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Optimization in Piston Design for High-speed Engine

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Abstract - *The population of the world, the change in technologies and the urban jungles are increasing drastically day-by-day which made the rise of demands of humans in many ways. Due to this many complexities are being faced by the industries, consumer services, local people, etc., in the way of transportations by investing more time in transportation only. In the near future, by 2050 the population of the world estimated to increase from 7 billion to 12 billion. In that case, the present day's automobiles will not be sufficient since they travel at very low speeds. As a result, the world will be investing more time in the way of transporting or delivering the goods, local transportation, etc., then investing time any other if there isn't any growth in the way of transportation. This made the emergency in the development of the high-speed engines. This paper aims at developing an optimized piston design which can be used in some high-speed internal combustion engines which can withstand high temperatures and pressures. The piston and its components are designed using the advanced material, Ti-6Al-4V. The modeling of the high-speed diesel engine and its components is done Autodesk Fusion 360. The designs are analyzed in Autodesk Fusion 360.*

Key Words: Autodesk Fusion 360, Piston, Connecting Rod, Ti-6Al-4V

1.INTRODUCTION

Pistons play a major role in internal and external combustion engines from the early ages in transferring and converting the energy of the fuel formed due to combustion to the reciprocation motion in reciprocating engines and rotary motion in rotary engines.

In both compression ignition automobile engines and spark ignition automobile engines, the piston located in the combustion chamber experiences a large exposure to high pressure and high temperatures. The connecting rod which connects the piston to the crankshaft of the engine and the pins and rings that connect the connecting rod to the piston and connecting the rod to crankshaft will also experience the effects of combustion of fuel in the combustion chamber.

The present paper aims at developing an optimized piston design which can be used in some high-speed internal combustion engines which can withstand high temperatures and pressures. The piston and its components are designed using the advanced material, Ti-6Al-4V. The designs are tested at high temperatures and pressures which are the assumed optimal working conditions in a high-speed engine and reflected the same environment.

In Autodesk Fusion 360 the design process of the high-speed piston and its components are designed. The high-speed piston and its components are assembled in Autodesk Fusion 360 Assembly. The modeled high-speed piston and its components are analyzed in Autodesk Fusion 360 Simulation

The design process of the high-speed piston and its components and the analysis process of the high-speed piston and its components using the advanced material, Ti-6Al-4V are detailed. Results such as Von Mises stress, Factor of Safety (FOS), Strain and Displacements, etc., are also discussed.

2. GOVERNING THEORY

The strategy utilized as a part of the geometric simulations of design in Solidworks Simulation is the Finite Element Analysis (FEA). Finite Element Analysis utilized as a part of simulation software or solvers, for the most part, includes three stages. They are as per the following:

A. Pre-processing: In this progression, the finite element mesh for the designed model is produced and boundary conditions, material properties, and loads are applied to the composed model.

B. Solution: In this progression, the solutions for the problems for the given loads and boundary conditions. The outcomes, for example, Von Mises stress, displacements, strain, thermal impacts, and so on., are acquired in this progression.

C. *Post-processing:* In this progression, the results are pictured as contours, deformed shapes, and plots. This progression helps in the investigating, confirmation and approval of results.

3. MATERIAL PROPERTIES

The advanced material, Ti-6Al-4V which is used in the study of the high-speed piston has the following material properties which are represented as Table1.

Table -1:

Properties	Alloy 1.2367
Density	4.43E-06 kg / mm³
Young's Modulus	113763 MPa
Poisson's Ratio	0.35
Yield Strength	882.5 MPa
Ultimate Tensile Strength	1034 MPa
Thermal Conductivity	0.0067 W / (mm C)
Thermal Expansion Coefficient	8.6E-06 / C
Specific Heat	526.3 J / (kg C)

4. METHODOLOGY

In Autodesk Fusion 360 the design process of the high-speed piston and its components are designed. The high-speed piston and its components are assembled in Autodesk Fusion 360 Assembly. The modeled high-speed piston and its components are analyzed in Autodesk Fusion 360 Simulation.

4.1 Piston and Its Components

The high-speed piston and its components are designed in Autodesk Fusion 360 Design. Figure 1 shows the isometric view of the high-speed piston and its components.

