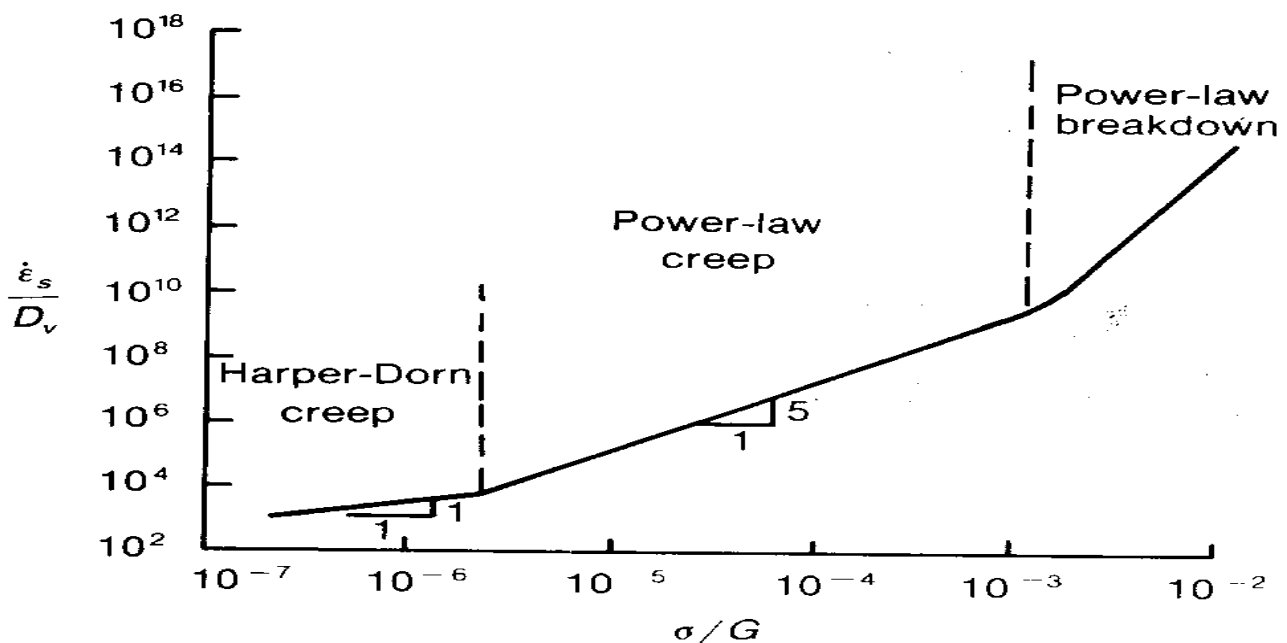


Fig.1.2 Influence of stress on steady-state creep rate schematic [23]

1.5 COMPOSITE

Composite Materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure.

Composites are made up of individual materials referred to as constituent materials. There are two categories of constituent materials: **matrix and reinforcement**. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties.

Usual composites have two phases:

- **Matrix Phase**

The primary phase, having a continuous character, is called matrix. Matrix is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it.

- **Dispersed (Reinforcing) Phase**

The second phase (or phases) is imbedded in the matrix in a discontinuous form. This secondary phase is called dispersed phase. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase.

Properties of Composites depend on

- Properties of phases
- Geometry of dispersed phase (particle size, distribution, orientation)
- Proportion of phase

1.6 CLASSIFICATION OF COMPOSITE MATERIALS

Composites are classified by the geometry of the reinforcement as particulate, flake and fibre or by the type of matrix as polymer, metal, ceramic and carbon as shown in fig.1.3

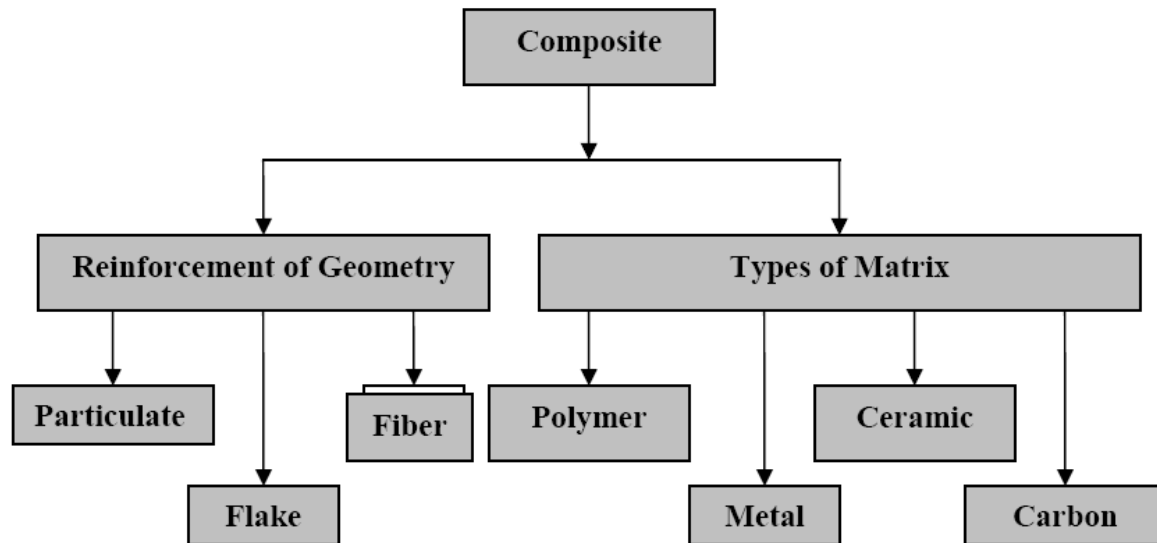


Fig 1.3 Classifications of Composite Materials

1.6.1 CLASSIFICATION BASED ON GEOMETRY OF REINFORCEMENT

Based on this, the composites are of the following types:

- (a) Particulate Composites
- (b) Flake Composites
- (c) Fibre Composites

(a) Particulate Composites

This class of composite consists of particles reinforced in a matrix of metal, alloy or ceramics shown in fig.1.4. They usually exhibit isotropic properties. Particulate composites have advantages such as improved strength, increased operating temperature and oxidation resistance.

(b) Flake Composites

It consists of flat reinforcement in the matrix as shown in fig.1.5 Typical flake materials are glass, mica, aluminium and silver. Flake composites provide advantages such as high out of plane flexural modulus, higher strength and low cost. However, flakes cannot be oriented easily therefore a limited number of materials are available for use.

(c) Fibre Composites

These composites consist of matrix reinforced by short (discontinuous) or long (continuous) fibre as shown in fig 1.6. Fibres are generally anisotropic and examples include carbon aramids.

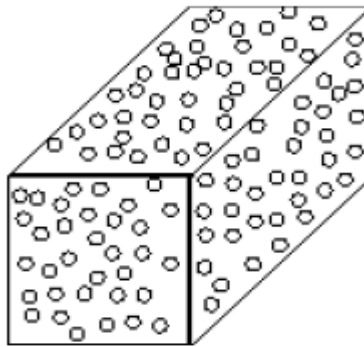


Fig 1.4 Particles as the reinforcement (Particulate composites)

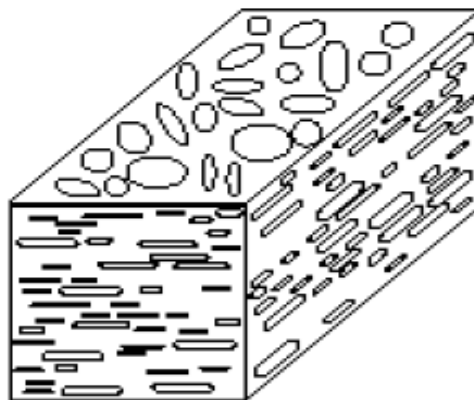


Fig 1.5 Flat flakes as the reinforcement (Flake composites)

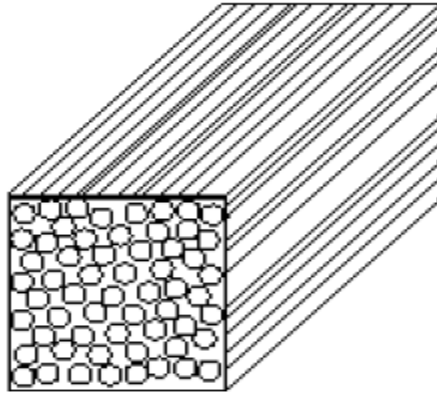


Fig 1.6 Continuous fibre (long fibre) reinforced composites

1.6.2 CLASSIFICATION BASED ON MATRIX

Based on the type of matrix, Composites are of the following types :

- (a) Polymer Matrix Composite (PMC)
- (b) Metal Matrix Composite (MMC)
- (c) Ceramic Matrix Composite (CMC)
- (d) Carbon –Carbon Composite

(a) Polymer Matrix Composite (PMC)

Polymer matrix composites are the most advanced composites. These composites consist of a polymer (e.g., epoxy, polyester, urethane etc) reinforced by thin-diameter fibres(e.g., graphite , aramids, boron etc).These are commonly employed due to their low cost, high strength, and simple manufacturing principle. As an example, graphite/ epoxy composites are approximately five times stronger than steel on a weight-for-weight basis.

Main drawback of Polymer Matrix Composites (PMCs) include low operating temperature, high coefficient of thermal and moisture expansion and low elastic properties in certain directions. However, the advantages include its strength, low cost, high chemical resistance and good insulating property.

(b) Metal Matrix Composite (MMC)

This class of composite materials consists of metallic matrix which is usually ductile.

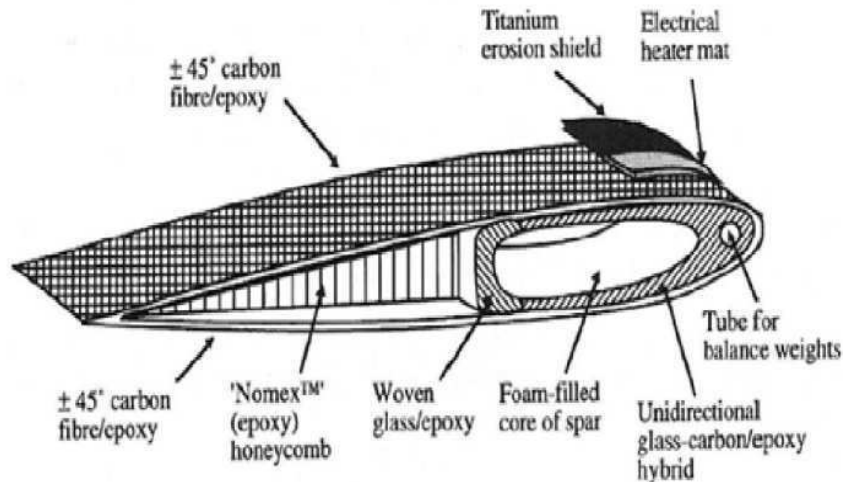


Fig 1.7 Metal Matrix Composites

The ductile matrix can be aluminium, copper, magnesium, titanium, nickel, super alloy or even an inter metallic compound. The reinforcing fibres may be graphite, boron carbide, alumina or silicon carbide. Fine whiskers of sapphire, silicon carbide, silicon nitride, wires of titanium, tungsten, molybdenum, beryllium and stainless steel etc have also been used as reinforcement. Compared to conventional engineering materials, these composites offer higher stiffness and strength, especially at elevated temperatures, low coefficient of thermal expansion and enhanced resistance to fatigue, abrasion and wear. Compared to organic matrix materials, they offer high heat resistance and improved electrical and thermal conductivity. Graphite-reinforced aluminium can be designed to have near zero thermal expansion in the fibre direction. Aluminium oxide-reinforced aluminium matrix composites have been extensively used in automotive connecting rods to provide high stiffness with low weight. Aluminium reinforced with silicon carbide whiskers has been fabricated into aircraft wing panels, providing 20-40% weight saving. Fibre reinforced super alloy has potential future for applications such as turbine blades.

(c) Ceramic Matrix Composite (CMC)

Ceramic matrix composites possess properties like high melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength. These materials can even be used at very high temperatures (i.e. above 1500°C).

(d) Carbon –Carbon Composite

These composites retain their properties even at exceptionally very high temperatures in the range of 3315°C. Their dimensional stability is also good and therefore can be used at elevated temperatures. They are 20 times stronger and 30% lighter than the Graphite fibres.

Carbon by itself is brittle and flaw sensitive like the ceramics. Reinforcement of the carbon matrix allows the composite to fail gradually and also gives advantages such as ability to withstand high temperatures, low creep at high temperatures, low density, good tensile and compressive strengths, high fatigue resistance, high thermal conductivity and high coefficient of friction.

1.7 ADVANTAGES OF USING COMPOSITES OVER CONVENTIONAL MATERIALS (METALS)

- Very high specific strength. Which means very high strength and low weight
- Great freedom of shape. Double curved and complex parts can be simple produced.
- High degree of integration possible. Which means simple integration of stiffeners, inserts, cores, and production of self supporting structures in one or two production cycles?
- Material can be tailored. Which means fit for the loads / performance the end product has to perform during its lifetime
- Excellent fatigue endurance concerning number of load cycles (many times higher than with metals) and residual fatigue strength (aramide and carbon epoxy laminates retain more than 60% of their residual static strength, which is far more higher than is possible with metals.)
- Excellent chemical resistance against acids, chemicals etc.
- Excellent weather/water resistance. Material has almost no corrosion, takes on little water which leads to low maintenance cost especially on the long run.

