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Material Selection Report

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Engine Characteristics Performance

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Contents

1	Introduction	1
1.1	Aims	1
1.2	Objectives	1
2	Component Design Specification (CDS)	2
2.1	Functional requirements	2
2.1.1	Interference Requirements.....	2
2.1.2	Maintenance	2
2.1.3	Materials	3
2.1.4	Design.....	3
2.1.5	Life Cycle/ Sustainability	3
2.1.6	Cost.....	3
2.1.7	Testing	3
2.1.8	Quality control.....	4
3	Material Selection	5
3.1	Material Properties.....	5
3.2	Evaluation Matrix	6
4	Manufacturing Process Selection	8
4.1.1	Machining.....	8
4.1.2	Sand Cast.....	8
4.1.3	Close die forging.....	8
4.2	Tolerances	9
4.3	Finish.....	10
5	Conclusion.....	11
6	References	12

Figure 1 Shows a CAD model of a piston that was used to produce the drawing and connecting rod that can be fitted to a Duratec..... 1

Figure 2 Shows a labelled image of a connecting rod (Iyas 2021a) and crankshaft (WAYKEN Rapid Manufacturing 2023). 2

Table 1 Shows the properties of materials that can be used to produce a connecting rod. Research for cost of materials were conducted. The weight of the CR is between 0.5-0.7kg. The costs were calculated providing a range on how much one CR will cost (RoyMech). 5

Table 2 Shows all the materials that are under consideration and the advantages and disadvantages for each of them. 5

Table 3 is an evaluation matrix used to determine which material is best for the component. The evaluation matrix is used to determine which material is best for the application. A weight is decided

on certain factors that determine the success of the component. The weight must equal 1 or 100%. A rating is then decided on each material and then multiplied by the weight. The sum of the values is compiled, the highest total is the material that will be used to produce the CR.	6
Figure 3 Figure 4 Shows a labelled diagram of the sand-casting process. Diagram b is a representation of what would be completed if the CR would be produced using this process (Engineering Product Design, 2022).	8
Figure 4 Figure 5 Shows the close die forging process (Brooks Forging Ltd, 2024).	8
Table 4 Shows the manufacturing processes advantages and disadvantages that can be used to produce the connecting rod.	9

1 Introduction

This report will show a 2.0 Litre Ford Duratec connecting rod Component Design Specification (CDS) which will outline all the criteria the component needs to meet to be deemed successful. Factors such as environmental/sustainability, design, maintenance etc will be evaluated. Material selection will be covered, this will investigate varied materials that can be used to produce the component. Research into manufacturing processes is conducted and then compared to see which process is most efficient whilst producing the component within tolerance.

1.1 Aims

- To produce a Component Design Specification
- Choose a material which is cost effective with good material properties.
- Research and describe different manufacturing processes and decide which is most cost effective and efficient.

1.2 Objectives

- Research factors that will affect the production, maintenance and any environmental considerations of the product.
- Gather information regarding material properties and compare against one another.
- Investigate into the advantages and disadvantages of each manufacturing process and decide which is best for the application.



Figure 1 Shows a CAD model of a piston that was used to produce the drawing and connecting rod that can be fitted to a Duratec.

2 Component Design Specification (CDS)

The 2.0 Litre (2L) Ford Duratec connecting rod (CR) is a component that connects a piston to the crankshaft. It transfers forces from the piston pin to the crank pin. The CR has tensile forces acting on it through the power stroke as the piston moves downwards. This is due to the expanding gases in the combustion chamber. Throughout the compression stroke the piston has a compressive force acting on it, this force is transferred to the CR. Bending forces are applied, this is due to the nonlinear motions and the crankshaft. These forces accumulate near the crankshaft journal (Dipl.-Ing, Karl-Heinz Dietsche Prof. et al. 2022).