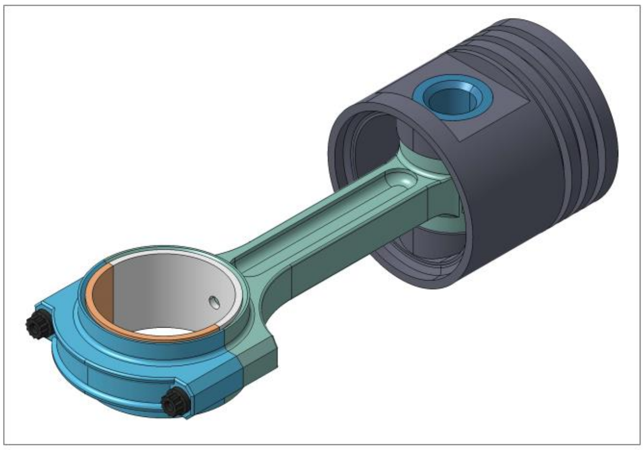

Fig -1: Piston and Its Components Isometric View

The high-speed piston and its components are shown in exploded view in Figure 2.

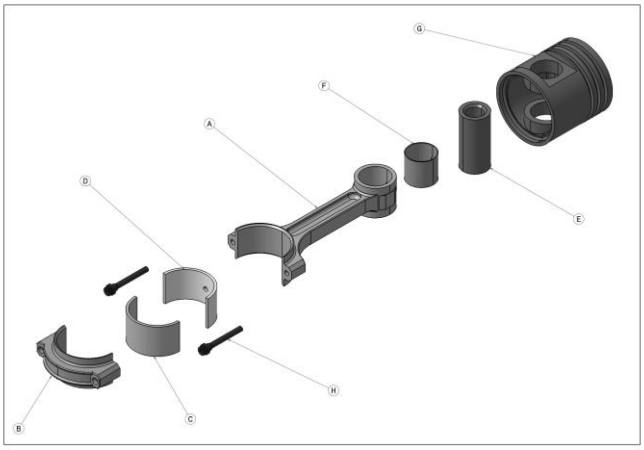

Fig -2: Piston and Its Components Exploded View

4.2 Models Meshing Details

Table 2 shows the general mesh settings and adaptive mesh refinement techniques used in the simulation of the high-speed piston and its components.

Table -2:

Average Element Size Solids	2
Element Order	Parabolic
Max. Turn Angle on Curves (Deg.)	60
Max. Adjacent Mesh Size Ratio	1.5
Max. Aspect Ratio	10
Minimum Element Size (% of average size)	20
Results Convergence Tolerance (%)	20
Portion of Elements to Refine (%)	10
Results for Baseline Accuracy	Von Mises Stress
Mesh Type	Solid
Nodes	248273
Elements	149853

The high-speed piston and its components meshing are shown in isometric view in Figure 3.

Fig -3: Piston and Its Components Mesh Isometric View

5. RESULTS AND DISCUSSIONS

The simulation studies conducted on the high- speed piston and its components using the advanced material, Ti-6Al-4V for its sustainability against high temperatures and pressures gives the results such as Von Mises stress, Factor of Safety (FOS), Strain and Displacements. The test conditions and the results are as follows:

5.1 Test Conditions

In this study conducted on the high- speed piston and its components using the advanced material, Ti-6Al-4V, the applied load value, and connector constraints in the load cases are shown in Table 3.

Table -3:

Constraints	Pins
Loads	
Type	Gravity
Magnitude	9.807 m / s²
X Value	9.807 m / s²
Y Value	-1.389E-16 m / s²
Z Value	1.007E-15 m / s²
Temperature	
Type	Applied Temperature
Value	600 C
Pressure	
Type	Pressure
Magnitude	10 MPa

5.2 Results

The results obtained after the simulation of high- speed piston and its components using the advanced material, Ti-6Al-4V in Autodesk Fusion 360 Simulation are shown in Table 4.

Table -4:

Name	Minimum	Maximum
Safety Factor		
Per Body	0.4608	15
Stress		
Von Mises	0.2143 MPa	1915 MPa
1st Principal	-591.9 MPa	1814 MPa
3rd Principal	-2097 MPa	1111 MPa
Normal XX	-1251 MPa	1297 MPa
Normal YY	-1278 MPa	1489 MPa
Normal ZZ	-1373 MPa	1437 MPa
Shear XY	-685.1 MPa	660.1 MPa
Shear YZ	-745.3 MPa	744.2 MPa
Shear ZX	-934.2 MPa	751.7 MPa
Displacement		
Total	0 mm	0.7873 mm
X	-0.763 mm	0.1313 mm
Y	-0.2374 mm	0.241 mm
Z	-0.2427 mm	0.215 mm
Reaction Force		
Total	0 N	2777 N
X	-1544 N	1503 N
Y	-1483 N	1408 N
Z	-2111 N	2208 N
Strain		
Equivalent	0.001411	0.02713
1st Principal	-1.168E-04	0.02558
3rd Principal	-0.02345	0.005054
Normal XX	-0.009492	0.0155
Normal YY	-0.01013	0.01447
Normal ZZ	-0.005186	0.01061
Shear XY	-0.01626	0.01567
Shear YZ	-0.01769	0.01766
Shear ZX	-0.02217	0.01784
Contact Pressure		
Total	0 MPa	955.2 MPa
X	-922.5 MPa	920.1 MPa
Y	-639.8 MPa	610 MPa
Z	-661.7 MPa	943.3 MPa
Temperature		
Temperature	599.9 C	600 C
Heat Flux		
Total	3.365E-11 W / mm²	1.433E-04 W / mm²