- Composites have excellent RAM features (Radar absorbing materials). It's also possible to make special laminates which are radar and sonar transparent.
- Excellent impact habits
- Excellent electrical habits, concerning isolation but also conduction, dielectric habits, EMS shielding etc. Structures can be tailored on RF transparency but can also be made RF reflecting. Great for telecom especially UMTS frequencies.
- Great thermal isolation habits, fire retardant habits, and high temperature performance.

1.8 USES OF COMPOSITE MATERIALS

- Extensively used in space technology and production of Aerospace components (tails, wings, fuselages, propellers).
- Used in the production of sport goods e.g. racing car bodies and bicycle frames etc.
- Used for general industrial and engineering structures.
- Used in high speed and fuel efficient transport vehicles.
- The shell composed of Cosmolite, a thermoplastic fibre-reinforced composite and the exterior surface Spectralite which incorporates DuPont Surlyn, an impact-resistant coating found on golf balls.
- Carbon composite is a key material in today's launch vehicles and spacecraft. It is widely used in solar panel substrates, antenna reflectors and yokes of spacecraft. It is also used in payload adapters, inter-stage structures and heat shields of launch vehicles.

1.9 LIMITATION OF COMPOSITES

- High cost of fabrication of composite materials. For example, a part made-up of graphite/epoxy composite may cost up to 10 to 15 times of materials cost.
- Mechanical characterization of composite structure is more complex than that of a metal structure. Composite materials are not isotropic (i.e. do not possess same properties in all the direction). For example, a single layer of graphite/epoxy composite requires nine stiffness and strength constants for conducting mechanical analysis while in the case of steel only four stiffness and strength constant are required.

- Repair of composite is not a simple process as compared to metals.
- Composites do not have good combination of strength and fracture toughness as compared to metals.

1.10 FUNCTIONALLY GRADED MATERIAL (FGM)

In 1987, a national project was initiated in Japan under the title 'Research on the Basic Technology for the Development of Functionally Graded Materials for Relaxation of Thermal-Stress'. The project was aimed to develop advanced heat shielding structural materials for future space programs.

Functionally Graded Material (FGM)

These may be characterized by the variation in composition and structure gradually over volume, resulting in corresponding changes in the properties of the material. The materials can be designed for specific function and applications. Various approaches based on the bulk (particulate processing), perform processing, layer processing and melt processing are used to fabricate the functionally graded materials.

In general, the highest temperature on the surface of space –plane is estimated on reach 2100K. Therefore material at the surface must be able to temperature as high as 2100K and temperature difference of 1600K. Currently, no industrial material is known that can withstand such severe thermo-mechanical loading. The concept of FGM has been proposed to prepare a new composite by using heat resistant ceramic on the high temperature side and tough metals with high thermal conductivity on the low-temperature side, with a gradual compositional variation from ceramic to metal. FGMs are therefore composite materials with a macroscopically inhomogeneous character. Continuous changes in composition result in gradient in the properties of FGMs. The difference in microstructure and properties between FGMs and conventional composite materials are illustrated in fig.1.8 FGMs offer great promise in applications where the operating conditions are severe. FGMs are ideal candidates for applications involving severe thermal gradients, ranging from thermal structures in advanced aircraft and aerospace engines to computer circuit boards.

very interested in the possibility of materials that can withstand very high thermal gradients. This is normally achieved by using a ceramic layer connected with a metallic layer.

- The Air Vehicles Directorate has conducted Quasi-static bending test results of functionally graded titanium/titanium boride test specimens which can be seen below. The test correlated to the finite element analysis (FEA) using a quadrilateral mesh with each element having its own structural and thermal properties.
- Advanced Materials and Processes Strategic Research Program (AMPSRA) have done analysis on producing a thermal barrier coating using ZrO₂ and NiCoCrAlY. Their results have proved successful but no results of the analytical model are published.
- The rendition of the term that relates to the additive fabrication processes has its origins at the RMRG (Rapid Manufacturing Research Group) at Loughborough University in the United Kingdom. The term forms a part of a descriptive taxonomy of terms relating directly to various particulars relating to the additive CAD-CAM manufacturing processes, originally established as a part of the research conducted by architect Thomas Modeen into the application of the aforementioned techniques in the context of architecture.

1.12 CYLINDER

Cylinders are widely used in chemical and petroleum industries, military and aerospace applications, and nuclear-power plants and are usually operated under high pressures, and high temperatures/temperature gradients, which may lead to significant stresses and creep deformations. Therefore, a precise analysis of the creep in cylinder would lead to develop a better understanding of the materials and operating parameters responsible for controlling the stresses and strain rates in the cylinders operating under severe thermo-mechanical loadings. The problem investigated in this work may be helpful to evolve principles for the designer of composite cylinders made of either uniform composites or Functionally Graded composites and to generate a more reliable design code.

2.1 REVIEW OF LITERATURE

The present work focuses attention on creep in cylinders. In some of the applications such as pressure vessel for industrial gases or a media transportation of high-pressurized fluids and composite rotors, the cylinder has to operate under severe mechanical and thermal loadings resulting in significant creep, which may lead to their reduced service life. Numerous investigators have carried out analysis of stress and strain/strain rates in cylinder. Some of these salient contributions are discussed as below.

Rimrott *et al.* [1] (1959) used generally accepted assumptions of constant density, zero axial strain and distortion energy theory and derived equation for creep rate, creep strains and creep stresses of a thick-walled, closed end, circular hollow cylinder subjected to internal pressure. Cylinder was assumed to be made of a homogeneous isotropic material. The strains are considered large and finite strain theory is used. It had been shown that by considering finite strains, the creep rate of a thick walled cylinder under internal pressure increases, even though the creep rate of the same material when subjected to constant true stress in simple tension is constant. It is also observed that the assumption of infinitesimal strains leads to a prediction of wall thickness, which is on unsafe side.

Johnson and Henderson *et al.* [2] (1961) presented the analysis of stresses and strains in a thick walled cylinder, under internal and external pressure. They analyzed the changes in distribution of stress and strain with time. The theoretical relations between stress, strain rate and time had been derived and applied to a number of metallic alloys at temperatures within their practical working range.

Bhatnagar and Arya *et al.* [3] (1974) used finite strain theory to study the creep behaviour of pressurized (internal, external and both internal as well as external) thick-walled cylinder made of anisotropic material under large strains. It was observed that anisotropy exhibits significant effect on the axial stress, strain and strain rate.

Arya and Bhatnagar *et al.* [4] (1976) presented creep analysis of thick-walled anisotropic cylinder subjected to combined internal and external pressure by considering elastic strains. The time hardening law had been used to obtain the fundamental equations for the creep in an orthotropic cylinder. The equations had been solved for the particular case of planar anisotropy. A numerical example pertaining to the case of internal pressure has been worked out and the results obtained for the anisotropic case are compared with those estimated for the isotropic case. It was observed that the radial and tangential strain rates for an anisotropic material were less than those noticed for an isotropic material, at all radii and at all times. The strain rates are observed to decrease with increase in material anisotropy. The study also reported that the differences in the values of the strain rates at the inner radius are very pronounced and it diminishes with increasing radius.

Bhatnagar *et al.* [5] (1980) analyzed the stress and strain rate distributions in a hollow thick circular cylinder rotating about its own axis with a constant angular speed. The cylinder was assumed to be made of a homogeneous and orthotropic material. The steady state creep is described by Norton's law. The effect of anisotropy and stress exponent ' n ' in the creep law has been studied. It was concluded that the stress and strain-rate distributions are significantly affected by the anisotropy of material and the value of exponent ' n '. The values of effective strain rate observed for anisotropic material are much lower than those obtained for the isotropic material. It was suggested that anisotropic material may be beneficial for the manufacture of cylinders because of longer life and ability to sustain larger forces without a risk of failure under creep.

Roy and Tsai *et al.* [6] (1988) proposed a simple and effective design method for thick composite cylinders. Micro and macro mechanics had been integrated by simple relations and the integrated approach has been adopted to enable the designer to instantly study the sensitivity of the micromechanical variables on the final design. The stress analysis was based upon 3-dimensional elasticity and assumes the cylinders in state of generalized plane strain. The failure of cylinder was predicted by using a 3-dimensional quadratic failure criterion. In addition, the design parameters and material use efficiency of multilayer closed cylinder subjected to internal pressure had also been studied.

Wang and Lin *et al.* [7] (1993) analyzed the stresses in composite cylindrical shells rotating with a constant speed about its longitudinal axis. The circumferential stress, motivated by the conventional thin shell theory, had been assumed to vary linearly through the thickness of the layer. The radial stress had been determined in terms of the circumferential stress through the equilibrium condition by using an average compatibility condition through the thickness of the thin layer. The numerical results obtained through the analysis show nearly perfect agreement with the exact solution reported for homogeneous and isotropic cylinders.

Gupta and Pathak *et al.* [8] (1999) derived elastic-plastic stresses for a rotating non-homogeneous cylinder using Seth's transition theory. The effect of angular speed on non-homogeneity had been discussed and depicted graphically. It was observed that a rotating cylinder made of non-homogeneous material with non-homogeneity increasing radially requires a high percentage increase in angular speed to become fully plastic than to its initial yielding as compared to homogeneous cylinder and was on the safer side of the design.

Tzeng *et al.* [9] (1999) investigated creep and stress relaxation behaviour of fiber-reinforced composite overwrapped cylinders based on anisotropic viscoelasticity. The analysis accounts for ply-by-ply variations of material properties, ply orientations, and temperature gradients through the thickness of cylinders. The viscoelasticity exists mainly in matrix-dominant properties such as transverse and shear, while the fiber-dominant properties behave more like elastic media. The study of thermal and mechanical stress relaxation in an overwrapped composite cylinder shows that the viscoelastic characteristics of composite cylinders were quite different from those of isotropic cylinders. Poisson effects from the creep behaviour in the transverse properties of the composite can result in a drastic change of stress and strain state of the cylinder.

Gupta *et al.* [10] (2000) obtained creep stresses and strain rates in a rotating non-homogeneous thick-walled cylinder by using Seth's transition theory. It has been observed that for a rotating non-homogeneous cylinder whose compressibility increases radially, the circumferential stress is maximum at the external surface for a lesser angular speed but reverse was the case at some higher angular speed where it becomes maximum at the internal surface. The axial stress becomes more compressive at the external surface with an increase in angular speed.

Yang *et al.* [11] (2000) proposed an analytical solution to calculate the stresses in a layered cylinder with FGM structure taking into account the elastic and creep behaviour of the material

following Norton's law. A two layered cylinder was considered, in which the inner layer was of homogeneous material with elastic behaviour and the outer layer was an FGM having creeping material. For the elastic material, the solution was exact, whereas for the creeping material, the solution was asymptotic. The FEM calculations show that the fifth-order asymptotic solution may be used to calculate the stresses for a long time creep. However, for a short time creep, the first order asymptotic solution is enough to calculate the stresses approximately.

Gupta and Pathak *et al.* [12] (2001) used Seth's transition theory to obtain creep stresses and strain rates in a thick walled circular cylinder made of compressible/incompressible materials subjected to internal pressure. It was observed that the circumferential stress has maximum value at the external surface of the cylinder made of incompressible material compared to those estimated in cylinder composed of compressible material. Introduction of thermal effects is observed to reduce the stresses at external surface of the cylinder in comparison to pressure effects only. Strain rates are found to be the maximum at internal surface of the cylinder made of compressible material and tend to decrease with radius. With the introduction of thermal effects, the creep rates are found to increase more at the internal surface than at the external surface, when compared to a cylinder subjected to pressure alone.

Tutuncu and Ozturk *et al.* [13] (2001) provided closed-form solutions for stresses and displacements in Functionally Graded cylindrical vessels subjected to internal pressure using the infinitesimal theory of elasticity. They had considered constant Poisson ratio but assumed material stiffness to vary through the wall thickness. The effect of inhomogeneity on the stress distribution has been investigated.

Tzeng *et al.* [14] (2002) presented a viscoelastic analysis to investigate the creep and stress relaxation in a rotating multilayer composite cylinder. The analysis accounts for layer by layer variation of material properties, composite fiber orientation, temperature and density gradients through thickness of cylinders. A closed form solution based on the corresponding elastic problem had been derived for a generalized plane strain state in a thick walled multilayered cylinder. Laplace transformation was then applied to obtain the numerical solution of viscoelastic problem.

Muliana and Ali *et al.* [15] (2006) analyzed the creep behaviour and collapse of thick-section and layered composite structures by using a nonlinear visco-elastic and multi-scale modeling

framework. The creep analysis of axially compressed laminated cylinder under surface pressure had been presented. It was shown that the compressive loading ratio, along with the residual stiffness of the structure after buckling, can affect the creep behaviour and the magnitude of the critical time for initiation of unstable response. The proposed models can be used to examine the serviceability life of the structures.

Jian Jun Chen *et al.* [16] (2006) described that the creep behaviour of a functionally graded cylinder was considered under both internal and external pressures. When the properties of the graded material are axis symmetric and dependent on the radial coordinate, an asymptotic solution can be derived on the basis of a Taylor expansion series. The approximate solutions calculated from different higher-order terms are compared with the results of finite element (FE) analysis using ABAQUS software. It was shown that, although the use of higher-order terms may help to obtain a more accurate result for the time-dependent behaviour of the cylinder, a fifth-order form has been sufficiently accurate to calculate the creep stress distribution with satisfactory approximation.

L.H. You *et al.* [17] (2007) described that Steady-state creep of thick-walled cylindrical vessels made of functionally graded materials subjected to internal pressure was investigated in this paper. Taking material parameters involved in Norton's law to be the functions of the radial coordinate, a simple and accurate method was developed from the strain rate–stress relations, Norton's law, deformation compatibility condition and equilibrium equation of axis symmetric, plane strain problems. The proposed approach was employed to calculate stresses and creep strain rates in the thick-walled cylindrical vessels. How variations of material parameters along the radial direction affect the stresses in the vessels was examined.

