Design and Analysis of Connecting Rod Using Aluminium Silicon Carbide

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Abstract: - —One of the main considerations in fuel economy and overall engine performance is the reduction of an engine component's weight while maintaining its strength. The objective of this study is to develop and analyze an engine connecting rod made out of Aluminium Silicon Carbide (Al-SiC) composite material which is light yet strong. The process starts by constructing a detailed CAD model of the connecting rod which will later be subjected to FEA (Finite Element Analysis) for stress, strain, and structural performance evaluation. Simulations will be done in real-life conditions where the engine is assumed to be running which makes it possible to compare the Al-SiC rod with conventional steel rods. Through several iterations, the goal is to improve the design in a way that enhances mechanical efficiency while maintaining structural integrity.

Keywords: weight reduction, engine components, fuel efficiency, performance, connecting rod, composite model, CAD model..

1. INTRODUCTION

To achieve optimal performance and durability, internal combustion engines rely on highly efficient, robust, and mechanically sound components. One of the components which require a lot of focus is the Connecting Rod. It is responsible for transmitting motion and force from the piston to the crankshaft. Steel components used in construction machines have their own benefits. These components are known for their strength and reliable structure, what still seems to be a preferred choice when it comes to connecting rods. Unfortunately, this is not all good. Steel components tragically increase the overall weight of the engine, consuming more fuel and emitting more harmful substances into environment. Especially the radial engine employs a unique arrangement of parts. These include: cylinders which are arranged radially around a central crankshaft. In this setup, the master-and-articulating rod mechanism is often employed due to the spacial complexity and compact design of radial systems. The frictional losses of the master rod are larger then those of the connecting rod, making it intuitive to guess that the master rod would connect to the crank shaft directly. This configuration ensures a consistent firing order, compact mechanical packaging, reliable compact design and maintains optimal performance. There are some challenges to this, though. Dynamic loads and thermal expansion create unwanted compliances which need to be accounted for during the design stage. These problems can effect things like operational height, cruise drag and yaw. Excellent alternatives to conventional metals come in the form of Aluminum Silicon Carbide (Al-SiC). It possess a huge advantage because it is composite. With Al-SiC we are able to achieve an enhanced. The connecting rod is arguably one of the most important constituents of an internal combustion engine since it serves as a mechanical link between a piston and a crankshaft. Every engine cycle places a complex combination of compressive, tensile and bending loads on the component. Tending to the reliability and performance of such components is of utmost importance to the efficiency and life of the engine. With the advent of modern engineering, there is more demand for sophisticated designs to be light in weight and efficacious in performance, especially in the automobile and aerospace industries, thus creating a challenge to rethink the design and materials of engineered systems. Connecting rods have been traditionally made from forged steel or cast iron due to their good mechanical properties. Nonetheless, these materials tend to increase the weight of the engine assembly, which in turn, greatly diminishes the fuel efficiency and power-to-weight ratio. This weight consideration becomes more important in high-performance aviation engines and in radial engine configurations. Radial engines utilize a master-and-articulating-rod mechanical system, resulting in a star-shaped configuration of cylinders. This increases structural and dynamic complexities and consequently, makes the component design more intricate. This Aluminum Silicon CThe increase in requirements for high fuel efficient and low emission automobiles have accelerated the advancements towards lightweight solutions in automotive and aerospace engineering. The connecting rod is arguably the most highly stressed structurally component of an engine. The connecting rod endures extreme dynamic loads and cyclic stress throughout its service life. Its funtions in mechanical engineering is to transmit combustion force from the piston to the crankshaft which makes its design, material selection and structural integrity very critical. Connecting rods are historically manufactured from forged steel due to its strength and reliability. Steel, however, poses a significant problem due to its density. The heavier weight increases the rotating mass, which in turn increases inertia making the engine sluggish and unresponsive. In recent times, further innovations have been carried out to use aluminum alloys because of the lightweight properties. Though useful, aluminum alloys struggle with fatigue resistance as well as lacking in mechanical stiffness under high temperatures or load conditions. The recent advancements of composite materials, particularly metal matrix composites, have opened new possibilities. Al-SiC is known to provide a combination of low density, high stiffness, thermal stability and excellent fatique allows it to outperform other materials for use in high performance automotive aplications.

