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Application of CAE Processes

ACHA6010

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1 Introduction

Computer-aided engineering (CAE) plays a significant role in enhancing the design process within mechanical engineering by incorporating advanced simulation and modelling techniques. CAE involves tools like finite element analysis (FEA), which allows engineers to simulate and evaluate the behaviour of components under various physical conditions. One significant benefit of FEA is its ability to be implemented early in the design phase, enabling engineers to assess how tolerances and design choices impact the functionality, performance, and quality of mechanical assemblies. This leads to optimized designs, reduced manufacturing costs, and significant time savings (Thilak, Jayaprakash, and Sivakumar, 2014).

In industries such as automotive, aerospace and energy, CAE is instrumental in enhancing risk assessment in mechanical design by firstly identifying any potential failure modes early in the design process. The Physics of Failure (PoF) analysis is a widely used model which allows engineers to simulate various failure modes such as fatigue, fracture, wear, and corrosion, thereby enabling a deeper understanding of the physical process that led to the component failure (Chary et al., 2012).

This report will take a comprehensive look into the CAE process by analysing and optimising an engine piston, a critical component in internal combustion engines. Using the CAE process and making changes based on simulation results. Initially modelled in SolidWorks and further analysed in Ansys Workbench, this report will cover various simulation techniques including rigid dynamics, steady-state thermal and static structural analyses to emulate realistic operating conditions. These results will be assessed for their accuracy and realism, identifying any limitations in the current process and proposing improvements to enhance the simulation's fidelity and achieve better results in future iterations.

2 Methodology

This section outlines the comprehensive methodologies employed to model, simulate, and analyse the assembly of engine components using simulation methods. The objective is to set up consistent simulations using continuity with constraints to capture the dynamic interactions and performance under operational stresses, ensuring the assembly's realism and functional viability. Software includes SolidWorks for modelling and Ansys Workbench for simulation.

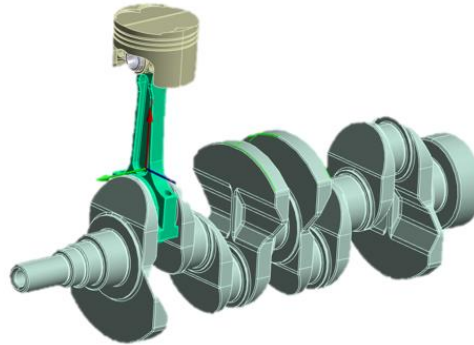


Figure 1 - Assembly in Ansys

2.1 Modelling and Assembly

2.1.1 SolidWorks

The Assembly, comprising of a crankshaft, connecting rod, gudgeon pin and piston, was a premade SolidWorks model. The decision to do all modifications to the piston in SolidWorks and then export them into Ansys. Making sure to use step files prior to exporting the parts and assembly.

2.1.2 Ansys Workbench

Once the assembly is imported into Ansys, the first thing was to do was rebuild the connections in the assembly. The assembly was configured with revolute joints to represent the mechanic connections where the components will interact.

Secondly, a dynamic force was applied to replicate the rotational motion of the crankshaft. To accurately model the way the piston would behave within a cylinder, a general joint was implemented, restricting the pistons movements exclusively to the Z axis. This setup mimics the linear motion of a piston in the cylinder during engine operation.

2.1.3 Ansys Granta

Using Granta to streamline the materials selection process, this reduces dependency on manual data entry and potential for user input error. Granta offers a comprehensive database which can enhance the consistency and reliability of the simulation results. However, there is limitations posed by relying on an existing database, limiting potential exploration in new or rarer materials if they are not catalogued.

2.2 Kinematic Simulation and Structural Analysis

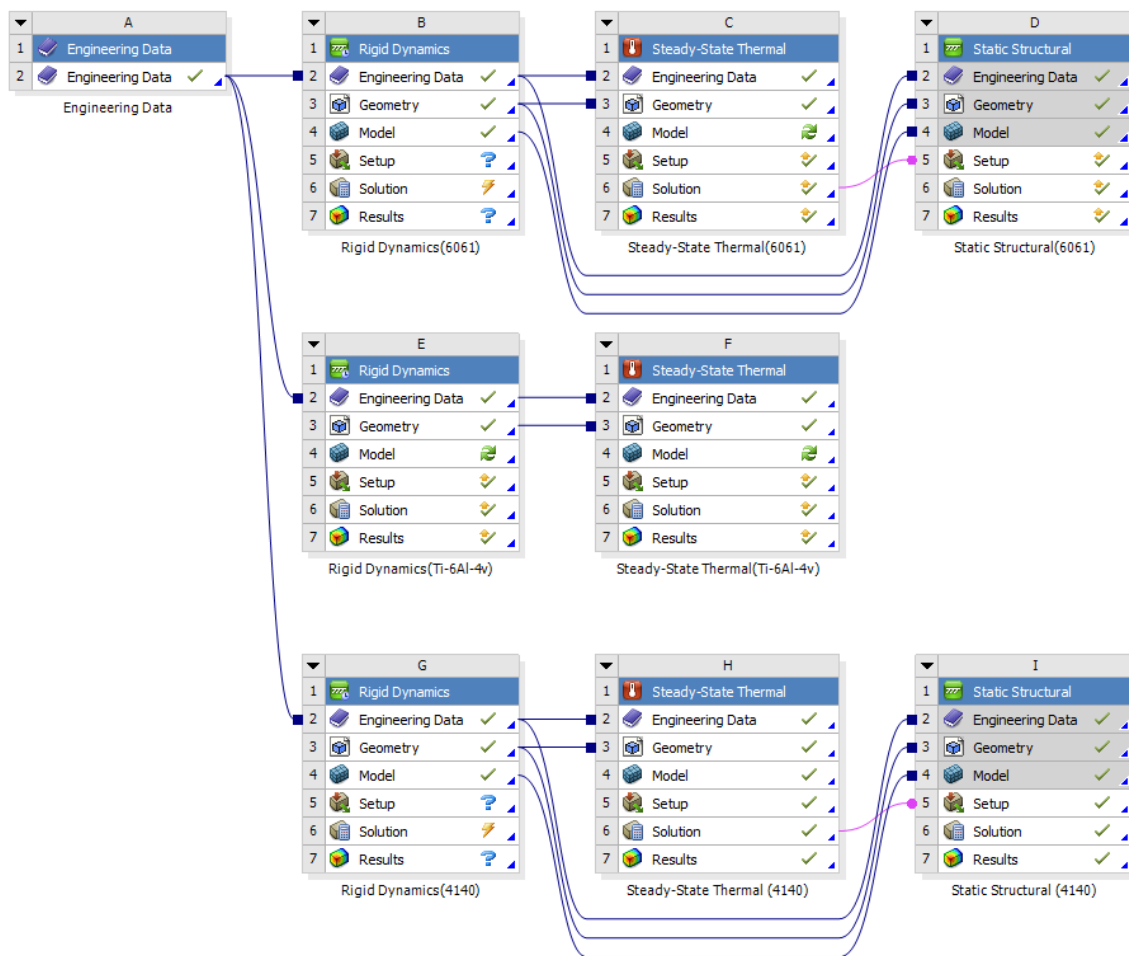


Figure 2 – Ansys Workflow

ANSYS Workbench was utilised to conduct a comprehensive dynamic simulation analysis of the piston, from user input, replicating realistic operational conditions, including kinematic forces, pressure and thermal loads. The interface allows the integration of various simulation methods simultaneously, enhancing the accuracy of the results.

This analysis workflow begins with a rigid dynamics simulation to determine the forces acting on the piston. Relevant timesteps are then captured and imported into the static structural analysis, further assessing the piston's response. Before finalising the static analysis, thermal factors are considered to accurately represent the material's behaviour. This sequential approach ensures the results incorporate realistic thermal effects, thereby improving the precision of the study.

2.3 Constraints

To ensure the simulation reflect real-world conditions as accurately as possible, several constraints were applied consistently. These are critical for maintain continuity and reliability of the studies.

2.3.1 Mesh Sizes

A standard mesh of 0.4mm was used for the main body of the piston. As the crown of the piston is subject to higher mechanical and thermal loads, a smaller mesh of 0.2mm was applied to capture more detail.

2.3.2 Forces and Kinematic Conditions

2.3.2.1 Maximum Pressure

A maximum pressure of 84.82 Bar (Vine, 2024), this was the peak pressure taken from Triumph 765 engine data.

2.3.2.2 Piston Forces

During the rigid dynamics section, the maximum forces were taken, this would then be imported into the static structural section. These forces would vary between materials due to weight and density.

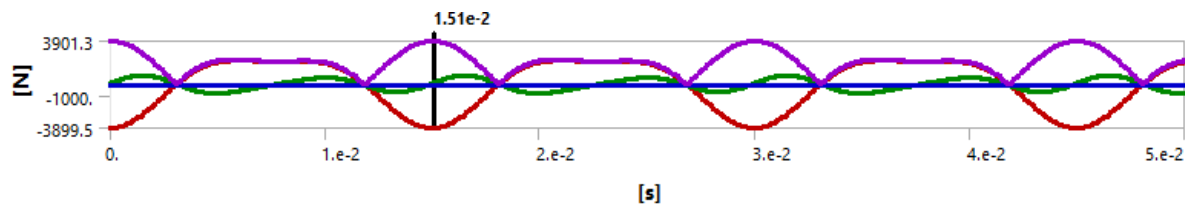


Figure 3 - Rigid Dynamics, Simulating Piston Forces

2.4 Boundary and Initial Conditions

2.4.1 Fixed Position or Weak Springs

While the Weak Springs function can stabilise the model without overly constraining the system, computing power had to be considered and the decision to use a fixed position was more suitable. Acting where the gudgeon pin would be. This fixed position meant more studies could be run in the given time frame.