H. Santos *et al.* [18] (2008) carried out research, which demonstrated that a study of thermoelastic analysis of functionally graded cylindrical shells subjected to transient thermal shock loading was carried out. A semi-analytical axis symmetric finite element model using the three-dimensional linear elasticity theory was developed. The three-dimensional equations of motion are reduced to two-dimensional ones by expanding the displacement field in Fourier series in the circumferential direction involving circumferential harmonics. The material properties are graded in the thickness direction according to a power law. The model has been

verified with the results of simple analytical isotropic cylindrical shells subjected to a transient thermal loading. Additional FGM results for stresses and displacements are presented.

Singh *et al.* [19] (2008) described that the steady state creep in Al-SiCP composite cylinder subjected to internal pressure was investigated. The creep behaviour of the material were described by threshold stress based creep law by assuming a stress exponent of 5. The effect of size and content of the reinforcement (SiCP), and operating temperature on the stresses and strain rates in the composite cylinder were investigated. The stresses in the cylinder did not have significant variation with varying size and content of the reinforcement, and operating temperature. However, the tangential as well as radial strain rates in the cylinder could be reduced to a significant extent by decreasing size of SiCP, increasing the content of SiCP and decreasing operating temperature.

Singh *et al.* [20] (2008) described that the steady state creep behaviour in an isotropic functionally graded composite cylinder, subjected to internal pressure had been investigated. The cylinder was assumed to be made of composite containing silicon carbide particles in a matrix of pure aluminium. The effect of imposing linear particle gradient on the distribution of stresses and strain rates in the composite cylinder had been investigated. The study reveals that for the assumed linear particle distribution, the radial stress decreases throughout the cylinder with increase in particle gradient, whereas the tangential, axial and effective stresses increases significantly near the inner radius but show significant decrease towards the outer radius. The strain rates in the composite cylinder could be reduced significantly by employing gradient in the distribution of reinforcement.

M. Shariyat *et al.* [21] (2009) described the Nonlinear transient thermal stress and elastic wave propagation analysis are developed for hollow thick temperature-dependent FGM cylinders subjected to dynamic thermomechanical loads. Stress wave propagation, wave shape distortion, and speed variation under impulsive mechanical loads in thermal environments are also investigated. In contrast to researches accomplished so far, a second-order formulation rather than a first-order one was employed to improve the accuracy. The FDM method (as a point-collocation FEM method) was used. It was known that other FEM methods cannot show the actual trend jumps due to distributing the abrupt changes in the quantities as the numerical errors and the residuals of the governing equations among the nodal results. Furthermore, the required

computational time and allocated computer memory are much reduced by the present solution algorithm. The cylinder was not divided into isotropic sub-cylinders. Therefore, artificial wave reflections from the hard interfaces are avoided. Time variations of the temperatures, displacements, and stresses due to the dynamic or impulsive loads are determined by solving the resulted highly nonlinear governing equations using an iterative updating solution scheme. A sensitivity analysis includes effects of the volume fraction indices, dimensions, and temperature-dependency of the material properties was performed. Results reveal the significant effect of the temperature-dependency of the material properties on the thermoelastic stresses and present some interesting characteristics of the thermoelastic and wave propagation behaviours.

Gupta *et al.* [22] (2009) described that a mathematical model had been developed to describe steady state creep in an isotropic functionally graded composite cylinder. The cylinder was subjected to internal pressure and was made of functionally graded composite containing linearly varying silicon carbide particles in a matrix of pure aluminium. The cylinder was assumed to creep according to a threshold stress-based creep law having a stress exponent 5. The effect of employing a linear gradient in the distribution of reinforcement had been observed on the variation of creep stresses and creep rates in the composite cylinder. It was observed that the radial stress in the cylinder decreases throughout with the increase in reinforcement gradient, whereas the tangential, axial, and effective stresses increase significantly near the inner radius but show significant decrease towards the outer radius. The strain rates in the composite cylinder could be reduced significantly by tailoring the distribution of reinforcement while maintaining the same average amount of reinforcement. The distribution of strain rate becomes relatively uniform with increase in particle gradient.

2.2 PROBLEM DESCRIPTION

Creep analysis of thick-walled cylinder made of an isotropic monolithic material has been the subject of numerous investigations. Prediction of creep life in many axis symmetric problems, including pressure vessels, is very important and complex task. Under severe mechanical and thermal loadings cylinders made of monolithic materials may not perform well. So my problem is basically to develop a model to describe steady state creep in a Functionally Graded thick walled composite cylinder.

A new material concept of Functionally Graded Materials (FGMs) emerged and led to the development of superior heat resistant materials. FGMs, among the most important non-homogeneous composites designed for high temperature application, show great promise in high-tech engineering fields. FGMs have a high potential for applications in components subjected to severe mechanical and thermal loadings because of their unique performance due to spatial tailoring of properties at microscopic level.

A critical review of literature reported reveals that the problem of determination of elastic stresses and deformations in a cylinder made of monolithic material has been dealt by several workers but the studies pertaining to creep deformations in a composite cylinder are limited. Further, a few studies related to creep behaviour of FGM cylinders have widened the knowledge of time-dependent mechanics for FGMs. There is still a lack of general understanding of the creep behaviour of FGM cylinders, especially when they are subjected to pressures. In the light of this, it is decided to investigate creep behaviour in a cylinder made of functionally graded composite. Thus, it becomes imperative to study the creep behaviour of composite cylinder with tailored distribution of reinforcement. A model will be developed to estimate the stresses and strain rates in cylinder made of FGM under different loading conditions. The results obtained shall be compared and analyzed to draw appropriate conclusions.

3.1 INTRODUCTION TO FINITE ELEMENT METHOD

The finite element method (FEM) is a numerical technique for solving problems which are described by partial differential equations or can be formulated as functional minimization. A domain of interest is represented as an assembly of finite elements. Approximating functions in finite elements are determined in terms of nodal values of a physical field which is sought. A continuous physical problem is transformed into a discretized finite element problem with unknown nodal values. For a linear problem a system of linear algebraic equations should be solved. Values inside finite elements can be recovered using nodal values.

Finite element method (FEM) is a numerical method for solving a differential or integral equation. It has been applied to a number of physical problems, where the governing differential equations are available. The method essentially consists of assuming the piecewise continuous function for the solution and obtaining the parameters of the functions in a manner that reduces the error in the solution.

Two features of the FEM are worth to be mentioned:

- 1) Piece-wise approximation of physical fields on finite elements provides good precision even with simple approximating functions (increasing the number of elements we can achieve any precision).
- 2) Locality of approximation leads to sparse equation systems for a discretized problem. This helps to solve problems with very large number of nodal unknowns.

3.2 HOW THE FEM WORKS

To summarize in general terms how the finite element method works we list main steps of the finite element solution procedure below.

1. **Discretize the continuum.** The first step is to divide a solution region into finite elements. The finite element mesh is typically generated by a preprocessor program. The description of mesh consists of several arrays main of which are nodal coordinates and element connectivities.

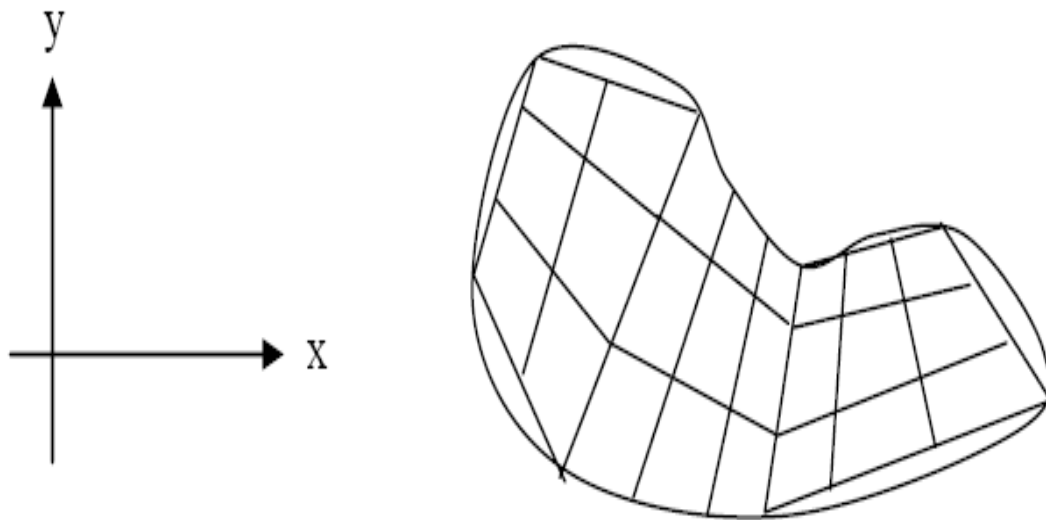


Fig.3.1 Discretized Domain

2. **Select interpolation functions.** Interpolation functions are used to interpolate the field variables over the element. Often, polynomials are selected as interpolation functions. The degree of the polynomial depends on the number of nodes assigned to the element.
3. **Find the element properties.** The matrix equation for the finite element should be established which relates the nodal values of the unknown function to other parameters.
4. **Assemble the element equations.** To find the global equation system for the whole solution region we must assemble all the element equations. In other words we must combine local element equations for all elements used for discretization. Element connectivities are used for the assembly process. Before solution, boundary conditions (which are not accounted in element equations) should be imposed.
5. **Solve the global equation system.** The finite element global equation system is typically sparse, symmetric and positive definite. Direct and iterative methods can be used for solution. The nodal values of the sought function are produced as a result of the solution.
6. **Compute additional results.** In many cases we need to calculate additional parameters. For example, in mechanical problems strains and stresses are of interest in addition to displacements, which are obtained after solution of the global equation system.

3.3 ADVANTAGES OF FEM

1. Element equation and stiffness matrix can be used for different element problems.
2. Complex domain or the complex problem can be simplified.
3. A single problem can be formulated in different ways using FEM.
4. It is versatile method works where other numerical technique fails.

3.4 ELEMENT TYPES AND DISCRETIZATION

We will discuss the element types and discretization in this section. It is important to be able to select an element type which is most suitable for the problem of interest, and to determine the shape functions for the chosen element type. Finally automatic mesh generation techniques are in practical sense also important to finite element analysis applications.

Element Types:

i) One-dimensional Elements

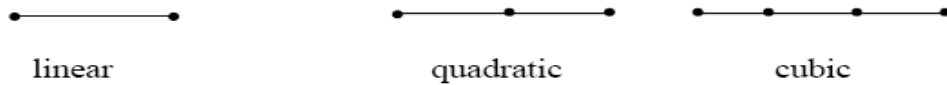


Fig 3.2 One Dimensional Elements

ii) Two-dimensional Elements

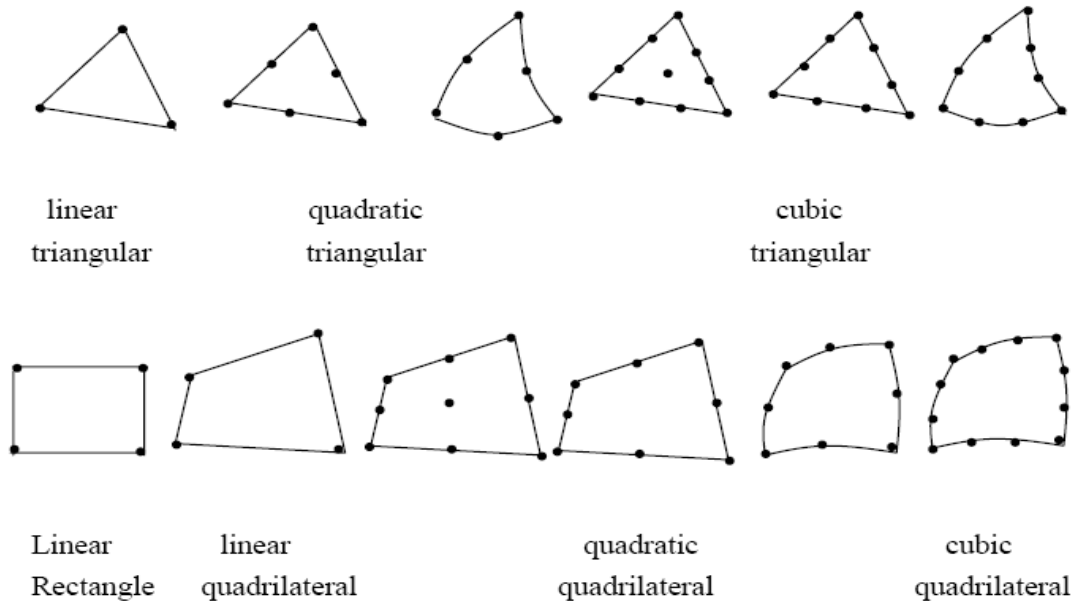


Fig 3.3 Two Dimensional Elements

iii) Three-dimensional Elements

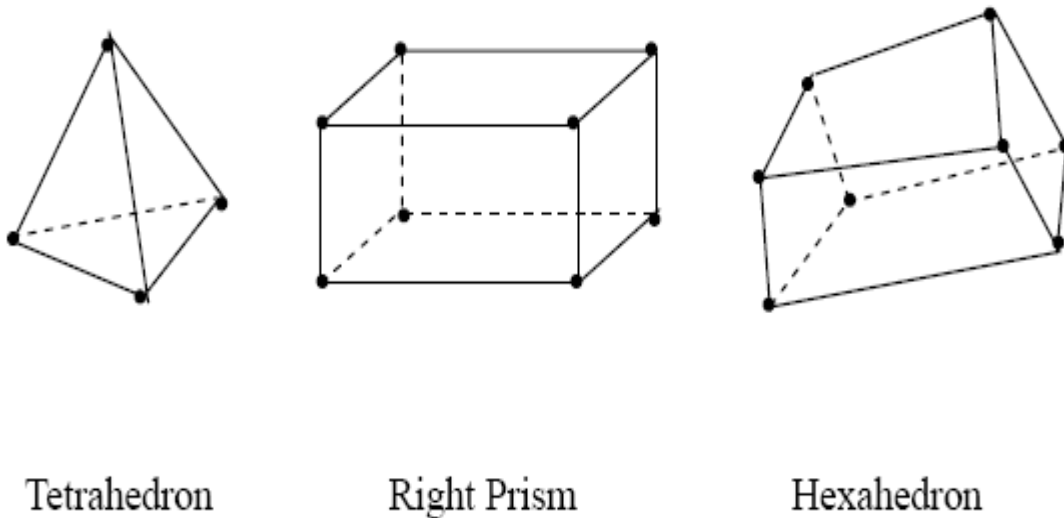


Fig 3.4 Three Dimensional Elements

3.5 APPLICATIONS OF FEM

A variety of specializations under the umbrella of the mechanical engineering discipline (such as aeronautical, biomechanical, and automotive industries) commonly use integrated FEM in design and development of their products. Several modern FEM packages include specific components such as thermal, electromagnetic, fluid, and structural working environments. In a structural simulation, FEM helps tremendously in producing stiffness and strength visualizations and also in minimizing weight, materials, and costs.

