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A ANALYSIS & PREDICTION OF PISTON PERFORMANCE USING TWO VARIENCE ANOVA METHOD

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ABSTRACT

Optimization of piston material using Artificial intelligence in CATIA Software performs. These algorithm based on Data collection and Simulink modelling orientated. Our work collect some material properties for different Terms and conditions than collects data performs ANOVA. Our observation Analysis of some parameters Like as MSE (Mean square error), Accuracy and Regression with our observation improve Accuracy and Reduction of Material detection Accuracy parameters.

Keyword: MSE, ANN, training algorithm, neural network layers, Different Mechanical properties.

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Today, the pistons designed by the suppliers based on load data determined by the engine performance targets. From this data the supplier estimates the temperatures of the piston and recommends a design that is suitable for the application.

This procedure is successful for the design of the piston, but gives no knowledge of the thermal interaction between the piston and its surrounding parts. The current trend in car engine development is to make smaller engines with higher specie power outputs to meet the demands for lower fuel consumption and emissions.

This leads to higher thermal loads on the engine and an increasing need to understand the heat balance of the complete engine in order to optimize the different engine parts and systems. A substantial part of the heat generated by the combustion is transported to the coolant through the piston and to the surrounding structure. It is therefore important to get an accurate description of these interactions.

The goal of Volvo Cars future combustion engine development is to increase power and efficiency and decrease fuel consumption while still maintaining reliability and durability of the highest possible level. As such, it is necessary to have a complete image of the thermal effect.

In the recent time automobile industry is growing with very rapid rate. The engine is one of the most important and crucial parts of any automobiles which are used for generating the power.

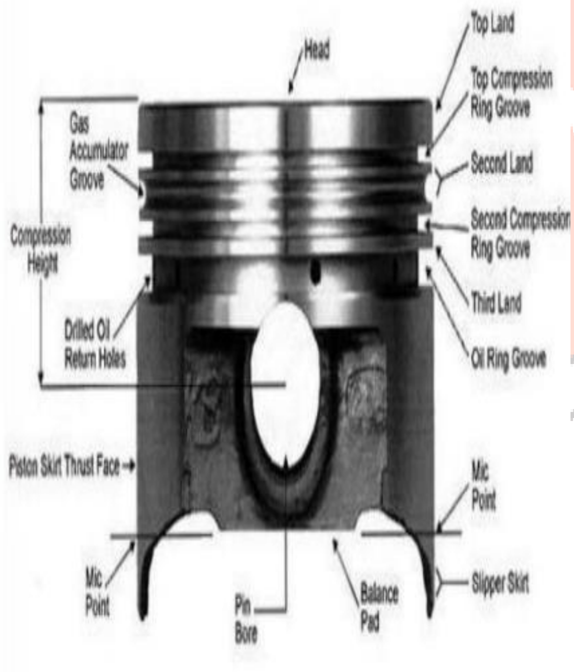


Fig. 1.1: Components of the piston.

1.2 MODELLING PISTON DESIGN

1.2.1 Modelling Criteria

The piston is designed according to the procedure and specification which are given in machine design and data hand books. The dimensions are calculated in terms of SI Units. The pressure applied on piston head, temperatures of various areas of the piston, stresses, strains, length, diameter of piston and hole, thicknesses, etc., parameters are taken into consideration Design Considerations for a Piston. In designing a piston for an engine, the following points should be taken into consideration: It should have enormous strength to withstand the high pressure.

- It should have minimum weight to withstand the inertia forces.
- It should form effective oil sealing in the cylinder.
- It should provide sufficient bearing area to prevent undue wear.
- It should have high speed reciprocation without noise.
- It should be of sufficient rigid construction to withstand thermal and mechanical distortions.
- It should have sufficient support for the piston pin.

1.2.2 Forces Effects

The major forces acting on the piston are as follows: Inertia force caused by the high frequency of reciprocating motion of piston Friction between the cylinder walls and the piston rings Forces due to expansion of gases.

1.3 MATERIAL BASED PISTON DESIGN FEATURES

1. Have sufficient mechanical strength and stiffness.
2. Can effectively block the heat reached the piston head.
3. High temperature corrosion resistance.
4. Dimensions as compact as possible, in order to reduce the weight of the piston

1.4 MATERIAL ORIENTED FUNCTIONS OF PISTON

- To receive the thrust force generated by the action of fuel in the cylinder and transmits to connecting rod.
- To reciprocate in the cylinder provide seal connecting force generator.
- Piston crown is a cylindrical part which tapers to a thinner section.
- Piston skirt is a cylindrical part of the piston below the pressure rings, keeping the piston in alignment with the cylinder. It can contain a scraper ring.

1.5 PISTON MATERIALS SELECTION FEATURES

The functions of the piston and the loads that act on it present a very special set of requirements for the piston material. If low piston weight is the goal, then a low-density material is preferred. Besides its design shape, the strength of the material is the deciding factor for the load capacity of the piston. The change in loads over time requires both good static and dynamic strength. Temperature resistance is likewise important, due to the loads.

A material with good machining properties supports cost-effective production in large quantities. The manufacture of the raw part should be as near to net shape as possible, and should contribute to high material quality. Suitable processes include gravity die casting and forging. The sliding and sealing surfaces demand high-precision finishing, which requires suitable machinability of the material.

As a light alloy with high conductivity, aluminum is particularly predestined to be used as a piston material. In the unalloyed state, however, its strength and wear resistance are too low. With the discovery of precipitation hardening by Wilm in 1906, aluminum alloys became well suited for technical purposes. Metals have a mutual solubility that varies with temperature, which is very low for certain metals at low temperatures in the solid state [1]. Phase diagrams, derived from cooling curves from the liquid range, depict these relationships particularly clearly.

In order to increase better functionality, the piston material should satisfy the following requirements:

- Light weight
- Good wear resistance
- High strength to weight ratio
- Free from rust
- Easy to cast
- Easy to machine
- Non magnetic
- Non toxic

Piston should be designed and fabricated with such features to satisfy the above requirements.

Generally pistons are made of Al alloy and cast iron. But the Al alloy is more preferable in comparison of cast iron because of its light weight which suitable for the reciprocating part. There are some drawbacks of Al alloys in comparison to cast iron that are the Al alloys are less in strength and in wearing qualities. The heat conductivity of Al is about of thrice of the cast iron. Al pistons are made thicker which is necessary for strength in order to give proper cooling.

1.6 PROBLEM IDENTIFICATION

We observe different research paper and Articles than we collect some points of problem identification following points are-

1. Main problem of piston material prediction lower Accuracy to found of related data collection.
2. Data collection of material different properties.
3. Selection of Prediction algorithm.
4. Selection of Analysis Software.
5. Iteration consume lot of time gives a result.
6. Compared with a conventional piston material optimization, this new energy conversion device shows the superiority such as structural simplicities, low manufacturing cost, and high power.
7. The biggest difference in structure is the elimination of the crankshaft and flywheel of engine and the piston and the mover of the linear generator are directly connected.

1.7 PROBLEM FORMULATION

For Our problem formulation prefer following some points-

1. We are choose higher Efficient and High Accuracy providing algorithm.

2. We collection of real time data collection of material properties.

3. Our proposed algorithm consume lower time duration of training of data.

4. Our observation and simulation Performs catia Software these are Support artificial intelligence methods.

5. Our simulation not only provide Prediction also gives real time application analysis in MATLAB simulation software.

1.8 OBJECTIVES

Our research objectives are as follows some points-

1. To Implement of proposed algorithm artificial neural network.

2. To identification of accuracy parameters for prediction of piston materials.

3. To collection of real time data related to manufacturing of mechanical piston.

4. To performs any application of Proposed Piston.

5. Improvement of steady state time periods of these application.

6. To observation of Prediction precious parameter like as R Square.

7. To study of Simulink modelling all outputs force, displacement, Viscosity total load.

1.9 SIGNIFICANCE OF THE WORK

The proposed study is expected:

i. To guide the operation and planning of the mechanical piston.
ii. To aid power system Engineers who may wish to design a material selection system newly.
iii. To serve as a research or academic and industrial material.
iv. To help validate the results obtained by other leading researchers who might have worked on this same or similar area.

1.10 PROJECT ORGNIZATION

Our project work are as following some point to given blow-

Chapter 1 Introduction of project work Optimization of piston material using Artificial intelligence.

Chapter 2 Literature review to comparison of old methods**.**

Chapter 3 To introduced about of materials and its properties Type.

Chapter 4 Our proposed methodology,

Chapter 5 Result and simulation.

Chapter 6 Future scope and Conclusion.

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

Hashim sheikh , Ankur Geete [1]: In the present work, optimization of piston with different materials has been done on the model of the piston with actual specifications of a two wheeler vehicle. The modelling has been performed on CATIA V5R12 software and further analyses have been carried out on ANSYS thermal analysis workbench. The expected outcome from this project was to find the thermal load that is minimum temperature and maximum heat flux over the surface and an attempt has been made to minimize the thermal load by optimizing the piston material to get some fruitful advantages. After analyses, it has been found the piston material AL 2024-T4 gives better temperature condition (239.29°C) but poor heat flux (0.39753 W/mm2) so this material is suggested for light or moderate vehicles where material AL 1100-O gives better heat flux (0.47726 W/mm2) but worst temperature condition (305.65°C) so this material is recommended for heavy vehicles.

Houliang Yu, Zhaoping Xu[2]: A free-piston generator (FPG) is a new type of energy converter, which eliminates the crankshaft and connecting rod mechanism. In order to achieve efficient energy conversion, the two-stroke thermodynamic performance optimization of a single-cylinder free-piston generator is investigated in this paper. Firstly, the components, four-stroke thermodynamic cycle, two-stroke thermodynamic cycle, and prototype system of the FPEG are presented in detail. The one-dimensional flow simulation model of the FPEG is created based on the gas dynamics equation, Weber combustion function, and heat transfer function, and then the model is validated by the data tested from the prototype system. According to the four-stroke experimental results of the FPEG, an effective power of 4.75 kW and a peak pressure of 21.02 bar have been obtained. Then, the two-stroke thermodynamic cycle is simulated and compared under the different control parameters of intake air pressure, injection timing, ignition timing, and valve timing through the simulation model. The optimized results show that an indicated thermal efficiency of 27.6%, an indicated power of 6.7 kW, and a maximal working frequency of 25 Hz can be achieved by the prototype system, when the two-stroke thermodynamic cycle is used.

Emilia Wołowiec-Korecka [3]: The “boost-diffusion” low-pressure nitriding used to low-frictional coatings manufacturing of aircraft engines’ piston rings is a nonsteady-state process; therefore, designing and prediction of the process’ kinetics by analytical solutions of Fick’s equations or numerical methods of diffusion are difficult, due to the nonlinear relationship between the diffusion coefficient and the rate of diffusion as well as nonsteady-state boundary conditions. The best solution in this case, as the practice and theory indicate, is computer-aided design based on neural networks. The paper describes neural network model and its training procedures based on data mining in the application to the monitoring and control of low-pressure nitriding process for creation of low-frictional coatings on gray irons and steels used for the piston rings manufacturing. The goal was to study the usefulness of the multilayer feed-forward perceptrons and radial basis function of neural networks for modeling of multiphase kinetic diffusion for low-pressure nitriding. As it was shown, the use of specialist networks that designate single features gives more accurate prediction results than the use of general networks that design several features at the same time. It has been proved that it is possible to construct an industrial application of the low-pressure nitriding based on artificial neural networks. The results of the research will be the basis for the development of innovative, specialized software supporting the design of gradient low-friction layers based on the FineLPN low-pressure nitriding and consequently the design of intelligent supervision over their manufacturing technology.

Mohammad-H. Tayarani-N., Xin Yao, and Hongming Xu [4]: Meta-heuristic algorithms are often inspired by natural phenomena, including the evolution of species in Darwinian natural selection theory, ant behaviors in biology, flock behaviors of some birds, and annealing in metallurgy. Due to their great potential in solving difficult optimization problems, meta-heuristic algorithms have found their way into automobile engine design. There are different optimization problems arising in different areas of car engine management including calibration, control system, fault diagnosis, and modeling. In this paper we review the state-of-the-art applications of different meta-heuristic algorithms in engine management systems. The review covers a wide range of research, including the application of meta-heuristic algorithms in engine calibration, optimizing engine control systems, engine fault diagnosis, and optimizing different parts of engines and modeling. The meta-heuristic algorithms reviewed in this paper include evolutionary algorithms, evolution strategy, evolutionary programming, genetic programming, differential evolution, estimation of distribution algorithm, ant colony optimization, particle swarm optimization, memetic algorithms, and artificial immune system.

La Ode Ichlas Syahrullah and Nazaruddin Sinaga [5]: This research studied the use of Artificial Neural Network (ANN) using feed-forward back-propagation model to optimize and predict the performance of a motorcycle fuel injection systems of gasoline. The parameters such as speed, throttle position, ignition timing and injection timing is used as the input parameters. While the parameters of fuel consumption and engine torque is used as the output layer. Lavenberg-Marquardt model type with train function tanh sigmoid and 25 neurons number is used to generate the target value and the desired output. Variation of ignition timing as optimization variable in a wide range of speed and throttle position is used in experimental tests. ANN is used to investigate the prediction of performance motorcycle engines and compared with the test results. Results showed that the operation of ANN in predicting engine performance is very good. From the test results obtained a smooth contour MAP compared to the initial state. The prediction result and performance test show a good correlation in small error value of training and test that is regression with range 0.98-0.99, mean relative error with range 0.1315-0.4281% and the root mean square error with range 0.2422-0.9754%. This study shows that the feed-forward back propagation on ANN model can be used to predict accurately the performance of a motorcycle engine injection system.

Jihai Jiang, Kelong Wang [6]: Due to their compact and simple design, axial piston pumps are widely used in hydraulic systems. The piston/cylinder lubricating interface is one of the most critical design elements in axial piston pumps, which fulfils the bearing and sealing function simultaneously. Also it is the main source of both friction and volumetric power loss. In order to realize the optimal design of efficient and reliable axial piston pump, an accurate model of the tribological interface in axial piston pump is needed to save the cost and time in the design process. This study is aimed at developing a comprehensive simulation tool to model the lubricating gap flow between the piston and cylinder, which consists of a main flow model according to a lumped parameter approach and a numerical model for piston/cylinder interface. The instantaneous pressure in each displacement chamber is obtained from the main flow model and utilized in the numerical model as an important boundary condition. An adaptive mesh is built for the oil film between piston and cylinder, on which the Reynolds equation is solved to get the pressure field. Also with the force balance check, the micro motion and gap height distribution is obtained. Couette flow, Poiseuille flow and squeeze flow are included in this numerical model. The simulation model proposed in this paper can provides a theoretical guidance for the structural design of axial piston pump [1]

Shengjun Wu, Zihao Cheng [7]: Piston is the main component of the engine. In the engine work process, pistons need withstand both the instantaneous high temperature heat load and the mechanical load during the reciprocating process. The coupling between the thermal load and the mechanical load leads to the malfunction occurrence [2] of piston deformation, piston pin boss cracking, piston side wear, and top thermal cracking caused by the uneven temperature. Therefore, pistons should have sufficient strength, stiffness, heat resistance, good thermal conductivity, small expansion coefficient and other properties. The reliability of pistons determines the reliability level of internal combustion engines. To improve the reliability level of the internal combustion engine, conducting the structural strength analysis of pistons to meet the design requirements is essential. The aided design model of the finite element software has been applied by many manufacturers [3]-[4].

Jigui ZHENG, Ye DENG[8]: Compact structure and high working efficiency are the characteristics of free Stirling linear generation device, whose power piston support components works in high frequency to produce elastic stiffness and to support the piston components. The structure of the power piston support components of free piston linear generator is designed. The mechanical properties of power piston are analyzed by finite element analysis method, and the experiment for the verification of stiffness is finished. The power piston support components are applied to the free piston linear Stirling generator, and the experiment shows that the operating performance is very well[5].

Wu, Yi Zeng, Dongjian[9]: The study of using DME as an alternative fuel on diesel engine started at early 90s. Experiments using DME as combustion fuel on all kinds of diesel engines done at Xi'an Jiaotong University and Shanghai Internal Combustion Engine Research Institute show that DME can achieve high efficiency, ultra-low emission, gentle, nonsmoker combustion and meet the stringent Euro III and California ULEV standard[1]. However, there is no thermal load analysis research done for DME fuelled diesel engine parts, particularly piston, which as an important part in engine, has the character of large heat affected area and difficult to release heat. The structure and performance has significantly high impact on the power, economy and emission of the engine. Therefore, it is important to analysis the thermal load of piston in DME fuelled diesel engine to make burning DME in diesel engine variable.

Shcherbachev Pavel [10]: The article describes the electro-hydraulic rotary motion drive with separate control of piston groups. Proposed various schemes of construction of the drive. It is shown that the proposed actuator has a wide range of speeds, can work in tracking the position and speed of the output shaft. A nonlinear mathematical model of the drive is represented. The results of numerical simulation and experimental data are shown. The method of synthesis of a special control signal, which increases the efficiency of the drive is given.