2.4.2 Thermal Considerations

Thermal Study Boundary Conditions										
	Heat Transfer Coefficient					Temperature (Celcius)				
	1	2	3	4	Average	1	2	3	4	Average
Crown	600	350	500	540	497.5		928.5			928.5
Crown Side	500	540	350	400	447.5	250	650	500	300	425
Top Groove	300	650	200	600	437.5	180	150	180	250	190
Middle Groove	300	650	200	600	437.5	180	150	180	250	190
Oil Groove	260	520	175	400	338.75	165	150	170	170	163.75
Underside	1500	750	250	200	675	95	90	90	90	91.25
Skirt	1000	400	150	300	462.5	110	110	120	90	107.5

Structural Study Boundary Conditions			
	Pressure	Inertia	Side
Max P	10537060	11371.29	7440.469
Max I	304222.2	18089.83	-1.10E-12
Max S	8907806	6954.198	8707.43

6061-T6 Aluminium Material Properties			
Temp (°C)	Young's Modulus		Poisson's Ratio
	Value	Unit	0.33
22	67	Gpa	Coefficient Thermal Expansion 22°C
100	70	Gpa	
150	68	Gpa	Thermal Conductivity
200	64	Gpa	
250	56	Gpa	Specific Heat Capacity
300	48	Gpa	
350	41	Gpa	0.896 J/g-°C
400	32	Gpa	
450	21	Gpa	
500	12	Gpa	

Figure 4 – Results of a Piston Thermal Study (Noble, 2024)

To accurately simulate the thermal behaviour of something which has a complex environment such as a piston, there is a need for quite a lot of information prior to starting. This example benefited from a detailed thermal study as seen in *figure 4* enhancing the simulation by being able to model thermal stresses more accurately. It must be noted that thermal data is often not readily available for all components, which can pose a significant limitation in simulations. The lack of specific thermal data can lead to inaccuracies which would affect the reliability of a design.

3 Validation

Validation plays a crucial role in both simulations and experiments, ensuring that the simulations accurately reflect real-world conditions. This process is essential for confirming the reliability of the Ansys Workbench in this study, thereby giving confidence in the design modifications carried out after. By comparing the simulation results with established benchmarks, the project reduces risks and enhances the efficiency of engine components. This validation process not only confirms the effectiveness of theoretical models but also facilitates their practical application, ensuring that the designs perform as expected when applied.

3.1 Test Cases

3.1.1 Cantilever Beam (Uniform Distributed Load)

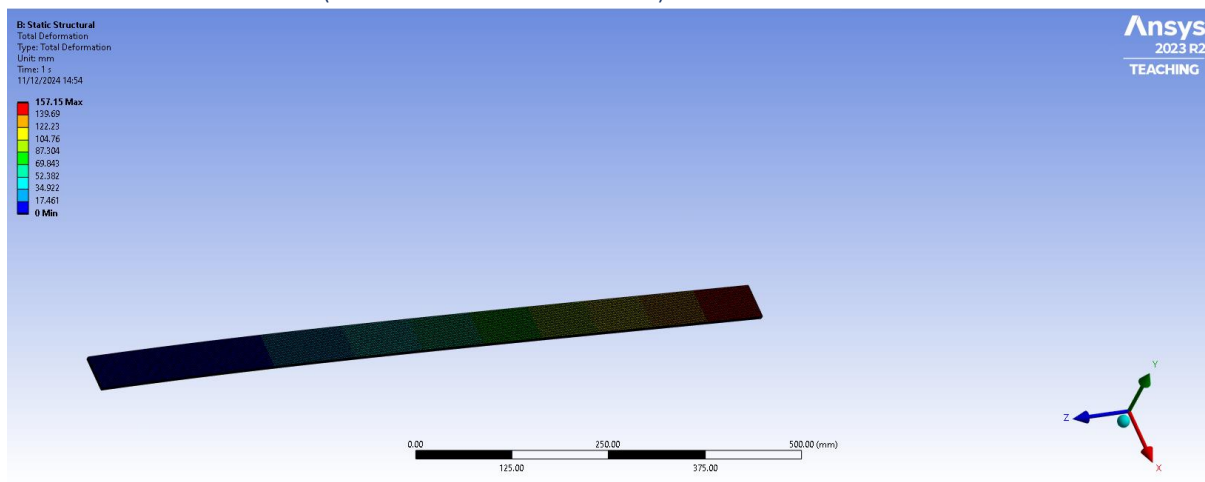


Figure 5 - Universally Distributed Load Validation in Ansys

Firstly, looking at a case study of a universally distributed load (UDL), replicating the setup described in the verification example provided by Dlubal Software (2018). The deformation expected was 157.143mm and the result was 157.15mm.

3.1.2 Bimetallic Strip

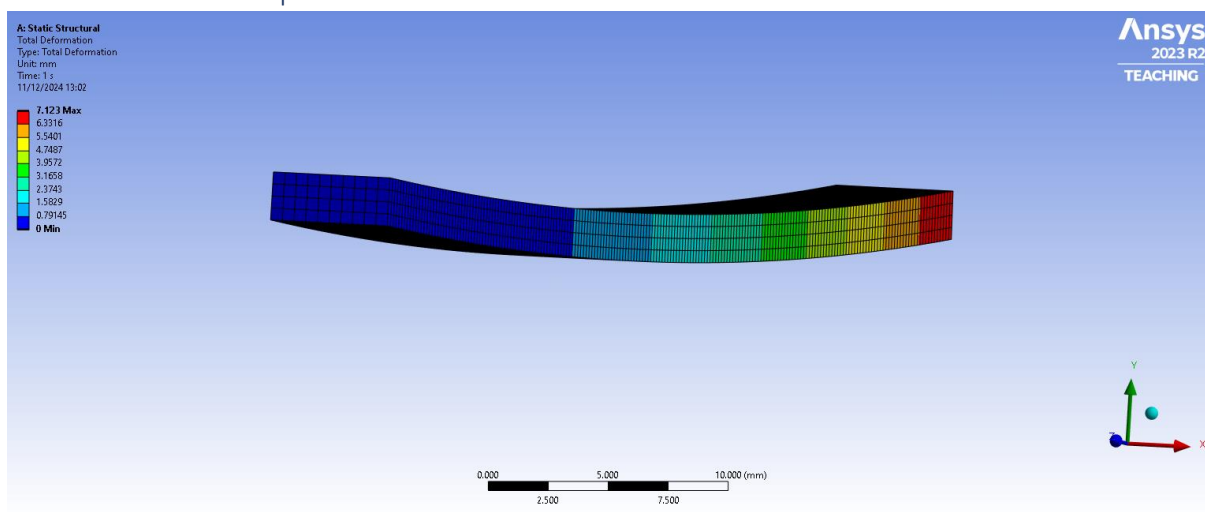


Figure 6 - Bimetallic Validation Example Ansys

Secondly, a bimetallic strip made consisting of copper and invar. The expected maximum deflection at a thermal load of 100°C, from an ambient temperature of 22°C, is 7.049 mm (Dlubal, 2018). The

outcome achieved was 7.123mm, showing an accuracy of 98.96% when compared to the target deflection.

The slight discrepancy observed can be attributed to mesh size underscoring the importance of precise setup and parameter control in finite element simulations.

This validation exercise confirms the robustness and accuracy of our simulation framework.

3.2 Mesh Independence Study

Mesh sizes in CAE can have a significant impact on the accuracy and efficiency of simulations. A well mapped mesh does have the ability to improve the preciseness of results, particularly in areas with complex geometry or high stress concentration (Cuillere & Francois, 2017).

Although, the influence of meshing accuracy does not always correlate with improved results, particularly in low-frequency model analysis. Thus, challenging the assumption that smaller mesh sizes inherently lead to higher calculation precision (Xie et al., 2018).