2. METHODOLOGY

The approach taken in this project combines design and simulation analysis for the evaluation of structural and thermal behavior of a connecting rod manufactured using Aluminium Silicon Carbide (Al/SiC). The first step to be done is to set the target as an optimized component in weight while keeping the mechanical strength within the boundaries set by the engine operating conditions. A 3D model of the connecting rod is developed with SolidWorks, which includes precision CAD features like the radial engine big end and small end, as well as the rod shank end. The model is then taken into ANSYS Workbench for Finte Element Analysis (FEA), which includes both structural and thermal simulations. Al SiC, aluminum alloy and mild steel were chosen in a three way comparative analysis for their mechanical and thermal properties of Young's modulus, Poisson ratio, density, and yield strength. For static structural analysis, an equivalent unidirectional static 26 MPa pressure load is set to simulate the forces during combustion in an engine. The level of mesh refinement is determined by the stress and deformation gradient which is predicted to occur in the most strained locations. In the case of thermal analysis, the material to be analysed is subjected to flux and temperature as well as the secondary conditions of heat expansion and conduction. Some of the ideal outputs for the analysis selection are the overall alteration, von mises s. The strategy adopted in this research is comprehensive, spanning advanced computer-aided design (CAD), finite element simulation, and comparative evaluation of materials, in developing and analyzing a high-performance connecting rod which incorporates Aluminium Silicon Carbide (Al-SiC). The preliminary part was defining the objectives of the mechanical design concerning the operation of the radial engines; this mainly focused on minimizing mass while preserving or improving cyclic loading structural integrity on the components. To analyze the material, three options were selected: mild steel, aluminum alloy, and Al-SiC, with selection focus on Young's modulus, yield strength, Poisson's ratio, and density. Notably, Al-SiC's advantage in strength to weight ratio and thermal conductivity stood out. During the static structural analysis, boundary conditions whereby combustion pressure in real-world scenarios exerting force is modeled on the piston pin were applied.

FIG 1

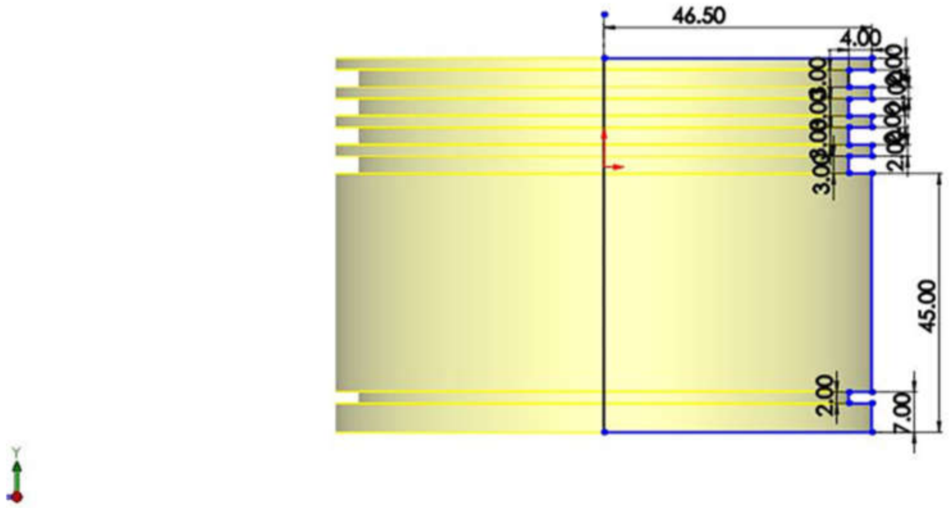

FIG 2

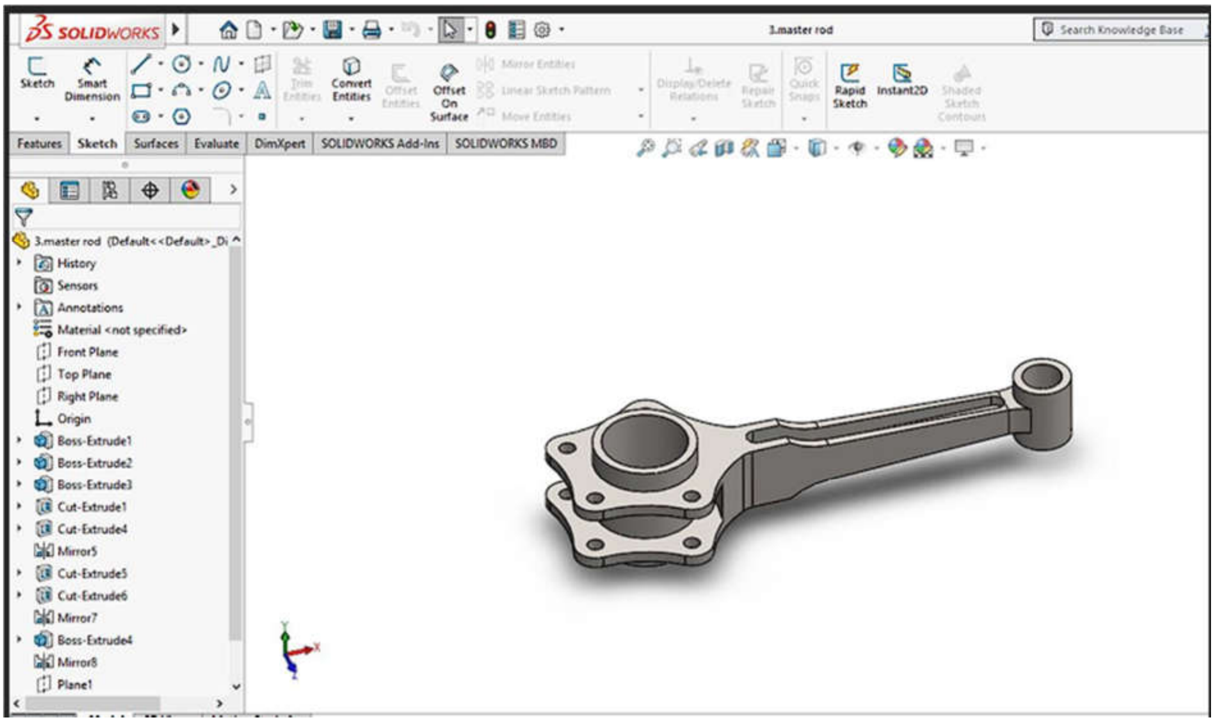
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FIG 3