O.F. Nikitin[11]: This paper deals with the regulation of hydraulic parameters of movement of the output link (total stock) speed - load V = f (R) when using multiple cylinders, with a hard or serial connection rods. The required speed of movement is performed by connecting the required number of effective working areas of hydraulic cylinders. Change in the effective speed while maintaining the load may lead to changes in pressure in the cavity involved in the work of the hydraulic actuator. Control parameter - the relative magnitude of the total effective working area of the piston cylinder involved in the reported time in the work, to the sum of the effective areas of the piston, available as part of the hydraulic drive. With the change (eg, decrease) of the speed of common stock in accordance with the change (increase) of the effective working area of the connected cylinders surmounted total load power can be increased at an aggregate stock at discharge pressure, if the permissible one is not exceeded, ie there is the opportunity to work with a constant power hydraulic drive. The total value of the load can be much more than you can overcome with one cylinder without increasing the total amount of pressure in the system with a corresponding change in speed while maintaining a given flow rate. The set of 7 relative performance curves = f (VL) in the relationship of piston areas 1: 2: 4 of the three hydraulic cylinders is 7 straight lines of varying length

Guo Feng, Zhao Chang-lu[12]: This paper investigates the piston motion control strategies of a single piston hydraulic free-piston diesel engine, which is intended to be a power supply for hydraulic propulsion systems. The Cycle fuel mass is determined by engine displacement and load. A closed loop control method is used in fuel injection timing control strategy to make the position of bottom dead center steady possibly. In each cycle, the injection timing is corrected by the compare between real bottom dead center position and designed bottom dead center position. The test results indicated that the advanced fuel injection control presented in this paper could improve engine performance and operational stabilization.

Isam Jasim Jaber and Ajeet Kumar Rai[13]: In this present work a piston and piston ring are designed for a single cylinder four stroke petrol engine using. Complete design is imported to ANSYS 14.5 software then analysis is performed. Three different materials have been selected for structural and thermal analysis of piston. For piston ring two different materials are selected and structural and thermal analysis is performed using ANSYS 19 software. Results are shown and a comparison is made to find the most suited design.

Lokesh Singh, Suneer Singh Rawat[14]: A piston is a component of reciprocating engines. Its purpose is to transfer force form expanding gas in the cylinder to the crank shaft via piston rod and a connecting rod. It is one of the most complex components of an automobile. In some engines the piston also acts as a valve by covering and uncovering ports in the cylinder wall. In present, work a three-dimensional solid model of piston including piston pin is designed with the help ANSYS software. The thermal stresses, mechanical stresses and couples thermo-mechanical stresses distribution and deformations are calculated. After that fatigue analysis was performed to investigate factor of safety and life of the piston assembly using ANSYS workbench software. Aluminium-silicon composite is used as piston material. The stress analysis results also help to improve component design at the early stage and also help in reducing time required to manufacture the piston component and its cost.

Michaël De Volder, Frederik Ceyssens[15]: Future micro robotic applications require actuators that can generate a high actuation force in a limited volume. Up to now, little research has been performed on the development of pneumatic or hydraulic micro actuators, although they offer great prospects in achieving high force densities. In addition, large actuation strokes and high actuation speeds can be achieved by these actuators.

CHAPTER 3

PISTON MATERIAL AND PROPERTIES FEATURES

3.1 OVERVIEW OF PISTON MATERIALS

Adverse working conditions make the requirements of the materials used in the piston very wide and diverse. Materials used in the piston manufacturing can be divided in the following groups:

- Cast iron

- Aluminium

- Steel

-Ductile iron

1. Cast Iron:

Cast iron is a group of iron-carbon alloys with a carbon content more than 2%.[1] Its usefulness derives from its relatively low melting temperature. The alloy constituents affect its colour when fractured: white cast iron has carbide impurities which allow cracks to pass straight through, grey cast iron has graphite flakes which deflect a passing crack and initiate countless new cracks as the material breaks, and ductile cast iron has spherical graphite "nodules" which stop the crack from further progressing.

Carbon (C) ranging from 1.8 to 4 wt%, and silicon (Si) 1–3 wt%, are the main alloying elements of cast iron. Iron alloys with lower carbon content are known as steel.

Cast iron tends to be brittle, except for malleable cast irons. With its relatively low melting point, good fluidity, castability, excellent machinability, resistance to deformation and wear resistance, cast irons have become an engineering material with a wide range of applications and are used in pipes, machines and automotive industry parts, such as cylinder heads, cylinder blocks and gearbox cases. It is resistant to damage by oxidation.

The earliest cast-iron artefacts date to the 5th century BC, and were discovered by archaeologists in what is now Jiangsu in China. Cast iron was used in ancient China for warfare, agriculture, and architecture.[2] During the 15th century, cast iron became utilized for cannon in Burgundy, France, and in England during the Reformation. The amounts of cast iron used for cannon required large scale production.[3] The first cast-iron bridge was built during the 1770s by Abraham Darby III, and is known as The Iron Bridge in Shropshire, England. Cast iron was also used in the construction of buildings.

Alloying Elements:

Cast iron's properties are changed by adding various alloying elements, or alloyants. Next to carbon, silicon is the most important alloyant because it forces carbon out of solution. A low percentage of silicon allows carbon to remain in solution forming iron carbide and the production of white cast iron. A high percentage of silicon forces carbon out of solution forming graphite and the production of grey cast iron. Other alloying agents, manganese, chromium, molybdenum, titanium and vanadium counteracts silicon, promotes the retention of carbon, and the formation of those carbides. Nickel and copper increase strength, and machinability, but do not change the amount of graphite formed. The carbon in the form of graphite results in a softer iron, reduces shrinkage, lowers strength, and decreases density. Sulfur, largely a contaminant when present, forms iron sulfide, which prevents the formation of graphite and increases hardness. The problem with sulfur is that it makes molten cast iron viscous, which causes defects. To counter the effects of sulfur, manganese is added because the two form into manganese sulfide instead of iron sulfide. The manganese sulfide is lighter than the melt, so it tends to float out of the melt and into the slag. The amount of manganese required to neutralize sulfur is 1.7 × sulfur content + 0.3%. If more than this amount of manganese is added, then manganese carbide forms, which increases hardness and chilling, except in grey iron, where up to 1% of manganese increases strength and density.[5]

Table 3.1 Comparative qualities of cast irons

Name	Nominal composition [% by weight]	Uses
Grey cast iron (ASTM A48)	C 3.4, Si 1.8, Mn 0.5	Engine cylinder blocks, flywheels, gearbox cases, machine-tool bases
White cast iron	C 3.4, Si 0.7, Mn 0.6	Bearing surfaces
Malleable iron (ASTM A47)	C 2.5, Si 1.0, Mn 0.55	Axle bearings, track wheels, automotive crankshafts
Ductile or nodular iron	C 3.4, P 0.1, Mn 0.4, Ni 1.0, Mg 0.06	Gears, camshafts, crankshafts
Ductile or nodular iron (ASTM A339)	—	—
Ni-hard type 2	C 2.7, Si 0.6, Mn 0.5, Ni 4.5, Cr 2.0	High strength applications
Ni-resist type 2	C 3.0, Si 2.0, Mn 1.0, Ni 20.0, Cr 2.5	Resistance to heat and corrosion

2. Aluminium

Aluminium (aluminum in American and Canadian English) is a chemical element with the symbol Al and atomic number 13. It is a silvery-white, soft, non-magnetic and ductile metal in the boron group. By mass, aluminium makes up about 8% of the Earth's crust, where it is the third most abundant element (after oxygen and silicon) and also the most abundant metal. Occurrence of aluminium decreases in the Earth's mantle below, however. The chief ore of aluminium is bauxite. Aluminium metal is highly reactive, such that native specimens are rare and limited to extreme reducing environments. Instead, it is found combined in over 270 different minerals.[7]

Aluminium is remarkable for its low density and its ability to resist corrosion through the phenomenon of passivation. Aluminium and its alloys are vital to the aerospace industry[8] and important in transportation and building industries, such as building facades and window frames.[9] The oxides and sulfates are the most useful compounds of aluminium.[8]

Despite its prevalence in the environment, no known form of life uses aluminium salts metabolically, but aluminium is well tolerated by plants and animals.[10] Because of these salts' abundance, the potential for a biological role for them is of continuing interest, and studies continue. Aluminium is the most widely used non-ferrous metal. The global production of aluminium in 2016 was 58.8 million metric tons. It exceeded that of any other metal except iron (1,231 million metric tons).

Aluminium is almost always alloyed, which markedly improves its mechanical properties, especially when tempered. For example, the common aluminium foils and beverage cans are alloys of 92% to 99% aluminium. The main alloying agents are copper, zinc, magnesium, manganese, and silicon (e.g., duralumin) with the levels of other metals in a few percent by weight.

Transportation (automobiles, aircraft, trucks, railway cars, marine vessels, bicycles, spacecraft, etc.). Aluminium is used because of its low density; Packaging (cans, foil, frame etc.). Aluminium is used because it is non-toxic[citation needed], non-adsorptive, and splinter-proof;
Building and construction (windows, doors, siding, building wire, sheathing, roofing, etc.). Since steel is cheaper, aluminium is used when lightness, corrosion resistance, or engineering features are important;
Electricity-related uses (conductor alloys, motors and generators, transformers, capacitors, etc.). Aluminium is used because it is relatively cheap, highly conductive, has adequate mechanical strength and low density, and resists corrosion; A wide range of household items, from cooking utensils to furniture. Low density, good appearance, ease of fabrication, and durability are the key factors of aluminium usage;
Machinery and equipment (processing equipment, pipes, tools). Aluminium is used because of its corrosion resistance, non-pyrophoricity, and mechanical strength.

3. Steel

Steel is an alloy of iron with typically a few percent of carbon to improve its strength and fracture resistance compared to iron. Many other additional elements may be present or added. Stainless steels are corrosion and oxidation resistant need typically an additional 11% chromium. Because of its high tensile strength and low cost, steel is best used in buildings, infrastructure, tools, ships, trains, cars, machines, electrical appliances, and weapons. Iron is the base metal of steel and it can take on two crystalline forms (allotropic forms): body centred cubic and face-centred cubic. These forms depend on temperature. In the body-centred cubic arrangement, there is an iron atom in the centre and eight atoms at the vertices of each cubic unit cell; in the face-centred cubic, there is one atom at the centre of each of the six faces of the cubic unit cell and eight atoms at its vertices. It is the interaction of the allotropes of iron with the alloying elements, primarily carbon, that gives steel and cast iron their range of unique properties.

In pure iron, the crystal structure has relatively little resistance to the iron atoms slipping past one another, and so pure iron is quite ductile, or soft and easily formed. In steel, small amounts of carbon, other elements, and inclusions within the iron act as hardening agents that prevent the movement of dislocations.

The carbon in typical steel alloys may contribute up to 2.14% of its weight. Varying the amount of carbon and many other alloying elements, as well as controlling their chemical and physical makeup in the final steel (either as solute elements, or as precipitated phases), slows the movement of those dislocations that make pure iron ductile, and thus controls and enhances its qualities. These qualities include the hardness, quenching behaviour, need for annealing, tempering behaviour, yield strength, and tensile strength of the resulting steel. The increase in steel's strength compared to pure iron is possible only by reducing iron's ductility.

Steel was produced in bloomery furnaces for thousands of years, but its large-scale, industrial use began only after more efficient production methods were devised in the 17th century, with the introduction of the blast furnace and production of crucible steel. This was followed by the open-hearth furnace and then the Bessemer process in England in the mid-19th century. With the invention of the Bessemer process, a new era of mass-produced steel began. Mild steel replaced wrought iron.

Further refinements in the process, such as basic oxygen steelmaking (BOS), largely replaced earlier methods by further lowering the cost of production and increasing the quality of the final product. Today, steel is one of the most common manmade materials in the world, with more than 1.6 billion tons produced annually. Modern steel is generally identified by various grades defined by assorted standards organisations.
Iron is commonly found in the Earth's crust in the form of an ore, usually an iron oxide, such as magnetite or hematite. Iron is extracted from iron ore by removing the oxygen through its combination with a preferred chemical partner such as carbon which is then lost to the atmosphere as carbon dioxide. This process, known as smelting, was first applied to metals with lower melting points, such as tin, which melts at about 250 °C (482 °F), and copper, which melts at about 1,100 °C (2,010 °F), and the combination, bronze, which has a melting point lower than 1,083 °C (1,981 °F). In comparison, cast iron melts at about 1,375 °C (2,507 °F).[3] Small quantities of iron were smelted in ancient times, in the solid state, by heating the ore in a charcoal fire and then welding the clumps together with a hammer and in the process squeezing out the impurities. With care, the carbon content could be controlled by moving it around in the fire. Unlike copper and tin, liquid or solid iron dissolves carbon quite readily.

All of these temperatures could be reached with ancient methods used since the Bronze Age. Since the oxidation rate of iron increases rapidly beyond 800 °C (1,470 °F), it is important that smelting take place in a low-oxygen environment. Smelting, using carbon to reduce iron oxides, results in an alloy (pig iron) that retains too much carbon to be called steel.[3] The excess carbon and other impurities are removed in a subsequent step.

Other materials are often added to the iron/carbon mixture to produce steel with desired properties. Nickel and manganese in steel add to its tensile strength and make the austenite form of the iron-carbon solution more stable, chromium increases hardness and melting temperature, and vanadium also increases hardness while making it less prone to metal fatigue.[4]

4. Ductile Iron

Ductile iron, also known as ductile cast iron, nodular cast iron, spheroidal graphite iron, spheroidal graphite cast iron[1] and SG iron, is a type of graphite-rich cast iron discovered in 1943 by Keith Millis.[2] While most varieties of cast iron are weak in tension and brittle, ductile iron has much more impact and fatigue resistance, due to its nodular graphite inclusions.

On October 25, 1949, Keith Dwight Millis, Albert Paul Gagnebin and Norman Boden Pilling received US patent 2,485,760 on a Cast Ferrous Alloy for ductile iron production via magnesium treatment.[3] Augustus F. Meehan was awarded a patent in January 1931 for inoculating iron with calcium silicide to produce ductile iron subsequently licensed as Meehanite, still produced in 2017.

Ductile iron is not a single material but part of a group of materials which can be produced with a wide range of properties through control of their microstructure. The common defining characteristic of this group of materials is the shape of the graphite. In ductile irons, graphite is in the form of nodules rather than flakes as in grey iron. Whereas sharp graphite flakes create stress concentration points within the metal matrix, rounded nodules inhibit the creation of cracks, thus providing the enhanced ductility that gives the alloy its name.[5]

Nodule formation is achieved by adding nodulizing elements, most commonly magnesium (magnesium boils at 1100 °C and iron melts at 1500 °C) and, less often now, cerium (usually in the form of mischmetal).[6] Tellurium has also been used. Yttrium, often a component of mischmetal, has also been studied as a possible nodulizer.

"Austempered Ductile Iron" (ADI) was discovered in the 1950s but was commercialized and achieved success only some years later. In ADI, the metallurgical structure is manipulated through a sophisticated heat treating process. The "aus" portion of the name refers to austenite.[7]

Table 3.2 Ductile iron compositions.

Chemical Composition % for Ferritic Ductile Iron Castings								
Fe	**C**	**Si**	**Ni**	**Mn**	**Mg**	**Cr**	**P**	**Cu**
Balance	**3.0 - 3.7**	**1.2 - 2.3**	**1.0**	**0.25**	**0.07**	**0.07**	**0.03**	**0.1**

Other ductile iron compositions often have a small amount of sulfur as well.

- Carbon 3.2 to 3.60%
- Silicon 2.2 to 2.8%
- Manganese 0.1 to 0.2%
- Magnesium 0.03 to 0.04%
- Phosphorus 0.005 to 0.04%
- Sulfur 0.005 to 0.02%
- Copper <0.40%
- Iron balance

Elements such as copper or tin may be added to increase tensile and yield strength while simultaneously reducing ductility. Improved corrosion resistance can be achieved by replacing 15% to 30% of the iron in the alloy with varying amounts of nickel, copper, or chromium.

Silicon as a graphite formation element can be partially replaced by aluminum to provide better oxidation protection. Much of the annual production of ductile iron is in the form of ductile iron pipe, used for water and sewer lines. It competes with polymeric materials such as PVC, HDPE, LDPE and polypropylene, which are all much lighter than steel or ductile iron; being softer and weaker, these require protection from physical damage.

Ductile iron is specifically useful in many automotive components, where strength must surpass that of aluminum but steel is not necessarily required. Other major industrial applications include off-highway diesel trucks, Class 8 trucks, agricultural tractors, and oil well pumps. In the wind power industry nodular cast iron is used for hubs and structural parts like machine frames. Nodular cast iron is suitable for large and complex shapes and high (fatigue) loads.

5. Tungsten

Tungsten, or **wolfram**,[9][10] is a chemical element with the symbol **W** and atomic number 74. Tungsten is a rare metal found naturally on Earth almost exclusively as compounds with other elements. It was identified as a new element in 1781 and first isolated as a metal in 1783. Its important ores include scheelite and wolframite, the latter lending the element its alternate name.

