MODAL AND KINEMATIC ANALYSIS OF A CONNECTING ROD FOR DIFFERENT MATERIALS

Kaliappan S¹, Revanth Raam AP ³, Charan B ⁴, Asswin S ⁵, Mohammed Ibrahim SM ⁶, Dr. T. Mothilal ⁷, M.D. Rajkamal ⁸

1 Associate Professor, Department of Mechanical Engineering, Velammal Institute of Technology, Chennai, India. kaliappa@yahoo.com
2 UG Student, Department of Mechanical Engineering, Velammal Institute of Technology, Chennai, India.
3 Professor, Department of Mechanical Engineering, Velammal Institute of Technology, Chennai, India.
4 Assistant Professor, Department of Mechanical Engineering, Velammal Institute of Technology, Chennai, India.

Abstract—The connecting rod is a vital component of any engine, which undergoes several stresses while in motion. The design of this component is very crucial to improve the durability of the engine and the mechanical efficiency of it. The main objective of this paper is to perform a modal analysis for the connecting rod for different materials as well as perform a kinematic analysis to verify their motion characteristic complies with the standard motion. The modal analysis helps in finding the natural frequency for the geometry of connecting rod for different materials. We are focusing in reducing the weight of the connecting rod by choosing the appropriate material that is safe and suitable for the task. Reducing the weight of the connecting rod not only improves the overall efficiency of the engine but also saves cost and unnecessary balancing weights for the rod. The requirement of strength for the connecting rod is preferred to make it durable.

Keywords—Connecting rod, Kinematic analysis, Weight optimization, Modal analysis.

I. INTRODUCTION

The connecting rod is best known for its use in internal combustion piston engines, such as automobile engines. A connecting rod is a shaft, which connects a piston to a crank or crankshaft in a reciprocating engine. Together with the crank, it forms a simple mechanism that converts reciprocating motion into rotating motion. Connecting rods in internal combustion engines are subjected to high cyclic loads comprised of dynamic tensile and compressive loads. They must be capable of transmitting axial tension and compression loads, as well as sustain bending stresses caused by the thrust and pull of the piston and by the centrifugal force of the rotating crankshaft.

The modern connecting rod is made of materials that include alloy elements of titanium, aluminum, magnesium, and polymeric connecting rods. Connecting rods for automotive applications are typically manufactured by forging from either wrought steel or powdered metal. They could also be cast. However, castings could have blow-holes, which are detrimental from durability and fatigue points of view. The fact that forgings produce blow-hole-free and better rods gives them an advantage over cast rods.

The connecting rod being such an important component for the engine has a great potential to help in improving the mechanical efficiency of the Engine. Since the connecting rod has so much potential to improve the overall efficiency of an engine, it has been the topic of research for decades. That is why we have decided to perform kinematic as well as modal analysis to find ways to improve the durability of the component as well as improve the efficiency. The modal analysis will help us to identify the natural frequencies of the connecting rod at different modes, which is crucial for the paper.

Kinematic analysis of a mechanism consists of calculating position, velocity and acceleration of any of its points or links. To carry out such an analysis, we have to know linkage dimensions as well as position, velocity and acceleration of as many points or links as degrees of freedom the linkage has. The commonly used methods to calculate such parameters are the relative velocity method and the instant center of rotation method.

II. LITERATURE REVIEW

A literature review is a text of a scholarly paper, which includes the current knowledge including substantive findings, as well as theoretical and methodological contributions to a particular topic. Literature reviews are secondary sources, and do not report new or original experimental work.

There is a vast amount of literature available in the design and analysis of Connecting rods. The literature survey done mainly focuses on three areas of interest. The areas of interest for the literature survey were mainly focused on Material Selection, Kinematic Analysis, Modal Analysis and Failure Analysis of the rod.

