An Overview of the Advancements and Upgrades Made to the Connecting Rods in the Internal Combustion Engine

M. Kathirselvam, Meiyalagan S., Raji C. and Sudhakar S.
Department of Mechanical Engineering, K.S.Rangasamy College of Technology, Tiruchengode, Namakkal, Tamil Nadu, India

Keywords: SI Engine, Connecting Rod, Composite Materials, Optimization.

Abstract: Automotive engineering design prioritizes lowering emissions and enhancing safety features. Connecting rod optimization, which transmit power from the piston to the crankshaft, is especially important for maximizing engine economy and performance. The weight and design of a connecting rod in an automotive engine have an impact on its performance. Therefore, in order to produce a connecting rod that is more affordable, robust, and lightweight, optimization and analysis are required. This article reviews the experiments, designs, and analyses of several researchers on the connecting rod of an engine. A detailed comparison table and graphs are included with the evaluation. Both seasoned and inexperienced scholars in the subject of vehicle design will find this article to be a useful resource.

1 INTRODUCTION

The connecting rod is a crucial part of IC engines, converting the piston's alternating transverse motion into the crankshaft's rotation. Its two eye-shaped extremities, the big end and tiny end, are connected by a beam-like shank. The rod's design and material must be carefully chosen to endure high stress and ensure smooth engine running. Due to the high-cycle fatigue stress experienced by the connecting rod, gas forces and inertial forces must be considered. It needs to be sturdy enough to hold external loads, sufficiently light to lessen inertial forces, and stiff sufficient to permit for a suitable link with the crankpin and Gudgeon pin. The identification of a particular connecting rod segment as an alternating mass can have a direct effect on the maximum value of alternating forces. Designing connecting rods requires special attention, and connecting rod optimization often uses both analytical and numerical approaches.

2 NUMERICAL ANALYSIS ON CONNECTING ROD

An internal combustion engine's connecting rod is an essential component. Using aluminium alloy (2024-T361) material can help reduce weight. According to Ebhojiaye and Eboigbe (2022), the connecting rod's extreme end is where distortion peaks. Consequently, the distortion will be reduced by thickening the rod's tiny end. The values obtained for the stress distribution was acceptable because the stress was minimal. Maximum deformation of 0.062428mm was recorded at the small connecting rod end, because the material thickness was unable to support the applied force at the rod end. The simulation results showed that von Mises stress present in the aluminum alloy (2024-T361) rod was less than its yield strength indicating that there can be material saving in the lowest stressed region.

Vinay Kumar et al. (2019) conducted a solid modelling study on connecting rods using aluminum alloy using CATIA V5 and ANSYS 14.0. The study analyzed the effects of tensile and compressive loads on the rods, focusing on normal stress and shear stress in the x-y plane. The results showed that Ansys was more effective than other software for identifying minimum stresses at the piston endand crank end cap, reducing material costs & improving material performance. A dynamic study of the connecting rod is necessary for additional optimisation, and finite element analysis will yield more precise findings. Antony et al. (2016) report that connecting rods made of aluminium undergo higher levels of stress induction than connecting rods made of teel. There's

Kathirselvam, M., S., M., C., R. and S., S.
An Overview of the Advancements and Upgrades Made to the Connecting Rods in the Internal Combustion Engine.
DOI: 10.5220/0013925600004919

In *Proceedings of the 1st International Conference on Research and Development in Information, Communication, and Computing Technologies (ICRDICCT'25 2025) - Volume 5*, pages 224-231
ISBN: 978-989-758-777-1

also a great opportunity to improve the design. For connecting rods, steel is consequently a better material choice.