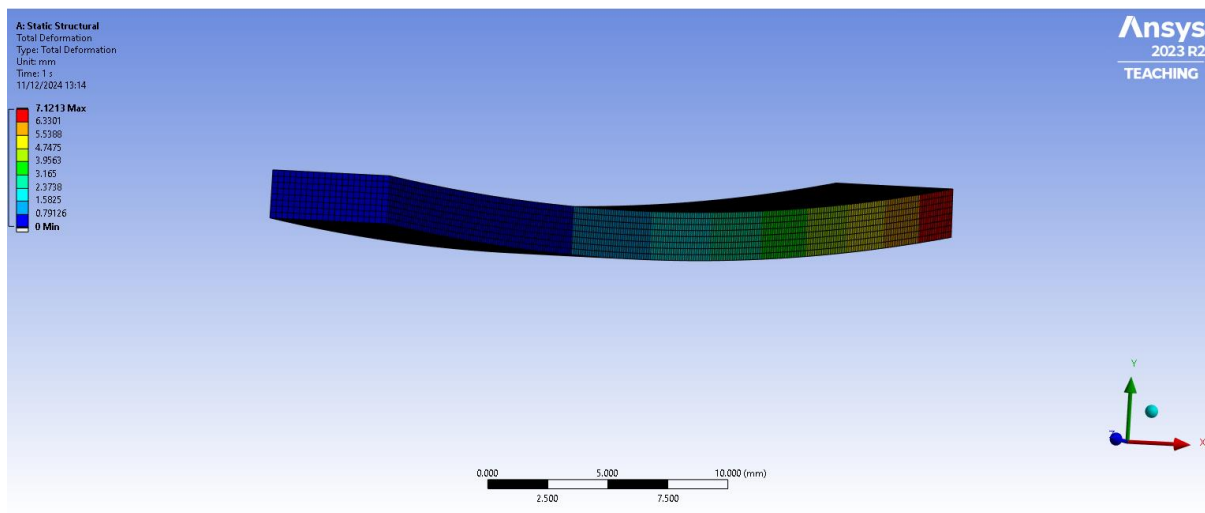


Figure 7 - Bimetallic Strip 0.25mm Mesh

In conclusion, the size and quality of the mesh in ANSYS IS vital for achieving accurate results and optimising computational efficiency. Using the Bimetallic Strip validation as an example, using a finer mesh example of 0.25mm (Figure 7) and then 0.1mm compared with the original 0.5mm. The results then showed a more accurate result of 7.1203mm, increase the accuracy marginally to 98.99%.

3.3 Boundary Conditions Influence

The accuracy of boundary conditions is vital to achieving reliable and applicable results. When it comes to simulating boundaries for engines, it comes with a host of complexities. A widely adopted methodology in industry involves using one-dimensional simulations to calculate general parameters for more intricate three-dimensional models. As highlighted by Silva de Lima *et al.* (2022), this approach effectively establishes boundary conditions necessary for three-dimensional modelling. However, its main limitation lies in the oversimplification of flow dynamics, where the flow is assumed to be uniform and unidirectional. In Engines, the flow field is naturally three-dimensional and non-uniform within the cross-section, which can introduce inconsistencies when compared to real-world conditions. Addressing these complexities is key to improving simulation fidelity and ensuring results accurately reflect practical applications.

Boundary condition inaccuracies are not limited to engine simulations, they present challenges across all fields of computational analysis. Whether in fluid dynamics, thermal simulations, or structural analysis, the quality of simulation outputs is tied to the accuracy of the input boundary conditions. The principle "garbage in, garbage out" applies. Imprecise or oversimplified inputs and assumptions can result in unreliable outcomes as they fail to represent real-world behaviour. This issue underlines the need for carefully defined conditions, derived from experimental data, theoretical calculations, or multi-fidelity simulations, to ensure models can capture the complexities of real systems accurately. Failure to do so compromises the reliability and applicability of results (Papadopoulos et al., 2011).

4 Results & Analysis

4.1 Chosen Designs and Material

The decision to do several materials to get a good spread of data and compare how different properties effect the outcome, then proceed with one chosen material and great several design iterations based on the outcome of the simulations. All materials are imported into Workbench from Granta.

4.1.1 6061-T6 Aluminium

The use of this broadly popular aluminium is supported by numerous studies highlighting its mechanical properties, findings indicate that 6061 is lightweight and display good thermal conductivity, an advantage in terms of stress and thermal handling (Reddy et al. 2024). Demonstrating that it can effectively withstand the temperature and mechanical forces a piston should face, thereby enhancing performance and durability.

4.1.2 2618-T6 Aluminium

A popular choice in race environments for its superior fatigue life and high-temperature strength. Its ductility enhances its resistance to cracking under extreme conditions meaning it can tolerate high cylinder temperatures effectively. Notably, 2618 has low silicon content resulting in a higher linear expansion rate, which although can be seen as an advantage, does entail some design changes to allow for piston-to-wall clearance to accommodate thermal expansion (jepistons.com, 2022).

4.1.3 4140 Steel

There have been several studies evaluating 4140 steel being used for pistons, especially in diesel engines. A study by Korivi, Haynes, and Torres (2022) showed 4140 exhibits good, elevated temperature strength although its thermal conductivity is low in comparison to other materials, such as 6061, which also featured in the study. The lower thermal conductivity is likely to show higher operating temperatures, especially in something such as a piston, which may lead to redesign considerations to fully leverage the materials strength advantages.

4.1.4 Ti-6Al-4V Titanium

Ti-6Al-4V, a titanium alloy, is increasingly used in critical engine components like connecting rods and engine valves, notably in motorcycles and high-performance vehicles. This alloy, constituting approximately 8% of the material in high-end motorcycles, preferred for its exceptional strength-to-weight ratio. This characteristic significantly reduces the overall weight of components, enhancing the performance and efficiency of the vehicles (Takebe, Takahashi, and Mori, 2020).

4.1.5 Expected Outcomes in a Simulated Environment

The Ansys simulations should illustrate each of the material properties and characteristics realistically and the results should represent these clearly. Materials with high thermal conductivity are expected to display reduced thermal stresses, indicating efficient heat management. Materials with higher strength-to-weight ratios should maintain structural integrity under high loads by demonstrating minimal deformation.

4.2 Steady-State Thermal

4.2.1 Importance

Steady-state thermal simulation is essential for understanding and optimising thermal performance in various engineering applications. The analysis allows for the determination of temperature distributions within models, which is necessary for ensuring reliability and performance in components. Thermal simulation is key for engine piston due to the harsh thermal environment they

operate in. Thermal simulations can guide the selection of suitable materials and cooling strategies, further enhancing the piston's efficiency and durability under operating conditions.