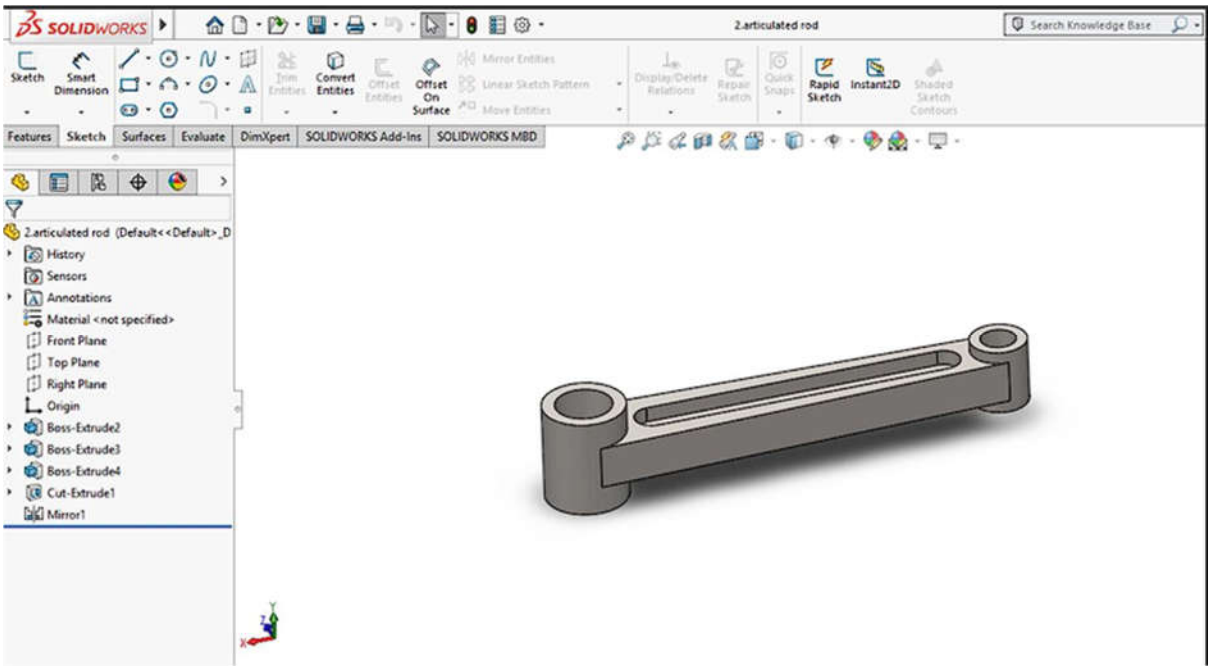
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FIG 4

FIG 5

Performance benchmarking for each version was done ’in ANSYS by subjecting them to identical loading and boundary conditions. The multi-physics simulation capabilities in the ANSYS Workbench environment enabled static and thermal analyses to be run simultaneously within a unified interface. Enhanced accuracy at the crank end and pin end fillet marked high-stress areas was also achieved through advanced meshing techniques such as finer mesh refinement. The accuracy of results as well as computation time were greatly improved by optimizing the solvers for convergence speed and computation cost.