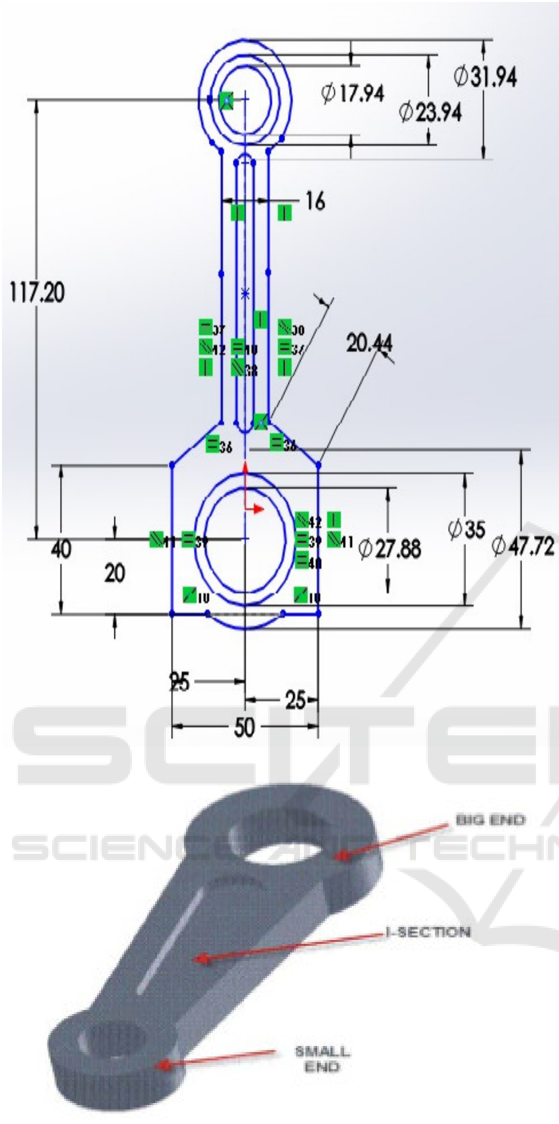

Figure 1: Schematic diagram of connecting rod.

Utilising SOLID WORK and ANSYS 15.0, Hussin et al. (2014) used the aluminium alloys 7068 T6 and T6511 to study solid modelling and analysis of connecting rods. The study found that Solid Work was effective in modelling and simulation, but Ansys was found to be more accurate in analysis. The study found minimum stresses at the piston end&crank end cap, reducing material costs. A finite element analysis will yield more accurate results than current results and is necessary for further optimisation. A dynamic analysis of the connecting rod is also needed. The study highlights the need for more accurate material optimization in connecting rod design and analysis. Figure 1 shows the Schematic Diagram of Connecting Rod (Abdusalam MH, Prabhat KS & Arvind SD 2014).

The connecting rod is made for maximum engine speed and pressure, according to Murthy et al. (2019). The big end area, small end area, and connection to the rod's small end all had substantial material reductions, according to finite element analysis. Analysis and computations suggest thinner I-sections. In addition to titanium's superior mechanical qualities, it is lighter than steel and has lower ductility than steel. Additionally, the new connecting rod form weighs less than the old one.

The greatest primary stress, as determined by Singh et al. (2015), was 411.32 MPa, which is lower than the 530 MPa yield compressive strength. While 0.053 mm was the greatest deformation determined by the conventional approach, 0.041 mm was the maximum deformation determined by ANSYS V14.0. This difference can be attributed to the consideration of simplification hypotheses in the classic calculation. The results were obtained at the Inner Dead Center, indicating that the maximum force is acting at that point. Using finite element analysis software for stress and deformation calculations saves time and provides results at all nodes of the structure. The connecting rod, which is hinged by a piston pin and a crank pin, experiences compressive forces, resulting in a design that behaves like a strut.

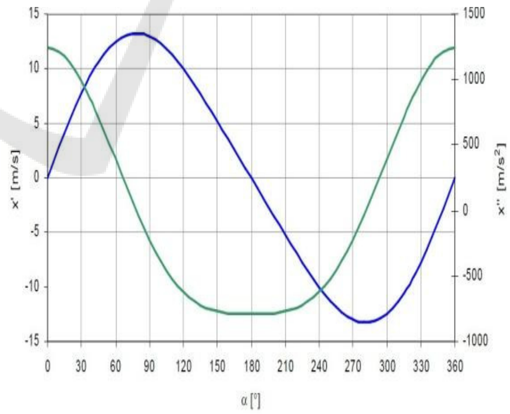

Figure 2: Acceleration and piston speed pattern dependent on crankshaft angular displacement.

Mohsin et al. (2015) performed a connecting rod study. They used Catia software to build the rod to actual dimensions and conducted axi-symmetric analysis to determine interference effects on joint stress behavior. The research discovered increased compressive stress in the bush, tensile stress development at the tiny end, and contact pressure development at the interface. Plots of the results were made for the von Misses, hoop, and radial stresses. Axial-symmetric alternatives were used to create three-dimensional perspectives. To ascertain the connecting rod's fatigue nature in light of load transfer fluctuations, more investigation was done. For the study, two load nature models, Models A and B, with assembly and service loads, were taken into consideration. Figure 2 shows the Acceleration and Piston Speed Pattern Dependent on Crankshaft Angular Displacement (Puran Singh et al.,2015).