4.2.2 Results of Steady-State Thermal Simulation

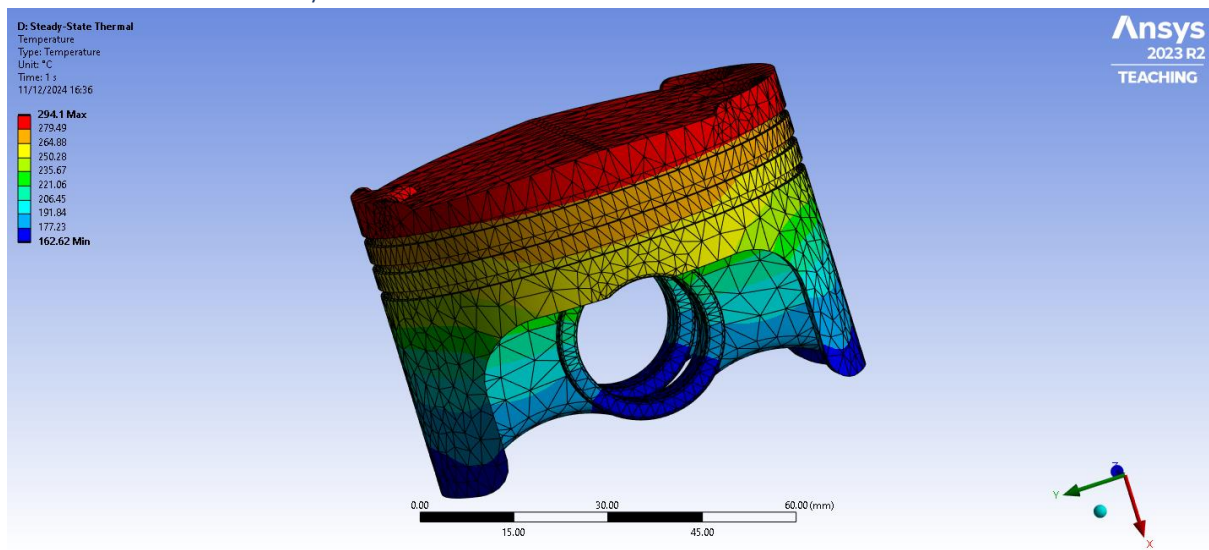


Figure 8 - 6061-T6 Piston A Thermal

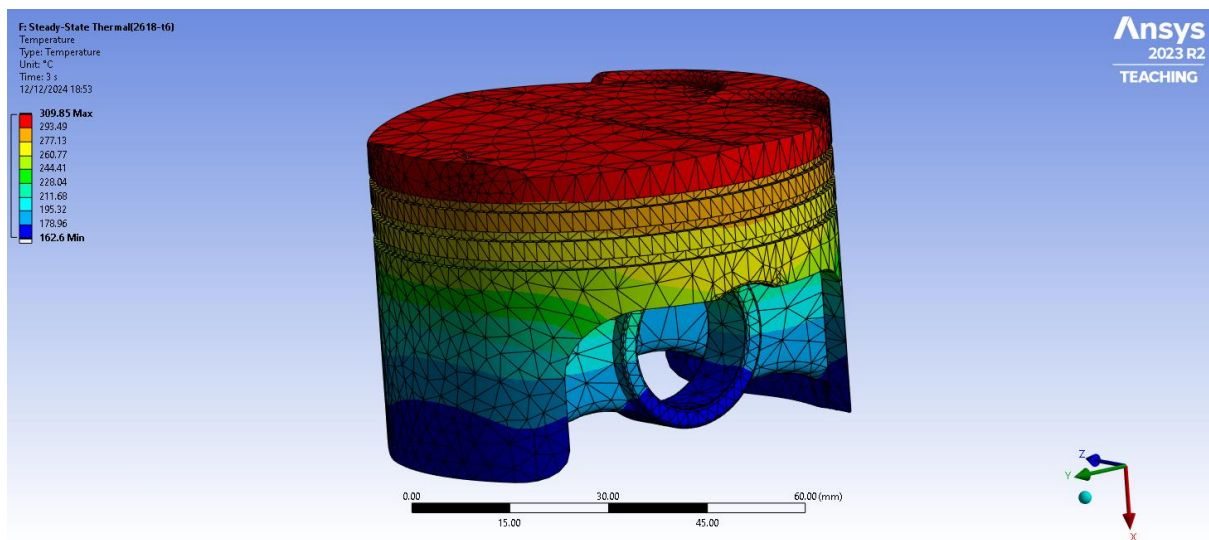


Figure 9 - Temperature 2618-T6

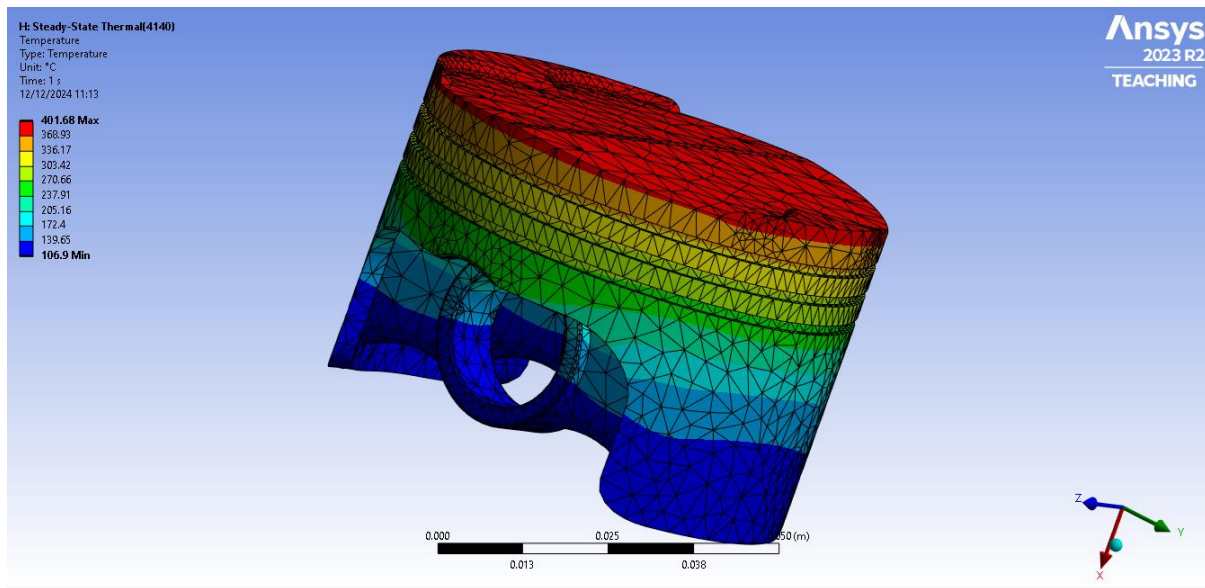


Figure 10 - Temperature 4140

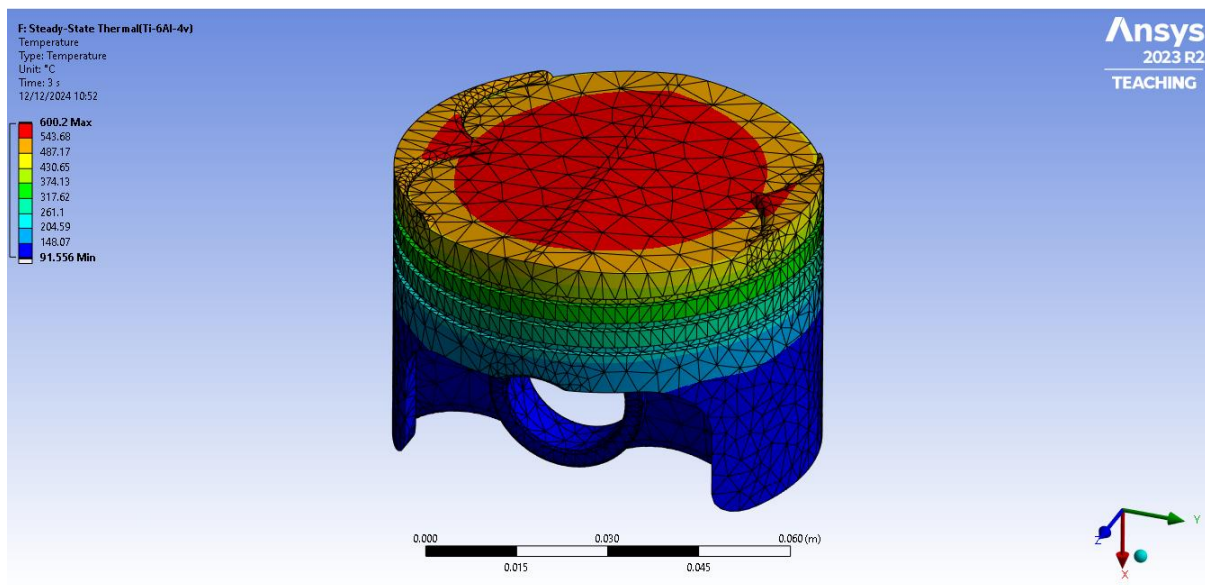


Figure 11 - Temperature Ti-6Al-4v

4.2.3 Thermal Study Findings

Overall, looking at the results in *table 1* the results align with theoretical expectations, with aluminium alloys demonstrating higher thermal performance, while steel and titanium, though stronger materials, highlight challenges in thermal management under steady-state conditions. This supports the importance of selecting materials that strike a balance between thermal and mechanical properties for piston applications.

4.3 Static Structural

4.3.1 Importance

Static structural analysis within the framework of finite element analysis is fundamental in automotive engineering. It is beneficial for the engineers to ensure the safety and performance of vehicle components by predicting stress distribution and fatigue life, guiding design optimisations, and contributing to the overall reliability of automotive systems.