3.IMPLEMENTATION

The design and virtual testing of a connecting rod for a radial engine was accomplished with computer design software alongside FEA tools parts were advanced CAD systems, through systematized approaches which were part of this project. At the onset, the master rod and radial using SolidWorks, a parametric engine modular powerful, 3D models of the engines' pivotal components to yield scratch. Both integrating traits of precise dimensional features and considering realistic constraints of engine assembly while structural frameworks with bounds were bordering the as built prototyping paradigm system. The connecting rod was designed for the cross-head-and-articulating rod sort of mechanism employed in all radial engines to ensure proper structural and mechanical traits and compatibility compatibility After CAD modeling, the designs were exported to ANSYS Workbench for Finite Element Analysis to be undertaken to study static and thermal behavior of the components. The goal of the study was to reproduce real-world operating conditions of the engine, high combustion pressures ignition along with temperature swings. In the frame of static structural analysis to the connecting rods a limiter load pressure of 26MPa, for simulating the forces during operation of the engine, was applied. From the models parameters total deformation, von Mises, stress, shear strain, and stress as well as level and even safety factor has been unearthed. Engine behavior were simulated realistically. A steeped meshing approach was used along with the assumption of isotropy and linear elastic deformation of materials to define the mechanical properties of each material in the ANSYS framework. This included Mild Steel, Aluminium Alloy and Aluminium Silicon Carbide (Al-SiC). Young's Modulus, Poisson's Ratio, Yield Strength and Density were incorporated along with other characteristics vital to work with initial material distortion under dynamic loading conditions. Engine motion restrictions were replicated with constraints beyond standard operating conditions while uniform pressure of 26 MPa was applied at piston pin area to mimic combustion force

Combution force was applied to the piston pin ea and the geometry of conecting rod was fixed at the crank end. Al-SiC underwent finite element meshing with skeletal tetrahedral form element generation being purely automatic. Through convergence alongside initial simulations of static structural stress reduction, result accuracy improved with heightened region detail around fillet corners and transition areas. Under same stress conditions, transversaly pceted dynamic loading condition performance was evaluated.

4. RESULTS AND DISCUSSIONS

The IoT-based monitoring system of floods and alerting was evaluated in a test scenario of a flood simulation. Controlled water levels were maintained to check sensor readings and alert system functionality. Ultrasonic sensors were used in this system to monitor different intervals of water increase. The sensors were placed at specific heights, namely Level 1, Level 2, and Level 3. Each sensor was set to 'trigger' when water reached its appropriate level. This sensor triggering was done by the microcontroller NodeMCU, which was able to receive the signal and subsequently activate LED and Buzzer indicators. At Level 1 blue LED was on, suggesting an alert level, which means caution should be looked after. Level 2 Yellow LED lit up and buzzer volume increased, which means a moderate level of danger. Level 3 Red LED is lit and buzzer sound changed to high frequency, which means critical alert of flood level. At the same time these alerts were set up via the GSM module. During testing alerts were clearly received around 5-7 seconds after the sensor picked them up. With these message received the level of flood water was also recorded assuring that the system is flawless in the construction of messages and the information picked is reliable. Also temperature and humidity sensors were installed, which continuously monitor the environmental conditions and have the dam recorder connected to them.