FEM allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements. FEM software provides a wide range of simulation options for controlling the complexity of both modeling and analysis of a system. Similarly, the desired level of accuracy required and associated computational time requirements can be managed simultaneously to address most engineering applications. FEM allows entire designs to be constructed, refined, and optimized before the design is manufactured.

3.6 ANSYS

ANSYS is general purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces called elements. The software implements equations that govern the behaviour of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations. ANSYS is the standard FEA teaching tool within the Mechanical Engineering Department at many colleges. ANSYS is also used in Civil and Electrical Engineering, as well as the Physics and Chemistry departments.

3.7 WHY ANSYS REQUIRED

ANSYS provides a cost-effective way to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping. With virtual prototyping techniques, users can iterate various scenarios to optimize the product long before the manufacturing is started. This enables a reduction in the level of risk, and in the cost of ineffective designs. The multi-faced nature of ANSYS also provides a means to ensure that users are able to see the effect of a design on the whole behaviour of the product, be it electromagnetic, thermal, mechanical etc.

3.8 STEPS TO SOLVING ANY PROBLEM IN ANSYS

Like solving any problem analytically, it is needed to define

- (1) the solution domain
- (2) the physical model
- (3) boundary conditions
- (4) the physical properties

Then solve the problem and present the results. In numerical methods, the main difference is an extra step called mesh generation. This is the step that divides the complex model into small elements that become solvable in an otherwise situation. Below describes the processes in terminology slightly more attune to the software.

1. **Build Geometry.** Construct a two or three dimensional representation of the object to be modeled and tested using the work plane coordinates system within ANSYS.
2. **Define Material Properties.** Now that the part exists, define a library of the necessary materials that compose the object (or project) being modeled. This includes thermal and mechanical properties.
3. **Generate Mesh.** At this point ANSYS understands the makeup of the part. Now define how the modeled system should be broken down into finite pieces.
4. **Apply Loads.** Once the system is fully designed, the last task is to burden the system with constraints, such as physical loadings or boundary conditions.
5. **Obtain Solution.** This is actually a step, because ANSYS needs to understand within what state (steady state, transient... etc.) the problem must be solved.
6. **Present the Results.** After the solution has obtained, there are many ways to present ANSYS' results, choose from many options such as tables, graphs, and contour plots.

3.9 ANALYSIS WHICH CAN BE DONE ON ANSYS

Structural analysis is probably the most common application of finite element method as it implies bridges and buildings, naval, aeronautical, and mechanical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools.

Static Analysis- Used to determine displacements, stresses, etc. under static loading conditions. ANSYS can compute both linear and nonlinear static analysis. Nonlinearities can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces, and creep.

Transient Dynamic Analysis- Used to determine the response of a structure to arbitrarily time-varying loads. All nonlinearities mentioned under Static Analysis above are allowed.

Buckling Analysis- Used to calculate the buckling loads and determine the buckling mode shape. Both linear buckling and non linear buckling analysis are possible.

In addition to the above analysis types, several special- purpose features are available such as Fracture Mechanics, Composite material Analysis, Fatigue, and both p-Method and Beam analysis.

THERMAL

ANSYS is capable of both steady state and transient analysis of any solid with thermal boundary conditions. Steady state thermal analysis calculates the effects of steady thermal loads on a system or component. Users often perform a steady state analysis before doing a transient thermal analysis, to help establish initial conditions. A steady state analysis also can be the last step of a transient thermal analysis; performed after all transient effects have diminished. ANSYS can be used to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following:

- Convection
- Radiation
- Heat flow rates
- Heat Fluxes(heat flow per unit volume)
- Heat generation rates(heat flow per unit volume)
- Constant temperature boundaries

A steady state thermal analysis may be either linear, with constant material properties; or nonlinear, with material properties that depend on temperature. The thermal properties of most material vary with temperature. This temperature dependency being appreciable, the analysis becomes nonlinear. Radiation boundary conditions also make the analysis nonlinear. Transient

calculations are time dependent and ANSYS can both solve distributions as well as create video time incremental displays of models.

4.1 MODELING AND ANALYSIS OF FGM CYLINDER

Following steps have been followed to model the FGM cylinder

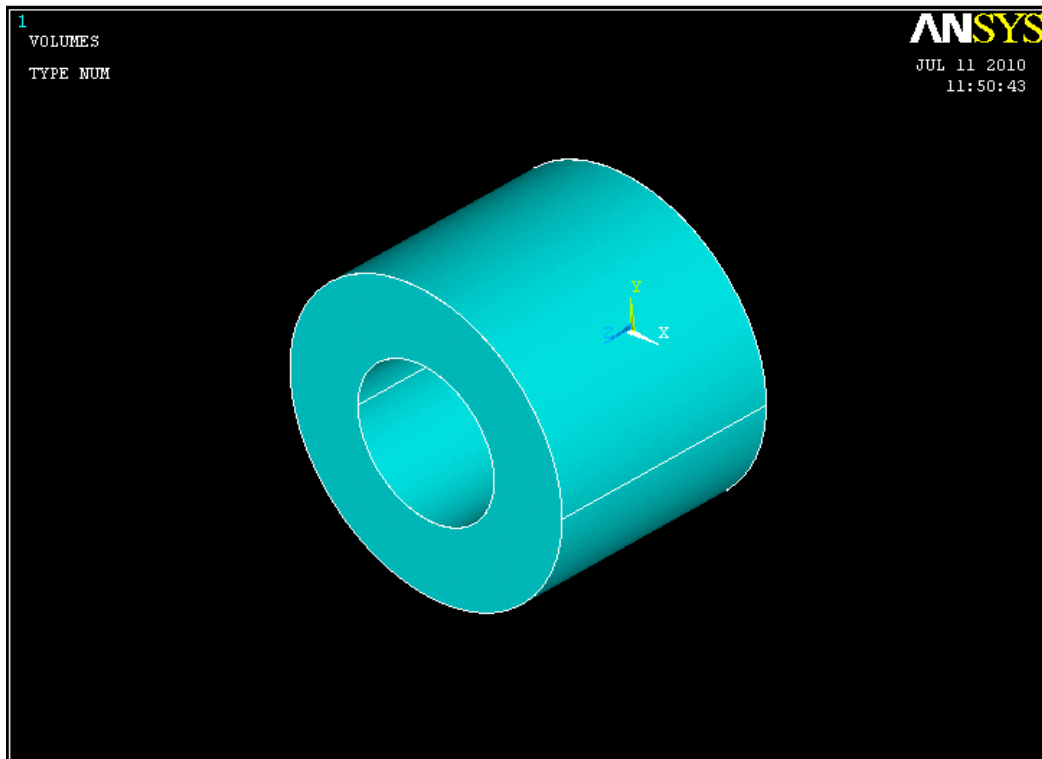


Fig 4.1 Cylinder model

Step 1:- To select the type of analysis under preferences.

- Select 'structural' from the menu as shown in figure 4.2.

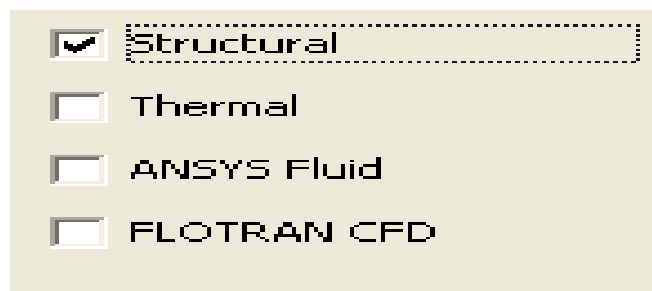


Fig 4.2 Selecting the Type of Analysis

Step 2:- To decide the finite element for the geometry.

- Select '8node82' element as shown in figure 4.3.
- Select element behavior as 'axis symmetric'.

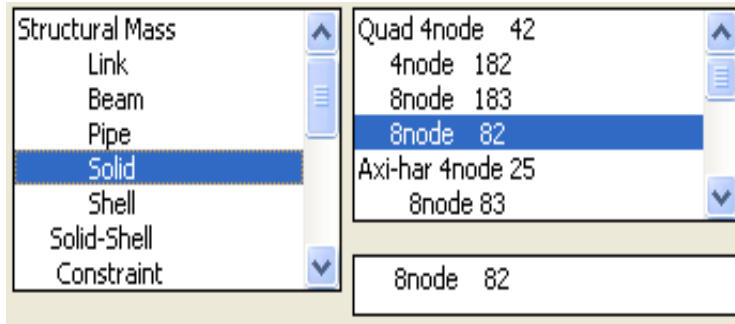


Fig 4.3 Selecting the Type of Element

Step 3:- Deciding the material properties.

- Give the values of Young modulus, Poisson ratio, Creep exponent as given in table 4.1.

Young modulus	Poisson ratio	Creep exponent
22000 N/mm ²	0.3	3.75

Table 4.1 Materials Values

Step 4:- Modeling

- Select a rectangular section from a cylinder of given dimensions as shown in figure 4.4 and then model it in Ansys as shown in figure 4.5.

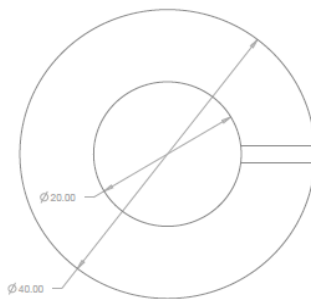


Fig 4.4 Rectangular section taken from cylindrical section

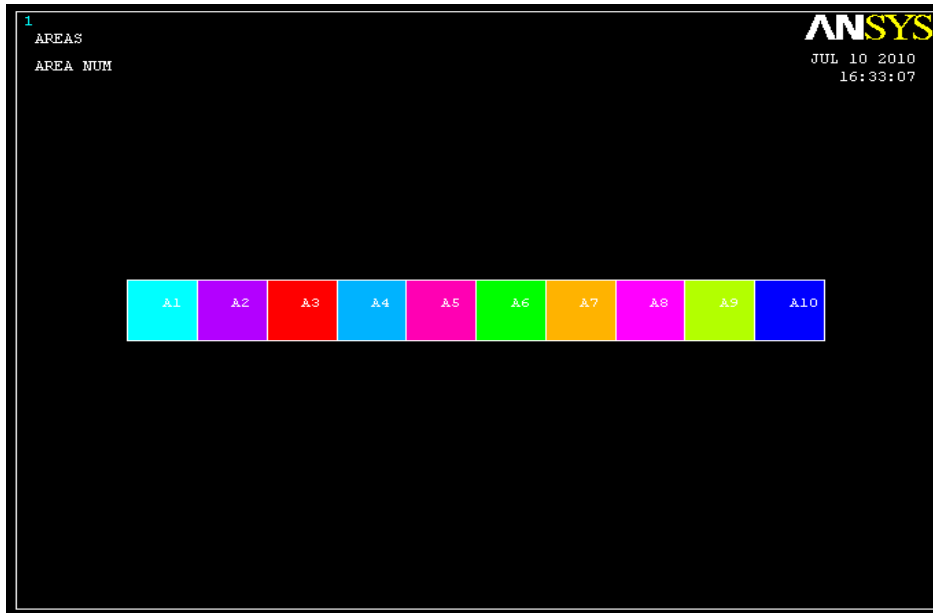


Fig 4.5 Modeling of Different Areas

Step 5:- Meshing

- Mesh the section by taking the Elements defined above.