4.3.2 Results

4.3.2.1 6061-T6 Piston A

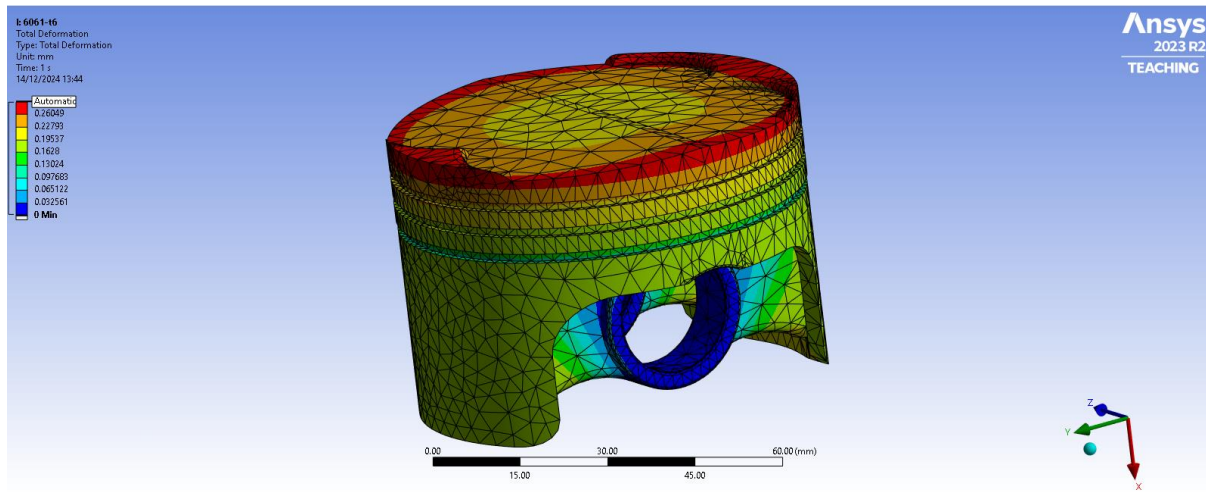


Figure 12 - 6061 Piston A Total Deformation

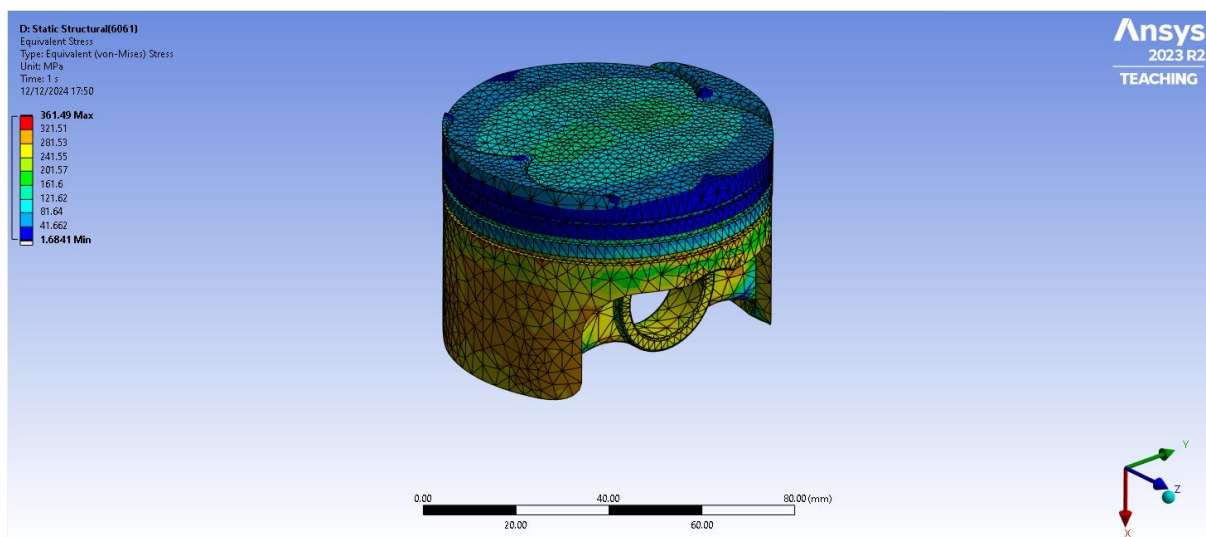


Figure 13 - 6061 Piston A Equivalent Stress

4.3.3 2618-T6 Aluminium

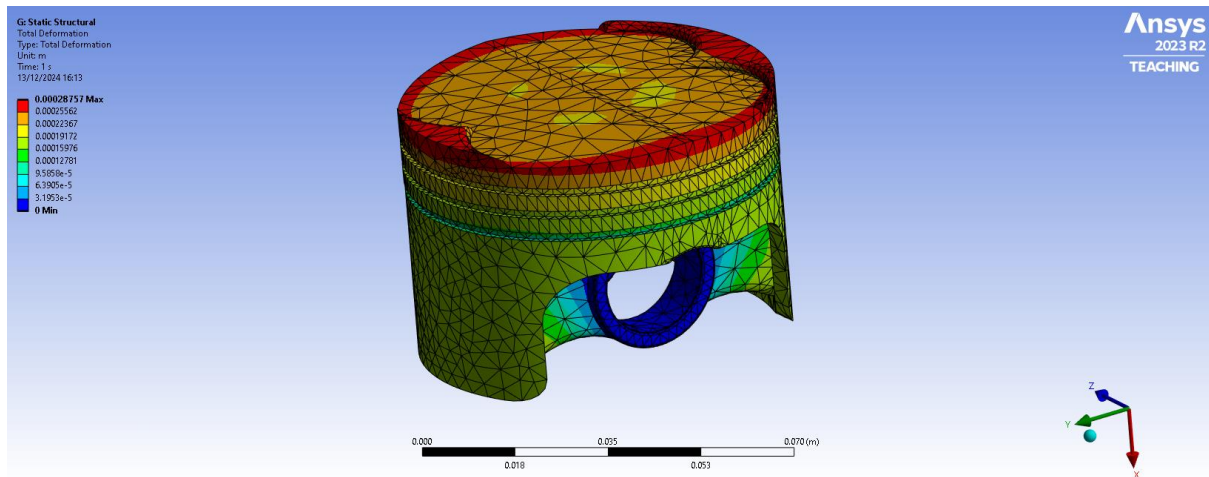


Figure 14 - 2618 Total Deformation

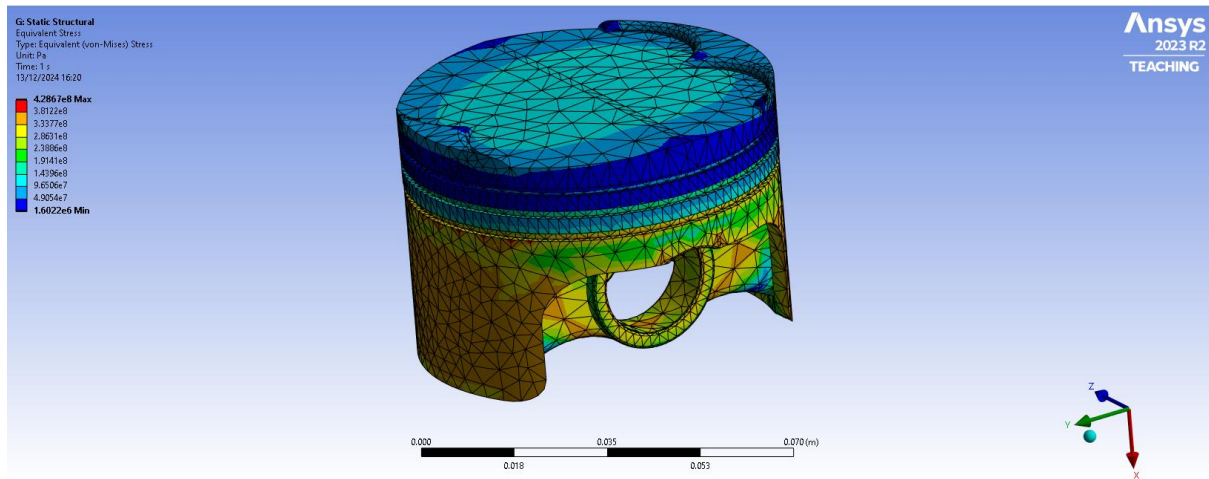


Figure 15 - 2618 Equivalent Stress

4.3.4 4140 Steel

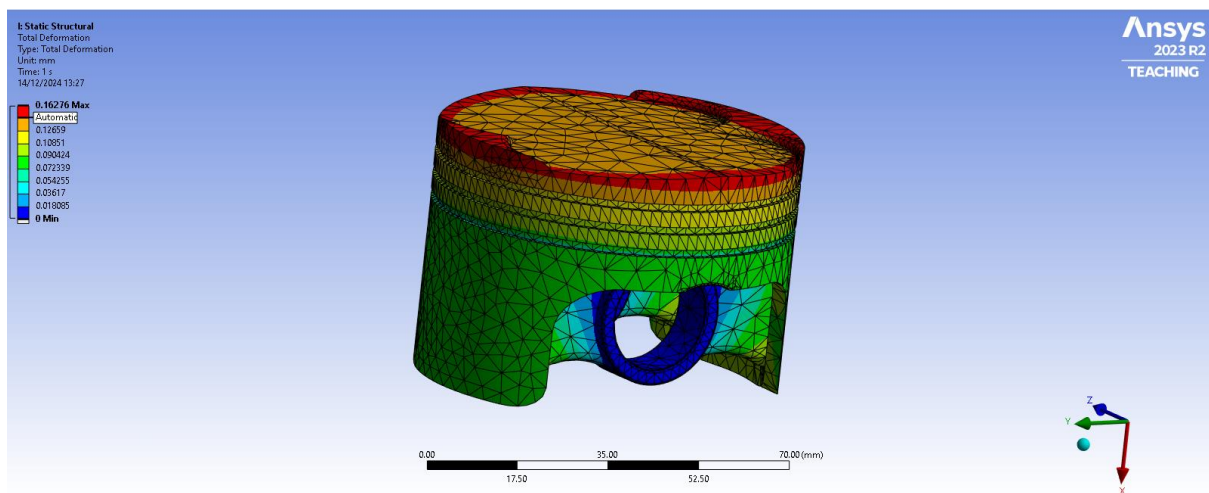


Figure 16 - 4140 Total Deformation

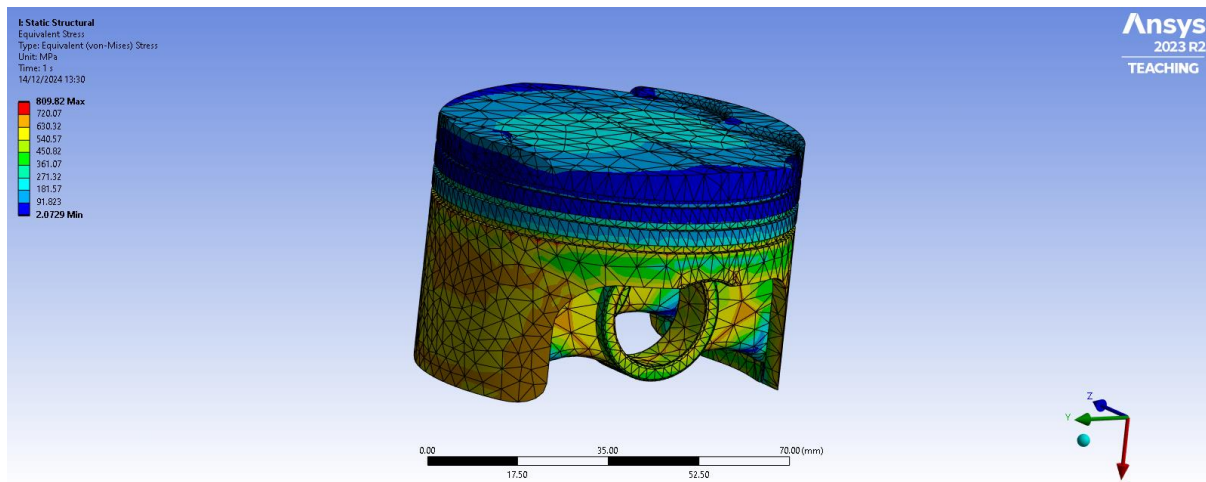


Figure 17 – 4140 Equivalent Stress

4.3.5 Ti-6Al-4V Titanium

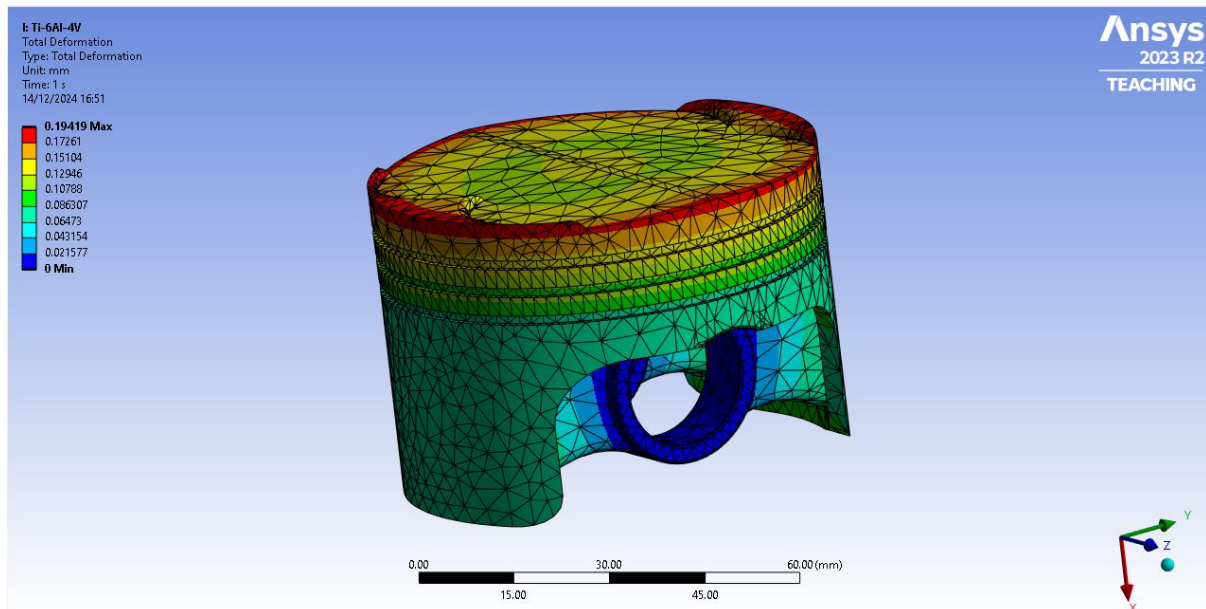


Figure 18 - Ti-6Al-4V Total Deformation

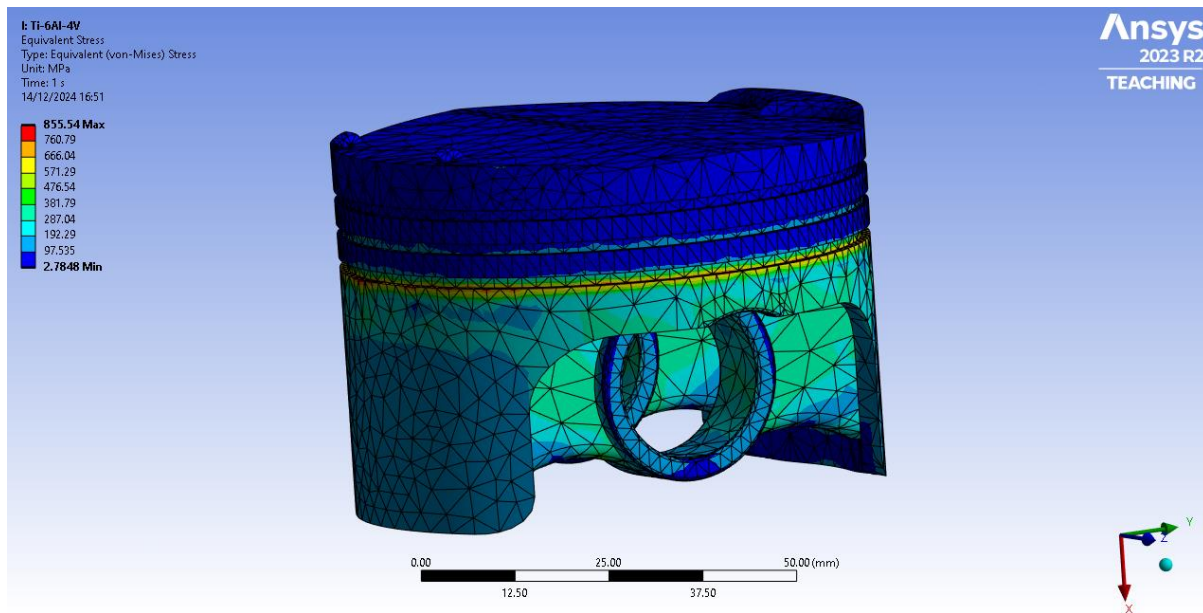


Figure 19 Ti-6Al-4V Equivalent Stress

4.4 Summary of Material Difference

Table 1 - Summary of Results for Different Materials

Parameters	Maximum/Minimum	6061-T6	4104	2618	Ti-6Al-4V
Weight (kg)	Max	0.41772	0.74362	0.26049	0.41961
Max Temperature (°C)	Max	294	401.68	309.85	600.2
Total Deformation (mm)	Max	0.29305	0.16276	0.28757	0.1895
	Min	0	0	0	0
Normal Elastic Strain(mm/mm)	Max	0.0049766	0.0033739	0.0057465	0.0071999
	Min	-0.0039136	-0.0029128	-0.0044277	-0.0032062
Shear Elastic Strain (mm/mm)	Max	0.0087493	0.0056547	0.0097221	0.009678
	Min	-0.0088917	-0.0056332	-0.0098723	-0.0094937
Equivalent (Von-Mises) Elastic Strain (mm/mm)	Max	0.0060766	0.0040926	0.0067859	0.0085235
	Min	4.7488e-5	1.3378e-5	3.5371e-5	0.00010697
Normal Stress (MPa)	Max	363.06	926.01	483.7	961.05
	Min	-708.01	-1456.6	-847.23	-1075.5
Shear Stress (MPa)	Max	198.17	438.87	235.97	410.96
	Min	-201.42	-437.19	-239.66	-403.14
Equivalent (von-Mises) Stress (MPa)	Max	359.33	809.82	428.6	855.54
	Min	1.5613	2.0729	1.6022	2.7848

4.5 Analysis of results

Firstly, focusing on the results in *table 1*, the simulation revealed that the material characteristics aligned with their expected properties. 6061-T6 exhibited moderate stress of 359.33MPa and a deformation of 0.29305mm, validating its use in general applications. 4101, showed significantly higher stress values and a lower deformation, reflecting its superior strength but limited ductility. As expected, the titanium showed the low deformation, highlighting its strength-to-weight ratio compared with 6061 which is a similar weight.