The study by Vinayakrao and Swami (2017) evaluated alternative materials for connecting rods with fewer stresses and a lighter weight. Using FEA analysis using ANSYS 18.1 software, the study found that the aluminum 7075-T651 connecting rod showed nearly the same amount of stress as the existing carbon steel connecting rod. The maximum stress generated in case 1 was almost the same in all materials, while in case 2, it was the same in all materials. However, the aluminum connecting rod had a significantly lower weight than the other two materials. The deflection of the current connecting rod made of CS (42CrMo4) and the connecting rod made of aluminium (7075-T651) is equal. Furthermore, it was discovered that the connecting rod made of aluminium, model number 7075-T651, weighed around 35% less.

Kushwah et al. (2021) conducted research on improving connecting rod material through ANSYS software analysis They discovered that the connecting rod's bulk and power may be decreased. If the wire is not attached, the design, material quality, or both parameters can be improved. The connecting rod's performance can be improved by changing the material composition. They also found that alloying materials can obtain desired properties by combining various materials with different qualities.

In a static structural study, Abhishek Kumar and Pankaj Panday (2019) compared the comparable elastic strains and von Mises stresses for structural steel and aluminum alloy. They discovered that, under some loading circumstances, aluminum alloy had more stresses and strength than structural steel. In order to maintain the necessary pressure produced within the cylinder, they optimized AA7068 aluminum alloy connecting rods, which needed less material and lower dimensions. Compared to the other materials employed in the investigation, the optimized material was shown to have a superior nature.

According to study, Atharuddin et al. (2019) found that using aluminum alloys instead of forged steel to replace a damaged connecting rod can lighten it and extend its lifespan. The study involved analyzing the force applied to the piston head and the effect of these forces on the connecting rod. The automotive industry is increasingly demanding components with high techno-economic performance, with the connecting rod being a key component in automobiles. The study explains the stresses to consider when designing the connecting rod and compares the results of the dissimilar materials used. The findings can be applied to designing any connecting rod in an automobile, aiming for weight and cost reduction as well as increasing the rod's life. The lighter weight and increased strength of the connecting rod can be achieved compared to the original design.

According to Ramani et al. (2014), there are two topics covered in their study: optimising for weight reduction and analysing the load and stress on the connecting rod. Compressive load is one extreme load, and tensile load is one of two load ranges in which the connecting rod may be constructed and improved. In addition, it is possible to optimise the current connecting rod and replace it with a new one that weighs 15% less.

Samal et al. (2015) used CATIA-V5 and a machine drawing textbook to create a 3D CAD model. They used MATLAB to compute piston forces at crucial crank angles and Radioss and Altair Hypermesh for finite element modelling. In the second load example, when the connecting rod was exposed to 37.3 bar of cylinder pressure at a 300-degree crank angle, the highest stress created was 227.3 MPa. The connecting rod was redesigned to be 11.3% lighter and have a maximum stress of 274.2 MPa, which is also below the material's yield strength because this stress was lower than the material's yield strength.

A study of the literature on connecting rods under various load situations and stress experiments was done by Gorane et al. (2023). They carried out optimisation research and analysis to create a more effective connecting rod design process. For the purpose of evaluating the connecting rod specifications, they used forged steel material, and they also chose I cross-sections. Weight optimisation followed topology optimisation, which considered the optimal material and cross-section. The optimisation of geometry was then carried out using the topology and FEA data. Following optimisation, the connecting rod was put through several load scenarios for testing, and the outcomes were consistent with the findings drawn and the existing design.

Chougale (2014) designed a two-wheeler connecting rod using analytical methods and FEA analysis. A physical model was created using CATIA V5, and stresses were calculated using ANSYS Workbench 14.5. Thermal analysis was performed on different materials. Results showed a significant reduction in weight, equivalent and maximum shear stress, and longer life cycles for new connecting rods compared to steel rods. The Al-360 connecting rod had a higher total heat flux of 32.765 W/$mm2$, which is higher than structural steel's total heat flux. The results were compared based on various performance factors.

3 HYBRID AND COMPOSITE MATERIAL WORKS ON CONNECTING ROD

Velliyangiri and Vinothkumar (2022) discovered that the minimum deformation, stress, and strain occur at a ratio of 2 boron carbide to 10% of the alumina oxide matrix of ordinary Al-1100. This ratio is better for deformation and displacement. With their superior mechanical qualities over traditional materials, composite materials in particular, aluminium 1100 boron carbide and aluminium oxide composites find use in a wide range of industries, including the automotive sector. After analysing the mechanical characteristics of the Al1100 metal matrix, the study discovered that the good tensile and compressive strengths were improved by the boron carbide reinforcement. Alumina oxide has a lower impact strength than pure 1100. While alumina oxide's metal matrix had a higher impact strength, boron carbide demonstrated superior compressive and tensile strengths. The FEA analysis revealed that the minimum strain and maximum von Mises stress occur at a ratio of 2 Boron Carbide to 10%, while the alumina oxide matrix of ordinary Al1100 is higher.