- Mustafa Kemal Kulecki [2007]

His paper on “Magnesium and its alloys applications in automotive industry” provides us with info about the properties of Magnesium and its alloys which make them a desirable material for connecting rod. Magnesium is the lightest of all the engineering metals, having a density of 1.74 g/cm3. It is 35% lighter thanaluminum (2.7 g/cm3) and over four times lighter than steel(7.86 g/cm3). The light weight property of Mg and its alloy is biggest advantage of this material when compared to others. Specific strength and specific stiffness of materials and structures are important for the design of weight saving components. The specific stiffness of Al and Fe is...
higher than Mg only in the ratio of 0.69% and 3.752%, respectively. On the other hand, the specific strength of Mg is considerably higher than that of Al and Fe in the ratio of 14.075% and 67.716%, respectively. Greater demand for reduced emissions and better fuel economy in passenger vehicles are the driving forces behind the expanding the use of magnesium. Weight reduction through Mg applications in the automotive industry is the effective option for decreasing fuel consumption and CO2 emissions. Developed magnesium alloys that withstand higher temperatures will enhance the usage of Mg in manufacturing engine blocks and transmission housings. Recently developed Mg-Al-Sr systems have excellent mechanical properties, good corrosion resistance and excellent castability. Mg alloys with Sr addition has better creep resistance than other alloy systems. Magnesium alloys can be joined by mechanical assembling and welding. A 22% to 70% weight reduction is possible for automotive components by using Mg alloys instead of alternative materials. The components that are made of Mg alloy have better strength-to-density ratio, ductility and energy absorbing characteristics. The disadvantages of Mg alloys are high reactivity in the molten state, galvanic corrosion resistance, fire hazard, inferior fatigue and creep. The design of the Mg alloy parts is important for adequate drainage, to prevent the accumulation of corrosive substances, such as water/moisture. Fe, Ni and Cu reduce the corrosion resistance of Mg alloys.

- J.W. Qiu, et al [2011]

They conducted a research to study the mechanical properties of titanium alloy connecting rod made by powder forging process. In this process, the microstructures of the material were also studied. The study concluded that two different types of microstructures exist in the powder forged parts: a lamellar α + β microstructure and a through-transus (necklace type) microstructure consisted by the fine martensite microstructure and equiaxial grains with branched internal dendrites, which only forms in the shank of the connecting rod.

- DR.B.K. Roy [2012]

He performed Design Analysis and Optimization of Various Parameters of Connecting Rod using CAE Softwares. Various designs of connecting rod were analysed and finally an optimal design was selected for Finite Element Analysis. Stress, Strain, Deformation, Life, Damage, Biaxiality Indication etc. were studied and analysed to get the good design parameters with taking into account the safe permissible stresses and factors which would affect the design if not taken into account.

- Suraj Pal, et al [2012]

They performed Design Evaluation and Optimization of Connecting Rod Parameters Using FEM. FEA Results obtained from design-optimized connecting rod has given sufficient improvement when compared to existing results. Weight of the connecting rod was reduced by 0.477g and thus inertia force has also been reduced. Fatigue results were also good in agreement with existing results. Stress was found to be maximum at piston end so material has been increased in stressed portion.

III. CALCULATIONS

The design of components essentially deals with finding out the dimensions or specifications for the connecting rod, the piston, the crankshaft, etc based on the Engine specification we have taken into consideration. This part therefore deals with the calculations that will help us obtain the necessary dimensions required for modeling the connecting rod.

The calculations were carried out based on an existing Kirloskar Engine and the dimensions for the connecting rod as well as all the other components were obtained with that as the basis. The calculation was divided into two parts for the calculation of the loads and pressure acting on the components of the Engine in one part and obtaining dimensions for the components based on the values obtained in the first part.

The following are the calculations associated with engine parameters.

Bore = 87.5 mm
Stroke = 110 mm
Rated Speed = 1500 rpm
Rated Output = 6 hp
Torque = 28.65 Nm

For Connecting Rod & Crank Shaft,
Crank radius = l / 2 = 110 / 2 = 55 mm
Where, l = Length of stroke.

For Low-Speed Engines,
Assume => L / r = 4.1
where, L - length of connecting rod
r - crank radius

L = 4.1 * crank radius = 4.1 * 55 = 225 mm.