4.6 Review of the Simulation Process

The results demonstrate a degree of realism, with the materials behaving as expected under thermal and mechanical loads, aligning with their documented properties such as thermal conductivity, strength, and expansion rates. Aluminium alloys exhibited superior thermal performance due to their high conductivity, while steel and titanium displayed greater mechanical strength but faced challenges in heat management. The stress distribution and deformation values are reasonable, particularly in high-stress areas like the crown, which align with typical real-world failure zones observed in piston designs.

There were some limitations which have impacted the accuracy of the simulation. The joint which the gudgeon pin is connect was modelled as a fixed using weak springs, due to computing power limitations, this does not accurately represent the real-world conditions where the piston would experience movement and flexibility. Additionally, no forces were applied to the piston skirts, which would typically experience some form of lateral force due to contact with the cylinder walls and in cases of piston slap these forces could be much more damaging (Ghazy, 2001). These combined, could result in an underestimated figure for stress and deformation in critical areas, reducing the reliability of the simulation.

5 Optimisation and Improvement

5.1 Iterative Design Based on FEA Results

5.1.1 Piston B Design

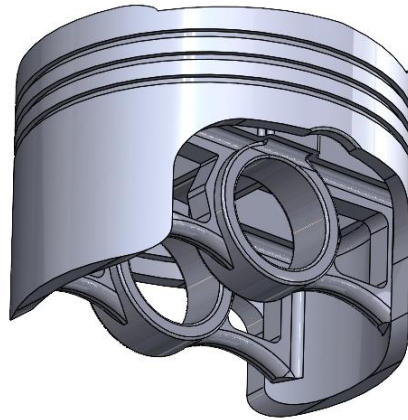


Figure 20 - Piston B SolidWorks

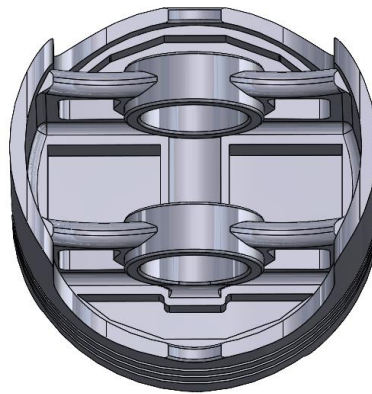


Figure 21 - Piston B SolidWorks Underside

The goal of the first design iteration was weight loss to lower the inertia forces on the piston. Sections of the piston were removed and cuts into the dome were implemented to reduce the overall mass.