X	-8.163E-05 W / mm^2	1.059E-04 W / mm^2
Y	-3.554E-05 W / mm^2	1.013E-04 W / mm^2
Z	-1.013E-04 W / mm^2	4.088E-05 W / mm^2

Reaction Forces

Constraint Name	Reaction Force		Reaction Moment	
	Magnitude	Component (X,Y,Z)	Magnitude	Component (X,Y,Z)
Pin1	214921 N	214921 N	108273 N mm	-95781 N mm
		376.5 N		3546 N mm
		-390 N		-50364 N mm
Pin2	272966 N	-272965 N	70302 N mm	-30568 N mm
		-378.2 N		9094 N mm
		390 N		62652 N mm

5.3 Surface Plots

The results are shown on the surface of the high- speed piston and its components which is called surface plots or contours.

Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10 and Figure 11 represents the surface plots on the high- speed piston and its components.

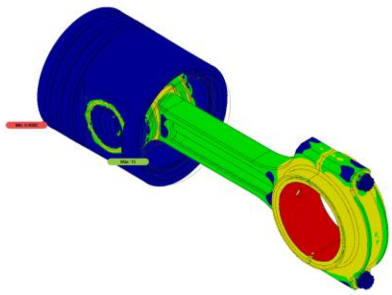

Fig -4: Factor of Safety

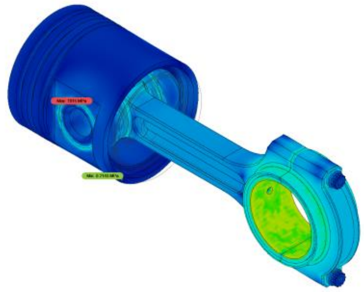

Fig -5: Von Mises Stress

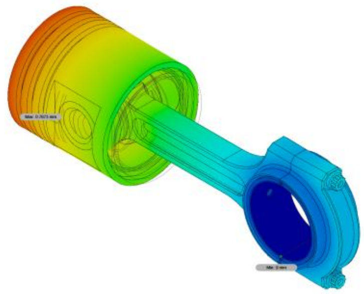

Fig -6: Displacement

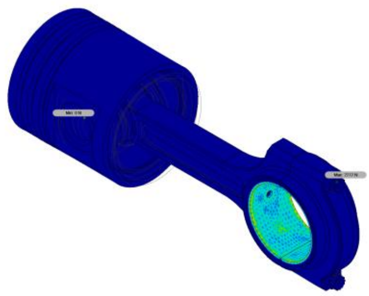

Fig -7: Reaction Force

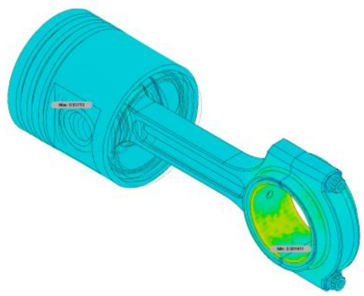

Fig -8: Strain

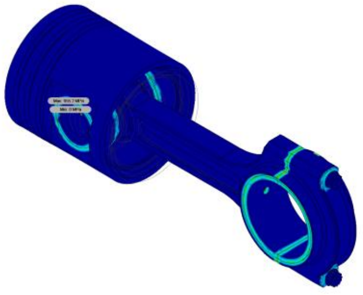

Fig -9: Contact Pressure

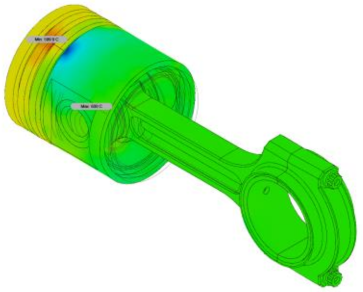

Fig -10: Temperature

Fig -11: Heat Flux

5.5 Interpretation of Results

From the results of the simulations studies conducted on the high- speed piston and its components, it can be observed the design is considered to be successful.

6. CONCLUSIONS

The high- speed piston and its components modeled are successful since the values factor of safety are higher than 3 in all components. From this study, we conclude that the optimization in piston design for high-speed engines is done by designing high- speed piston and its components using the advanced material, Ti-6Al-4V.

Suggestions: The skirt used on piston has a value of 0.4 which means it will wear after some period of operations but not more frequently. This skirt should be replaced when it wears.

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