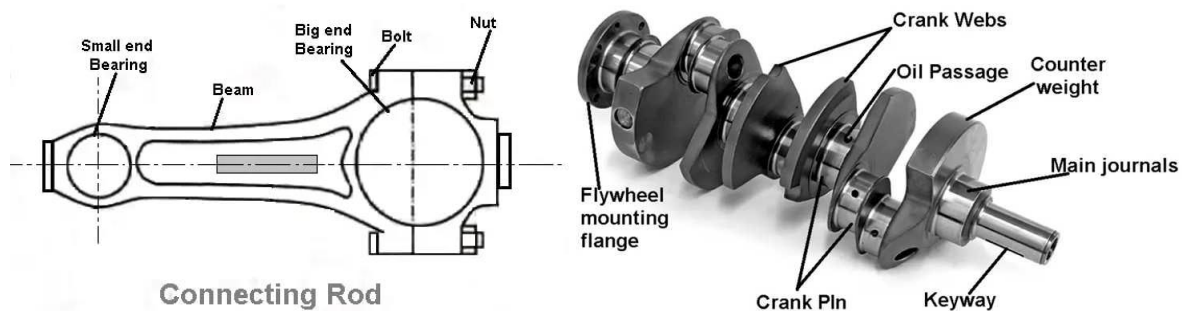


Figure 2 Shows a labelled image of a connecting rod (Iyas 2021a) and crankshaft (WAYKEN Rapid Manufacturing 2023).

2.1 Functional requirements

The CR must be able to have a load bearing capacity. Throughout the components life it will experience dynamic forces. The CR should have sufficient ability to withstand repeated periods of loading without fatigue failure. Engine components must be produced with tight tolerances if not, the engine could fail (Iyas 2021b).

2.1.1 Interference Requirements

The CR must fit bearings, these bearings are vital to the engine's performance. Bearings are placed in the big and small end of the CR. A gudgeon pin is used to attach the piston to the CR (Iyas 2021b). These pins can be press fitted or held in by a circlip. The power produced from the engine is transferred from the piston to the gudgeon pin through the CR to the crankshaft. To ensure maximum efficiency bearings are used to reduce friction. The inertia forces applied to the CR can ovalize the big end causing the bolts to bend outwards. If the bolt force is insufficient the CR bolted joint will open towards the crank journal pin side (MAHLE GmbH (Ed.) 2014).

2.1.2 Maintenance

The design should allow for easy installation and removal when servicing and repairing. Maintenance of the CR will include visual inspections ensuring that there are no stress fractures or excessive wear to the part. Inspected the bearing will give a greater understanding of how the CR is performing.

2.1.3 Materials

Durability and strength are most important as the CR will have to handle a wide range of high compressive loads from combustion and the tensile loads from inertia. If the CR's weight is high, it affects all the components connected to it. Weight can be minimised by reducing the length of the CR or lowering deck height.

2.1.4 Design

The shank of the connecting rod is an area which can help provide the most strength and durability whilst reducing the weight. The H profile is used in the motorsport industry because of the load it is under at high revolutions per minute (RPM). Furthermore, the design must ensure that the CR is balanced. If the CR is not balanced it can increase wear on the engine components whilst decreasing the engines efficiency. The CR and cap are individual to one another, this can be found by an identification number.

The geometry of the small end on the CR needs to be considered as it must withstand a large amount of surface pressure. The Parallel connecting rod design is typically used as it is simple and easy to produce. However, weight reduction can be carried out thus decreasing inertia forces. This means the small end can have a chamfer on it, therefore the lower part is wider than the upper. The lower part is subjected to larger forces thus making it larger than the upper (MAHLE GmbH (Ed.) 2014).

2.1.5 Life Cycle/ Sustainability

The life cycle of the component is dependent on how it is used. In motorsport it would be under increased stress constantly leading to potential failure. Integrating the H-shaped cross section closer to the big end will spread the stress evenly. The three areas of the component that can be improved to increase the life cycles are; the knuckle of the big end and the shank. The material chosen needs abundant and recyclable, this ensures sustainability whilst being cost effective. The process used needs to minimise waste and ensure it is not damaging the environment.