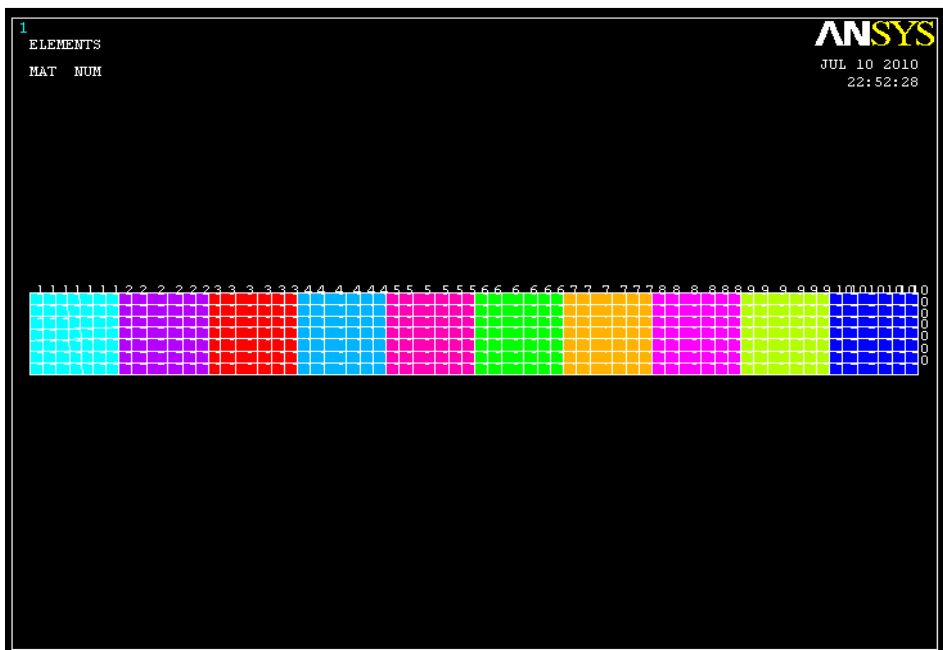


Fig 4.6 Meshed Area

Step 6:- Load and Boundary Conditions

- Apply constraint on the lower edge in y-direction as shown in the figure 4.7.

- Now apply load on both the transverse edges in opposite direction.

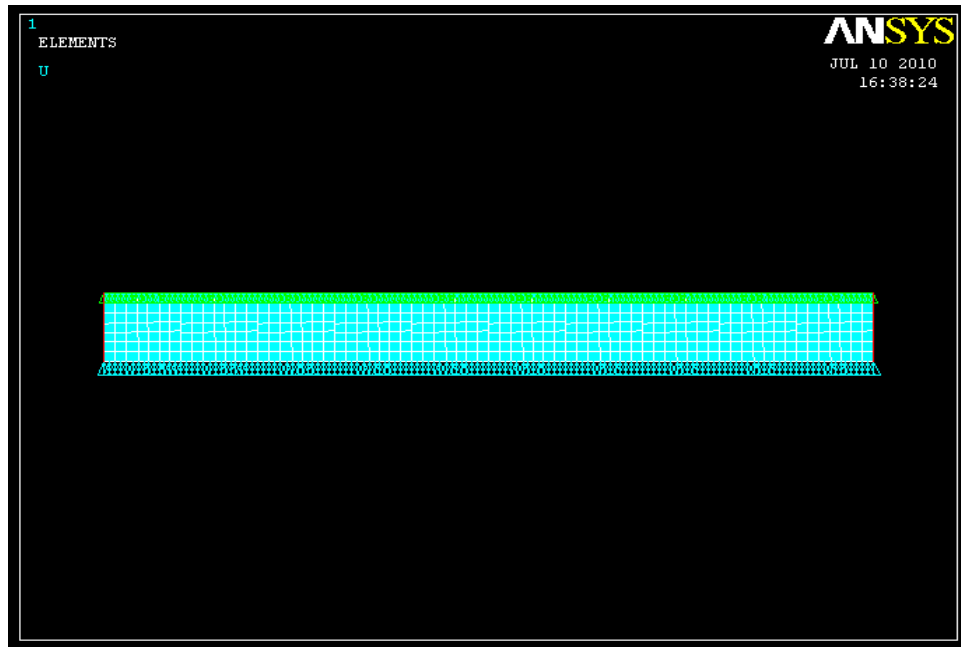


Fig 4.7 Load and Boundary Condition

Step 7:- Solution

- Go to solution and select solve to get the desired results.
- Display the nodal solutions.
- Display the graphical solutions.
- For time analysis results go to Timehistpostpro.

The results have been obtained by Modeling and Analysis in Ansys software for the problem which had undertaken by Jian Jun Chen in his research paper named as “Creep Analysis for a Functionally Graded Cylinder Subjected to Internal and External Pressure”. In his work he had mathematically modeled his problem using Taylor Expansion Series. The results obtained in the present work are well versed with the above mentioned paper.

5.1 VALIDATION OF RESULTS FOR RADIAL STRESSES WHEN CYLINDER SUBJECTED TO INTERNAL PRESSURE

The results obtained by Jian Jun Chen [16] are in the Graphical form as shown below:

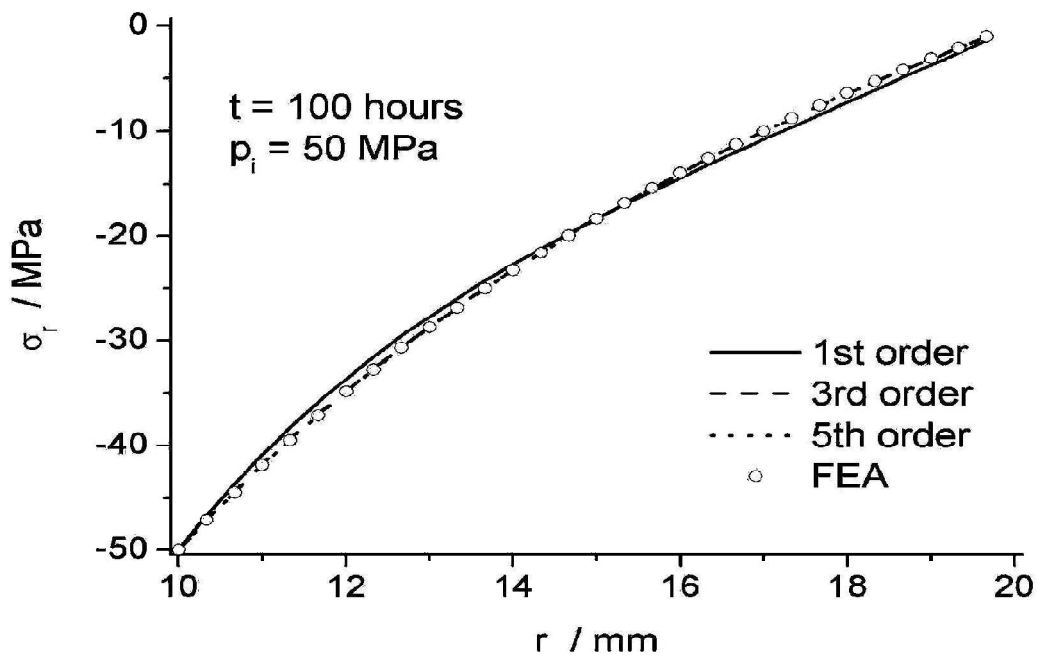


Fig. 5.1 Graph Showing Results of Jian Jun Chen [16] for Radial Stresses

In the Fig. 5.1 the horizontal axis shows the radius of cylinder and vertical axis shows the radial stresses. It is clear from the graph that the radial stresses (σ_r) are inversely proportional to radius (r). In his work he had shown the results for three iterations for the given time ($t=100h$) at given internal pressure ($p_i = 50$ MPa).

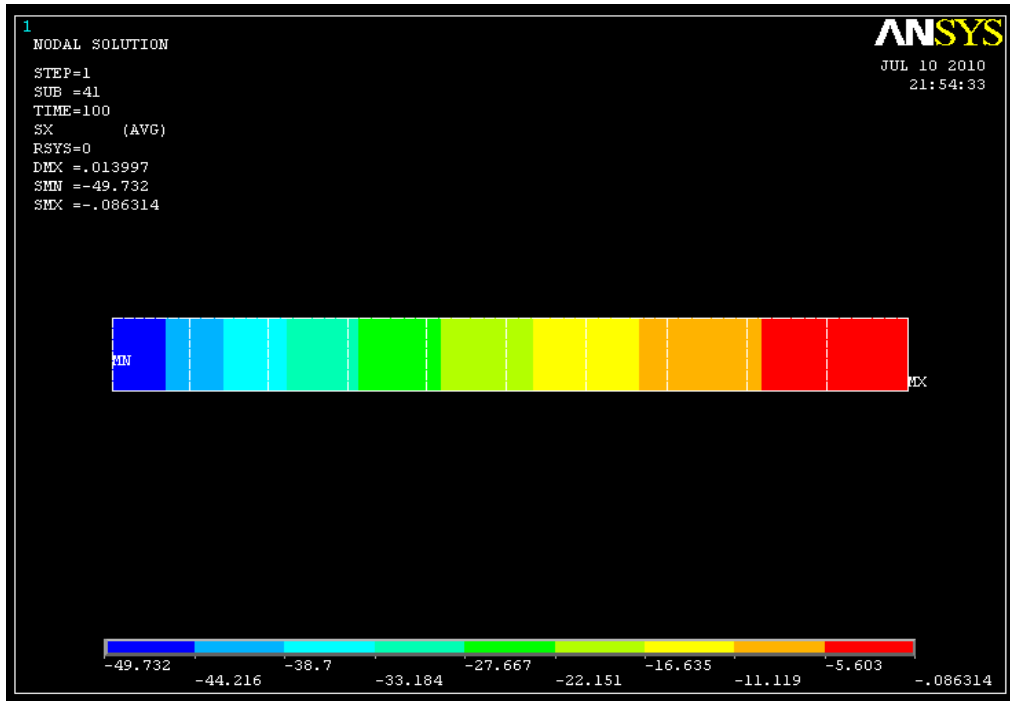


Fig. 5.2 Variation of Radial Stresses along the Radius

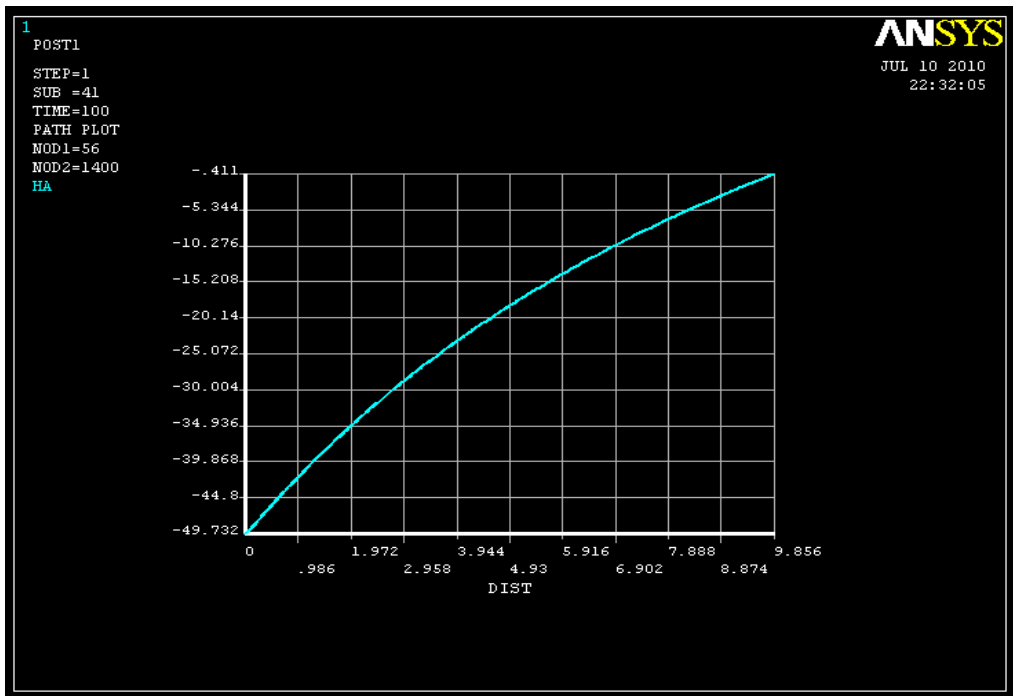


Fig. 5.3 Graph for Radial Stresses along the Radius

The results obtained in the present work by using Ansys software with internal pressure of 50 MPa on a cylinder of internal radius 10mm and external radius of 20mm are shown in Fig. 5.2 and Fig. 5.3. It is clear in the both the figures that as the radius increase i.e. as we move from

inner radius to outer radius the radial stresses get decreased. From the above discussion it is clear that our results are in accordance with the results of the Jian Jun Chen [16].

5.2 VALIDATION OF RESULTS FOR CIRCUMFERENTIAL STRESSES

The results obtained by Jian Jun Chen [16] are in the Graphical form as shown below:

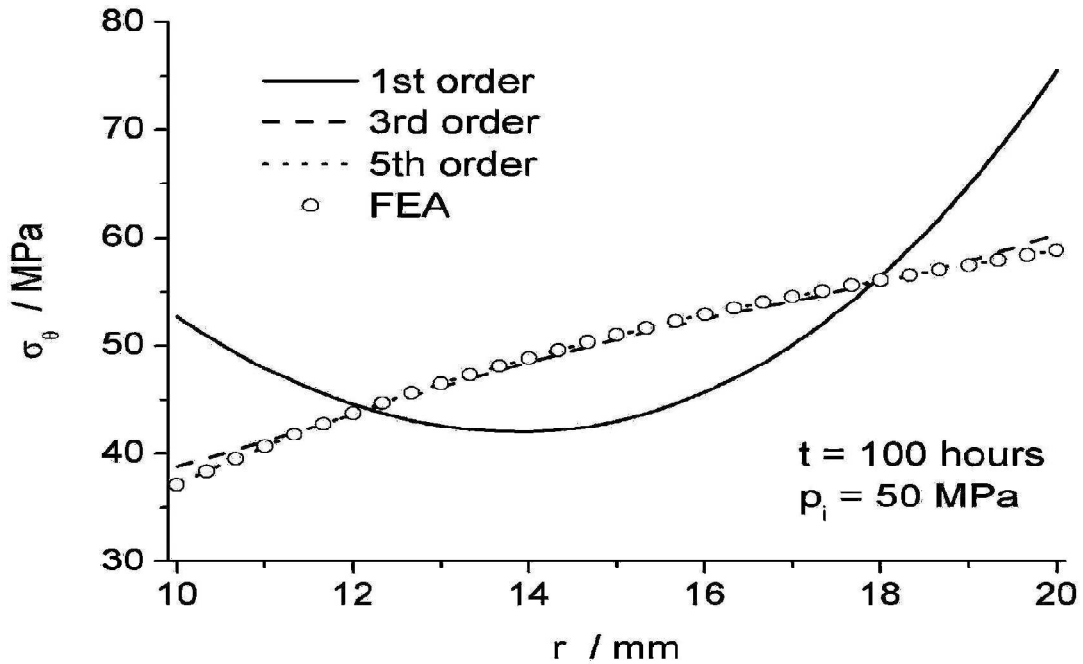


Fig. 5.4 Graph Showing the Results of Jian Jun Chen [16] for Circumferential Stresses

In the Fig. 5.4 Jian Jun chen [16] showed the results for circumferential stresses. The horizontal axis varies the radius of cylinder and vertical axis varies the circumferential stresses. It is clear from the graph that the circumferential stresses (σ_{θ}) are proportional to radius (r). He applied internal pressure $p_i = 50$ MPa for time period of 100 hours.