A = 11t²

Pₐ = σ₀A
[1+a(L/K₁⁺)²]

Vacuum Pressure for the Engine,

P₁V₁ = Mrt₁

P₁ = mRT₁
V₁

R value specific for air,
P₁ = 1.225Kg * 287.058 J/KgK * 305 K
P₂ = 107.252 * 10³ N/m²
P₂/P₁ = (C.R)²

C.R – Compression Ratio, γ = 1.4
P₂ = P₁ (C. R)² = 0.107 * (17.5)¹.⁴ = 5.883 N/mm²
Force acting on Connecting Rod,
\[ F_c = \frac{\pi D^2}{4} P^2 \text{N/mm}^2 \]
\[ F_c = 35378.794 \text{ N} \]
\[ F_c = 35.378 \text{ KN} \]
Let we assume Factor of Safety (FoS) = 5
\[ F_s = F \text{(FoS)} \]
where, \( F_s \) – Critical Buckling Load
\[ F_s = 35.378 \times 5 \]
\[ F_s = 176.893 \text{ KN} \]
By Rankine’s formula,
\[ F_s = \frac{\sigma_c A}{[1 + a(L/K_{xx})^2]} \]
\[ \sigma_c = 330 \text{ N/mm}^2 \]
\[ a = 1/7500 \]
\[ K_{xx} = 1.78t \]
\[ A = 11t^2 \]
Assume the material as steel,
\[ 176.893 \text{ KN} = \frac{330 \text{ N/mm}^2 \times 11t^2}{[1 + (1/7500)(225/1.78t)^2]} \]
\[ t = 7 \text{ mm} \]
With \( t = 7 \text{ mm}, \) the specifications for the Engine components are calculated. The cross-section of the connecting rod is assumed to be I-section.

The following are the calculations associated with the Specification of Engine components.
\[ t = 7 \text{ mm} \]
\[ B = 4t = 28 \text{ mm} \]
\[ H = 5t = 35 \text{ mm} \]
At middle section, \( H = 5t = 35 \text{ mm} \)
At bottom section, \( H = 1.5t = 43.75 \text{ mm} \)
At top section, \( H = 0.9t = 31.5 \text{ mm} \)
\[ P_s = d_c l_p (P_b) \]
\[ d_p = \text{diameter of piston pin} \]
\[ l_p = \text{length of piston pin} \]
\[ (P_b) = \text{allowable bearing pressure} \]
\[ F_c = d_c l_p (12.5 \text{Mpa}) \]
The allowable bearing pressure of 12.5Mpa.
\[ l_p = 2d_p = 2 \times 43.75 \]
\[ l_p = 87.5 \text{mm} \]
For big end,
\[ P_s = d_c l_p (P_b) \]
\[ 35378.794 = d_c l_p (10 \text{N/mm}^2) \]
\[ 35378.794 = 1.25d_c^2 (10) \]
\[ d_c = 53.20 \text{mm} \]
\[ (l/d_c) = 1.25 \]
\[ l_c = 66.50 \text{mm} \]
Nominal diameter = \( d_c/0.8 \)

The distance between the center,
\[ l = \text{dia of crank pin} + 2(\text{thickness of bush}) + \text{nominal dia of bolt (d)} + \text{clearance} \]
\[ l = 53.20 + 2(3) + d + 3 \]
\[ P_i = 4222.18 \text{ N} \]
\[ \sigma_t = 60 \text{ N/mm}^2 \]
\[ P_i = 2(\pi d_c^2/4) \sigma_t \]
\[ d_c = 6 \text{mm} \]
\[ d = 6/0.8 = 7.5 \]
\[ d = 8 \text{mm for M8} \]
\[ M_b = (P_i)_{\text{max}} D/6 \]
\[ l = 53.20 + 2(3) + 8 + 3 = 70.2 \text{mm} \]
\[ l = 71 \text{mm} \]
\[ M_b = (4222.18 \times 71) / 6 = 49962.46 \text{Nmm} \]
\[ M_b = 49.96 \text{Nm} \]

Outside diameter for big end = \( d_c + 2t_c \)
\[ = 53.20 + 8 \]
\[ = 62.5 \text{mm} \]
Outside diameter for small end = \( d_c + 2t_b \)
\[ = 43.75 + 2(4) \]
\[ = 53 \text{mm} \]

IV. DESIGN AND MODELING

The design and modeling for the components and the analysis done were made possible with the help of Computer Aided Engineering. We have made use of various softwares categorized under the CAE to aid us in performing the analysis and obtain the results. The software used for modeling and analysis were Creo, CATIA and ANSYS. Using the specifications obtained through calculations the modeling was done in Creo.

The design part was done in detail to obtain the dimensions required for the modeling of the components. These
dimensions will be used in the software which comes as a part of Computer Aided Engineering. The software that we chose to do the modeling was Creo. The reason for choosing Creo is due to its easy user interface and the powerful features it offers to design the required components with much less effort.

