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Design and Analysis of piston using finite element analysis

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Abstract

Computer aided engineering (CAE) tools allow engineers to design product and to simulate these designs for residual stress, structural response, pre-processing and post processing fatigue and similar effects on the machine component. CAE allows engineers to load the component at its extreme conditions and simulate its response or otherwise it is not possible to do it because of safety limitations of cost consideration. Particularly for automobile components CAE helps to analyze them for crash simulation, creep and fatigue test on virtual component leading to reduction in time consuming trial and error procedure for design the prototype and it also helps to reduce the cost of manufacturing. The leading manufactures have accepted simulation as a part of early design process with prototyping and testing are done to ultimately verify the designs. Piston design is carried out with the help of CAE tool and various stresses such as maximum principal stresses, minimum principal stresses, Von mises stresses, total deflection occurred during working condition are evaluated. The parameters used for the simulation are operating gas pressure and material properties of piston.

keywords: Computer CAD, CAE, Optimization, FEA.

1. Introduction

CAE analysis tools offer the tremendous advantage of enabling designers to consider virtually any modling option without incurring the expensive actual manufacturing of the machine component and machine time associated to make machine component. The ability to try new designs or concepts on the computer gives the opportunity to eliminate problems before beginning production. Additionally, designers can quickly and easily determine the sensitivity of specific molding parameters on the quality and production of the final part.

The complex parts can be simulated easily by CAE tool. In this article case study is demonstrated with the help of piston design by CAE tool. Engine pistons are one of the most complex components among all automotive or other industry field components. There are significant research works proposing, for engine pistons designs, new geometries, materials and manufacturing techniques, and this evolution has undergone with a continuous improvement over the last decades and required thorough examination of the smallest details. The piston damage mechanisms have different origins and are mainly wear, temperature, and fatigue related. Among the fatigue damages, thermal fatigue and mechanical fatigue, either at room or at high temperature, play a prominent role. [2]

2. CAE Procedure

2.1 Conventional Approach

In conventional approach conception ideas are converted into sketches or engineering drawing. With the help of this drawings the prototypes i.e. product which looks same as that of final product are made. It is launched in the market after testing of prototype which gives acceptable results. The thing is, product is launched after doing many practical testing and many trial and error procedures which consumes more time and cost too[1]. Figure 1 depicts the flow process adopted for conventional design approach.

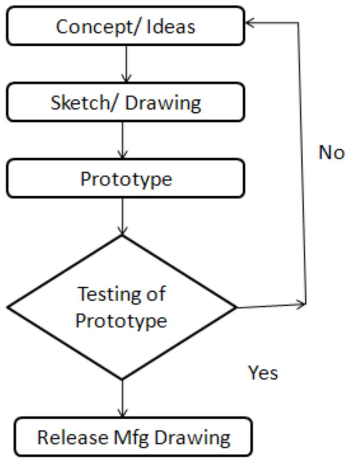

Figure 1: Conventional Approach

2.2 CAE Approach

In CAE approach some steps are same as that of conventional method. Here also ideas, concepts are converted into engineering drawing, but it is then modelled on computer. Geometric model of product is made by the use of solid work software like CAD which enables better visualization of simple as well as complex models.

These models then further used for computerized analysis by using different CAE tools (FEA software's) depending upon the application before the prototype is been made to check whether the components is going to work according to its intended function. After that once appropriate results are obtained the final practical testing is carried out [1]. Figure 2 show the CAE approach for design a machine component.