The free element is remarkable for its robustness, especially the fact that it has the highest melting point of all known elements barring carbon (which sublimes at normal pressure), melting at 3,422 °C (6,192 °F; 3,695 K). It also has the highest boiling point, at 5,930 °C (10,710 °F; 6,200 K).[11] Its density is 19.25 grams per cubic centimetre,[12] comparable with that of uranium and gold, and much higher (about 1.7 times) than that of lead.[13] Polycrystalline tungsten is an intrinsically brittle[14][15] and hard material (under standard conditions, when uncombined), making it difficult to work. However, pure single-crystalline tungsten is more ductile and can be cut with a hard-steel hacksaw.[16]

Tungsten occurs in many alloys, which have numerous applications, including incandescent light bulb filaments, X-ray tubes, electrodes in gas tungsten arc welding, superalloys, and radiation shielding. Tungsten's hardness and high density make it suitable for military applications in penetrating projectiles. Tungsten compounds are often used as industrial catalysts.

Tungsten is the only metal in the third transition series that is known to occur in biomolecules, being found in a few species of bacteria and archaea. However, tungsten interferes with molybdenum and copper metabolism and is somewhat toxic to most forms of animal life.[17][18]

3.2 MATERIAL PROPERTIES AND FEATURES

Mechanical properties of material are related to the behavior under load or stress in tension, compression or shear.

Properties are determined by engineering tests under appropriate conditions, commonly determined mechanical properties are the tensile strength, elastic limit, creep strength, stress rupture, fatigue, elongation (ductility), impact strength (toughness and brittleness), hardness, and modulus of elasticity(ratio of stress to elastic strain-rigidity). Usually, the strain may be elastic (present only during stressing) or plastic (permanent) deformation.

Mechanical properties are helpful in determining whether or not a material can be produced in the desired shape and also resist the mechanical forces anticipated.

The words mechanical and physical are often erroneously used interchangeably. The above are mechanical properties. Sometimes modulus of elasticity is considered to be a physical property of a material because it is an inherent property that cannot be changed substantially by practical means such as heat treatment or cold working.

The mechanical properties of a material affect how it behaves as it is loaded. The elastic modulus of the material affects how much it deflects under a load, and the strength of the material determines the stresses that it can withstand before it fails. The ductility of a material also plays a significant role in determining when a material will break as it is loaded beyond its elastic limit. Because every mechanical system is subjected to loads during operation, it is important to understand how the materials that make up those mechanical systems behave.

A material's property (or material property) is an intensive property of some material, i.e. a physical property that does not depend on the amount of the material. These quantitative properties may be used as a metric by which the benefits of one material versus another can be compared, thereby aiding in materials selection.

A property may be a constant or may be a function of one or more independent variables, such as temperature. Materials properties often vary to some degree according to the direction in the material in which they are measured, a condition referred to as anisotropy. Materials properties that relate to different physical phenomena often behave linearly (or approximately so) in a given operating range[further explanation needed]. Modeling them as linear can significantly simplify the differential constitutive equations that the property describes.

3.2.1 Bulk Modulus ((10^6 psi)):

The bulk modulus of a substance is a measure of how resistant to compression that substance is. It is defined as the ratio of the infinitesimal pressure increase to the resulting relative decrease of the volume.[1] Other moduli describe the material's response (strain) to other kinds of stress: the shear modulus describes the response to shear, and Young's modulus describes the response to linear stress. For a fluid, only the bulk modulus is meaningful. For a complex anisotropic solid such as wood or paper, these three moduli do not contain enough information to describe its behaviour, and one must use the full generalized Hooke's law.

It is given by the ratio of pressure applied to the corresponding relative decrease in volume of the material. The relation is given below.

$$\mathbf{B = \Delta P /(\Delta V/V)}$$

Where:

B: Bulk modulus

ΔP: change of the pressure or force applied per unit area on the material

ΔV: change of the volume of the material due to the compression

V: Initial volume of the material in the units of in the English system and N/m^2 in the metric system.

3.2.2 Thermal Conductivity ((W/m K)):

Thermal conductivity is the ability of a given material to conduct or transfer heat. It is generally denoted by the symbol ‘k’ or sometimes\(\lambda\). The reciprocal of this physical quantity is referred to as thermal resistivity. Materials with high thermal conductivity are used in heat sinks, on the other hand, materials with low values of \(\lambda\) used as thermal insulators. Learn the thermal conductivity formula here.

Thermal conductivity (κ) defines the correlation between heat flux per unit area and temperature gradient as:

$$\mathbf{Q=-\kappa\nabla T}$$

Where

Q = heat flux per unit area, Q (W m^{-2})

K = thermal conductivity

∇T = temperature gradient

The negative sign in Eq. shows that the flow of heat is from high temperature to low temperature.
Eq. describes the relationship between thermal conductivity and specific heat as:

$$\kappa \approx \Sigma C v \lambda$$

Where v and λ are averaged phonon group velocity and mean free path, respectively.

In the International System of Units (SI), thermal conductivity is measured in watts per meter-kelvin (W/(m·K)). Some papers report in watts per centimeter-kelvin (W/(cm·K)).

In imperial units, thermal conductivity is measured in BTU/(h·ft·°F) [12].The dimension of thermal conductivity is M1L1T−3Θ−1, expressed in terms of the dimensions mass (M), length (L), time (T), and temperature (Θ).

Other units which are closely related to the thermal conductivity are in common use in the construction and textile industries. The construction industry makes use of units such as the R-value (resistance) and the U-value (transmittance). Although related to the thermal conductivity of a material used in an insulation product, R- and U-values are dependent on the thickness of the product.

Likewise the textile industry has several units including the tog and the clo which express thermal resistance of a material in a way analogous to the R-values used in the construction industry.

There are several ways to measure thermal conductivity; each is suitable for a limited range of materials. Broadly speaking, there are two categories of measurement techniques: *steady-state* and *transient*. Steady-state techniques infer the thermal conductivity from measurements on the state of a material once a steady-state temperature profile has been reached, whereas transient techniques operate on the instantaneous state of a system during the approach to steady state. Lacking an explicit time component, steady-state techniques do not require complicated signal analysis (steady state implies constant signals). The disadvantage is that a well-engineered experimental setup is usually needed, and the time required to reach steady state precludes rapid measurement.

In comparison with solid materials, the thermal properties of fluids are more difficult to study experimentally. This is because in addition to thermal conduction, convective and radiative energy transport are usually present unless measures are taken to limit these processes. The formation of an insulating boundary layer can also result in an apparent reduction in the thermal conductivity.[13][14]

3.2.3 Density (g/cm³):

The **density** (more precisely, the **volumetric mass density**; also known as **specific mass**), of a substance is its mass per unit volume. The symbol most often used for density is ρ (the lower case Greek letter rho), although the Latin letter D can also be used. Mathematically, density is defined as mass divided by volume:[1]

$$\rho = m/v$$

Where ρ is the density, m is the mass, and V is the volume.

In some cases (for instance, in the United States oil and gas industry), density is loosely defined as its weight per unit volume,[2] although this is scientifically inaccurate – this quantity is more specifically called specific weight.

For a pure substance the density has the same numerical value as its mass concentration. Different materials usually have different densities, and density may be relevant to buoyancy, purity and packaging. Osmium and iridium are the densest known elements at standard conditions for temperature and pressure.

To simplify comparisons of density across different systems of units, it is sometimes replaced by the dimensionless quantity "relative density" or "specific gravity", i.e. the ratio of the density of the material to that of a standard material, usually water. Thus a relative density less than one means that the substance floats in water.

The density of a material varies with temperature and pressure. This variation is typically small for solids and liquids but much greater for gases. Increasing the pressure on an object decreases the volume of the object and thus increases its density. Increasing the temperature of a substance (with a few exceptions) decreases its density by increasing its volume. In most materials, heating the bottom of a fluid results in convection of the heat from the bottom to the top, due to the decrease in the density of the heated fluid. This causes it to rise relative to more dense unheated material.

The reciprocal of the density of a substance is occasionally called its specific volume, a term sometimes used in thermodynamics. Density is an intensive property in that increasing the amount of a substance does not increase its density; rather it increases its mass.

3.2.4 Toughness (MPa):

In materials science and metallurgy, **toughness** is the ability of a material to absorb energy and plastically deform without fracturing. One definition of material toughness is the amount of energy per unit volume that a material can absorb before rupturing. It is also defined as a material's resistance to fracture when stressed.

Toughness is related to the area under the stress–strain curve. In order to be tough, a material must be both strong and ductile. For example, brittle materials (like ceramics) that are strong but with limited ductility are not tough; conversely, very ductile materials with low strengths are also not tough. To be tough, a material should withstand both high stresses and high strains. Generally speaking, strength indicates how much force the material can support, while toughness indicates how much energy a material can absorb before rupturing.

The toughness of a material can be measured using a small specimen of that material. A typical testing machine uses a pendulum to strike a notched specimen of defined cross-section and deform it. The height from which the pendulum fell, minus the height to which it rose after deforming the specimen, multiplied by the weight of the pendulum is a measure of the energy absorbed by the specimen as it was deformed during the impact with the pendulum. The Charpy and Izod notched impact strength tests are typical ASTM tests used to determine toughness.

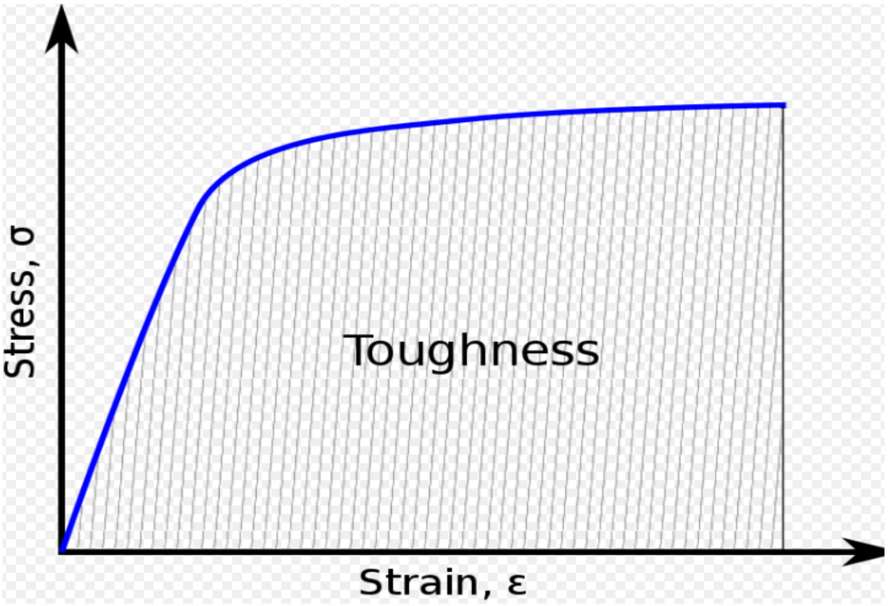


Fig 3.1 Toughness as defined by the area under the stress-strain curve.

3.2.5 Plasticity

Plasticity, ability of certain solids to flow or to change shape permanently when subjected to stresses of intermediate magnitude between those producing temporary deformation, or elastic behaviour, and those causing failure of the material, or rupture (*see* yield point). Plasticity enables a solid under the action of external forces to undergo permanent deformation without rupture. Elasticity, in comparison, enables a solid to return to its original shape after the load is removed. Plastic deformation occurs in many metal-forming processes (rolling, pressing, forging) and in geologic processes (rock folding and rock flow within the earth under extremely high pressures and at elevated temperatures). Plastic deformation is a property of ductile and malleable solids. Brittle materials, such as cast iron, cannot be plastically deformed, though at elevated temperatures some, such as glass, which is not a crystallized solid, do undergo plastic flow.

Plasticity, as the name of a science, refers either to mathematical descriptions of what happens in plastic deformation in terms of stresses, strains, and loads or to physical explanations of plastic flow in terms of atoms, crystals, grains, and motions of structural defects (dislocations) within crystals.

3.2.6 Malleability:

Malleability is a substance's ability to deform under pressure (compressive stress). If malleable, a material may be flattened into thin sheets by hammering or rolling. Malleable materials can be flattened into metal leaf. One well-known type of metal leaf is gold leaf. Many metals with high malleability also have high ductility. Some do not; for example lead has low ductility but high malleability.

Metals are described as malleable (can be beaten into sheets) and ductile (can be pulled out into wires). This is because of the ability of the atoms to roll over each other into new positions without breaking the metallic bond.

If a small stress is put onto the metal, the layers of atoms will start to roll over each other. If the stress is released again, they will fall back to their original positions. Under these circumstances, the metal is said to be elastic.

Malleability is a physical property of matter, usually metals. The property usually applies to the family groups 1 to 12 on the modern periodic table of elements. It is the ability of a solid to bend or be hammered into other shapes without breaking. Examples of malleable metals are gold, iron, aluminum, copper, silver, and lead.

Gold and silver are highly malleable. When a piece of hot iron is hammered it takes the shape of a sheet. The property is not seen in non-metals. Non-malleable metals may break apart when struck by a hammer. Malleable metals usually bend and twist in various shapes.

Zinc is malleable at temperatures between 100 and 200 °C but is brittle at other temperatures.[1]

3.2.7 Strength (MPa):

Strength of metal , also called **mechanics of materials**, deals with the behavior of solid objects subject to stresses and strains. The complete theory began with the consideration of the behavior of one and two dimensional members of structures, whose states of stress can be approximated as two dimensional, and was then generalized to three dimensions to develop a more complete theory of the elastic and plastic behavior of materials. An important founding pioneer in mechanics of materials was Stephen Timoshenko.

The study of strength of materials often refers to various methods of calculating the stresses and strains in structural members, such as beams, columns, and shafts. The methods employed to predict the response of a structure under loading and its susceptibility to various failure modes takes into account the properties of the materials such as its yield strength, ultimate strength, Young's modulus, and Poisson's ratio; in addition the mechanical element's macroscopic properties (geometric properties), such as its length, width, thickness, boundary constraints and abrupt changes in geometry such as holes are considered.

Types of loadings to Strength measurement

Transverse loadings – Forces applied perpendicular to the longitudinal axis of a member. Transverse loading causes the member to bend and deflect from its original position, with internal tensile and compressive strains accompanying the change in curvature of the member.[1] Transverse loading also induces shear forces that cause shear deformation of the material and increase the transverse deflection of the member.

Axial loading – The applied forces are collinear with the longitudinal axis of the member. The forces cause the member to either stretch or shorten.[2]

Torsional loading – Twisting action caused by a pair of externally applied equal and oppositely directed force couples acting on parallel planes or by a single external couple applied to a member that has one end fixed against rotation.

- **Stress Parameters for Resistance**

Material resistance can be expressed in several mechanical stress parameters. The term *material strength* is used when referring to *mechanical stress* parameters. These are physical quantities with dimension homogeneous to *pressure* and *force per unit surface*. The traditional measure unit for strength are therefore MPa in the International System of Units, and the psi between the United States customary units. Strength parameters include: yield strength, tensile strength, fatigue strength, crack resistance, and other parameters.

- *Yield strength* is the lowest stress that produces a permanent deformation in a material. In some materials, like aluminium alloys, the point of yielding is difficult to identify, thus it is usually defined as the stress required to cause 0.2% plastic strain. This is called a 0.2% proof stress.[6]

- *Compressive strength* is a limit state of compressive stress that leads to failure in a material in the manner of ductile failure (infinite theoretical yield) or brittle failure (rupture as the result of crack propagation, or sliding along a weak plane – see shear strength).
- *Tensile strength* or *ultimate tensile strength* is a limit state of tensile stress that leads to tensile failure in the manner of ductile failure (yield as the first stage of that failure, some hardening in the second stage and

breakage after a possible "neck" formation) or brittle failure (sudden breaking in two or more pieces at a low-stress state). The tensile strength can be quoted as either true stress or engineering stress, but engineering stress is the most commonly used.

- *Fatigue strength* is a more complex measure of the strength of a material that considers several loading episodes in the service period of an object, and is usually more difficult to assess than the static strength measures. Fatigue strength is quoted here as a simple range. In the case of cyclic loading it can be appropriately expressed as an amplitude usually at zero mean stress, along with the number of cycles to failure under that condition of stress.

- *Impact strength* is the capability of the material to withstand a suddenly applied load and is expressed in terms of energy. Often measured with the Izod impact strength test or Charpy impact test, both of which measure the impact energy required to fracture a sample. Volume, modulus of elasticity, distribution of forces, and yield strength affect the impact strength of a material. In order for a material or object to have a high impact strength, the stresses must be distributed evenly throughout the object. It also must have a large volume with a low modulus of elasticity and a high material yield strength.

3.2.8 Fatigue (MPa)

In materials science, **fatigue** is the weakening of a material caused by cyclic loading that results in progressive and localised structural damage and the growth of cracks. Once a **fatigue crack** has initiated, each loading cycle will grow the crack a small amount, typically producing striations on some parts of the fracture surface. The crack will continue to grow until it reaches a critical size, which occurs when the stress intensity factor of the crack exceeds the fracture toughness of the material, producing rapid propagation and typically complete fracture of the structure.