Prakash and Bagade's study from 2021 make recommendations for changes to the connecting rod's design, material, and production method. In comparison to forging and sintering steel, advanced materials such as micro-alloyed steel and C70 (crackable) steel provide more strength and stiffness. Heat treatment can reduce residual strains, whereas shot peening extends fatigue life and strengthens fatigue. Compared to traditional materials, MMC'ssuch as Al-15% Al2O3 and Al-10% SiC are lighter and more rigid. Small holes can be drilled at appropriate locations to reduce stress in the shank section. The modified model reduces maximum Von-Mises stress by 3.395%, resulting in more uniform stress distribution and improving overall performance and durability.

For connecting rods constructed of aluminium alloy 6082, Janutienė et al. (2015) developed a thermo-mechanical method that increased mechanical qualities, safety, durability, and reduced production costs. Impact strength was double that of the previous workpiece, and ultimate strength rose by up to 25%. The hardness varied from 58 to 62 HRB, and the fibrous microstructure inhibited brittle fracture and component deformation.

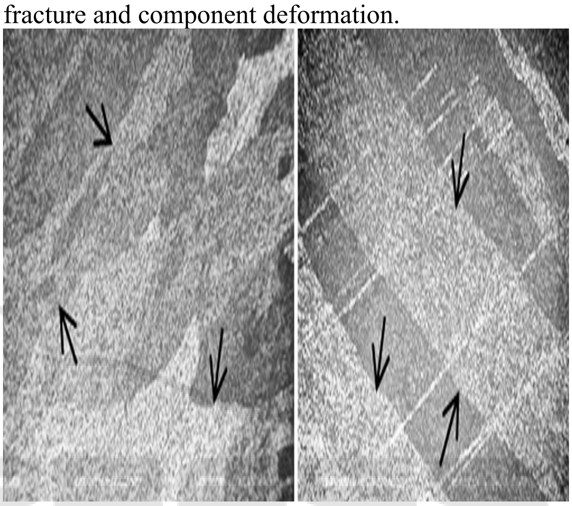

Figure 3: Regime A: Cross-cut of forging (Black arrows mark the boundaries of coarse recrystallized grains).

Forces acting on the piston head and connecting rod were examined by Selvakumar et al. (2021). For displacement, von-misses stress, and strain intensity output, they examined the pressure in the crank end bearing & the bottom part of the connecting rod. They found that Al6061, the material used for connecting rods, has high deformation and low von-misses stress, resulting in lower life and strength. However, Al6061+SiC, with high von-misses stress, has high strength. Aluminium 6061+SiC has greater hardness than aluminium 6061. Figure 3 shows the Regime A: Cross-cut of Forging (Black Arrows Mark the Boundaries of Coarse Recrystallized Grains) (Rasa Kandrotaitė J. 2016).

Nitturkar et al. (2020) conducted a solid modelling study on a connecting rod using NX 10 and ANSYS Workbench. The study found that the minimum stresses were found at the piston end&crank end cap, reducing material costs. A finite element study must come first, followed by a dynamic analysis of the connecting rod for additional optimisation. The connecting rod's tiny end was where the greatest tension was discoveredIn contrast to other materials, forged steel is less rigid and weighs more, and connecting rods made of aluminium, magnesium, and beryllium alloy exhibit more erratic behaviour. Beryllium alloy connecting rods have the lowest von Mises stress, lowest von Mises strain, and maximum displacement. This study emphasizes the requirement for more precise material optimization outcomes.

4 EXPERIMENTAL WORKS ON CONNECTING ROD

The stress on a connecting rod in a two-wheeler was analysed by Khan et al. (2016) using the photoelasticity approach and finite element analysis. The finite element analysis results and the experimental results showed a substantial difference, with tensile stresses being found to be larger than compressive stresses at both ends of the research. It was found that the little end of the connecting rod caused larger strains than the big end. The stress concentration effect was found to be minimal in the core and to exist at both ends. It was discovered that the fillet portion on both ends was where the connecting rod had the highest likelihood of failing. According to the finite element study, the rod's risks of failure were highest at the fillet portions on both ends, where maximum stresses were also created. The connecting rod's fillet portions need to have material added to them in order to prevent these pressures and failures. Figure 4 shows the (Left) Experimental Setup and (Right) Tensile and Compressive Loads Acting from Both Ends.

Figure 4: (left) Experimental setup and (right) Tensile and compressive loads acting from both ends.