The results obtained in the present work by using Ansys software are shown in Fig. 5.5 and Fig. 5.6. It is clear in the both the figure that as the radius increase i.e. as we move from inner radius to outer radius the circumferential stresses get increased. From the above discussion it is clear that our results are in accordance with the results of the Jian Jun Chen [16].

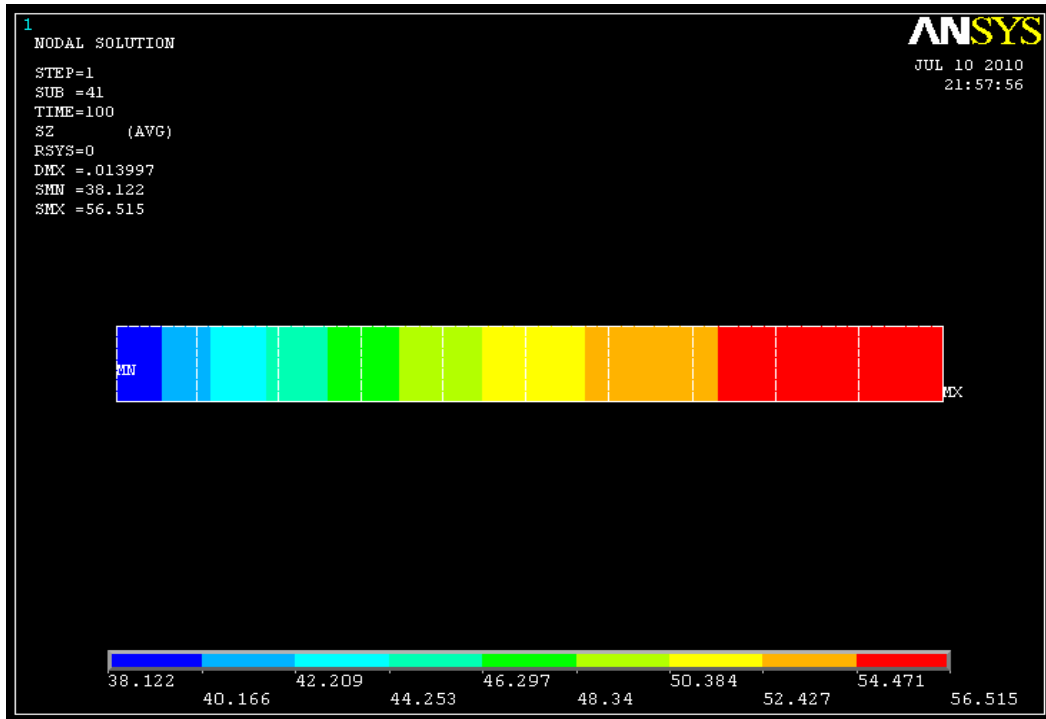


Fig. 5.5 Variation of Circumferential Stresses along the Radius

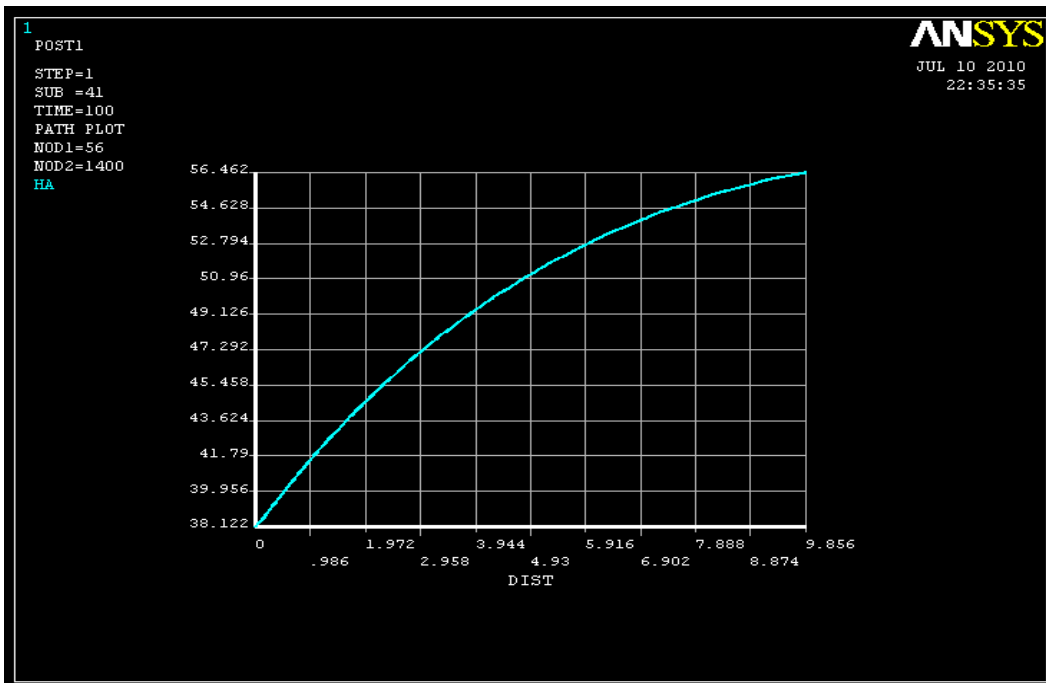


Fig. 5.6 Graph for Circumferential Stresses along the Radius

5.2.1 VALIDATION OF TIME DEPENDENT RESULTS FOR CIRCUMFERENTIAL STRESSES

The results obtained by Jian Jun Chen [16] are in the Graphical form as shown below:

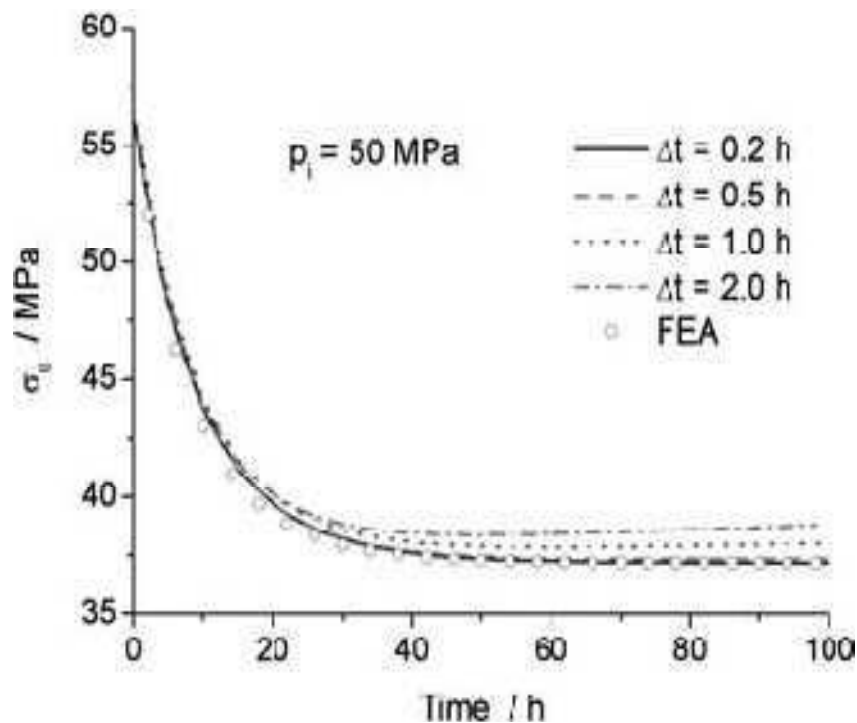


Fig. 5.7 Graph Showing the Results of Jian Jun Chen [16] for Circumferential Stresses with Respect to Time

In the Fig. 5.7 Jian Jun chen [16] showed the results for circumferential stresses with respect to time. The horizontal axis varies the time and vertical axis varies the circumferential stresses.

The results obtained in the present work by using Ansys software are shown in Fig. 5.8. It is clear in the figure that as the time increase circumferential stresses get decreased. From the above discussion it is clear that our results are in accordance with the results of the Jian Jun Chen [16].

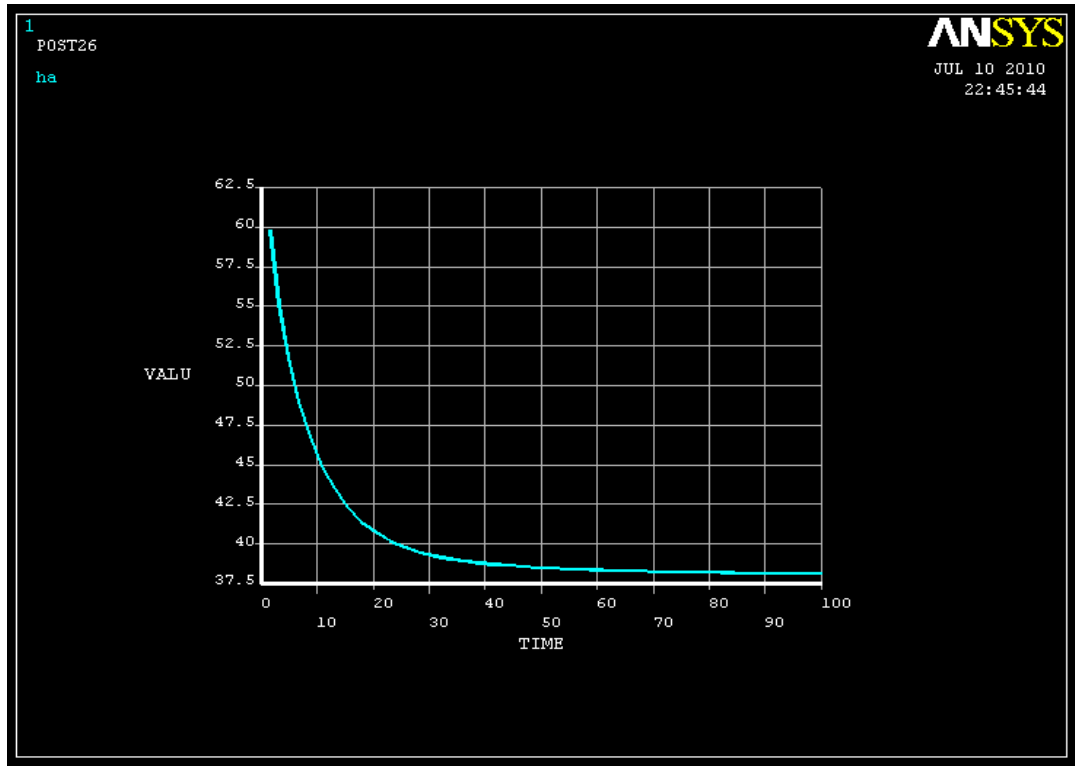


Fig. 5.8 Graph Showing the Results for Circumferential Stresses with Respect to Time

5.3 VALIDATION OF RESULTS FOR RADIAL STRESSES WHEN CYLINDER SUBJECTED TO INTERNAL PRESSURE

In the Fig. 5.9 the horizontal axis shows the radius of cylinder and vertical axis shows the radial stresses. It is clear from the graph that the radial stresses (σ_r) are proportional to radius (r). In his work he had shown the results for three iterations for the given time (t=100h) at given external pressure ($p_0 = 50$ MPa). When we move from internal radius to outer radius the stresses are increased. At the inner radius of cylinder the stresses are approximately zero and at the outer radius radial stresses are maximum.