Fatigue has traditionally been associated with the failure of metal components which led to the term **metal fatigue**. In the nineteenth century, the sudden failing of metal railway axles was thought to be caused by the metal crystallising because of the brittle appearance of the fracture surface, but this has since been disproved.[1] Most materials seem to experience some sort of fatigue-related failure such as composites, plastics and ceramics.[2]

To aid in predicting the fatigue life of a component, fatigue tests are carried out using coupons to measure the rate of crack growth by applying constant amplitude cyclic loading and averaging the measured growth of a crack over thousands of cycles. However, there are also a number of special cases that need to be considered where the rate of crack growth obtained from these tests needs adjustment. Such as: the reduced rate of growth that occurs for small loads near the threshold or after the application of an overload; and the increased rate of crack growth associated with short cracks or after the application of an underload.[2]

If the loads are above a certain threshold, microscopic cracks will begin to initiate at stress concentrations such as holes, persistent slip bands (PSBs), composite interfaces or grain boundaries in metals.[3] The nominal maximum stress values that cause such damage may be much less than the strength of the material, typically quoted as the ultimate tensile strength, or the yield strength.

3.2.8.1 Characteristics of fatigue:

- In metal alloys, and for the simplifying case when there are no macroscopic or microscopic discontinuities, the process starts with dislocation movements at the microscopic level, which eventually form persistent slip bands that become the nucleus of short cracks.
- Macroscopic and microscopic discontinuities (at the crystalline grain scale) as well as component design features which cause stress concentrations (holes, keyways, sharp changes of load direction etc.) are common locations at which the fatigue process begins.
- Fatigue is a process that has a degree of randomness (stochastic), often showing considerable scatter even in seemingly identical samples in well controlled environments.
- Fatigue is usually associated with tensile stresses but fatigue cracks have been reported due to compressive loads.[10]
- The greater the applied stress range, the shorter the life.
- Fatigue life scatter tends to increase for longer fatigue lives.
- Damage is irreversible. Materials do not recover when rested.
- Fatigue life is influenced by a variety of factors, such as temperature, surface finish, metallurgical microstructure, presence of oxidizing or inert chemicals, residual stresses, scuffing contact (fretting), etc.
- Some materials (e.g., some steel and titanium alloys) exhibit a theoretical fatigue limit below which continued loading does not lead to fatigue failure.
- High cycle fatigue strength (about 10^4 to 10^8 cycles) can be described by stress-based parameters. A load-controlled servo-hydraulic test rig is commonly used in these tests, with frequencies of around 20–50 Hz. Other sorts of machines—like resonant magnetic machines—can also be used, to achieve frequencies up to 250 Hz.
- Low-cycle fatigue (loading that typically causes failure in less than 10^4 cycles) is associated with localized plastic behavior in metals; thus, a strain-based parameter should be used for fatigue life prediction in metals. Testing is conducted with constant strain amplitudes typically at 0.01–5 Hz.

Historically, fatigue has been separated into regions of high cycle fatigue that require more than 104 cycles to failure where stress is low and primarily elastic and low cycle fatigue where there is significant plasticity. Experiments have shown that low cycle fatigue is also crack growth.[4]

Fatigue failures, both for high and low cycle, all follow the same basic steps process of crack initiation, stage I crack growth, stage II crack growth, and finally ultimate failure. To begin the process cracks must nucleate within a material. This process can occur either at stress risers in metallic samples or at areas with a high void density in polymer samples. These cracks propagate slowly at first during stage I crack growth along crystallographic planes, where shear stresses are highest. Once the cracks reach a critical size they propagate quickly during stage II crack growth in a direction perpendicular to the applied force. These cracks can eventually lead to the ultimate failure of the material, often in a brittle catastrophic fashion.

3.2.8.2 Stages of fatigue:

- **Crack initiation**

The formation of initial cracks preceding fatigue failure is a separate process consisting of four discrete steps in metallic samples. The material will develop cell structures and harden in response to the applied load. This causes the amplitude of the applied stress to increase given the new restraints on strain. These newly formed cell structures will eventually break down with the formation of persistent slip bands (PSBs). Slip in the material is localized at these PSBs, and the exaggerated slip can now serve as a stress concentrator for a crack to form. Nucleation and growth of a crack to a detectable size accounts for most of the cracking process. It is for this reason that cyclic fatigue failures seem to occur so suddenly where the bulk of the changes in the material are not visible without destructive testing. Even in normally ductile materials, fatigue failures will resemble sudden brittle failures.

- **Crack growth**

Most of the fatigue life is generally consumed in the crack growth phase. The rate of growth is primarily driven by the range of cyclic loading although additional factors such as mean stress, environment, overloads and underloads can also affect the rate of growth. Crack growth may stop if the loads are small enough to fall below a critical threshold.

When the rate of growth becomes large enough, fatigue striations can be seen on the fracture surface. Striations mark the position of the crack tip and the width of each striation represents the growth from one loading cycle. Striations are a result of plasticity at the crack tip.

When the stress intensity exceeds a critical value known as the fracture toughness, unsustainable fast fracture will occur, usually by a process of microvoid coalescence. Prior to final fracture, the fracture surface may contain a mixture of areas of fatigue and fast fracture.

3.2.9 Coefficient of Friction

The coefficient of friction is dimensionless and it does not have any unit. It is a scalar, meaning the direction of the force does not affect the physical quantity.

The coefficient of friction depends on the objects that are causing friction. The value is usually between 0 and 1 but can be greater than 1. A value of 0 means there is no friction at all between the objects; such is possible with Superfluidity. All objects, otherwise, will have some friction when they touch each other. A value of 1 means the frictional force is equal to the normal force. It is a misconception that the coefficient of friction is limited to values between zero and one. A coefficient of friction that is more than one just means that the frictional force is stronger than the normal force. An object such as silicone rubber, for example, can have a coefficient of friction much greater than one.

The friction force is the force exerted by a surface when an object moves across it - or makes an effort to move across it.

Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other.[2] There are several types of friction:

- **Dry friction** is a force that opposes the relative lateral motion of two solid surfaces in contact. Dry friction is subdivided into *static friction* ("stiction") between non-moving surfaces, and *kinetic friction* between moving surfaces. With the exception of atomic or molecular friction, dry friction generally arises from the interaction of surface features, known as asperities
- **Fluid friction** describes the friction between layers of a viscous fluid that are moving relative to each other.[3][4]
- **Lubricated friction** is a case of fluid friction where a lubricant fluid separates two solid surfaces.[5][6][7]
- **Skin friction** is a component of drag, the force resisting the motion of a fluid across the surface of a body.
- **Internal friction** is the force resisting motion between the elements making up a solid material while it undergoes deformation.[4]

When surfaces in contact move relative to each other, the friction between the two surfaces converts kinetic energy into thermal energy (that is, it converts work to heat). This property can have dramatic consequences, as illustrated by the use of friction created by rubbing pieces of wood together to start a fire. Kinetic energy is converted to thermal energy whenever motion with friction occurs, for example when a viscous fluid is stirred. Another important consequence of many types of friction can be wear, which may lead to performance degradation or damage to components. Friction is a component of the science of tribology.

Friction is desirable and important in supplying traction to facilitate motion on land. Most land vehicles rely on friction for acceleration, deceleration and changing direction. Sudden reductions in traction can cause loss of control and accidents.

3.2.10 Machinability

Machinability is the ease with which a metal can be cut (machined) permitting the removal of the material with a satisfactory finish at low cost.[1] Materials with good machinability (free machining materials) require little power to cut, can be cut quickly, easily obtain a good finish, and do not wear the tooling much. The factors that typically improve a material's performance often degrade its machinability. Therefore, to manufacture components economically, engineers are challenged to find ways to improve machinability without harming performance.

Machinability can be difficult to predict because machining has so many variables. Two sets of factors are the condition of work materials and the physical properties of work materials.[2] The condition of the work material includes eight factors: microstructure, grain size, heat treatment, chemical composition, fabrication, hardness, yield strength, and tensile strength.[3] Physical properties are those of the individual material groups, such as the modulus of elasticity, thermal conductivity, thermal expansion, and work hardening.[3] Other important factors are operating conditions, cutting tool material and geometry, and the machining process parameters.[3]

Machinability can be based on the measure of how long a tool lasts. This can be useful when comparing materials that have similar properties and power consumptions, but one is more abrasive and thus decreases the tool life. The major downfall with this approach is that tool life is dependent on more than just the material it is machining; other factors include cutting tool material, cutting tool geometry, machine condition, cutting tool clamping, cutting speed, feed, and depth of cut. Also, the machinability for one tool type cannot be compared to another tool type (i.e. HSS tool to a carbide tool).

- **Stainless Steel**

Stainless steels have poor machinability compared to regular carbon steel because they are tougher, gummier and tend to work harden very rapidly.[4] Slightly hardening the steel may decrease its gumminess and make it easier to cut. AISI grades 303 and 416 are easier to machine because of the addition of sulphur and phosphorus.[10]

- **Aluminium**

Aluminium is a much softer metal than steel, and the techniques to improve its machinability usually rely on making it more brittle. Alloys 2007, 2011 and 6020 have very good machinability.[10]

- **Other Materials**

Thermoplastics are difficult to machine because they have poor thermal conductivity.[9] This creates heat that builds up in the cutting zone, which degrades the tool life and locally melts the plastic. Once the plastic melts, it just flows around the cutting edge instead of being removed by it. Machinability can be improved by using high lubricity coolant and keeping the cutting area free of chip build up.

Composites often have the worst machinability because they combine the poor thermal conductivity of a plastic resin with the tough or abrasive qualities of the fiber (glass, carbon etc.) material.

The machinability of rubber and other soft materials improves by using a very low temperature coolant, such as liquid carbon dioxide. The low temperatures chill the material prior to cutting so that it cannot deform or stick to the cutting edge. This means less wear on the tools and easier machining.

CHAPTER 4

PROPOSED MATERIAL OPTIMIZATION METHODOLOGY

4.1 PROPOSED PREDICTION/OPTIMIZATION ANALYSIS METHOD

1. INTRODUCTION TO ANOVA

A common approach to figure out a reliable treatment method would be to analyse the days it took the patients to be cured. We can use a statistical technique which can compare these three treatment samples and depict how different these samples are from one another. Such a technique, which compares the samples on the basis of their means, is called ANOVA.

Analysis of variance (ANOVA) is an analysis tool used in statistics that splits an observed aggregate variability found inside a data set into two parts: systematic factors and random factors. The systematic factors have a statistical influence on the given data set, while the random factors do not. Analysts use the ANOVA test to determine the influence that independent variables have on the dependent variable in a regression study.

The t- and z-test methods developed in the 20th century were used for statistical analysis until 1918, when Ronald Fisher created the analysis of variance method.[1][2] ANOVA is also called the Fisher analysis of variance, and it is the extension of the t- and z-tests. The term became well-known in 1925, after appearing in Fisher's book, "Statistical Methods for Research Workers."[3] It was employed in experimental psychology and later expanded to subjects that were more complex.

Analysis of variance (**ANOVA**) is a collection of statistical models and their associated estimation procedures (such as the "variation" among and between groups) used to analyze the differences among group means in a sample. ANOVA was developed by the statistician Ronald Fisher. The ANOVA is based on the law of total variance, where the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether two or more population means are equal, and therefore generalizes the *t*-test beyond two means.

Analysis of Variance (ANOVA) is a parametric statistical technique used to compare datasets. This technique was invented by R.A. Fisher, and is thus often referred to as Fisher's ANOVA, as well. It is similar in application to techniques such as t-test and z-test, in that it is used to compare means and the relative variance between them. However, analysis of variance (ANOVA) is best applied where more than 2 populations or samples are meant to be compared.

Statistics Solutions is the country's leader in Analysis of Variance (ANOVA) and dissertation statistics. The use of this parametric statistical technique involves certain key assumptions, including the following:

1. **Independence of case:** Independence of case assumption means that the case of the dependent variable should be independent or the sample should be selected randomly. There should not be any pattern in the selection of the sample.

2. **Normality:** Distribution of each group should be normal. The Kolmogorov-Smirnov or the Shapiro-Wilk test may be used to confirm normality of the group.

3. **Homogeneity:** Homogeneity means variance between the groups should be the same. Levene's test is used to test the homogeneity between groups.

If particular data follows the above assumptions, then the analysis of variance (ANOVA) is the best technique to compare the means of two, or more, populations.

2. ANALYSIS OF VARIANCE (ANOVA) HAS THREE TYPES

One way analysis: When we are comparing more than three groups based on one factor variable, then it said to be one way analysis of variance (ANOVA). For example, if we want to compare whether or not the mean output of three workers is the same based on the working hours of the three workers.

Two way analysis: When factor variables are more than two, then it is said to be two way analysis of variance (ANOVA). For example, based on working condition and working hours, we can compare whether or not the mean output of three workers is the same.

K-way analysis: When factor variables are k, then it is said to be the k-way analysis of variance (ANOVA).
Key terms and concepts:

Sum of square between groups: For the sum of the square between groups, we calculate the individual means of the group, then we take the deviation from the individual mean for each group. And finally, we will take the sum of all groups after the square of the individual group.
Sum of squares within group: In order to get the sum of squares within a group, we calculate the grand mean for all groups and then take the deviation from the individual group. The sum of all groups will be done after the square of the deviation.

F –ratio: To calculate the F-ratio, the sum of the squares between groups will be divided by the sum of the square within a group.

Degree of freedom: To calculate the degree of freedom between the sums of the squares group, we will subtract one from the number of groups. The sum of the square within the group's degree of freedom will be calculated by subtracting the number of groups from the total observation.
BSS df = (g-1) for BSS is between the sum of squares, where g is the group, and df is the degree of freedom.
WSS df = (N-g) for WSS within the sum of squares, where N is the total sample size.
Significance: At a predetermine level of significance (usually at 5%), we will compare and calculate the value with the critical table value. Today, however, computers can automatically calculate the probability value for F-ratio. If p-value is lesser than the predetermined significance level, then group means will be different. Or, if the p-value is greater than the predetermined significance level, we can say that there is no difference between the groups' mean.

Analysis of variance (ANOVA) in EXCEL: In EXCEL, analysis of variance (ANOVA) can be performed in many ways. We can perform this test in EXCEL by clicking on the option "one way ANOVA," available in the "compare means" option. When we are performing two ways or more than two ways analysis of variance (ANOVA), then we can use the "univariate" option available in the GLM menu. EXCEL will give additional results as well, like the partial eta square, Power, regression model, post hoc, homogeneity test, etc. The post hoc test is performed when there is significant difference between groups and we want to know exactly which group has means that are significantly different from other groups.
Extension:

MANOVA**:** Analysis of variance (ANOVA) is performed when we have one dependent metric variable and one nominal independent variable. However, when we have more than one dependent variable and one or more independent variable, then we will use multivariate analysis of variance (MANOVA).

ANCOVA**:** Analysis of covariance (ANCOVA) test is used to know whether or not certain factors have an effect on the outcome variable after removing the variance for quantitative predictors (covariates).

3. DESIGN-OF-EXPERIMENTS TERMS

Balanced design

An experimental design where all cells (i.e. treatment combinations) have the same number of observations.

Blocking

A schedule for conducting treatment combinations in an experimental study such that any effects on the experimental results due to a known change in raw materials, operators, machines, etc., become concentrated in the levels of the blocking variable. The reason for blocking is to isolate a systematic effect and prevent it from obscuring the main effects. Blocking is achieved by restricting randomization.

Design

A set of experimental runs which allows the fit of a particular model and the estimate of effects.

DOE

Design of experiments. An approach to problem solving involving collection of data that will support valid, defensible, and supportable conclusions.[18]

Effect

How changing the settings of a factor changes the response. The effect of a single factor is also called a main effect.

Error

Unexplained variation in a collection of observations. DOE's typically require understanding of both random error and lack of fit error.

Experimental unit

The entity to which a specific treatment combination is applied.

Factors

Process inputs that an investigator manipulates to cause a change in the output.

Lack-of-fit error

Error that occurs when the analysis omits one or more important terms or factors from the process model. Including replication in a DOE allows separation of experimental error into its components: lack of fit and random (pure) error.

Model

Mathematical relationship which relates changes in a given response to changes in one or more factors.

Random error

Error that occurs due to natural variation in the process. Random error is typically assumed to be normally distributed with zero mean and a constant variance. Random error is also called experimental error.

Randomization

A schedule for allocating treatment material and for conducting treatment combinations in a DOE such that the conditions in one run neither depend on the conditions of the previous run nor predict the conditions in the subsequent runs.[nb 1]

Replication

Performing the same treatment combination more than once. Including replication allows an estimate of the random error independent of any lack of fit error.

Responses

The output(s) of a process. Sometimes called dependent variable(s).

Treatment

A treatment is a specific combination of factor levels whose effect is to be compared with other treatments.