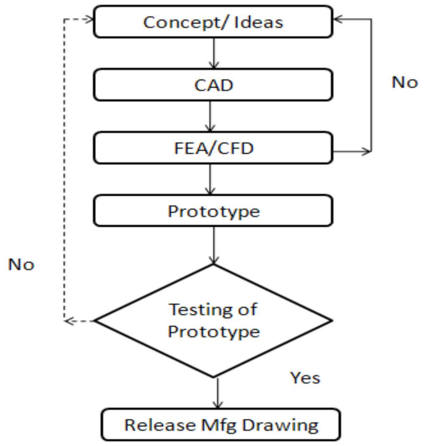

Figure 2: CAE Approach

3. Finite Element Analysis (FEA)

FEA tool is the mathematical idealization of real system. It is a computer based method that breaks geometry into element and links a series of equation to each, which are then solved simultaneously to evaluate the behaviour of the entire system. It is useful for problem with complicated geometry, loading, and material properties where exact analytical solution are difficult to obtain. Most often used for structural, thermal, fluid analysis, but widely applicable for other type of analysis and simulation.

4. Methodology of Piston Analysis

The Piston during the working condition exposed to the high gas pressure and high temperature gas because of combustion. At the same time it is supported by the small end of the connecting rod with the help of piston pin (Gudgeon pin). So the methodology for analyzing the piston is considered as; the gas pressure given 20 Mpa is applied uniformly over top surface of piston (crown) and arrested all degrees of freedom for nodes at upper half of piston pin boss in which piston pin is going to fix. Considering the type of fit between piston pin and piston is clearance fit, only the upper half of piston pin boss is considered to be fixing during the analysis.[7]

4.1 Material Properties of Piston:-

Material of Piston Table 1: - Aluminum alloy 201.0 Structural Properties of Aluminum Alloy

Material	Young's Modulus E (Mpa)	Poisson's Ratio μ	Density (ρ) kg/m3	Coefficient of thermal Expansion A (/ k)	Thermal Conductivity K (W/m k)	specific heat, J/KG *k
Al Alloy	69e3	0.33	2710	1.80E-05	171	890

Table 2:- Chemical Composition of Aluminum Alloy:

Material	Al	Cu	Mg	Si	Zn	Fe	Ni
Al Alloy	Balanced	4-5	0.30	17	1.5	1.3	0.2

Material of Piston Table 3: - Aluminum alloy A390-T5 Structural Properties of Aluminum Alloy:

Material	Young's Modulus E (Mpa)	Poisson's Ratio µ	Density (ρ) kg/m3	Coefficient of thermal Expansion A (/ k)	Thermal Conductivity K (W/m k)	specific heat, c J/KG *C
Al Alloy	70e3 Mpa	0.33	2710	23e-6	234	963

Table 4: Chemical Composition of Aluminum Alloy:

Material	Al	Cu	Mg	Si	Zn	Fe	Ni
Al Alloy	90.7-94.7	3.8-4.9	1.2-1.8	Max 0.5	Max0.25	Max 0.5	0.2

4.2 Geometry:

The below image shows the geometry of piston imported into the simulation software for Analysis. Before going to import a geometrical model of piston which can be prepared by modelling software's like Solid Work, the geometrical modelling can also done in the analysis software's like ANSYS. Figure 3 show the piston created by CAD software for further analysis.

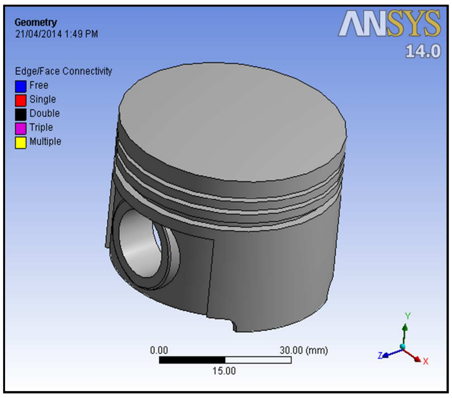

Figure 3. Geometry of piston

4.3 Finite Element Model:

The element selected for meshing the piston model is solid187 tetrahedron type of element which is higher order tetrahedral element. The mesh count for the model contains 71910 numbers of nodes and 41587 numbers of elements. Figure 4 shows the meshed model of piston.