5.1.2 Piston B Simulation Results

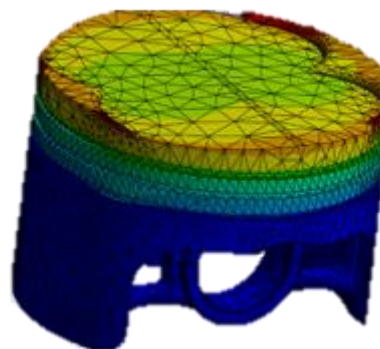


Figure 22 - Piston B Thermal Results

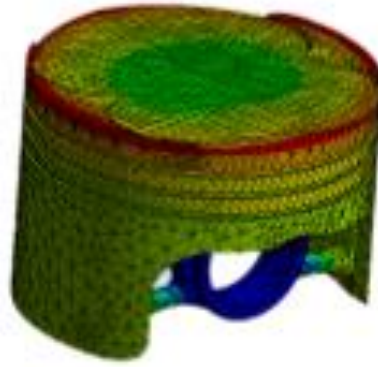


Figure 23 - Piston B Total Deformation

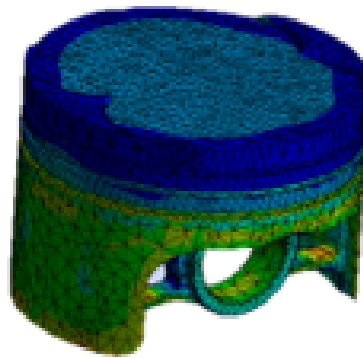


Figure 24 – Piston C Equivalent Stress

With a weight decrease of 46.65% this goal was achieved, accompanied by a notable drop in maximum temperature seen on the crown of the piston, from 294°C in Piston A to 150.61°C in Piston B. Maximum deformation was nearly halved from 0.29305 mm to 0.12153 mm which suggests enhanced structural integrity. The stress patterns also showed reductions, specifically the equivalent stress, going from 359.33 MPa to 334.08 MPa. These changes collectively enhance performance and durability, allowing the piston to handle operate stresses more efficiently.

5.1.3 Piston C Design

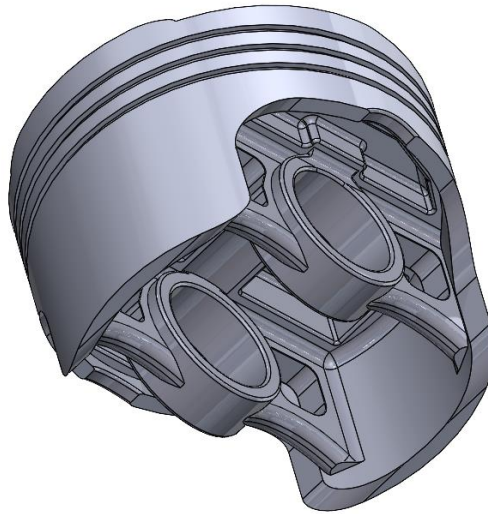


Figure 25 - Piston C SolidWorks

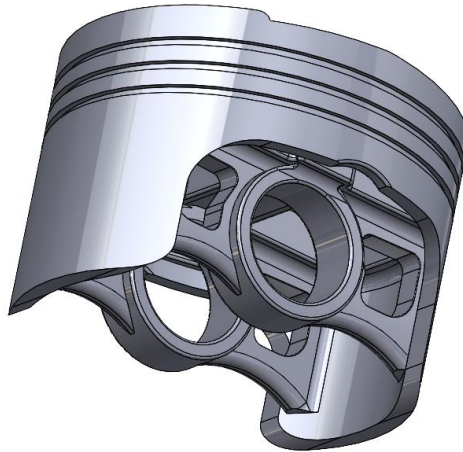


Figure 26 - Piston C Different View SolidWorks

As a result of Piston B's simulation, an updated design incorporated larger radii and filleted cutouts, these dimensions of the cutouts were also slightly reduced, aiming to bolster fatigue resistance and gain a longer operational lifespan.

5.1.4 Piston C Simulation Results

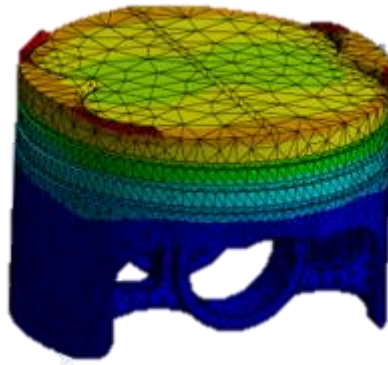


Figure 27 - Piston C Thermal Study Results

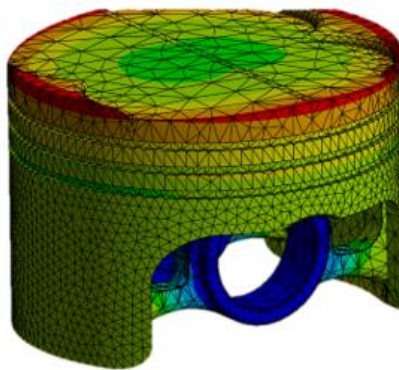


Figure 28 - Piston C Total Deformation

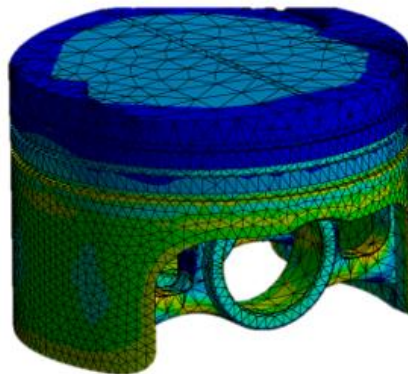


Figure 29 - Piston C Equivalent Stress

As noted in figure 24 and 30, the lower overall stress was not the entire story, as fatigue tests carried out in section 5.3. A slight increase in weight to 0.22581 kg from Piston B's 0.22379 kg, representing a minimal weight change of about 0.90%. However, this slight increase in mass brought about improved thermal and mechanical characteristics. The maximum temperature experienced by Piston C slightly decreased to 151.33°C from 150.61°C, indicating a more stable thermal response. Total deformation continued to decrease, dropping from 0.12153 mm in Piston B to 0.11935 mm in Piston C, suggesting further gains in the structural rigidity and integrity of the design. The stress profiles also saw further improvements; for instance, the maximum equivalent stress was reduced to 344.39

MPa from 334.08 MPa. This progression highlights a careful balance between weight and performance optimisations.

5.2 Summary of Original Against Optimised Design

Table 2 - Summary of Results for Different Piston Designs

Parameters	Maximum/Minimum	6061-T6 Piston A	6061-T6 Piston B	6061-T6 Piston C
Weight (kg)	Max	0.41772	0.22379	0.22581
Temperature (C°)	Max	294	150.61	151.33
Total Deformation (mm)	Max	0.29305	0.12153	0.11935
	Min	0	0	0
Normal Elastic Strain(mm/mm)	Max	0.0049766	0.0035757	0.0039752
	Min	-0.0039136	-0.0039518	-0.0042688
Shear Elastic Strain (mm/mm)	Max	0.0087493	0.007237	0.0073298
	Min	-0.0088917	-0.0068167	-0.0062166
Equivalent (Von-Mises) Elastic Strain (mm/mm)	Max	0.0060766	0.0053238	0.0052138
	Min	4.7488e-5	4.8842e-5	3.1578e-5
Normal Stress (MPa)	Max	363.06	214.38	305.23
	Min	-708.01	-418.15	-389.87
Shear Stress (MPa)	Max	198.17	181.4	183.72
	Min	-201.42	-170.86	-155.53
Equivalent (von-Mises) Stress (MPa)	Max	359.33	334.08	344.39
	Min	1.5613	2.6339	1.6725

5.3 Fatigue Life Setup and Results

Because the forces from the triumph are used and the iterations to the piston B to make it lighter would bring it closer to a motorcycle piston, the next step is to make the rpm in ridged dynamics more realistic to the triumph so using 50% of the max rpm, 5750rpm, these were uploaded into the new Piston B model.

The Goodman method was chosen as it facilitates the assessment of design safety margins and survival rates, which are essential for ensuring the durability of pistons under operational stresses. With its wide use in evaluation of fatigue stress for various piston studies, indicates that it can provide a more reliable framework for predicting the fatigue life of components subjected to cyclic loading (He et al., 2024).

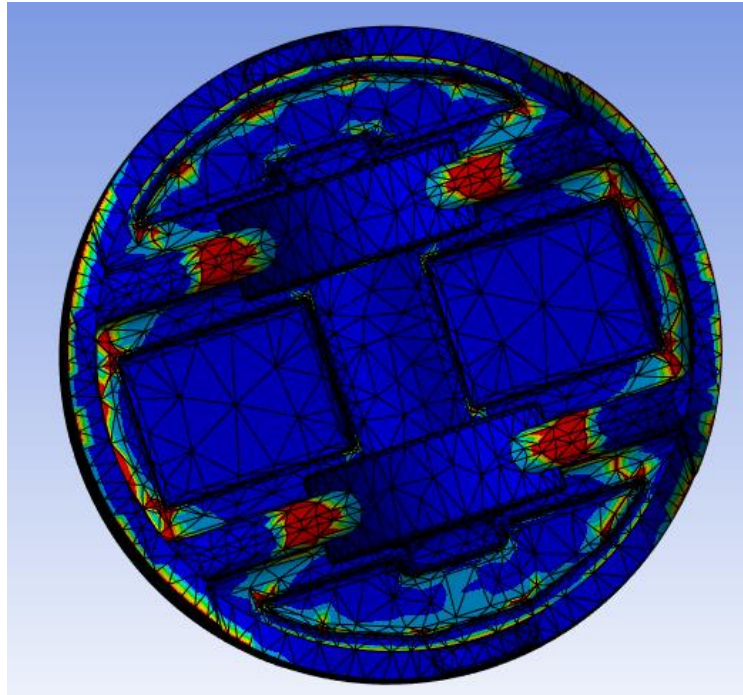


Figure 30 -Piston B Fatigue tool, Damage

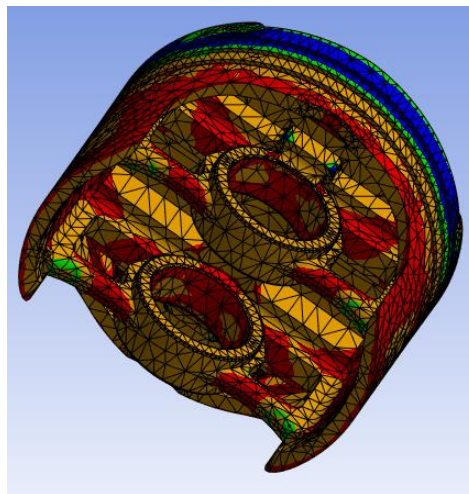


Figure 31 – Piston B Fatigue Tool, Safety Factor

Looking at the design of Piston B. The thinning the inner walls, lack of radii and fillets on the cutouts, has shown up as possible problem areas.