The following is the procedure followed to create the models in Creo:

In this part, the detailed procedure for modelling parts in Creo is explained for understanding the basics behind modelling in Creo.

- First the design calculations for the Connecting rod, Piston, Cylinder Block & Crank Shaft is done by obtaining the necessary data.
- Then the collected data’s and calculations are put together and evaluated using Design Data Book.
- After evaluation a rough sketch of the designs are made.
- Now using the sketch, a solid 3D model of connecting rod is drawn using the CREO Parametric 2.0 tool in .prt format.
- Similarly, the Piston Cylinder Block, Crank Shaft, Bolt & the Nut are also drawn as individual part files in .prt format.
- Now the Assembly module is opened and the Connecting Rod is included as a base model.
- The other part files are included one by one and are constrained together with the Connecting Rod.

The options used in drawing the part files are,
1. Sketch,
2. Extrude,
3. Round.

The constrains used in assembling the part files together are,
1. Automatic,
2. Parallel,
3. Normal,
4. Angle Offset,
5. Coincident.

The above list shows the fundamental tools used in the modeling process. The apparent size of this list shows the less effort needed to do modeling of components in Creo. It clearly shows how simple it is to model components with the help of Creo. This is one of the many reasons for choosing Creo for the modeling part in our project.

The modeling of the components in 3D were done with the help of Creo 3.0 Parametric Software. The part diagrams drawn were assembled in CATIA for Kinematic analysis and imported to Ansys for Modal analysis.

The following are the models that were created using Creo software.
From the literature survey we did, we were able to finalize the materials we think would be suitable for the task. We have decided to use three different materials all of which belong to the alloy family. The reason for choosing alloy is due to the many advantages they possess compared to metals.

The following are the Material Alloys finalized for Analysis:

1. Aluminium Alloy 7068
2. Magnesium Alloy AZ91
3. Titanium Alloy Ti 6Al-4V (Grade 5)

There are many reasons for choosing these three materials for the analysis part. Aluminium Alloy happens to be the most widely used material in the manufacturing of connecting rod while Due to low fatigue life, when used under high stress situations drag racing only. It can be used safely with daily driving. Aluminium rods are the best choice for DSM’s, strong and light. Titanium is used mainly where the engine produces high horsepower and revolves at high rpm compared to other engines. That is why it can be use in daily driving, endurance racing, and drag racing. Magnesium Alloy is used in making the different parts in automotive industry but the cases of implementing it for connecting rod seems rare. Of the three materials Magnesium Alloy happens to be the cheapest material available in our country at present. The analyses we’ll perform will help us in understanding the reason for why certain materials is preferred over the other for the making of a connecting rod. That is one of the reason for choosing these materials.

The following table shows of comparison of the physical properties of the three different materials taken into consideration. The properties taken into consideration for preference is the density of the material as our main focus lies on reducing the weight of the connecting rod and so the material which is less dense is to be preferred and the analysis will help in determining whether it is safe in the frequency domain.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Properties</th>
<th>Aluminium Alloy 7068</th>
<th>Magnesium Alloy AZ91</th>
<th>Titanium Alloy Ti 6Al-4V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Density (kg/m³)</td>
<td>2770</td>
<td>1800</td>
<td>4620</td>
</tr>
<tr>
<td>2</td>
<td>Thermal Expansion Coefficient (°C)</td>
<td>2.3 x 10⁻⁵</td>
<td>2.6 x 10⁻⁵</td>
<td>9.4 x 10⁻⁵</td>
</tr>
<tr>
<td>3</td>
<td>Specific Heat (J/kg°C)</td>
<td>875</td>
<td>1024</td>
<td>522</td>
</tr>
<tr>
<td>4</td>
<td>Yield Strength (MPa)</td>
<td>280</td>
<td>193</td>
<td>930</td>
</tr>
<tr>
<td>5</td>
<td>Ultimate Strength (MPa)</td>
<td>310</td>
<td>255</td>
<td>1070</td>
</tr>
<tr>
<td>6</td>
<td>Young’s Modulus (GPa)</td>
<td>71</td>
<td>45</td>
<td>96</td>
</tr>
<tr>
<td>7</td>
<td>Poisson’s Ratio</td>
<td>0.33</td>
<td>0.35</td>
<td>0.36</td>
</tr>
<tr>
<td>8</td>
<td>Bulk Modulus (GPa)</td>
<td>69.6</td>
<td>50</td>
<td>114.3</td>
</tr>
<tr>
<td>9</td>
<td>Shear Modulus (GPa)</td>
<td>26.7</td>
<td>16.7</td>
<td>35.3</td>
</tr>
</tbody>
</table>