2.1.6 Cost

The cost of the component is reliant on the material and manufacturing process that is chosen. Additionally, factors such as utilities, delivery costs of materials, tools, hardware involved in the production need to be included. Material will be bought in bulk as it is cost effective. Forged CR's are sold range from £300 - £800 (Raceline). Hardware is often provided with the part, to minimise production costs sourcing parts from another company can be done.

2.1.7 Testing

A series of prototypes can be developed in Computer Aided Design (CAD) software. CAD can test the component's ability to withstand compressive, tensile and failure point using finite element (FE)

analysis. From these tests conducted in software the successful prototypes can be manufactured and fully tested by placing it within an engine.

2.1.8 Quality control

There specific measuring tools used to accurately gauge the success of a product. These include Vernier calliper, height gauges, micrometres and magnifier to inspect the part. These tools measure the component to check that it is within tolerance. If the tolerance is very small, then a coordinate measuring machine can be used to accurately measure the parts dimensions.

Additionally, it is important that the surface finish of the component is checked. This is vital for engine parts to ensure they are correctly sealing, lubricating and performing as they should. This is checked using surface roughness testers.

Non-destructive tests ensures the component is capable of performing.

- Ultra sonic testing – this process involves using a machine that emits ultra sonic waves to detect internal cracks and voids within the component.
- Magnetic Particle inspection – this process uses a magnetic powder to spot cracks or defects on the surface of the component. The component is magnetised and then the powder is applied to the part, the powder is then drawn to the defects on the part.

3 Material Selection

3.1 Material Properties

Table 1 Shows the properties of materials that can be used to produce a connecting rod. Research for cost of materials were conducted. The weight of the CR is between 0.5-0.7kg. The costs were calculated providing a range on how much one CR will cost (RoyMech).

Material	Density (g/cm ³)	Ultimate Tensile strength (MPa)	Yield strength. (MPa)	Youngs modulus (GPa)	Melting point (degrees)	Cost of material per CR (£)
Aluminium Alloy	2.7	600	400	70	660	0.89-1.25
Mild Carbon Steel	7.85	400-550	250	200	1450	0.22-0.31
Cast Iron	7.3	414	276	170	1150	0.34-0.47
Titanium Alloy	4.507	434	380	116	1668	6.82-9.55
Steel Alloy	7.85	572	545	200	1420	1.50-2.10

Table 2 Shows all the materials that are under consideration and the advantages and disadvantages for each of them.

Material	Advantages	Disadvantages
Aluminium Alloy	- Aluminium is an abundant material. - Good strength to weight ratio compared to other materials. - Performs very well under dynamic loading. - Can work in varied temperatures. - Due to the materials surface characteristics, a wide range of surface finishes can be applied. (AZO Materials 2008)	- Prices for aluminium alloys can be cheap but when compared to steel it can be costly. - Whilst aluminium has a good strength to weight ratio it is not as strong as other materials. (Sahana Shamshi 2022)
Mild Carbon Steel	- Mild steel has a lower carbon content. Good Machinability, the material is easy to shape and work with. - Mild steel is less expensive than typical steel. This is due to there being less chromium and other alloying elements (Pawle 2022).	- Heavy compared to other materials. - Material properties are not as good as the materials in Table 1.
Cast Iron	- Low-cost material. - Cast Iron has a high compressive strength tolerance with high wear resistance. - Cast Iron has good casting properties, Sand casting is cost effective and efficient process. This allows for a greater volume of components produced (SHAFI 2021).	- Cast iron is a brittle material because of this, the material cannot withstand large impacts. - Like Mild carbon steel it has a high strength to weight ratio. This means that if a CR were to be produced the weight of the part will be heavy.
Titanium	- Titanium is harder than steel whilst being lighter like aluminium. This makes it an ideal material for the CR as weight needs to be minimised to decrease the inertia forces and then strength to help withstand the compressive forces. - Excellent fatigue strength, this means if the CR were to come under stress the	- The extraction and production of the material causes the cost of material to be high. - Difficult to machine - Compared to aluminium it is not abundant, meaning there is a limited availability.

	material would be able to cope (Kabita Sharma 2023).	
Steel Alloys	- Low distortion allowing for finer tolerances to be achieved. - Cost effective material. - Machinability of the material is good. - High vanadium content allowing for advanced material properties (MAHLE GmbH (Ed.) 2014)	- Strength to weight ratio is lower compared to titanium. - Limited corrosion resistance, - Limited availability on high quality material

3.2 Evaluation Matrix

Table 3 is an evaluation matrix used to determine which material is best for the component. The evaluation matrix is used to determine which material is best for the application. A weight is decided on certain factors that determine the success of the component. The weight must equal 1 or 100%. A rating is then decided on each material and then multiplied by the weight. The sum of the values is compiled, the highest total is the material that will be used to produce the CR.