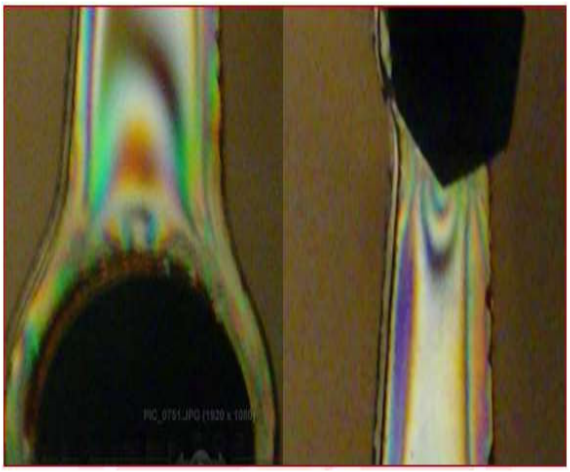

Figure 5: Displays the fringes that developed at both the compressive and tensile loads.

Li et al. (2017) investigated the emissions, performance, and combustion of a SI engine running on a combination of gasoline and butanol. In comparison to G100, they discovered that B10 and B30 had enhanced combustion phasing, shorter flame generation times, and longer main combustion durations. Butanol lowered BTE, while B30 reduced CO, UHC, and NOX emissions while producing better results with equivalent BTE. M30, E30, and B30 alcohol alternative fuels showed similar combustion phasing. When fuelling with butanol-gasoline blends, the research suggests postponing the timing of sparking since B30 engine performance and emissions beat G100. Figure 5 shows the Displays the Fringes that Developed at Both the Compressive and Tensile Loads.

Rakić et al. (2016) identified stress and surface roughness as the majorreasons of connecting rod fractures. The engine's prolonged use at full load had an impact on the breakage as well. In order to avoid rod breakage in the forthcoming, it is suggested to raise the radius of rounding in areas where stress concentration is higher, schedule polishing during final machining, and enhance control over engine components during serial manufacturing. The study suggests that increasing the radius of rounding and scheduling polishing within the final machining process can help reduce stress on the connecting rod and prevent future rod breakage. Figure 6 shows the (a) The Fractured Connecting Rod (b) The Metallographic Specimen Utilised for Macro-Structural Examination (Intersection A-A) (Roger Rabb 1995).

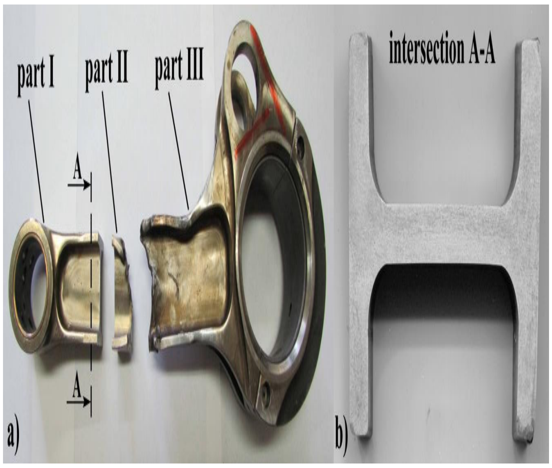

Figure 6: (a) The fractured connecting rod (b) The metallographic specimen utilised for macro-structural examination (Intersection A-A).

After one million fatigue cycles, as shown in Figure 7, Bari et al. (2017) investigated the fatigue-related failure of a connecting rod in a car owing to street usage design and discovered that a stronger chassis was required for the Global GT1 engine. It is anticipated that the material has a safe service life of at least ninety minutes at 11,000 RPM. Scale accumulation in the steel caused microcracks to develop, which spread under fatigue stress and eventually caused the item to fail unexpectedly. Due to improper refurbishment or sulfurized oil, the fracture surface displayed brittle inclusions that were sulfurized. The connecting rod broke towards the conclusion of the exhaust stroke, mostly as a result of fatigue loading, and the engine management system heard noises prior to failure. Based on estimates, the maximum bending stress at the shank centre would be equivalent to 25% of the maximum stress after a single engine cycle. The highest stress found at the large end of the FE simulation corresponds with the real fracture location.

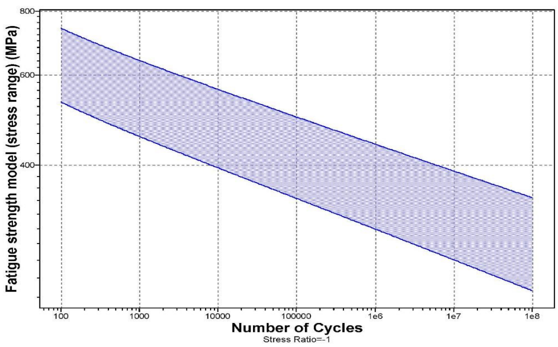

Figure 7: Probable fatigue strength vs fatigue cycle of low alloy steel AISI 4140.