Table 1: Comparison of Properties

VI. MODAL ANALYSIS AND RESULTS

Modal analysis is the study of the dynamic properties of systems in the frequency domain. Modal analysis calculates the natural frequencies of the system alone. Modal is the simplest analysis and the only thing it does is give the “resonance frequencies” of the geometry. It is not related to a loading at this stage, only to the geometry. Resonance frequencies change due to the shape of your model and the way it is constrained only.

In physics, resonance is a phenomenon in which a vibrating system or external force drives another system to oscillate with greater amplitude at specific frequencies. Frequencies at which the response amplitude is a relative maximum are known as the system’s resonant frequencies or resonance frequencies.

The following is the procedure followed for modal analysis:
- The assembled part files from Creo is first to be imported through the IGES format.
- The imported model is given the proper connections for the meshing process.
- Once the connections are done, the part has to be meshed.
- The mesh that has been selected is fine mesh with a relevance of 1 and adaptive curvature.
- The type of mesh may be varied depending on accuracy and computer’s processing power.
- The analysis settings are set for modal analysis of six nodes and the required solutions are added.
- The solution is evaluated for all the six nodes and the natural frequency are obtained.
- The natural frequencies of the three materials are compared to find out which one is better.

The following are the result obtained for various materials.

**Aluminium Alloy 7068**
The Figure 6 shows the equivalent Von-Mises Stress induced on the connecting rod.

From the Figure 6 shown above it is clear the connecting rod experiences a minimum Von-Mises stress of 529 kPa at both ends and a maximum of 205 GPa near the Big end of the connecting rod. Theses stresses are induced at a natural frequency of 338.7 Hz.

The natural frequencies obtained for the connecting rod made of Aluminium Alloy 7068 for all the six modes is plotted in the form of graph in Figure 7 and is represented below.

**Magnesium Alloy AZ91**
The Figure 8 shows the equivalent Von-Mises Stress induced on the connecting rod.

From the Figure 8 shown above it is clear that the connecting rod experiences a minimum Von-Mises stress of 30.72 kPa at both ends and a maximum of 5.6 GPa near the Big end of the connecting rod. Theses stresses are induced at a natural frequency of 333.73 Hz.

The natural frequencies obtained for the connecting rod made of Magnesium Alloy AZ91 for all the six modes is plotted in the form of graph in Figure 9 and is represented below.

**Titanium Alloy Ti 6Al-4V**
The Figure 10 shows the equivalent Von-Mises Stress induced on the connecting rod.

From the Figure 10 shown above it is clear that the connecting rod experiences a minimum Von-Mises stress of 529 kPa at both ends and a maximum of 205 GPa near the Big end of the connecting rod. Theses stresses are induced at a natural frequency of 338.7 Hz.
The natural frequencies obtained for the connecting rod made of Titanium Alloy Ti 6Al-4V for all the six modes is plotted in the form of graph in Figure 11 and is represented below.

![Fig. 11 Mode vs. Frequency Titanium Alloy](image1)

The comparison of the natural frequencies for the materials used for analysis is plotted in the form of graph in Figure 12 below.

![Fig. 12 Graph for comparison Natural Frequencies](image2)

**Interpretation of Modal Analysis**

From the Mode shapes and Natural Frequencies obtained in the Modal Analysis of the Connecting Rod, we can conclude as to which material to choose which will satisfy our criteria. The following is the summary:

1. The Aluminium Alloy 7068 has the highest Natural Frequency at Mode 1 and the rest of the modes.
2. The Magnesium Alloy AZ91 has the lowest density compared to all other alloys in the analysis.
3. The Titanium Alloy Ti 6Al-4V has the highest strength of all the alloys in comparison.
4. The Natural Frequencies of Magnesium AZ91 is very close to that of Aluminium 7068.
5. The Mode shapes of all the three materials resemble each other with very slight variations for all the six modes.
6. The material with the highest Poisson ratio seems to have the highest resonant frequency.
7. The Equivalent Von-Mises stress induced in greatest for Aluminium Alloy and least in Magnesium Alloy.
8. The Total Deformation is a maximum for Aluminium Alloy and minimum for Titanium Alloy for the resonant frequency.