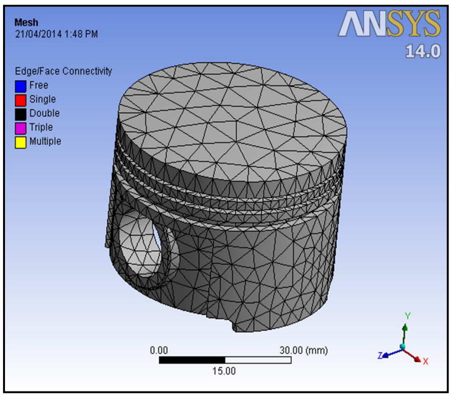

Figure 4. Meshed model of piston

4.4 Loading & Boundary Conditions:

Figure 5 shows the loading and boundary conditions considered for the analysis. The uniform pressure of 20 Mpa is applied on crown of piston which is indicated by red colour and the model is constrained on upper half of piston pin hole as shown by violet colour.

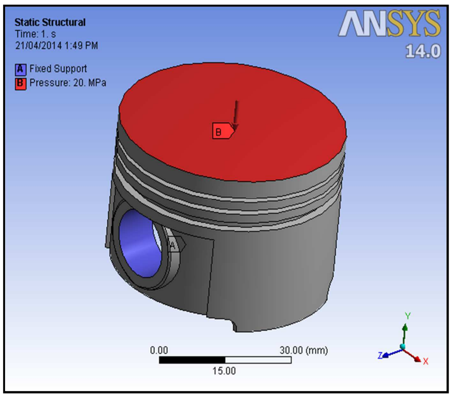

Figure 5. Loading & Boundary Conditions on piston

Bajaj pulsar Two wheeler Piston structural analysis Result with Aluminium A390-T5 material:-

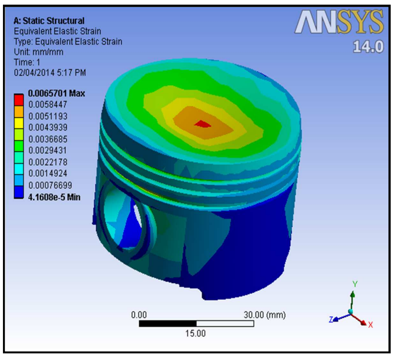

Figure 6. Equivalent Elastic Strain

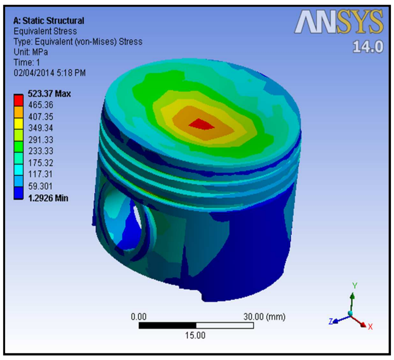

Figure 7. Equivalent Stress

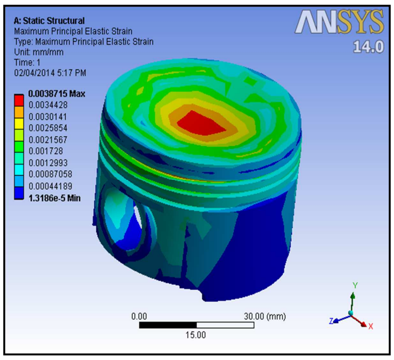

Figure 8. Max Principal Elastic Strain

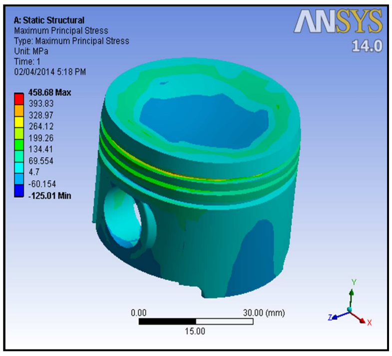

Figure 9. Max Principal Stress

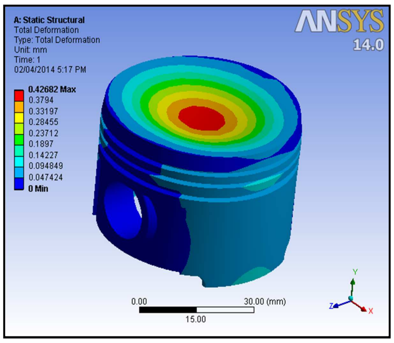

Figure 10. Total Deformation

Bajaj pulsar Two wheeler Piston structural analysis Result with Aluminium alloy 201.0 material:-