Cervelin et al. (2019) introduced a novel method for signal conditioning force measurements in crank-slider systems. Utilising data processing methods, by using this method, the connecting rod force is less affected by interference and noise. The immediate IMEP approach serves as its foundation. The method was tested on a small-sized sintered connecting rod, which reacted linearly to static axial forces. Dynamic tests were performed to confirm that the approach is applicable. The anticipated outcomes of the static and dynamic testing showed that, at least in low-frequency situations, glueing a tee rosette to the midspan of a connecting rod can convert it into a force transducer. Since the friction forces within the slider crank are usually larger than the 6 N taken into consideration in the study, consistent connecting rod outcomes are anticipated to be superior. The same SNR may be maintained by using a low-pass filter with a smaller pass band. As a result of the suggested measuring method, the results may be directly tested in reciprocating machine applications, which makes them pertinent to the research of mechanisms and mechanical compound design. An improved representation of real behaviour is made possible by the dynamic connecting rod stresses, which can record friction forces, motor torque, instantaneous pressure, and other data immediately inside the machine. Further tests are needed to ensure the method provides coherent results at higher speeds.

5 CONCLUSIONS

In piston engines, the connecting rod plays a critical role in transferring loads from the piston to the crankshaft. Diesel engines with high torque at low rotation rates put a lot of stress on the crankshafts, pistons, and other engine parts. The fatigue strength of the rod is limited by several factors, including mistakes in material composition, technical malfunctions, and poor design. This study employs both computational and experimental investigation of the failure of a connecting rod using advanced stress analysis utilizing the finite element method (FEM).

The results exhibited that the main cause of failure in connecting rods was excessive bending stress, leading to cracks and ultimately fractures. Additionally, the study highlighted the importance of proper material selection and design considerations in improving the fatigue strength of connecting rods in piston engines.

The surface finish and heat treatment processes play a crucial role in enhancing the durability of connecting rods.

Overall, a holistic approach that considers all these factors is essential for preventing failures and improving the performance of connecting rods in piston engines. Furthermore, regular inspection and maintenance of connecting rods can help identify potential issues before they lead to catastrophic failures. By implementing these measures, engine manufacturers can ensure the reliability and longevity of their products.

REFERENCES

Abdusalam MH, Prabhat KS & Arvind SD “Design and Analysis of Connecting Rod Using Aluminium Alloy 7068 T6, T6511”, International Journal of Mechanical Engineering and Technology (IJMET), 2014, Vol 05, pp: 57-69.

Abhishek Kumar &. Pankaj Panday “Comparative Study of Connecting Rod Materials Using NumericTechnique”, International Journal of Innovative Trends in Engineering (IJITE), 2019, Vol 08, pp: 19-26.

Akbar Khan H, Dhananjay RD & Mirza MM “Experimental Stress Analysis ofTwo-Wheeler Connecting Rod Using Photoelasticity”, IJARIIE, 2016, Vol 02, pp: 1141-1150.

Ambrish Tiwari, Jeetendra Kumar Tiwari & Sharad Kumar Chandrakar “Fatigue Analysis of Connecting Rod Using Finite Element Analysis to Explore Weight and Cost Reduction Opportunities for a Production of Forged Steel Connecting Rod”, International Journal of Advanced Mechanical Engineering, 2014, Vol 04, pp: 782-802.

Andoko& Nanang Eko Saputro “Strength analysis of connecting rods with pistons using finite element method”, MATEC Web of Conferences 204, 2018.

AndokoAndoko, Imam Muda Nauri, Paryono Paryono, Pradhana Kurniawan, Dhanang Reza Pradica, Raymond Philander Jeadi, RiduwanPrasetya, and TurnadLenggo Ginta “Failure Analysis of Connecting Rod”, AIP Conference Proceedings 2262, 2020.

Antony S, Arjun A &Shinos TK “Design and Analysis of a Connecting Rod”, International Journal of Engineering Research & Technology (IJERT), 2016, Vol 05, pp: 188-192.

Bari K, Rolfe A, Christofi A, Mazzuca C & Sudhakar KV “Forensic Investigation of a Failed Connecting Rod from a Motorcycle Engine”, Case studies in engineering failure analysis, 2017.

Daramy Vandi Von Kallon & Bai Kamara “FEA of a Lab-Scale IC Engine Connecting Rod”, Proceedings of the 2nd African International Conference on Industrial Engineering and Operations Management Harare, 2020

DewenJiaa, Yunpeng Lia, Xiwen Denga, Jilin Leia& Wei Dengb “Design research on forging mark of connecting rod”, Engineering Failure analysis, 2019.