4. DATA LEVEL AND ASSUMPTIONS

The level of measurement of the variables and assumptions of the test play an important role in ANOVA. In ANOVA, the dependent variable must be a continuous (interval or ratio) level of measurement. The independent variables in ANOVA must be categorical (nominal or ordinal) variables. Like the t-test, ANOVA is also a parametric test and has some assumptions. ANOVA assumes that the data is normally distributed. The ANOVA also assumes homogeneity of variance, which means that the variance among the groups should be approximately equal. ANOVA also assumes that the observations are independent of each other. Researchers should keep in mind when planning any study to look out for extraneous or confounding variables. ANOVA has methods (i.e., ANCOVA) to control for confounding variables.

Testing of the Assumptions

The population from which samples are drawn should be normally distributed.

2. Independence of cases: the sample cases should be independent of each other.

3. Homogeneity of variance: Homogeneity means that the variance among the groups should be approximately equal.

These assumptions can be tested using statistical software (like Intellectus Statistics!). The assumption of homogeneity of variance can be tested using tests such as Levene's test or the Brown-Forsythe Test. Normality of the distribution of the scores can be tested using histograms, the values of skewness and kurtosis, or using tests such as Shapiro-Wilk or Kolmogorov-Smirnov. The assumption of independence can be determined from the design of the study.

It is important to note that ANOVA is not robust to violations to the assumption of independence. This is to say, that even if you violate the assumptions of homogeneity or normality, you can conduct the test and basically trust the findings. However, the results of the ANOVA are invalid if the independence assumption is violated. In general, with violations of homogeneity the analysis is considered robust if you have equal sized groups. With violations of normality, continuing with the ANOVA is generally ok if you have a large sample size.

5. DATA FORECASTING AND PREDICTION

Different forecasting methods have been employed to predict future number of diseases occurrences. The prediction results have been useful in assisting the making of policy to reduce disease incidence. Various techniques that have been applied to predict disease incidence inhuman, including Multivariate Markov chain model to project the number of tuberculosis (TB) incidence in the United States from 1980 to 2010 [1], exponential smoothing to forecast the number of human incidence of Schistosomahaematobium at Mali [2], ARIMA model to forecast the SARS epidemic in China [3], a Bayesian dynamic model to monitor the influenza surveillance as one factor of SAR Sepidemic [4], seasonal autoregressive models to analyze Cutaneous leishmaniosis (CL) incidence in Costa Rica from1991 to 2001 [5], the application of decomposition method[6] and seasonal ARIMA to predict number of Salmonellosis human incidence [7].Whilst some have employed several forecasting models, earlier approaches to forecasting is often based on a single forecasting technique. Due to numerous numbers of available forecasting techniques with difference performance, selection of the most appropriate prediction model to yield better prediction results becomes critical. Besides, a single technique may not yield the same prediction accuracy for different type of datasets. Thus, this further highlights the importance of selecting an appropriate forecasting model for each specific dataset. Analysis of Variance (ANOVA) is one of the commonly used statistical methods to compare among several groups. In this paper, ANOVA was used for selecting forecasting method based on comparison of means between forecasting results; that is for testing a significant different between group means. ANOVA is often used when a user needs to compare performance which involves more than two parameters. The advantage of ANOVA over other tests such as simple t-tests is that ANOVA can detect effect of interaction between variables. It could also be used to test more complex hypotheses in existing problem [8]. When differences between groups exist, a post hoc test can then be conducted to identify which group that differs from the others. In this paper, Duncan multiple range test was used. This paper aims to provide the empirical results for evaluating and finding the appropriate method in estimating future number of Salmonellosis disease incidence. Different forecasting methods were used to address the goal, including regression, decomposition, and ARIMA. The results were evaluated using ANOVA and Duncan multiple test.

CHAPTER 5

RESULT AND SIMULATION

5.1 SIMULATION TOOL

CATIA (**computer-aided three-dimensional interactive application**) is a multi-platform software suite for computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), 3D modeling and Product lifecycle management (PLM), developed by the French company Dassault Systèmes.

Since it supports multiple stages of product development from conceptualization, design and engineering to manufacturing, it is considered a CAx-software and is sometimes referred to as a 3D Product Lifecycle Management software suite. Like most of its competition it facilitates collaborative engineering through an integrated cloud service and have support to be used across disciplines including surfacing & shape design, electrical, fluid and electronic systems design, mechanical engineering and systems engineering.

Besides being used in a wide range of industries from aerospace and defence to packaging design, CATIA has been used by architect Frank Gehry to design some of his signature curvilinear buildings[2] and his company Gehry Technologies was developing their Digital Project software based on CATIA.[3]

The software has been merged with the company's other software suite 3D XML Player to form the combined Solidworks Composer Player.

CATIA started as an in-house development in 1977 by French aircraft manufacturer Avions Marcel Dassault to provide 3D surface modeling and NC functions for the CADAM software they used at that time[4] to develop the Mirage fighter jet. Initially named CATI (conception assistée tridimensionnelle interactive – French for interactive aided three-dimensional design), it was renamed CATIA in 1981 when Dassault created the subsidiary Dassault Systèmes to develop and sell the software, under the management of its first CEO, Francis Bernard. Dassault Systèmes signed a non-exclusive distribution agreement with IBM,[5] that was also selling CADAM for Lockheed since 1978. Version 1 was released in 1982 as an add-on for CADAM.

During the eighties CATIA saw wider adoption in the aviation and military industries with users such as Boeing and General Dynamics Electric Boat Corp.[6][7][8]

Dassault Systèmes purchased CADAM from IBM in 1992, and the next year CATIA CADAM was released. During the nineties CATIA was ported first in 1996 from one to four Unix operating systems, and was entirely rewritten for version 5 in 1998 to support Windows NT.[9] In the years prior to 2000, this caused problems of incompatibility between versions that led to $6.1B in additional costs due to delays in production of the Airbus A380.[10]

With the launch of Dassault Systèmes 3DEXPERIENCE Platform in 2014,[11] CATIA became available as a cloud version.[12][13]

5.2 PISTON-DESIGN AND THERMAL TEMPERATURE DISTRIBUTION ANALYSIS CATIA

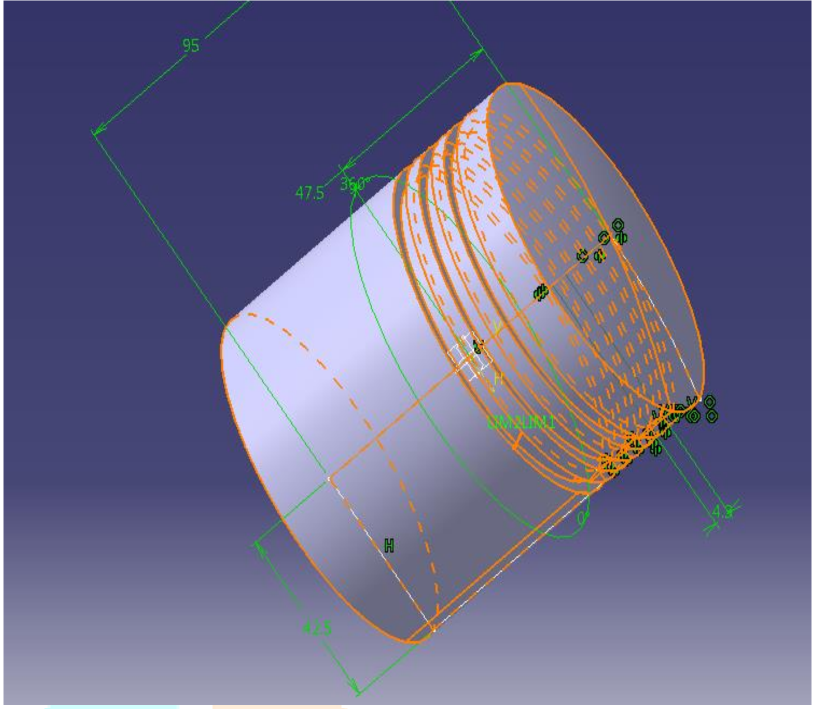


Fig. 5.1 CATIA Design specification.

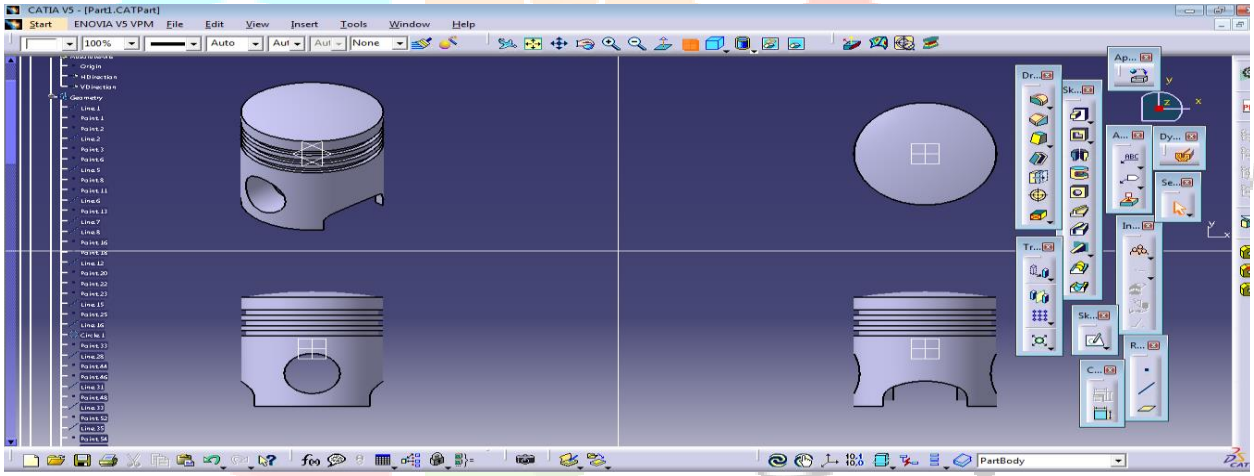


Fig. 5.2 All Views of Piston.

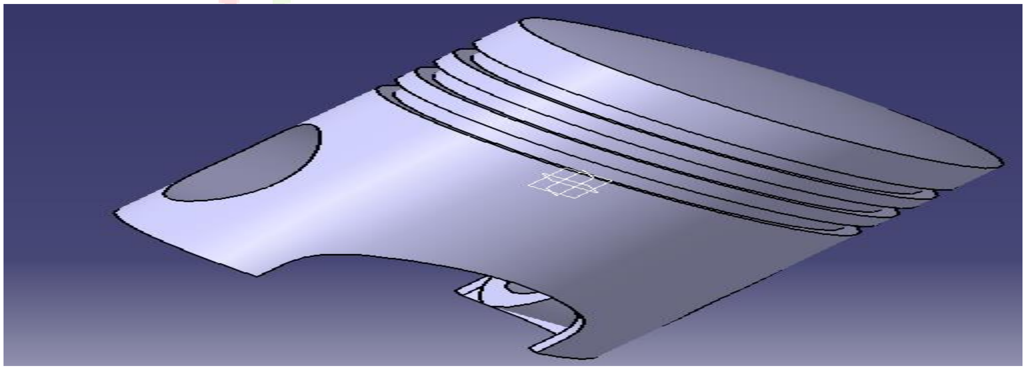


Fig. 5.3 Side View.

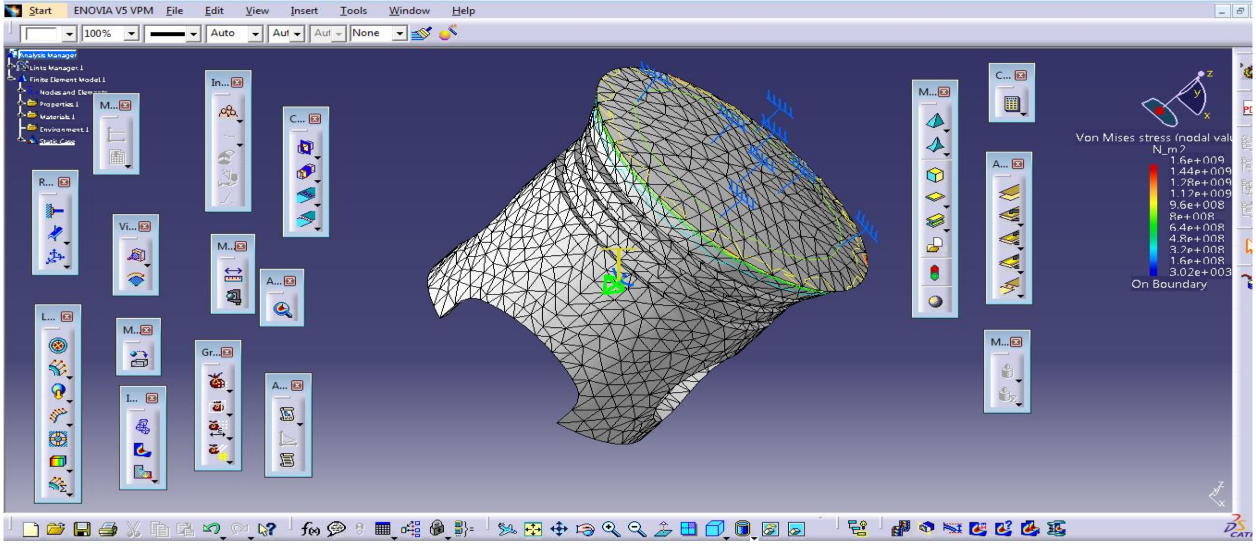


Fig. 5.4 Piston Temperature upper surface distribution.

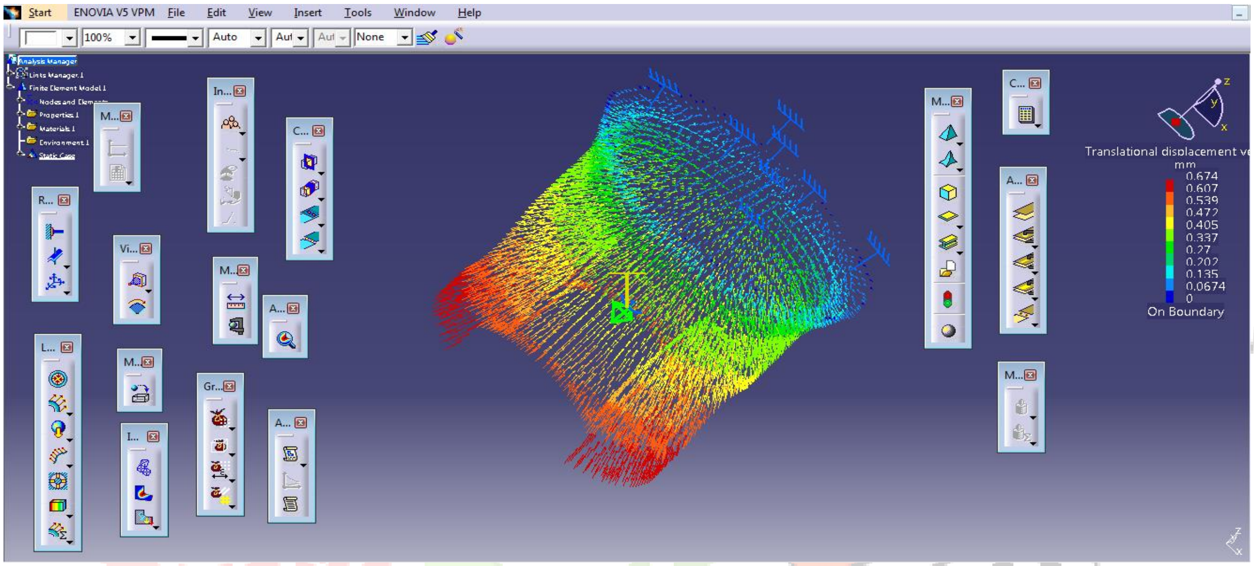


Fig. 5.5 All Piston Temperature Gradient Distribution.