The results obtained by Jian Jun Chen [16] are in the Graphical form as shown in Fig 5.9:

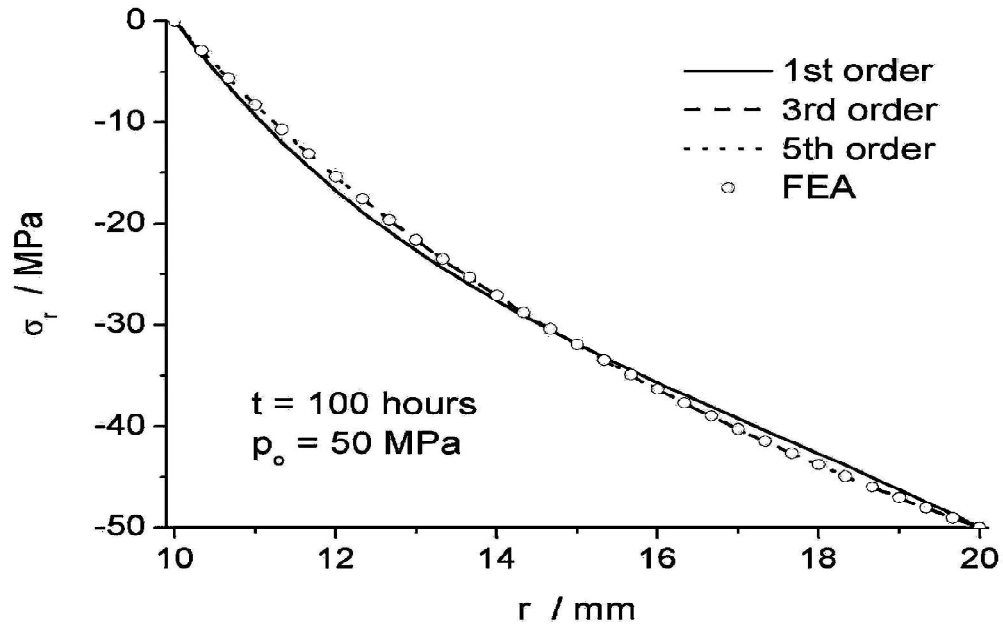


Fig. 5.9 Graph Showing Results of Jian Jun Chen [16] for Radial Stresses

The results obtained in the present work by using Ansys software with external pressure of 50 MPa on a cylinder of internal radius 10mm and external radius of 20mm are shown in Fig. 5.10 and Fig. 5.11. It is clear in the both the figure that as the radius increase i.e. as we move from inner radius to outer radius the radial stresses get increased. From the above discussion it is clear that our results are in accordance with the results of the Jian Jun Chen [16].

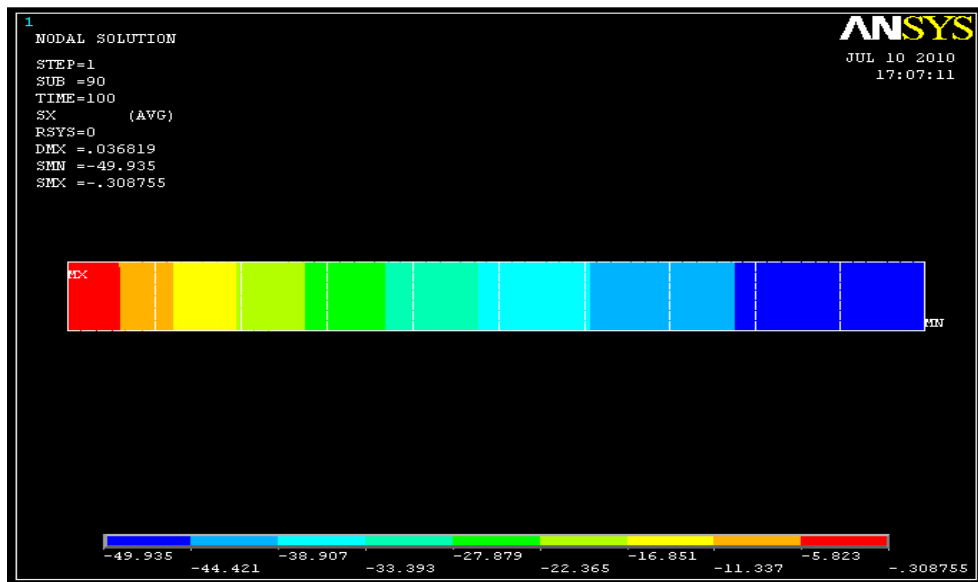


Fig. 5.10 Variation of Radial Stresses along the Radius

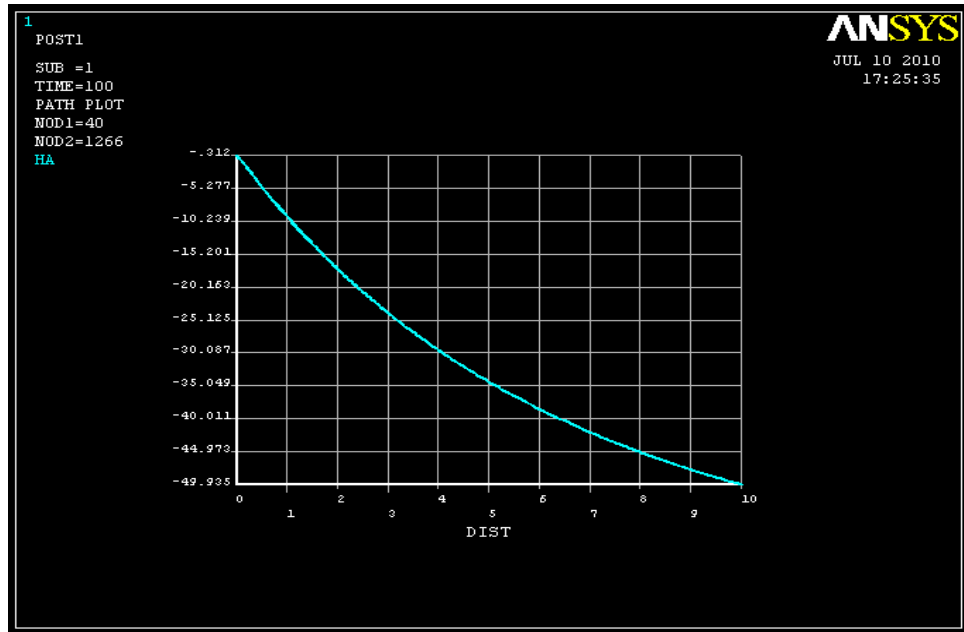


Fig. 5.11 Graph for Radial Stresses along the Radius

5.4 VARIATION OF STRESSES BY VARYING OF INTERNAL PRESSURE FOR RADIAL STRESSES

The effect of varying internal pressure is seen in the further study. The results are seen in the figures 5.12 and 5.13 in graphical and stress variation view for radial stresses at 75 MPa.

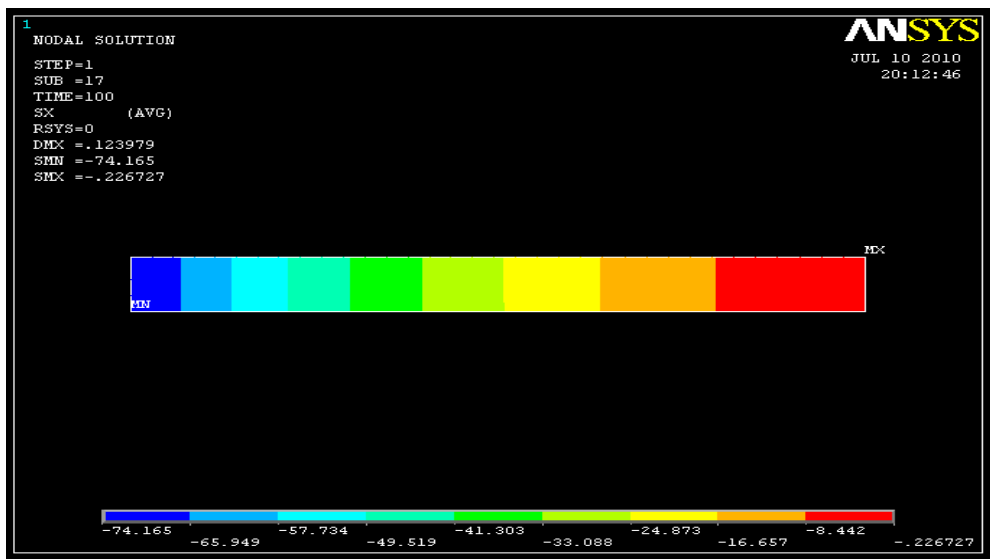


Fig. 5.12 Variation of Radial Stresses along the Radius for Pressure 75 MPa

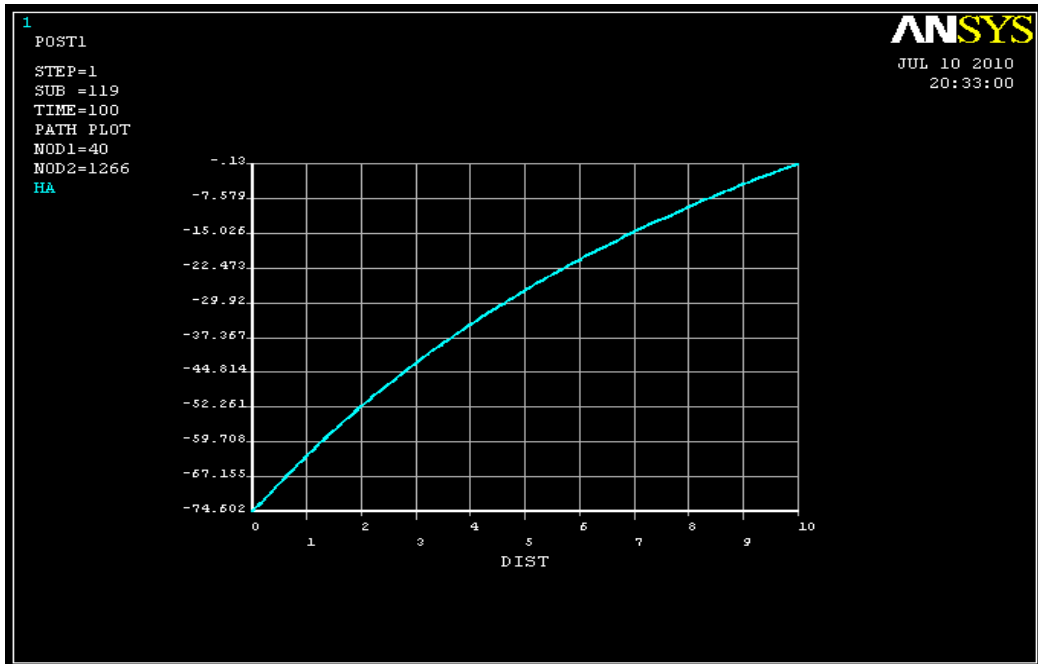


Fig. 5.13 Graph for Radial Stresses along the Radius for Pressure 75 MPa

The results for the variation of radial stresses at the internal pressure of 100 MPa are shown in figure 5.14 and 5.15.

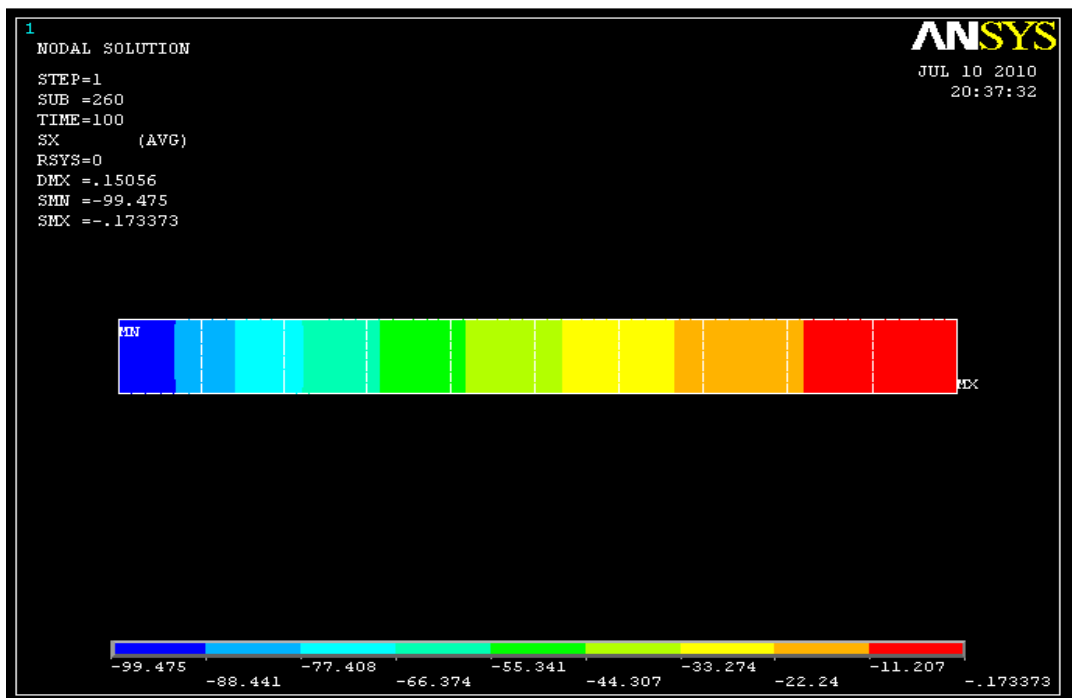


Fig. 5.14 Variation of Radial Stresses along the Radius for Pressure 100 MPa

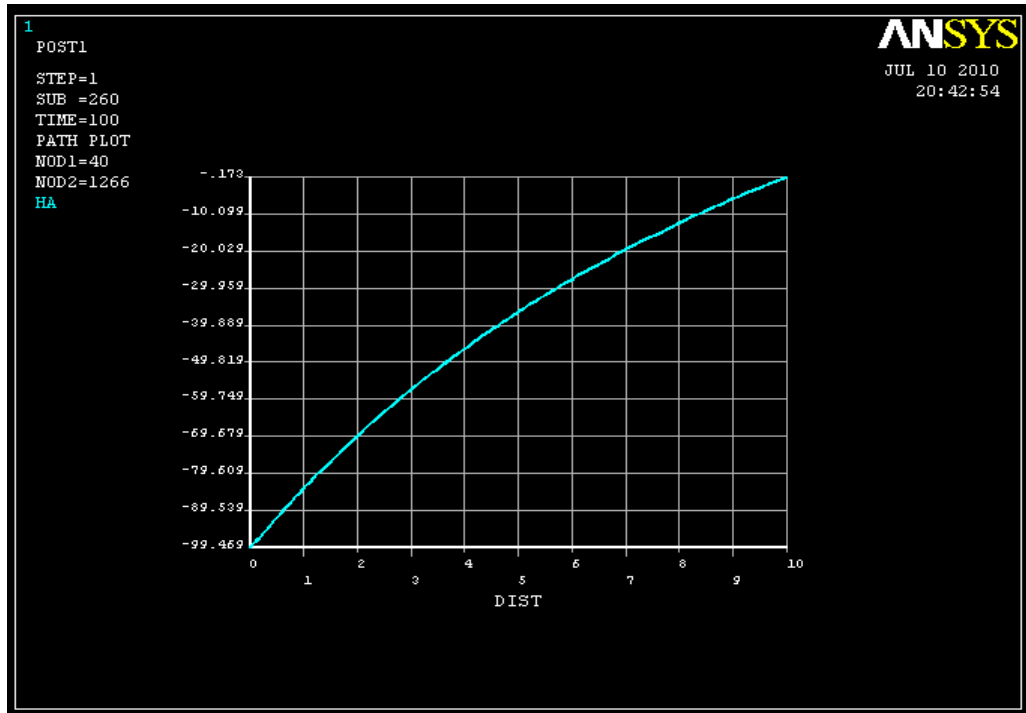


Fig. 5.15 Graph for Radial Stresses along the Radius for Pressure 100 MPa

From the figure 5.12, 5.13, 5.14 and 5.15 it is clear that as we increase the internal pressure the radial stresses increases in the same proportion as the internal pressure increase in both the cases.