Material Factors	Weight	Aluminium Alloy		Mild Carbon Steel		Cast Iron		Titanium		Steel Alloy	
		Rating	Value	Rating	Value	Rating	Value	Rating	Value	Rating	Value
Strength	0.15	8	1.2	7	1.05	7	1.05	9	1.35	9	1.35
Stiffness	0.1	7	0.7	7	0.7	6	0.6	9	0.9	8	0.8
Weight	0.15	7	1.05	5	0.75	3	0.45	8	1.2	6	0.9
Fatigue resistance	0.15	6	0.9	5	0.75	7	1.05	8	1.2	7	1.05
Temperature resistance	0.1	6	0.6	3	0.3	7	0.7	8	0.8	7	0.7
Machinability	0.1	7	0.7	4	0.4	3	0.3	4	0.4	7	0.7
Cost	0.15	5	0.75	8	1.2	8	1.2	1	0.15	5	0.75
Environmental impact	0.1	8	0.8	8	0.8	8	0.8	5	0.5	6	0.6
Total	1		6.7		5.95		6.15		6.5		6.85
Rank		2		5		4		3		1	

Table 3 shows that Steel alloy has good strength and stiffness which allows it to withstand high compression forces. Titanium would be the ideal material as it would increase performance, however compared to the steel alloy it is harder to machine and the cost is significantly higher. Furthermore, the recyclability is much harder as the material must be heated more due to the melting point. Titanium is a limited material, if the CR were to be mass produced it would not be cost effective whilst not using the material effectively. Steel alloys offer similar material properties but for a lower cost with less of an environmental impact.

Steel Alloy 36MnVS4BY is typically used as a connecting rod. The steel alloy has advanced material properties allowing for it to withstand high temperature and forces. This steel provides a high yield

point with increased ductility. This is due to the vanadium content within the material. This reason the material has great properties is due to the finely distributed vanadium carbonitride precipitation during cooling after the forging process. The microstructure is ferritic, and the ferrite portion is larger than similar steel alloys (MAHLE GmbH (Ed.) 2014).

4 Manufacturing Process Selection

4.1.1 Machining

Machining in the automotive/ motorsport industry involves typically using a computer numerical control machine (CNC). A component will be produced using Computer aided design (CAD), this file is later used to produce G-code, this code provides a set of instructions for the machine to follow. This means that the part can be produced more efficiently whilst have very fine tolerances. It decreases the probability of part failing compared to if a human was producing the component.

4.1.2 Sand Cast

Prior to the process beginning a mould must be created. When creating the mould, a finished version of the component needs to be used. This pattern is then placed into a flask which is then filled with moulding sand. This is then packed around the pattern to create the mould. Once the cavity and cores are formed the pattern is removed producing a negative mould. There needs to be a cope and a drag which are then secured together, once this is complete the metal pouring can begin, the metal is poured into the pouring cup which then flows through the runners into the mould. The metal is given time to cool and solidify before the mould is separated revealing the finished component. Machining is conducted on the component to remove sharp edges and meet tolerances (Engineering Product Design 2022).