Ebhojiaye RS &Eboigbe CI “Design and Analysis of 80cc, 4-Stroke Spark Ignition Engine Connecting Rod”, Journal of Science and Technology Research, 2022, Vol 4, pp: 278- 288.

Fanil Desai, Kirankumar Jagtap&Abhijeet Deshpande “Numerical and Experimental Analysis of Connecting Rod”, International Journal of Emerging Engineering Research and Technology, 2014, Vol 2, pp: 242-249.

Fengjun Zhang and Yi Zhang “Setting of Natural Fracture Splitting Surface on Connecting Rod and Its Formation Mechanism”, Metals, 2020, Vol 10.

Fuertes JP, Murillo O, Leon J, Luis C, Salcedo D, Puertas I &Luri R “Mechanical properties analysis of an Al-Mg alloy connecting rod with submicrometric structure”, Procedia Engineering, 2015, Vol 132, pp:313 – 318.

Fuertes JP, Luis CJ, Luri R, Salcedo D, Leon & Puertas “Design, simulation and manufacturing of a connecting rod from ultra-fine-grained material and isothermal forging”, Journal of Manufacturing Processes, 2016, Vol 21, pp: 56–68.

Gu Z, Yang S, Zhao Y & Dai X “Fracture splitting technology of automobile engine connecting rod”, Int J Adv Manuf Technol ,2005, Vol 25, pp; 883-887.

Leonardo Cervelin, Carlos AF, Rodolfo CCF, Julio NS & Cesar AP “Measurement of the friction forces between piston and cylinder in reciprocating machines using the connecting rod strain behavior”, Mechanical Systems and Signal Processing, 2019, Vol 130, pp: 677-691.

Mohsin Ali MH & Mohamed Haneef “Analysis of Fatigue Stresses on Connecting Rod Subjected to Concentrated Loads at The Big End”, Materials Today, 2015, Vol 02, pp: 2094 - 2103.

Momin atharuddin, sandeepkumar JA, Hussain P & Mallikarjuna reddy P “design & analysis of a connecting rod with Different materials”, Journal of engineering science, 2019, Vol 10, pp: 184-196.

Murthy BSN, Adarsh Kumar K, Abdul MS, Praveen SSS “Design and Analysis of Connecting Rod for Weight and Stress Reduction”, International Journal of Engineering Research & Technology (IJERT), 2019, Vol 07.

Mustafa Guven Gok & Omer Cihan “Investigation of Failure Mechanism of a DCI Engine Connecting Rod”, European Journal of Technique, 2021, Vol 11, pp: 222-22.

Nitturkar HD, Kalshetti SM &Nadaf AR “Design and Analysis of Connecting Rod using Different Materials”, International Research Journal of Engineering and Technology (IRJET), 2020, Vol 07, pp: 1011-1017.

Poppy Puspitasari, Dewi IzzatusTsamroh,MochamadAchy arsyah, Beny Bandanajaya and Dewi puspitasari “Multistage artificial aging optimization for tensile properties of Duralium using Response Surface Method (RSM)”, MATEC Web of Conferences 204, 2018.

Pradeep Kumar D & Prakash Kumar P “A Review on Analysis of Connecting Rod Using Finite Element Method”, International Journal of Science, Engineering and Technology, 2023.

Prasanta Kumar Samal, Murali B, Abhilash &Tajmul Pasha “Finite Element Analysis of Connecting Rod of IC Engine”, MATEC, 2015.

Prathamesh SG, Vijay BR, Vijaykumar J, Kuldeep A, Mahajan Sachin RK & Anil Shirgire, European Chemical Bulletin, 2023, Vol 12, pp: 2861-2871.

Priyabrata Parida, Mausam Acharya, Ajay Purty & Chandan Soren "Analysis of Connecting Rod Under Different Material Condition", International Journal of Engineering Research & Technology (IJERT), 2021, Vol 10, pp: 616- 628.

Puran Singh, Debashis Pramanik & Ran Vijay Singh "Fatigue and Structural Analysis of Connecting Rod's Material Due to (C.I) Using FEA", International Journal of Automotive Engineering and Technologies, 2015, Vol 04, pp: 245-253.

Ramani JD, Sunil Shukla & Pushpendra KS "FE-Analysis of Connecting Rod of I.C.Engine by Using Ansys for Material Optimization", Journal of Engineering Research and Applications, 2014, Vol 04, pp: 216-220.

Rasa Kandrotaitė J "Behaviour of Truck's Compressor's Connecting Rods Made of Aluminium Alloy under Different Manufacturing Conditions", Transport, 2016, Vol 31, pp: 41-46.