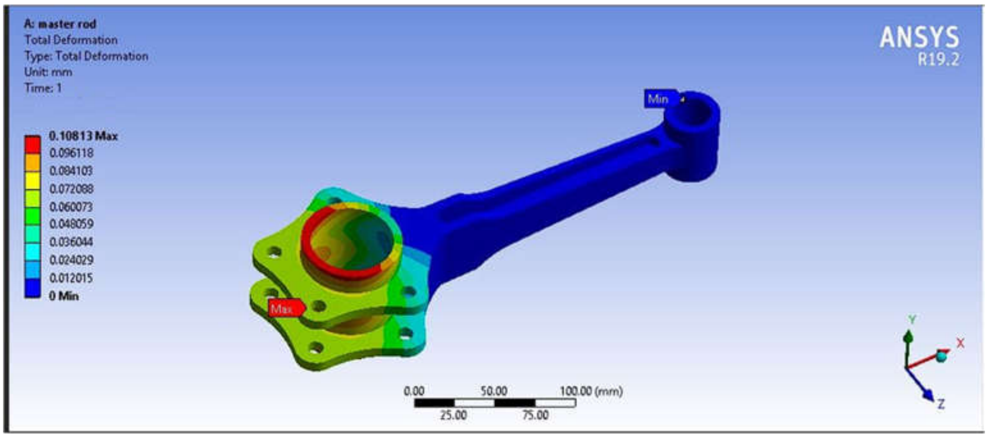
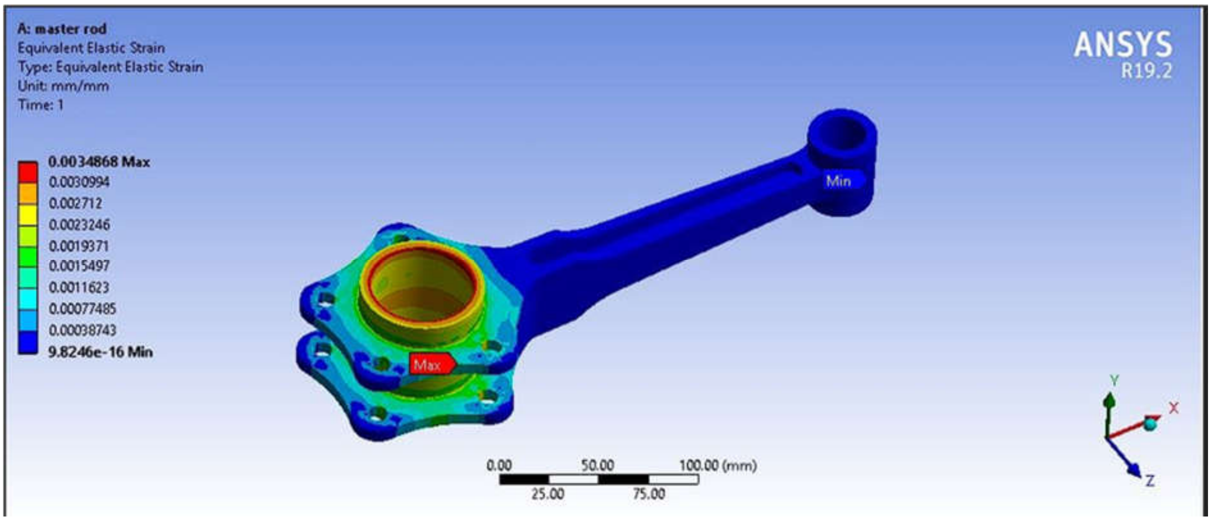


Fig 6 total deformation in Al-Sic which has highest deformation is 0.10613 and minimum total deformation is 0

Fig 7 Strain in Al-Sic which has highest strain is 0.0034868 and minimum strain is9.82426



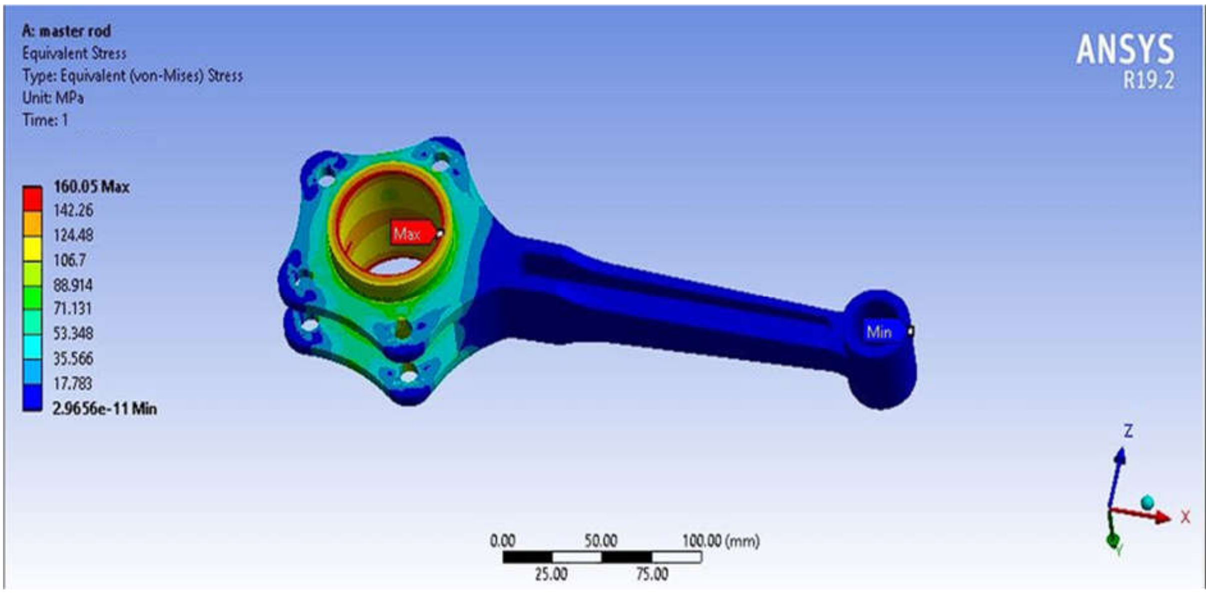
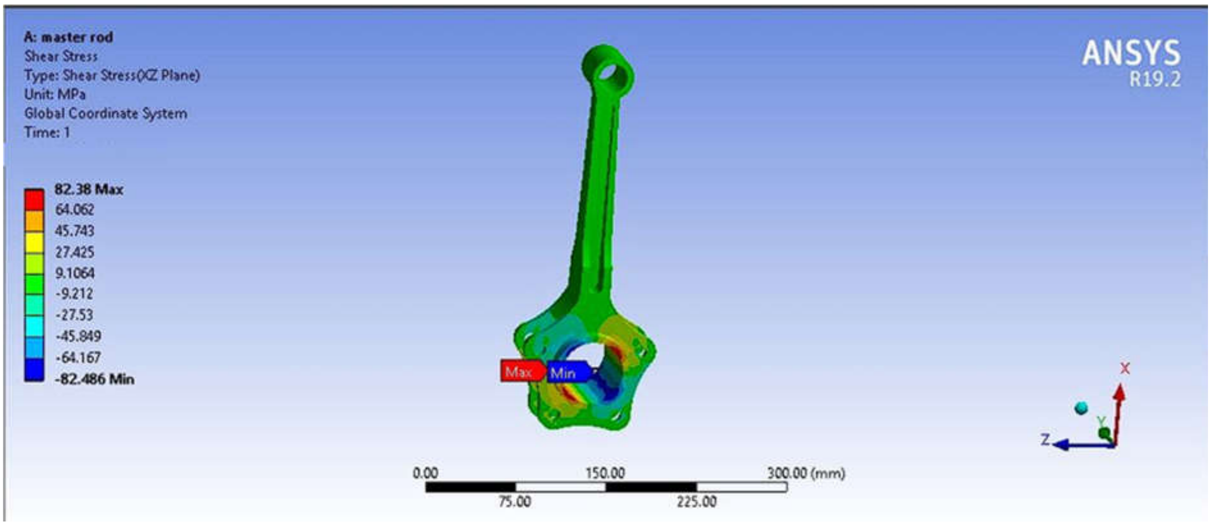