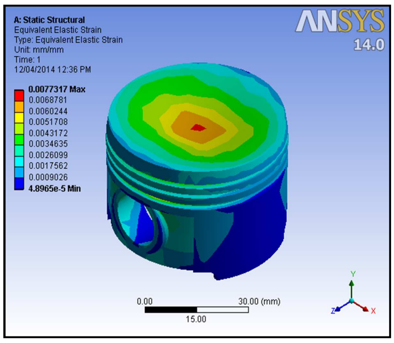

Figure 11. Equivalent Elastic Strain

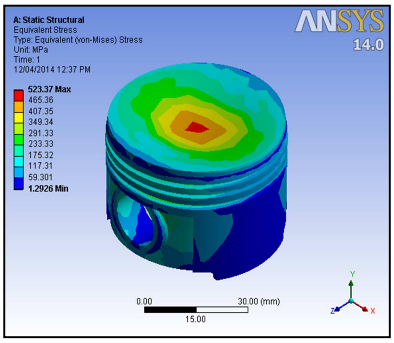

Figure 12. Equivalent Stress

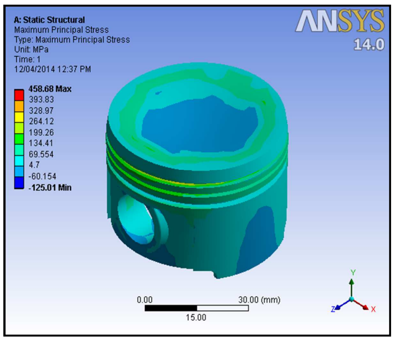

Figure 13. Max Principal Elastic Strain

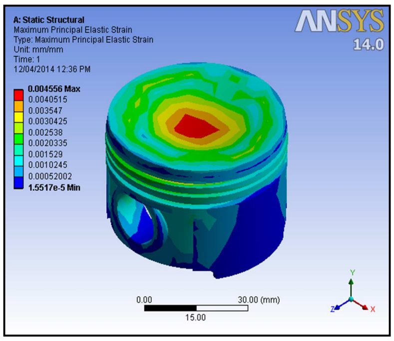

Figure 14. Max Principal Stress

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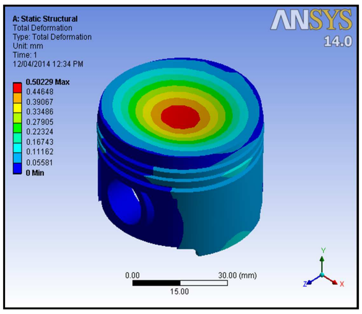

Figure 15. Total Deformation

5. FINAL RESULTS:-

Table 5 shows the FEA results for each piston made of different materials and the differences that occur between them:-

Table 5: Results of FEA of the Aluminium A390-T5 piston and Aluminium alloy 201.0 piston.

	Analysis Result	A390-T5	A 201.0
1	Equivalent (von mises)Stress	523.37	523.37
2	Maximum Principal Elastic strain	0.0038715	0.004556
3	Maximum Principal stress	458.68	458.68
4	Total Deformation	0.42682	0.50229
5	Equivalent Elastic strain	0.00657	0.0077317

6. CONCLUSIONS:-

The results show that despite of the aluminium alloy A390-T5 piston having larger directional deformations than Aluminium alloy 201.0 piston.

So with these results the best choice for the material for our application is the Aluminium A390-T5 alloy.

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