Using the safety factor minimum of 0.47261, a second fatigue tool was implemented, and this result was used as the scale factor to output a realistic life cycle of the piston. Due to the safety factor being less than one, a result in which the material fails is expected. With a minimum of 1.8112×10^5 and a maximum of 1×10^8 . Meaning the material could fail as early as 181,120 cycles, averaging 50mph at 5750rpm means last 31.5 minutes and get the engine 26.25 miles. This underscores potential premature failure, necessitating design modifications.

Piston C, as discussed in section 5.1.3 had changes made to improve the results in the fatigue tests due to weak spots showing up during simulation. *Figure 32* shows the Piston C model achieving a fatigue life of $1e8$, an improvement in durability due to the design adjustments.

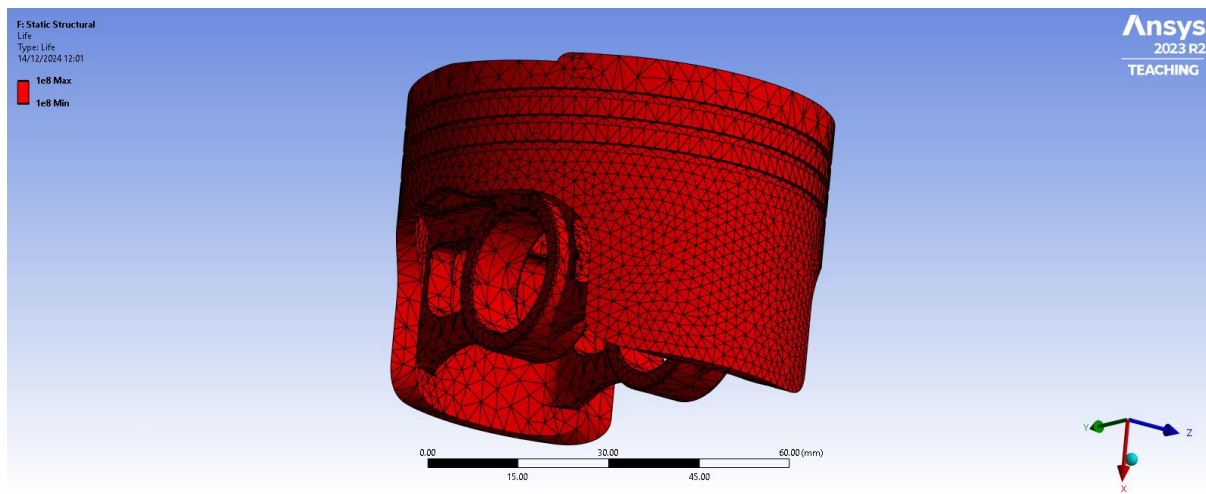


Figure 32 - Piston C, Fatigue Life

The significance of conducting fatigue testing up to 1,000,000,000 cycles, particularly in the context of very high cycle fatigue (VHCF), is highlighted by the need to understand the fatigue behaviour of materials under extreme cyclic loading conditions (Mohamad, 2020). In automotive especially, components are often subjected to an extremely high number of load cycles before failure occurs. And so, obtaining fatigue data helps engineers create a design based on suitable material choices, leading to reliable components.

6 Conclusion

This report has demonstrated the application of computer-aided engineering (CAE) processes to analyse and improve an engine piston design using simulation techniques. Using SolidWorks for modelling and Ansys Workbench for simulation, various analyses, including rigid dynamics, steady-state thermal, and static structural, were conducted to replicate realistic operating conditions. The results revealed that the materials behaved as expected under thermal and mechanical loads, aligning with their documented properties. Aluminium alloys exhibited superior thermal performance due to high thermal conductivity, while steel and titanium materials showed greater mechanical strength but faced challenges with heat dissipation.

The iterative design process, which included Piston B and Piston C, highlighted significant improvements in structural integrity, weight reduction, and thermal response. These refinements were achieved by strategically reducing mass, enhancing stress distribution, and addressing potential failure areas, as highlighted in fatigue life analyses. Despite these successes, limitations such as fixed constraints on the gudgeon pin and the absence of forces on the piston skirts were identified, affecting simulation accuracy.

To further enhance the results, future work should focus on incorporating realistic joint conditions, such as using the weak springs feature in Ansys, lateral forces on the piston skirts and crown, and more detailed transient thermal-mechanical simulations. Additionally, validating the numerical results against experimental data will increase confidence in the model's fidelity.

Overall, this study highlights the effectiveness of CAE tools in optimising piston design, showcasing their potential to improve component performance, reduce material usage, and enhance durability in real-world applications.

Word Count: 3143

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8 Appendix

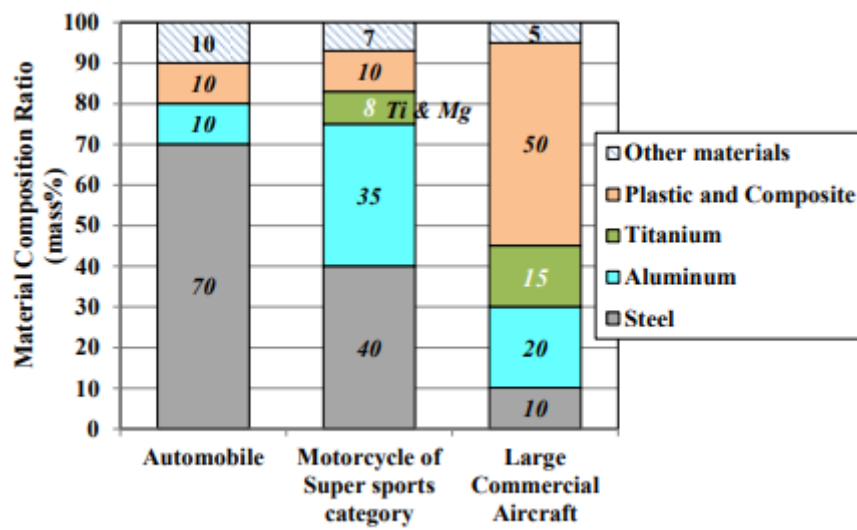


Figure 33 – Titanium Usage in Various Vehicles (Takebe, Takahashi, and Mori, 2020)

Material Characteristics	4032	2618
Tensile Strength	55,000 psi	64,000 psi
Yield Strength	46,000 psi	54,000 psi
Fatigue Endurance	16,000 psi	18,000 psi
Modulus of Elasticity	11,400 psi	10,400 psi
Melting Point	990 – 1,060 F	1,020 – 1,180 F

Figure 34 - Material Properties 2618 (jepistons.com, 2022)

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	Aluminum, 2618, T6			C:	Materials data from Granta EduPack 2022 R2 Edition: Level 3 Table: MaterialUniverse Record name: Aluminum, 2618, T6
4	Aluminum, 6061, T6			D:	Materials data from Granta EduPack 2022 R2 Edition: Level 3 Table: MaterialUniverse Record name: Aluminum, 6061, T6
5	Low alloy steel, AISI 4140, normalized			C:	Materials data from Granta EduPack 2022 R2 Edition: Level 3 Table: MaterialUniverse Record name: Low alloy steel, AISI 4140, normalized
6	Titanium, alpha-beta alloy, Ti-6Al-4V, cast			D:	Materials data from Granta EduPack 2022 R2 Edition: Level 3 Table: MaterialUniverse Record name: Titanium, alpha-beta alloy, Ti-6Al-4V, cast
*	Click here to add a new material				

Properties of Outline Row 6: Aluminum, 6061, T6					
	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	2712.9	kg m ⁻³		
4	Isotropic Secant Coefficient of Thermal Expansion				
9	Isotropic Elasticity	Tabular			
19	Bilinear Isotropic Hardening				☒
23	Multilinear Isotropic Hardening	Tabular			
26	S-N Curve	Tabular			
30	Tensile Yield Strength	Tabular			
33	Tensile Ultimate Strength	Tabular			
36	Isotropic Thermal Conductivity	Tabular			
39	Specific Heat Constant Pressure, C _p	Tabular			
42	Isotropic Resistivity	3.9988E-08	ohm m		

Figure 35 - Materials List in Engineering Database, Imported from Granta