Fig 8 stress in Al-Sic which has maximum stress is 160.05 and minimum strain is 2.9656

Fig 9 shear stress in Al-Sic which has maximum shear stress is 82.38 and minimum shear stress is -82.486



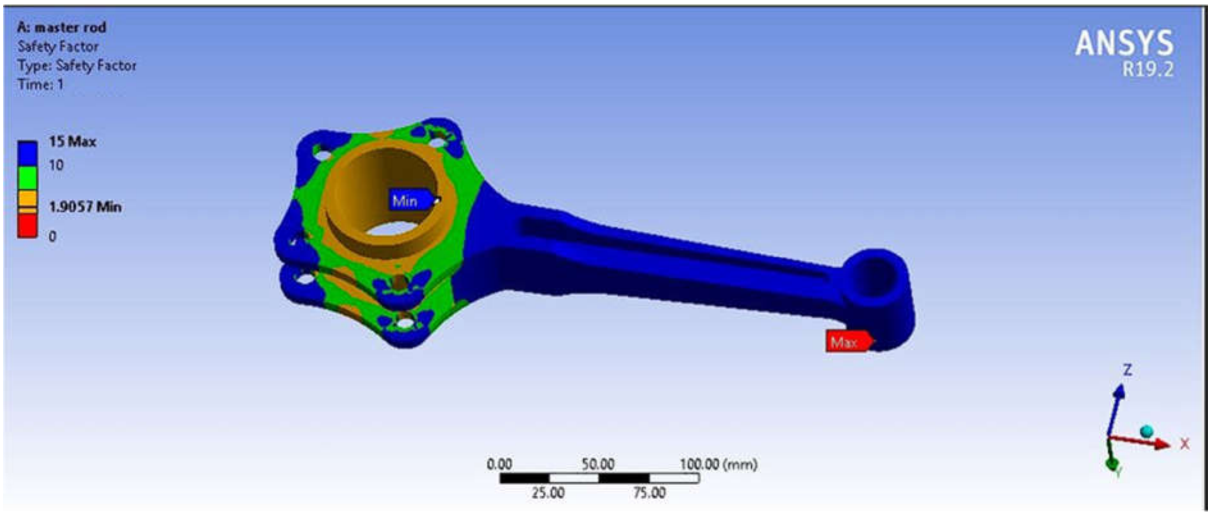


Fig 10 safety factor in Al-Sic which has safety factor is 15 and minimum safety factor is 0