5.3 ALUMINIUM MATERIAL ANALYSIS

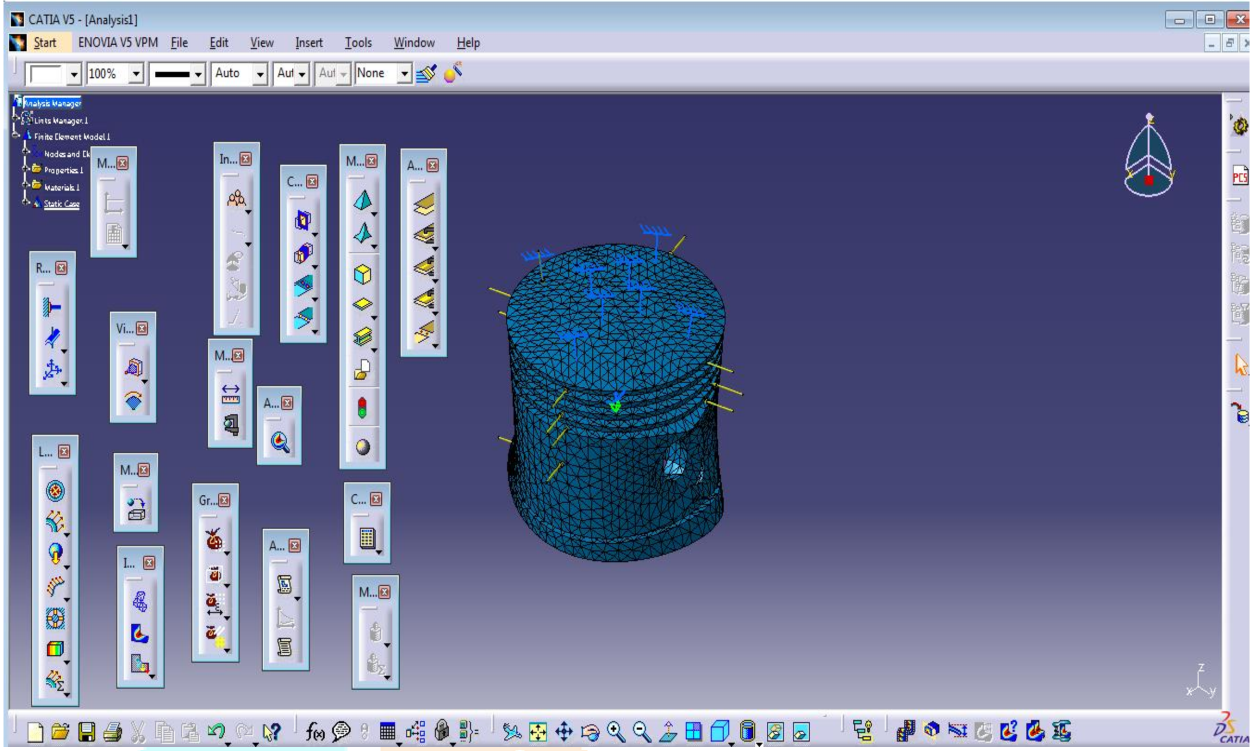


Fig. 5.6 Aluminium material FEM analysis.

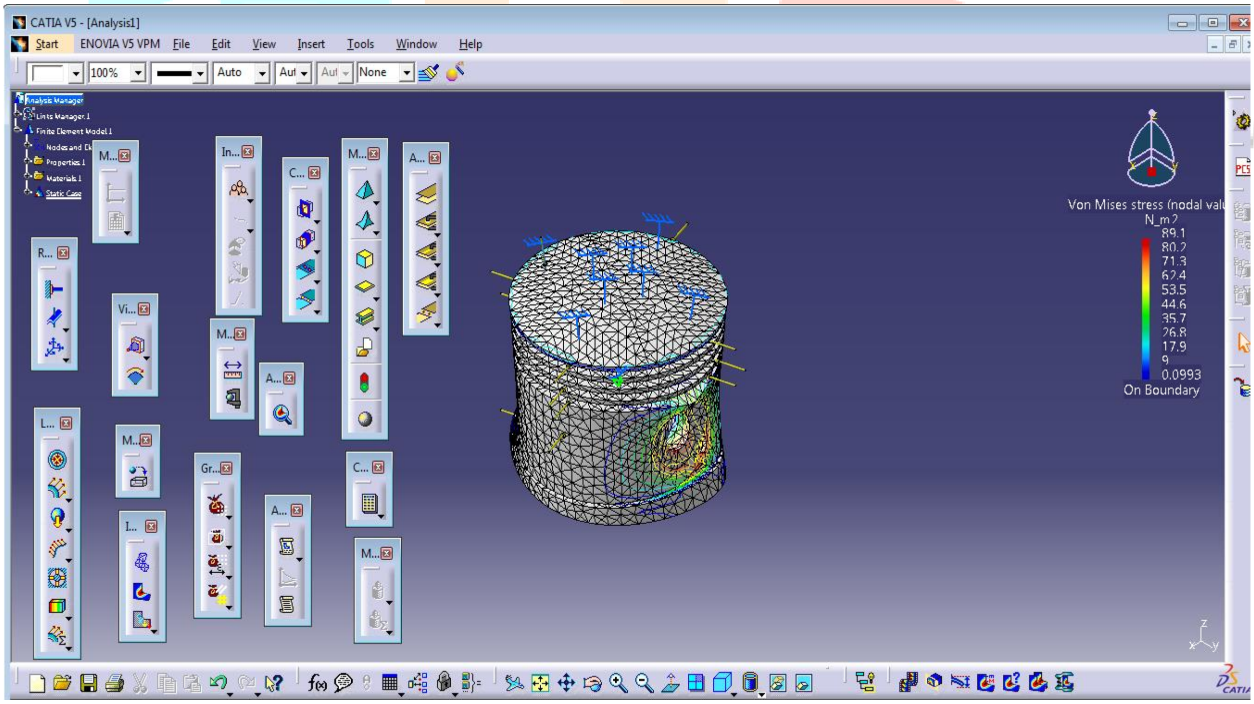


Fig. 5.7 Stress Distribution.

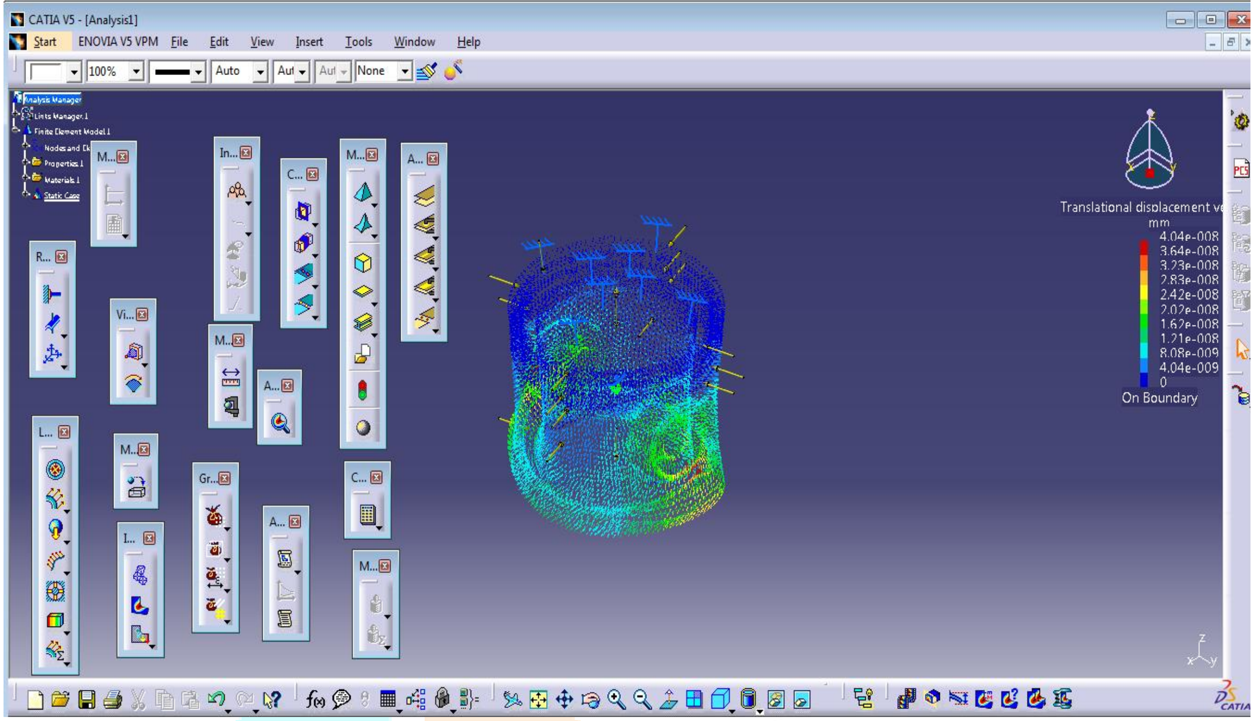
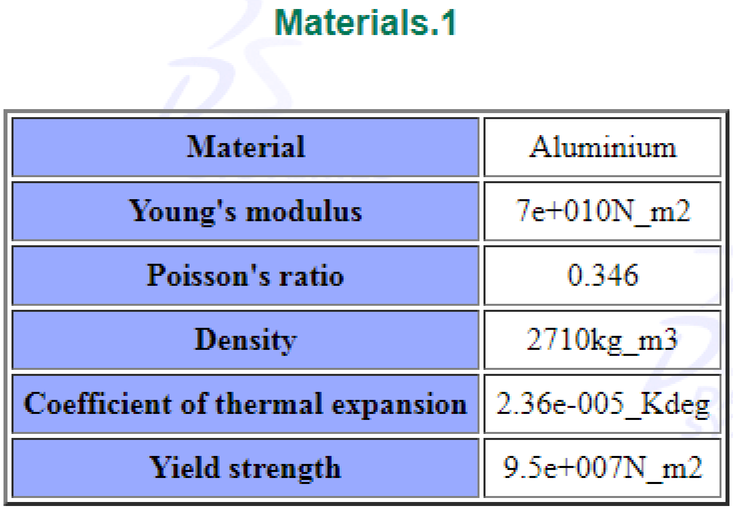


Fig. 5.8 Deformation.

Table 5.1 Material properties I.



Materials.1

Material	Aluminium
Young's modulus	7e+010N_m2
Poisson's ratio	0.346
Density	2710kg_m3
Coefficient of thermal expansion	2.36e-005_Kdeg
Yield strength	9.5e+007N_m2

5.4 STEEL MATERIAL ANALYSIS

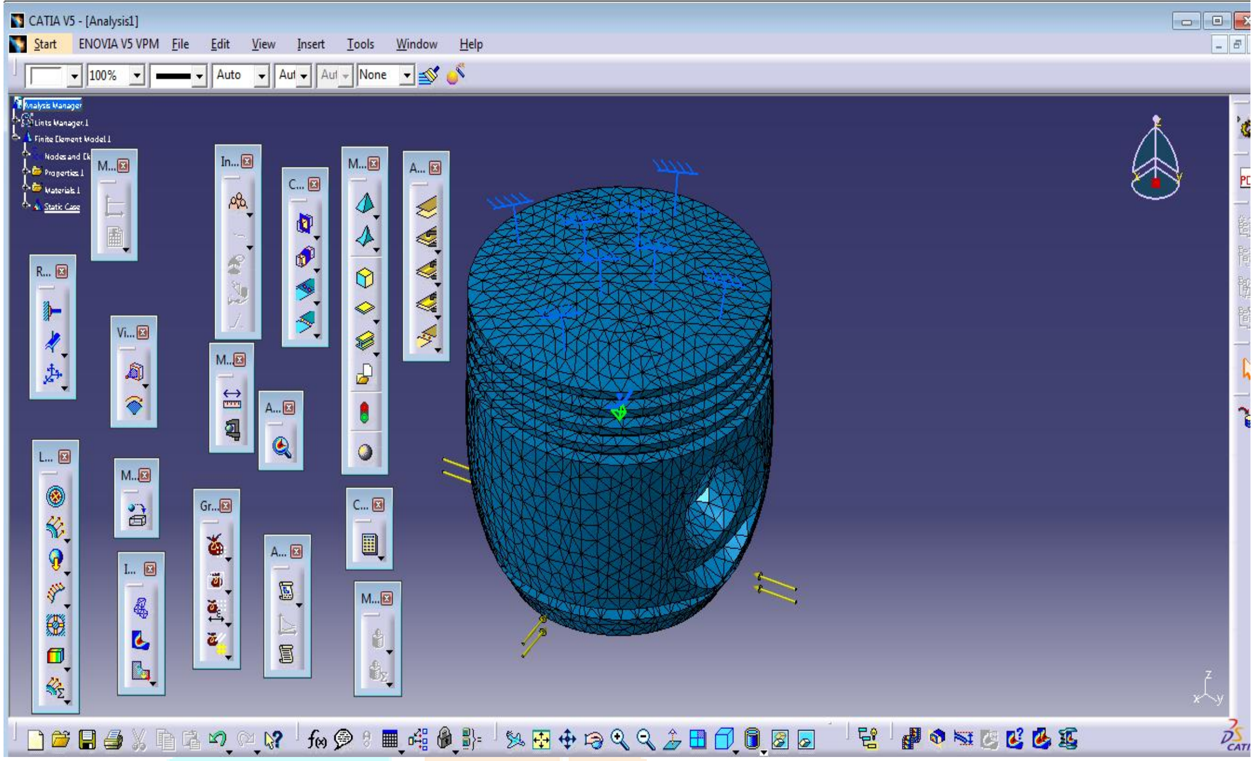


Fig. 5.9 STEEL material FEM analysis.

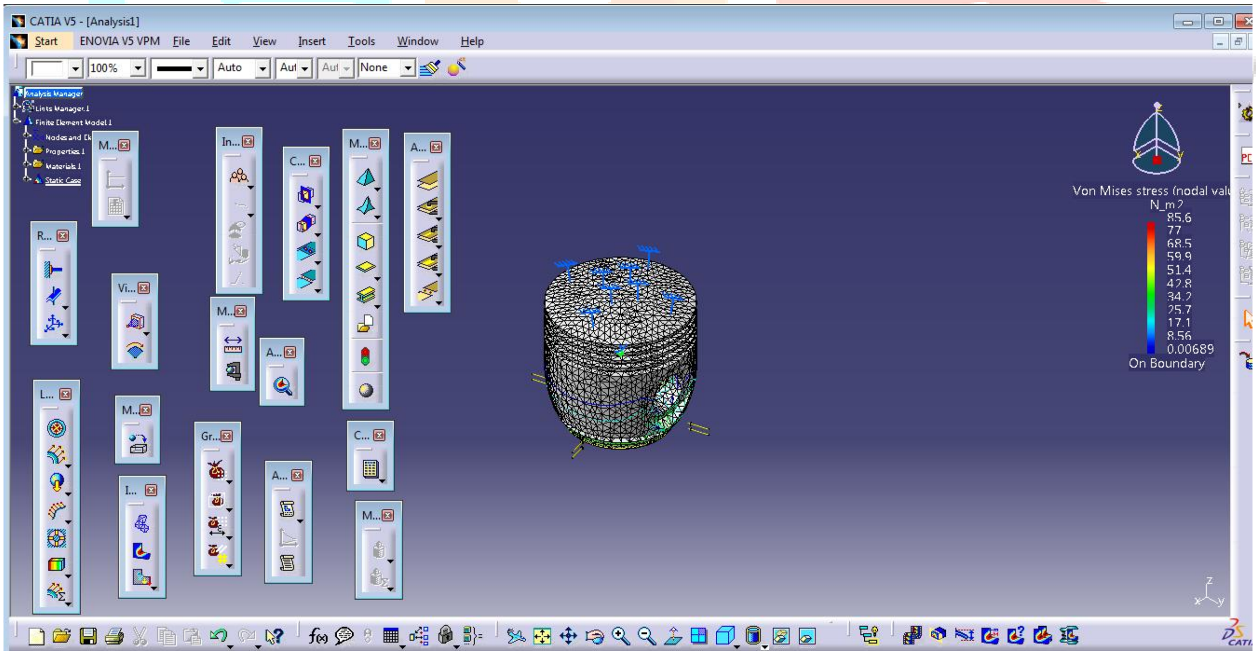


Fig. 5.10 Stress Distribution.

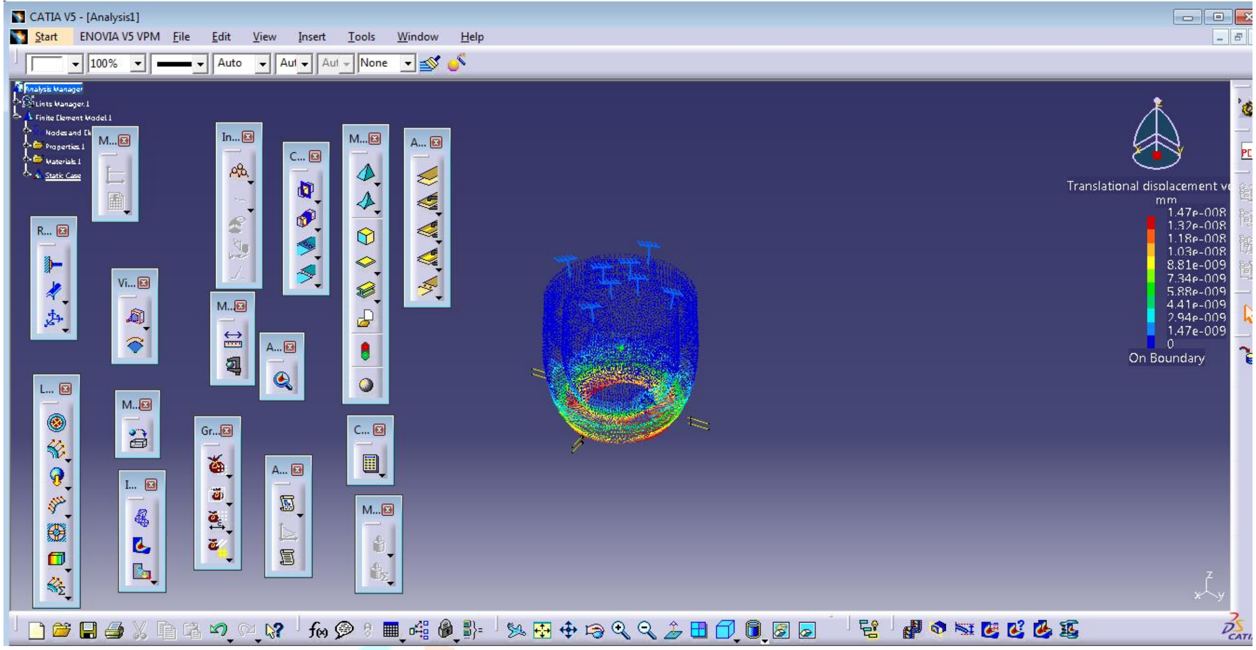
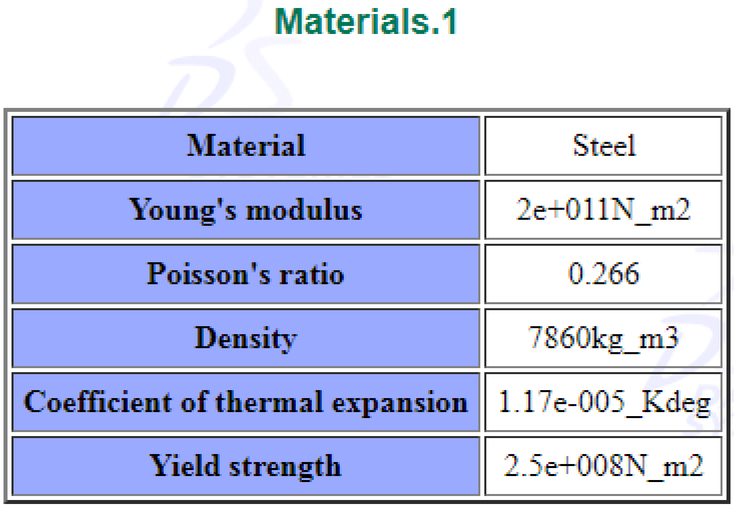


Fig. 5.11 Deformation.