5.5 VARIATION OF STRESSES BY VARYING OF INTERNAL PRESSURE FOR CIRCUMFERENTIAL STRESSES

The results for the variation of circumferential stresses at the internal pressure of 75 MPa are shown in figure 5.16 and 5.17 and similarly results for internal pressure of 100MPa are shown in figure 5.18 and 5.19. From the figures it is clear that the circumferential stresses increases more as compared to radial stresses.

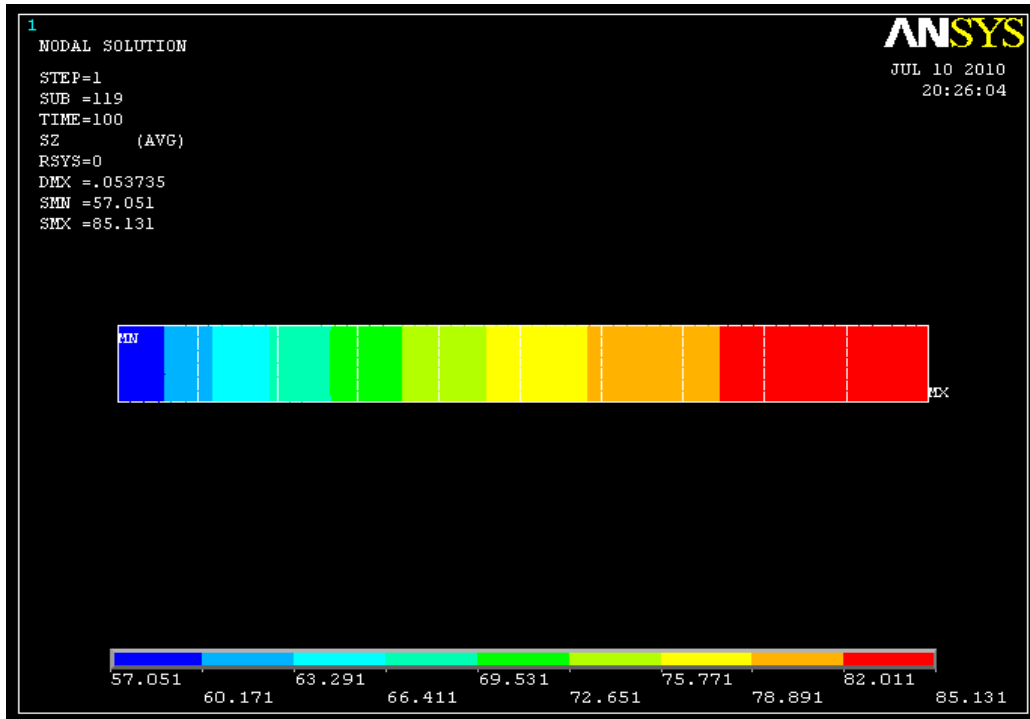


Fig. 5.16 Variation of Circumferential Stresses along the Radius for Pressure 75 MPa

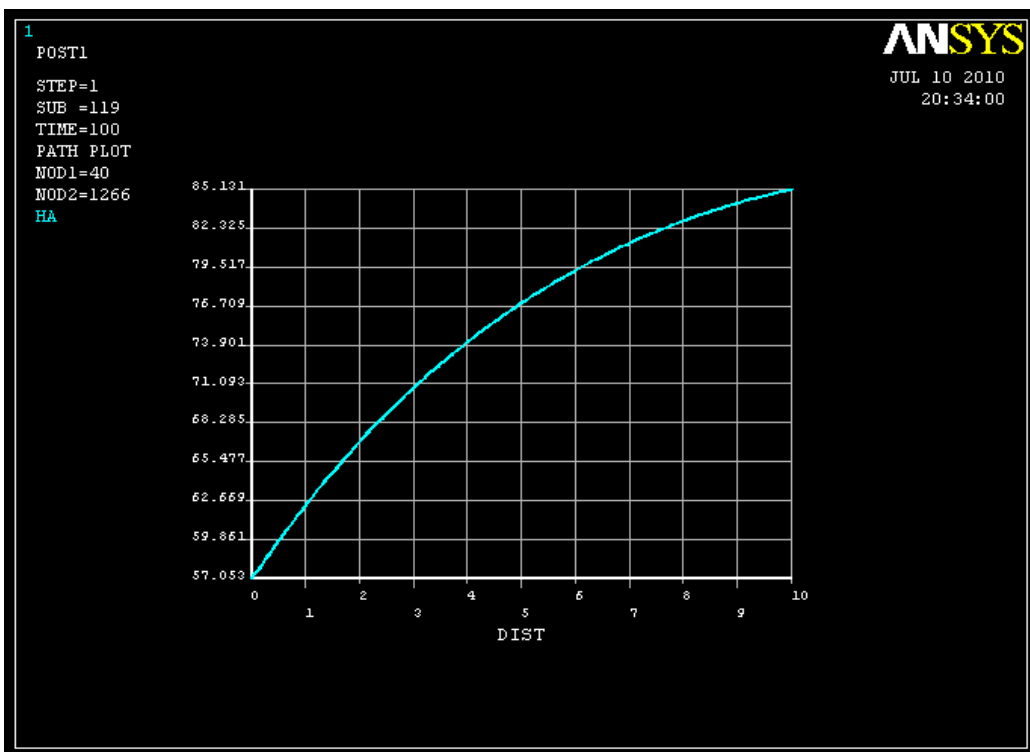


Fig. 5.17 Graph for Circumferential Stresses along the Radius for Pressure 75 MPa

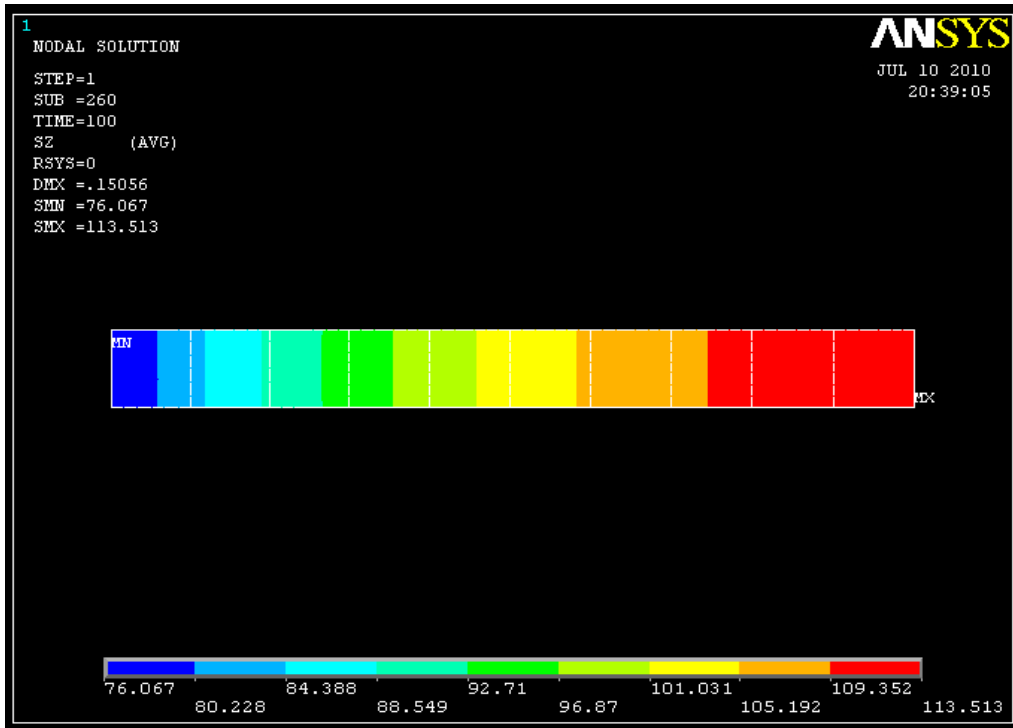


Fig. 5.18 Variation of Circumferential Stresses along the Radius for Pressure 100 MPa

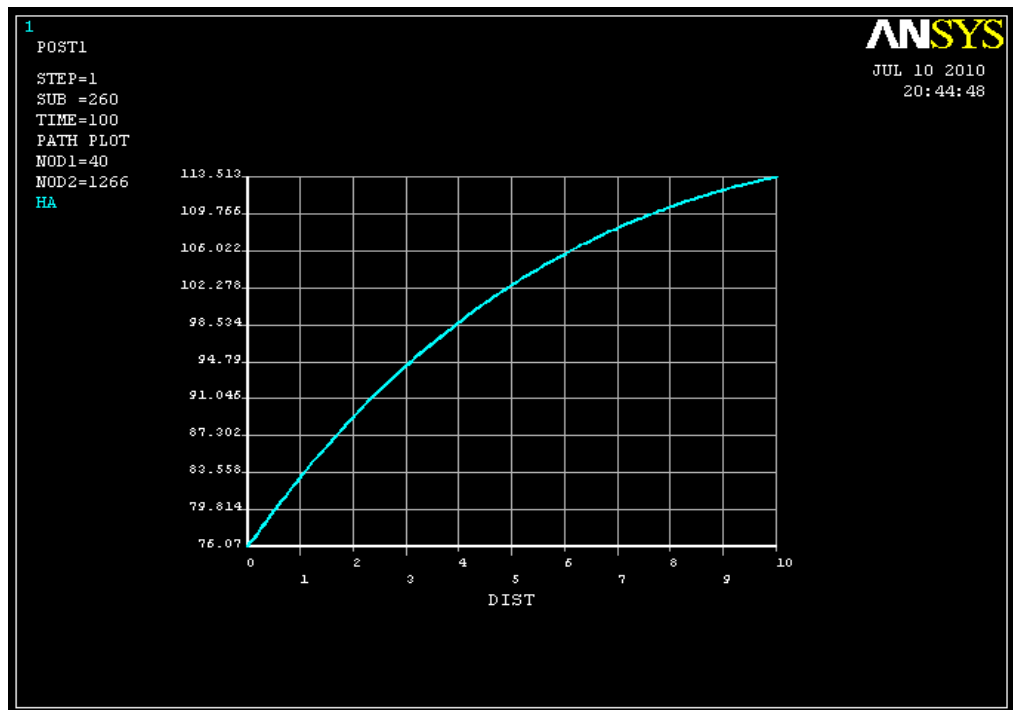


Fig. 5.19 Graph for Circumferential Stresses along the Radius for Pressure 100 MPa

**RANGE OF VALUES FOR RADIAL AND CIRCUMFERENTIAL STRESSES FOR
INTERNAL PRESSURE**

Internal pressure (MPa)	Radial stresses (MPa)	Circumferential stresses (MPa)
50	-49.732 to -0.86314	38.122 to 56.515
75	-74.166 to -0.22672	57.051 to 85.131
100	-99.475 to -0.17337	76.067 to 113.513

Table 5.1

**MAXIMUM VALUES FOR RADIAL AND CIRCUMFERENTIAL STRESSES FOR
INTERNAL PRESSURE**

Internal pressure (MPa)	Radial stresses (MPa)	Circumferential stresses (MPa)
50	-49.732	56.515
75	-74.166	85.131
100	-99.475	113.513

Table 5.2

Table 5.1 and 5.2 shows that with increase in internal pressure radial stresses as well as circumferential stresses increases but the level of increment in the case of circumferential stresses is more as compared to the radial stresses which is as per the theory which says that both radial as well as circumferential stresses are directly proportional to the internal pressure applied.

6.1 CONCLUSION

Based on results presented in the preceding section, the following conclusions are drawn:

- Radial stresses and circumferential stresses are directly proportional to internal pressure.
- Results of the present work are well validated with the results of Jian Jun Chen.
- With the use of designing software's different simulations and iterations can be made for the designing purpose which give an edge over the conventional experimental methods used in regard to time and money involved.
- Ansys is very powerful designing software which gives results in both graphical and analytical form in both static and dynamic problems.

6.2 SCOPE FOR FURTHER STUDY

The scope of the study on cylinders using software's gives a path for further development in manufacturing and designing methods. From the upcoming time more powerful software's could be used for the prediction of varies defects and stress levels at different points within the cylinders which could be helpful in enhancing the life of cylinder used for different industrial purposes, hence giving a maintaince free run and thus helping the industries economically.

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