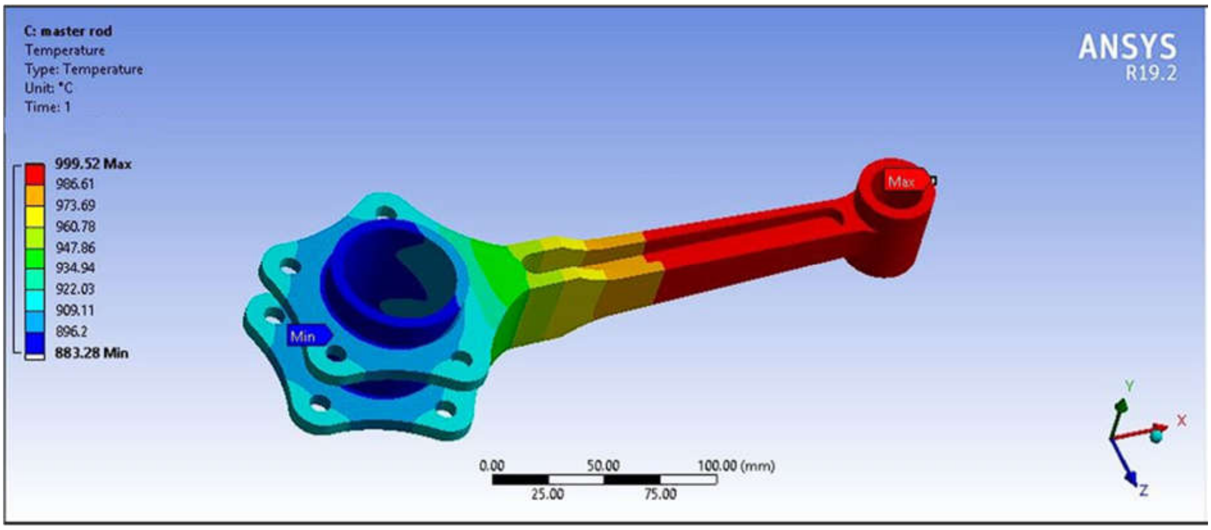


Fig 11 image shows the total temperature of which has the highest temperature is 999.52 and minimum total temperature is 883.28

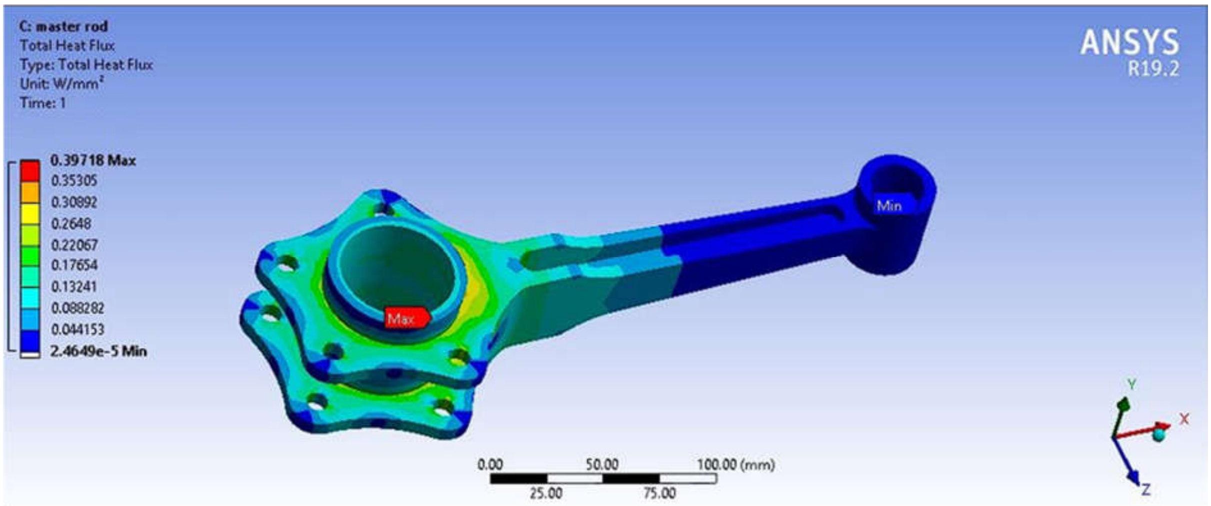


Fig 12 image shows the heat flux of which the highest heat flux is 0.39178 and minimum heat flux is 2.4649

however, yield a maximum equivalent stress of 160.7 MPa which was very close to its yield limit. This means that while mild steel is strong, the fact that it has a density of 7800kg/m3 does pose concern as it would, in turn, have a considerable weight disadvantage on the component. This is . This remarkble increase in weight efficiency did, however, have a downside as the overall mechanical strenmgthdecreased acting as a retarding factor for Aluminium Alloy. While better than mild steel, these factors made the alloy not highly suitable for high-load applications. Al-SiC proved to be the most ideal material.