Table 5.2 Material properties II.



Materials.1

Material	Steel
Young's modulus	2e+011N_m2
Poisson's ratio	0.266
Density	7860kg_m3
Coefficient of thermal expansion	1.17e-005_Kdeg
Yield strength	2.5e+008N_m2

5.5 IRON MATERIAL ANALYSIS

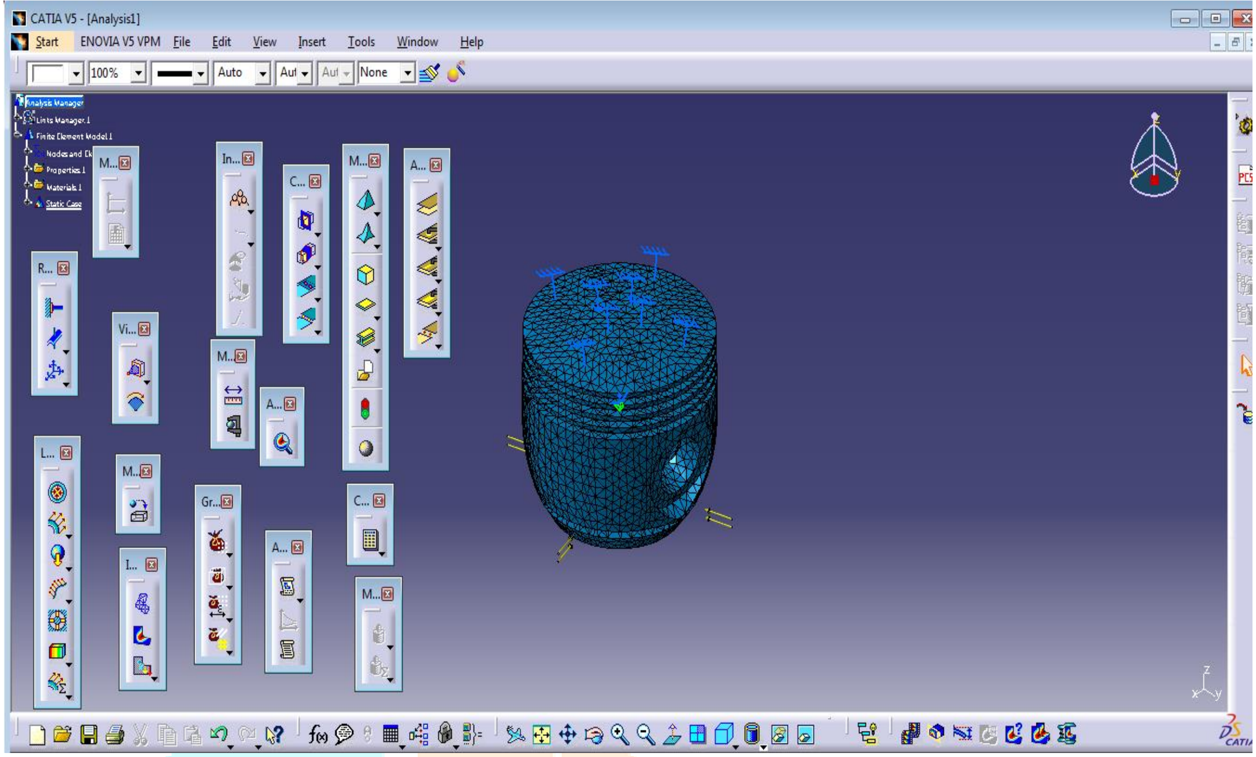


Fig. 5.12 IRON material FEM analysis.

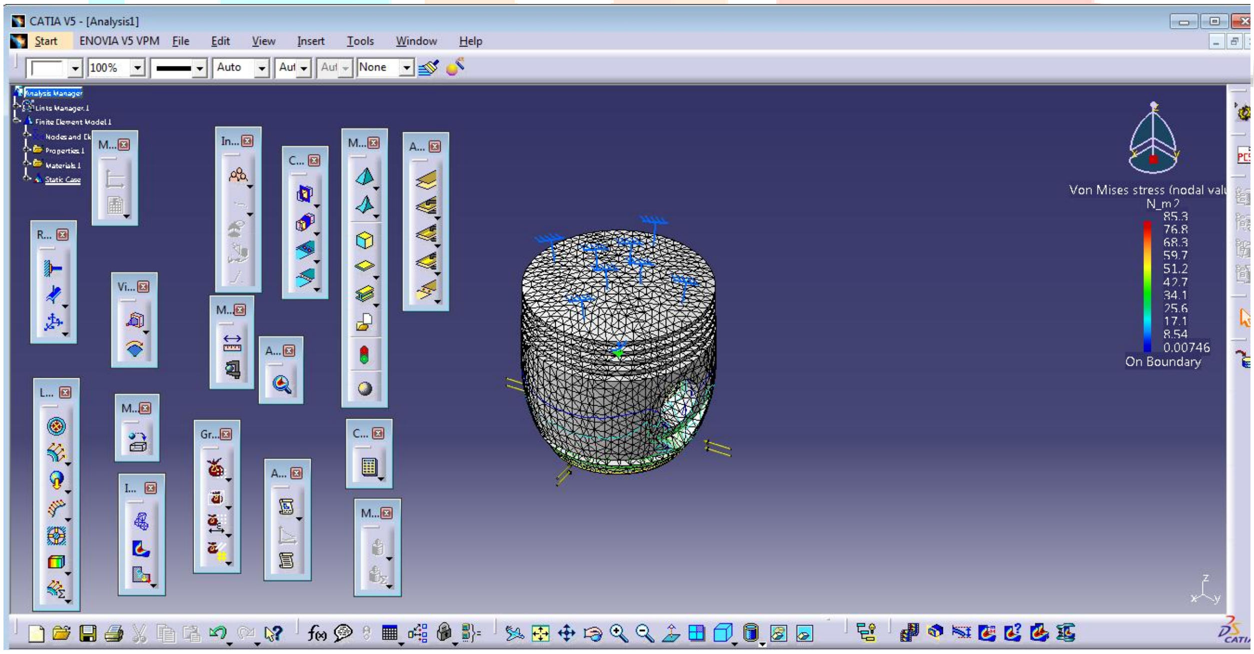


Fig. 5.13 Stress Distribution.

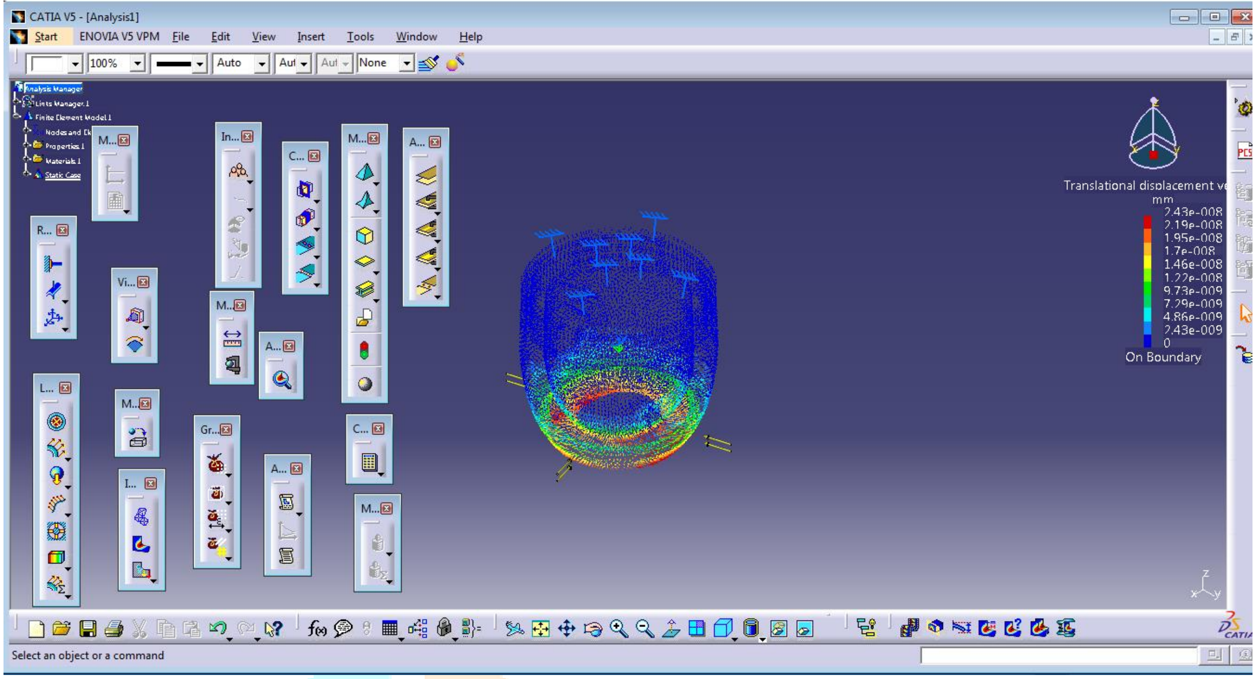
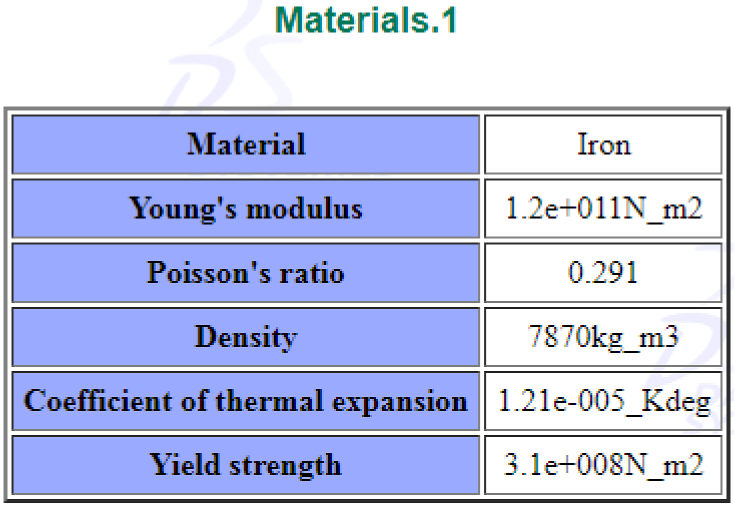


Fig. 5.14 Deformation.

Table 5.3 Material properties III.



Materials.1

Material	Iron
Young's modulus	1.2e+011N_m2
Poisson's ratio	0.291
Density	7870kg_m3
Coefficient of thermal expansion	1.21e-005_Kdeg
Yield strength	3.1e+008N_m2

5.6 TUNGSTEN ALLOYS MATERIAL ANALYSIS

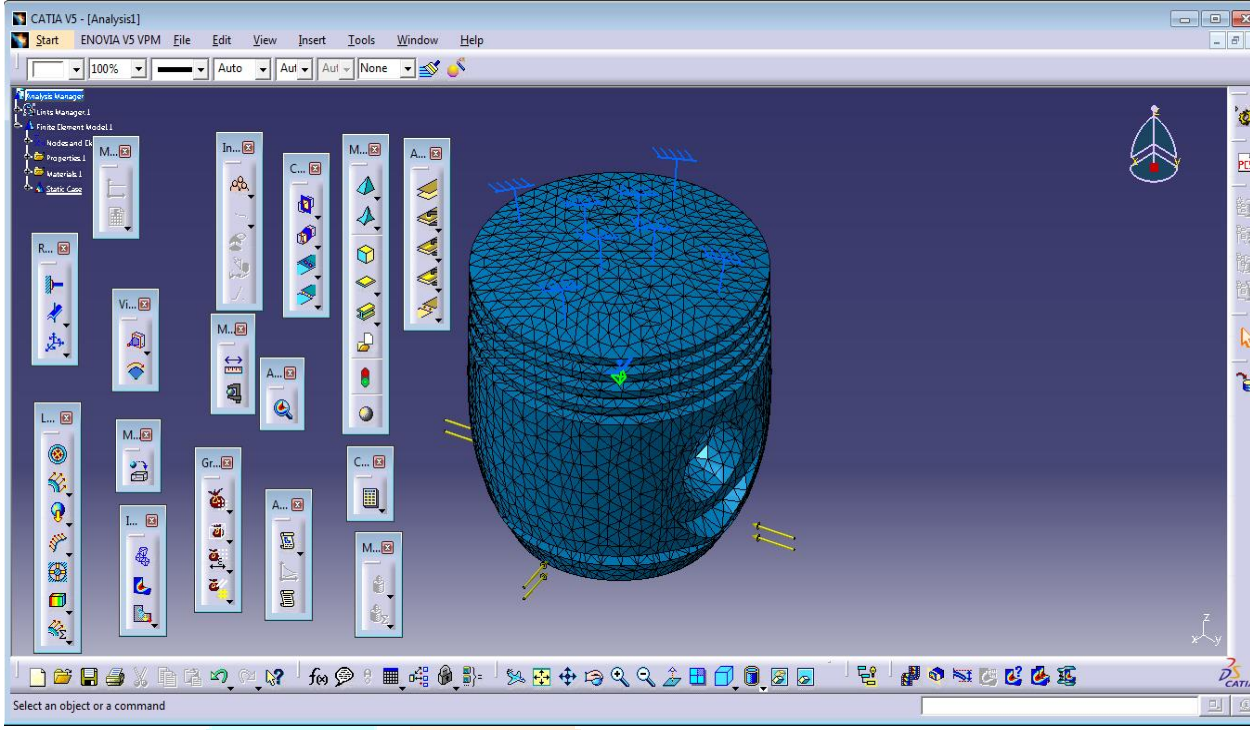


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Fig. 5.15 TUNGSTEN ALLOYS material FEM analysis.

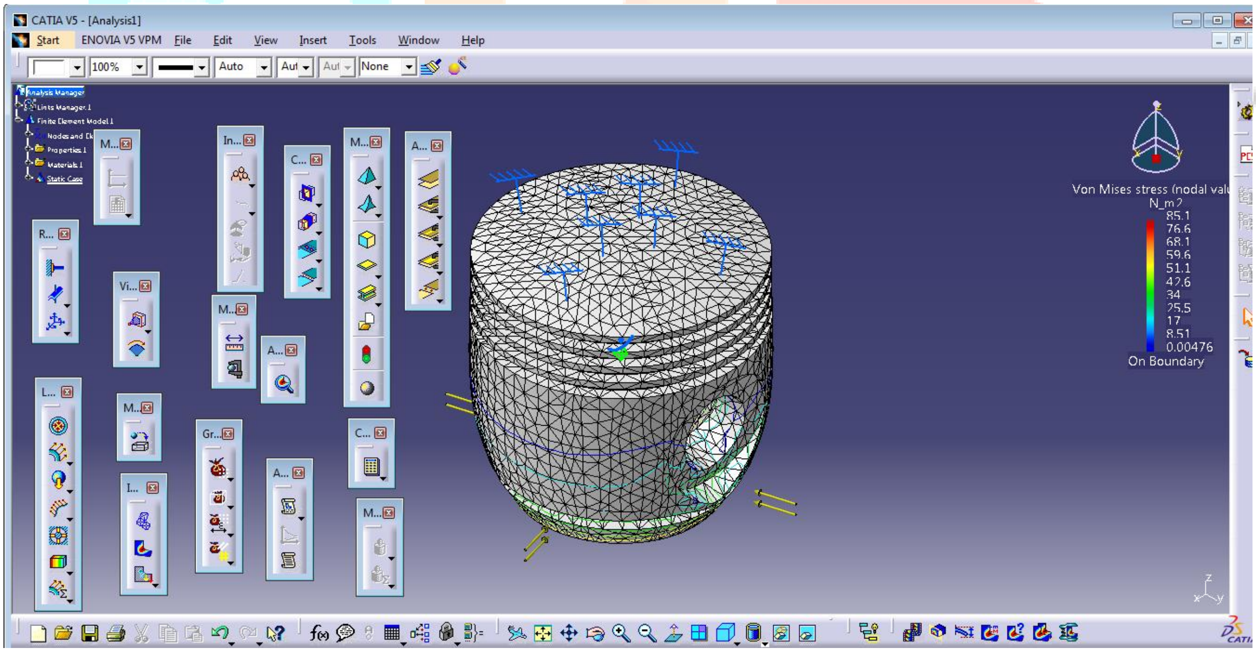


Fig. 5.16 Stress Distribution.