Rianti Dewi Sulamet-Ariobimo, Muhammad Fadhlan, Yoska Oktaviano, Tono Sukarnoto, YusepMujalis& Amal Witonohadi "The effects of I-Beam thickness to microstructure and compression load of thin wall ductile iron connecting rod", International Journal of Lightweight Materials and Manufacture, 2023, Vol 06, pp: 392-404.

Roger Rabb "Fatigue Failure of a Connecting Rod", Wartsila Diesel International Ltd, 1995, pp: 97-112.

Saharash Khare, Singh OP, Bapanna Dora K &Sasun C "Spalling investigation of connecting rod"Engineering Failure Analysis, 2012, Vol 19, pp: 77-86.

Satish Sanjeev Marathe & Prayag Satish Patil "Modelling and Analysis of Connecting Rod for Multicylinder Engine by FEA Approach", Indian Journal of Applied Research, 2020, Vol 10.

Selvakumar S, Abhinand P, Ajai Baranidaran, Aswin Paroli& Mebin Thomas "Analysis and Evaluation of connecting rod using composite materials (Al+SiC)", International Journal of Advances in Engineering and Management (IJAEM), 2021, Vol 03, pp: 01-11.

Shaik Rafi & Amara Nageswara Rao "Design and Numerical Analysis of Connecting Rod with Different Materials", International Journal of Research Publication and Reviews, 2023, Vol 04, pp: 2133-2142.

Shubham Chougale "Thermal and Structural Analysis of Connecting Rod of An Ic Engine", Journal of Emerging Technologies and Innovative Research (JETIR), Vol 04, pp: 209-215.

Slavko Rakic, UgljesaBugaric, Igor Radisavljevic& Zeljko Bulatovic "Failure analysis of a special vehicle engine connecting rod", Engineering Failures Analysis, 2016.

Strozzi A, Baldini A, Giacopini M, Bertocchi E & Mantovani S "A Repertoire of Failures in Connecting Rods for Internal Combustion Engines, And Indications on Traditional and Advanced DESIGN METHODS", Engineering Failures Analysis, 2015.

Sudheer Singh K, Amit Agrawal & Koli CS "A Review Study on Simulation Analysis of Connecting Rod of Engine", International Journal of Science, Engineering and Technology, 2021.

Tanya Buddi & Rana RS "Fabrication and finite element analysis of two-wheeler connecting rod using reinforced aluminum matrix composites Al7068 and Si3N4", Materials Today: Proceedings, 2021, Vol 44, pp: 2471–2477.

Veda Prakash V "Connecting Rod Testing for Improvement of Engine Performance with Nano Composite Material Approch", International Journal of Mechanical Engineering, 2021, Vol 06, pp: 4344- 4352.

Velliyangiri B & Vinothkumar S "Design Analysis and Comparative Mechanical Properties of Al -Metal Matrix S.I Engine Connecting Rod", International Research Journal of Modernization in Engineering Technology and Science, 2022, Vol 04, pp: 5995- 6000.

Vinay Kumar K, Mahesh M, Sharan P, Gopi J & Venkatesh J "Design and Analysis of a Connecting Rod", International Journal of Research in Engineering, Science and Management, 2019, Vol 02, pp: 401- 405.

Vinayakrao BA & Swami MC "Analysis and Optimization of Connecting Rod used in Heavy Commercial Vehicles", International Journal of Engineering Development and Research, 2017, Vol 05, pp: 684-707.

Yoo YM, Haug EJ & KK Choi "Shape Optimal Design of an Engine Connecting Rod", Journal of Mechanisms, Transmissions, and Automation in Design, 1984, Vol 106, pp: 415-419.

Yu Li, Jinke Gong, Wenhua Yuan, Jun Fu, Bin Zhang and Yuqiang Li "Experimental investigationoncombustion, performance, and emissions characteristics of butanol as an oxygenate in a spark ignition engine", Advances in Mechanical Engineering, 2017, Vol 09.

Zhongjian Pan & Yi Zhang "Numerical investigation into high cycle fatigue of aero kerosene piston engine connecting rod", Engineering Failure Analysis, 2020.

Zhou Shi &Shuqing Kou "Inverse Reconstruction of Fracture Splitting Connecting Rod and its Strength and Fatigue Life", J Fail. Anal. and Preven, 2018.

Zhu Jun-chao, Zhu Han-hua, Fan Shi-dong, Xue Liang-jun& Li You-feng "A Study on the influence of Oil film lubrication to the Strength of Engine Connecting Rod Components", Engineering Failures Analysis, 2015.