5.CHALLENGES AND FUTURE SCOPE

One of the prominent issues when designing and studying the engine parts, for example the connecting rod, is how to preserve the optimal level of mechanical strength and the mass of the material. Traditional materials, for instance mild steel, ensures adequate mechanical performance but adds to the weight of an engine assembly beyond its losing fuel efficiency and dynamic response. On the other hand high performance lightweight materials Al-SiC, Aluminium-Silicon Carbide, have great mechanical and thermal properties but face issues related to cost and complexity during manufacturing.

The design and modeling stage faces challenges in refinement such as, accurate replication of boundary conditions as well as real-world fatigue and thermal stress taking into consideration mesh refinement. Stress and deformation distribution is easy to calculate using Finite Element Analysis, however evaluating the enduring level of simulated wear, crack growth, and structural integrity under changing load forces over time is much more complex. The calculations for the engine cycle may be oversimplified due to steps required for the simulation.

Including practical testing with engine conditions on physical prototypes will enable validation of the models improving the accuracy of the simulations, these changes would further enhance relia.

5.1 Choice of Materials and Mechanical Trade-offs

One of the main problems to solve in an attempt to optimize an engine component is its mechanical strength versus the material mass, for example, in the case of the engine’s connecting rod. Traditional materials such as mild steel have satisfactory mechanical properties; however, they tend to increase the weight of the engine assembly. Additional mass burden reduces fuel efficiency and adversely impacts the engine’s dynamic response. On the other hand, lightweight materials, such as Aluminium Silicon Carbide (Al-SiC), feature advanced thermal and mechanical properties, but their more intricate manufacturing processes coupled with higher production cost pose challenges.

5.2 Constraints for Modeling and Simulation

When in the design stage through to the simulation phase, one of the most notable issues in emulating actual engine conditions is consideration of the boundary conditions. Loads, one cycle fatigue thermal and stress also require focus. To compute stress and deformation caused by static forces, application of Finite Element Analysis (FEA) works well. However, the structural dynamics poses challenges of modeling progress loss, stem crack, and fracture under various loads. In order to achieve an entire engine cycle simulation, overly simplistic methods need to be employed.

5.3 Justification for Experimental Validation

As an enhancement to the evaluation through simulations, it is necessary to include physical testing on prototypes with real engine loading to validate and improve computational models aimed at predictions. Reliability and accuracy of the predictions, as well as trust in the models, could be experimentally verified. Such simulations were hardly tested for calibration accuracy, and parameter assessing in simulation durability during virtually applied thermal-mechanical tension is another case for consideration.

5.4 Advanced Optimization and Manufacturing Methods

As a part of future work, it is planned to incorporate more sophisticated optimization strategies like artificial intelligence or machine learning for failure prediction and topology optimization, which at later steps will be more focused on detail design refinement. The development of these strategies will improve geometry and the use of materials in a smarter way. Furthermore, there is a possibility of using additive manufacturing for Al-SiC which may make precise and economical fabrication of such high-performance composites accessible for broad use in engines.

6. CONCLUSION

While it did add value in terms of weight, aluminium alloy had poorer performance in mechanical loading cases. However, Al-SiC with the least deformation and highest yield strength of 305 MPa proved best due to its remarkable thermal performance. It was shown that the connecting rod made from Al-SiC had greater features of lower thermal expansion, better dissipation of heat, and thus greater structural integrity under changing operating temperatures.The results from the simulations proved that Al-SiC offers a solution to increase fuel economy due to the decreased weight of the components without losing mechanical performance.

The analysis revealed that while mild steel maintained robust mechanical properties, its excessive density made it less desirable for weight-sensitive applications such as aerospace and automotive engines. Aluminium alloy offered an improved alternative in terms of weight but showed slightly reduced mechanical performance under load.

The final project of is to analyze how the stress and strain and safety factor and stress factor and the project also shows the how the heat transfer and heat flux is been transferred among the connecting rod.as we done comparison between the three componets of mild steel ,Al-Alloy ,Al-Sic for the stress,strain,shear stress,safety factor and for the total temperature we have known the Al-Sic have less heat transfer among the three connecting rod.

For the static analysis we have used the ansys version and for the cad design we have used the solid works as we know the title is design and analysis of connecting rod using the aluminium silicon carbide we have concluded that the what the test we have done till now the aluminium silicon carbide among the test the Al-Sic has the highest possbilites with less cost and high efficeny which can be used in the future scope. Which can be used the future car engine which can be used to increase the efficeny and reduce the cost of the car by the manufacturing automobile industry.

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