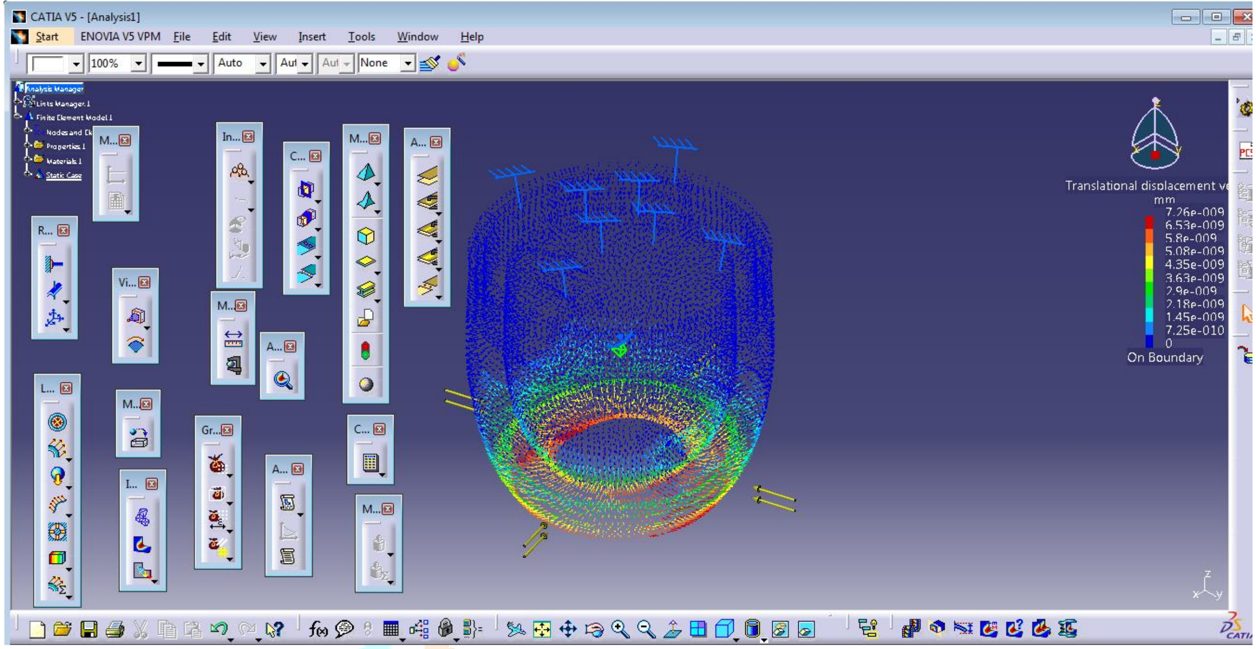
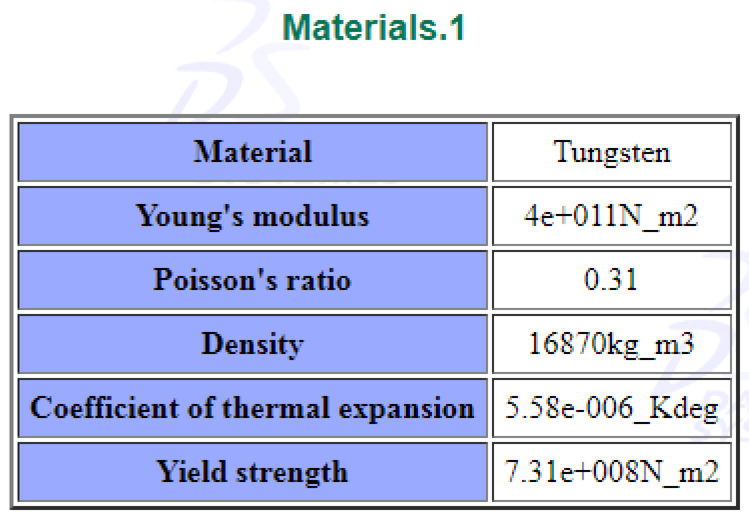


Fig. 5.17 Deformation.

Table 5.4 Material properties IV.

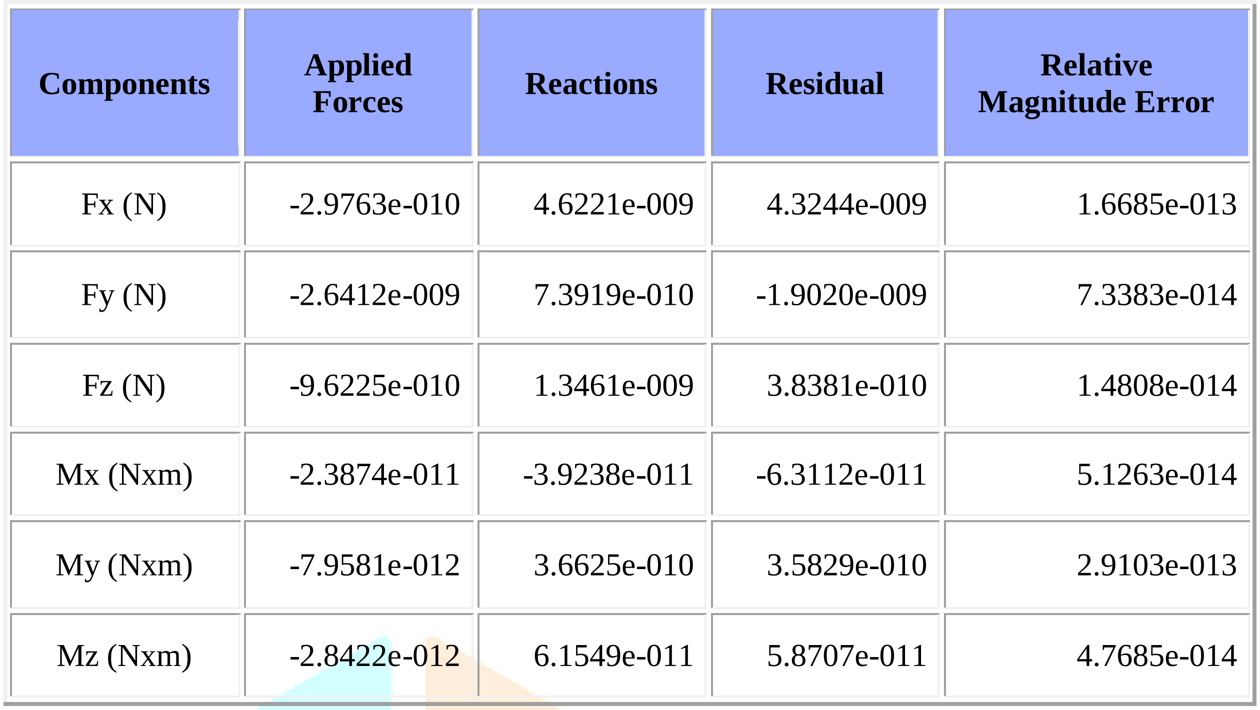


Materials.1

Material	Tungsten
Young's modulus	4e+011N_m2
Poisson's ratio	0.31
Density	16870kg_m3
Coefficient of thermal expansion	5.58e-006_Kdeg
Yield strength	7.31e+008N_m2

Table 5.1 Analysis Parameters.

Table 5.5 Relative Magnitude Error.

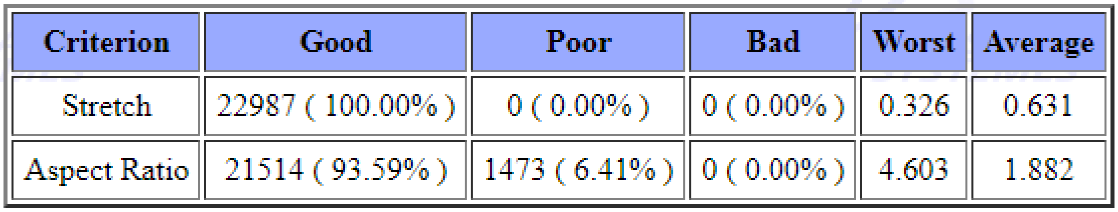


Components	Applied Forces	Reactions	Residual	Relative Magnitude Error
Fx (N)	-2.9763e-010	4.6221e-009	4.3244e-009	1.6685e-013
Fy (N)	-2.6412e-009	7.3919e-010	-1.9020e-009	7.3383e-014
Fz (N)	-9.6225e-010	1.3461e-009	3.8381e-010	1.4808e-014
Mx (Nxm)	-2.3874e-011	-3.9238e-011	-6.3112e-011	5.1263e-014
My (Nxm)	-7.9581e-012	3.6625e-010	3.5829e-010	2.9103e-013
Mz (Nxm)	-2.8422e-012	6.1549e-011	5.8707e-011	4.7685e-014

5.7 COMPARISON BETWEEN DIFFERENT MATERIALS

MATERIALS	STRESS DISTRIBUTION	DEFORMATION
ALUMINIUM	89.1	4.04×10^{-8}
STEEL	85.6	1.47×10^{-8}
IRON	85.3	2.43×10^{-8}
TUNGSTEN ALLOYS	85.1	7.26×10^{-9}

5.8 ANOVA OPTIMIZATION



Criterion	Good	Poor	Bad	Worst	Average
Stretch	22987 (100.00%)	0 (0.00%)	0 (0.00%)	0.326	0.631
Aspect Ratio	21514 (93.59%)	1473 (6.41%)	0 (0.00%)	4.603	1.882

Table 5.6 ANOVA SUMMARY OUTPUT.

Observation	*Predicted STRETCH*	*Residuals*	*Standard Residuals*
1	99.28269	0.717309	0.192558
2	6.799894	-6.79989	-1.8254
3	0	0	0
4	4.882981	-4.55698	-1.2233
5	1.996474	-1.36547	-0.36656

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.996525
R Square	0.993062
Adjusted R Square	0.743062
Standard Error	4.164843
Observations	5

Table 5.7 RESIDUAL OUTPUT.

Table 5.8 PROBABILITY OUTPUT.

PROBABILITY OUTPUT

Percentile	*STRETCH*
10	0
30	0
50	0.326

70	0.631
90	100

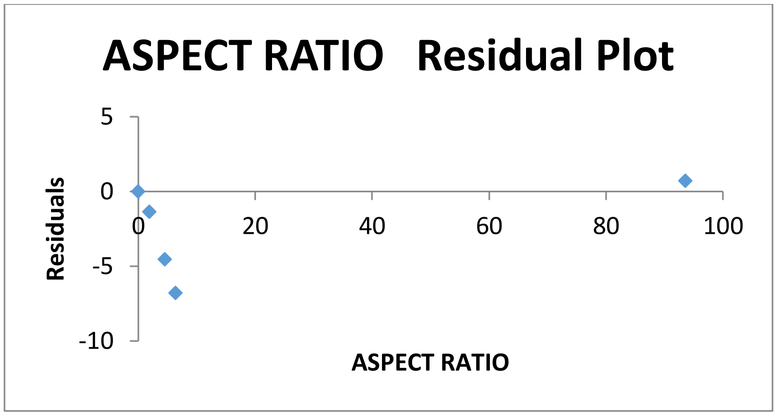


Fig. 5.18 Residual plot.

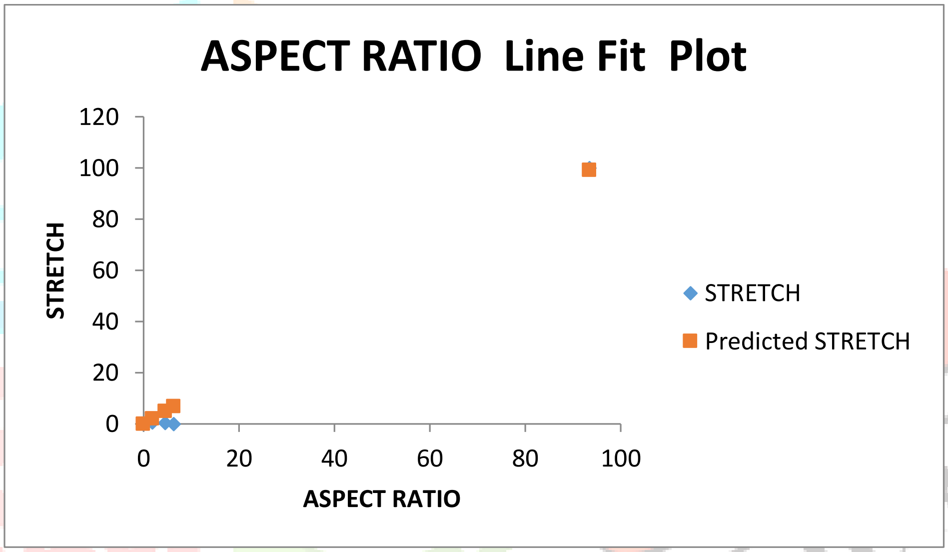


Fig. 5.19 Line Fit .

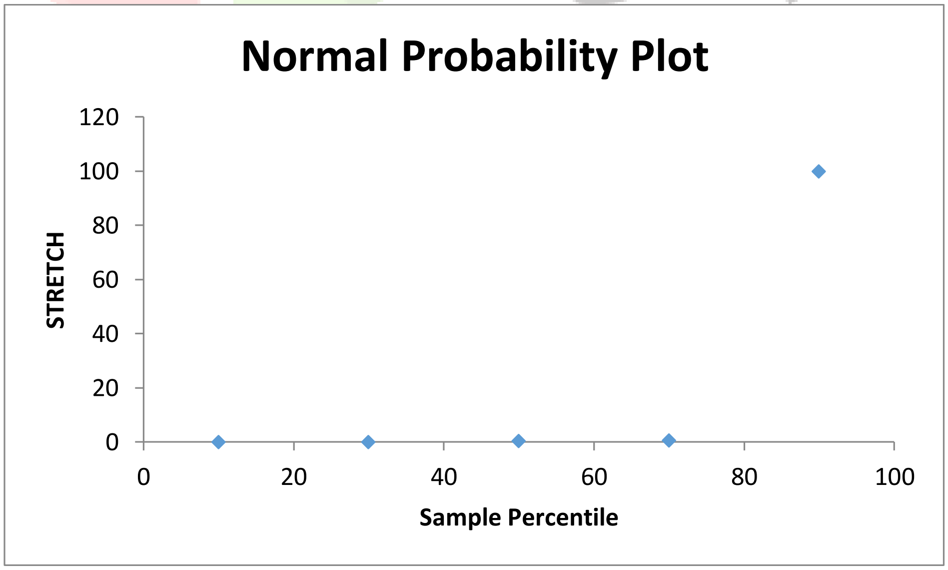


Fig. 5.20 Normal Plot.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

The intent of this work is the use of ANOVA to estimate the performance of a piston with the material properties system using the initial timing differences. To train the network speed, throttle position, displacement timing and material are used as an input and the output are regression piston material and displacement and accuracy. These studies consistently use piston material and displacement tested to be developed.

In this work are identified Tungsten alloys is a best material of piston design because its observation obtained lower Deformation at $7.26X10^{-9}$ and Stress distribution at 85.1. Also Observed prediction maximum accuracy at 99.0%.

This research work focused on issues related to selective assembly of products comprising multiple components each having one or more critical quality characteristics. As the individual components are usually produced by different operations/processes, the dimensional distributions of them are invariably different and when such components are assembled at random the quality characteristics of final assemblies exhibit variations. While random assembly is adapted in most of the manufacturing industries, which facilitates precision assemblies out of relatively less precision components, often it leads to problems like wide variation of assembly tolerance, generation of surplus parts and reduction in manufacturing system efficiency. Another common practical issue with assembly precision is, when the components are produced with high accuracy, the manufacturing cost would go up and there will be a drastic increase in the manufacturing cost of the product.

6.2 FUTURE SCOPE

Due to limitations of computer processing hardware, a very high setting of mesh could not be obtained. Also, because of the same reason explicit dynamic analysis could not be performed which could have shown a more close real to life analysis of the piston. So, for future work, a higher mesh setting can be applied for analysis and explicit dynamic analysis can also be performed.

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