**VII. KINEMATIC ANALYSIS**

Kinematic analysis of a mechanism consists of calculating position, velocity and acceleration of any of its points or links. To carry out such an analysis, we have to know linkage dimensions as well as position, velocity and acceleration of as many points or links as degrees of freedom the linkage has. The commonly used methods to calculate such parameters are the relative velocity method and the instant center of rotation method.

The Kinematic Analysis was carried out with the help of CATIA software. The characteristics in Kinematics we wanted to study were:

1. Angular Speed Vs. Crank Angle
2. Angular Acceleration Vs. Crank Angle
3. Oscillation Angle Vs. Crank Angle

These characteristics were analyzed to verify if the motion of the connecting rod we have designed, complied with the motion of the existing connecting rod in usage. That is one of the reasons for performing the Kinematic Analysis.

The following is the procedure for Kinematic Analysis:

1. The part diagrams modelled in Creo are converted into CATIA part diagrams.
2. The converted part diagrams are then imported into the CATIA graphical user interface.
3. In the CATIA interface they are assembled together to form a CATIA product.
4. The assembled product is then designated into a mechanism by providing it with suitable constrains in motion.
5. After the Mechanism is entirely built it must be put into simulation to get the desired results.
6. The simulation can be done in two ways one of which is Simulation by command and the other is the Simulation with Laws.
7. Simulation with law is preferred as it gives us the required result with maximum accuracy.
8. This type of simulation requires certain formulas to make it simulate and get the parameters like acceleration, velocity, etc.

To get the graphical representation of the simulations certain sensors are used which are provided within the CATIA software. The following graphs were obtained in the Kinematic Analysis of the Connecting Rod. The three graphs have crank angle as the X-Axis plotted against Angular speed, Angular acceleration and Oscillation angle on the Y-Axis.
Interpretation of Kinematic Results

On performing the analysis, we found our results conforming to the standard motion of the connecting rod which is sinusoidal in nature. The results of kinematic analysis can be summarized as follows:

- The Connecting rod has a plane motion which is a combination of translation and rotation.
- The variation of angular displacement of connecting rod is sinusoidal in nature.
- The maximum angular velocity occurs at the end of the piston stroke and the minimum angular velocity occurs at the middle of the stroke.
- The motion of connecting rod almost resembles a Simple Harmonic Motion.
- The angular acceleration reaches maximum value at the middle of the stroke, while it reaches minimum value at the end of the stroke.

The Kinematic Analysis for different materials shows very negligible differences and hence the graphs were the same for all the three materials.

VIII. RESULTS

Kinematic analysis is performed over existing connecting rod and newly proposed connecting rod. The results of the kinematic analysis is obtained in the form of two graphs. One graph is plotted between Transmission angle vs. Pinion Angle and the other graph is plotted between Oscillation angle vs. Pinion Angle. The above mentioned kinematic analysis over the two different designs of connecting rod will be carried over using CATIA Software.

IX. CONCLUSION

From the results obtained from the analyses we see that Aluminium Alloy has the highest natural frequency in the modal analysis and that is why Aluminium Alloy is commonly used for manufacturing Connecting rod. However, we notice that the natural frequencies of Magnesium Alloy are very close to that of Aluminium Alloy, which makes it safe to be used as a material for connecting rod. Magnesium Alloy is the lightest among all other alloys, which helps in reducing the weight of the rod. In addition, Magnesium Alloy can be easily manufactured by Die Casting method, which is cost-effective for high volume production than Sand casting.

However due to the fracturing nature of Magnesium Alloy it cannot be used as connecting rod for high load engines. Therefore, we conclude that Magnesium is best suited for low load ranging applications. The reduced weight not only increases the efficiency of the device but also makes it durable. These devices include Lawn Mowers, Generators, Compressors, Pumps, etc.

The advantages of Magnesium AZ91 Alloy are as follows:

- Lowest density (~1.8 g/cm³) of all metallic constructional materials.
- High specific strength.
- Good castability, suitable for high pressure die-casting.
Good machinability.
High thermal conductivity.
High dimensional stability.
Good electromagnetic shielding property.
High damping characteristics.
100% recyclability.

REFERENCES