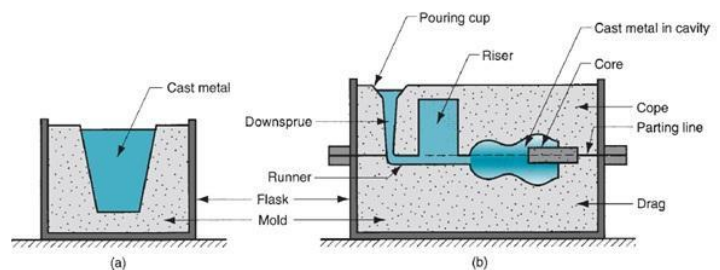


Figure 3 Figure 4 Shows a labelled diagram of the sand-casting process. Diagram b is a representation of what would be completed if the CR would be produced using this process (Engineering Product Design, 2022).

4.1.3 Close die forging

The forging process can produce components with advanced material properties whilst reducing waste. The forging process aligns the grain structure of the material which allows for advanced material properties. This means that the CR would be able to withstand larger forces when in use allowing for increased performance. The forging process involves heating the material to high temperatures before then compressing it into a die/mould with high compressive forces (Bambhania 2021).

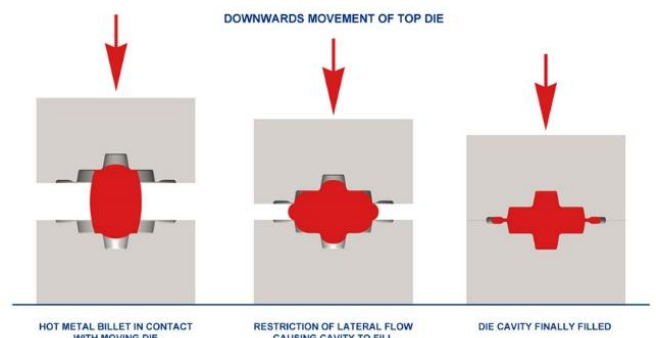


Figure 4 Figure 5 Shows the close die forging process (Brooks Forging Ltd, 2024).

Table 4 Shows the manufacturing processes advantages and disadvantages that can be used to produce the connecting rod.

Manufacturing Process	Advantages	Disadvantages
Machining	• CNC machine, this is more efficient and precise. • This decreases labour costs however operators are still needed to supervise and operate the machine. • Consistency, reliability, the machines can run if they are needed.	• Billets of material are used, the billet is then machined into the component. Costs for materials are then increased. Not very economical.
Sand Casting	• A large variety of parts can be produced using the sand-casting method. • Variety of materials can be used in the sand-casting process. • Simple tools and material are used in the process it is a low-cost process. • multiple components can be produced in the same mould, this decreases the cost whilst increasing efficiency.	• Low strength compared to the machining process. • The surface finish is rough because of the sand mould wall surface. • The surface quality of the mould and the shrinkage of the material once it has cooled leads to poor dimensional accuracy. • High probability of defects due to porosity, shrinkage and pouring (Engineering Product Design 2022).
Forging	• Improves components strength, durability and reliability. • Precision, tight tolerances • Minimal post process requirements • Material savings, economical.	• There is high initial cost when forging. If the production level is low, it becomes more expensive. • Limited material costs (Bambhanian 2021)

Overall, the forging process improves the components material properties, this ensures the components reliability thus increasing its life cycle. It requires little post processing which saves production time and decreases costs. The process provides components with tight tolerances which is ideal for engine components.

4.2 Tolerances

When producing components tolerances are provided as no component can be manufactured to the correct dimensions. This is due to deformations through machining forces, play in guides of the machining tools, tool wear etc. The effect caused by these factors is shown in the finish product. The part has dimensions and surface deviations from the engineering drawing. To ensure that the part produced can be used, tolerances are used (Dipl.-Ing, Karl-Heinz Dietsche Prof. et al. 2022).

Weight of the CR is important, therefore tolerances are set on the weight of the component. The forging process can be full automated, this reduces costs for labour and can produce a component with the tolerance range of 1% in raw part weight (MAHLE GmbH (Ed.) 2014).

International Organisation of Standardisation (ISO) tolerance system for cylinders is ISO 286. The code number defines the tolerance degree. This standard is used to produce engine components.

4.3 Finish

After the CR has completed the forging process, Post processing beings to produce the finished part. Machining is carried out on the part to ensure that the part is within tolerance. Furthermore, pin holes for lubrication and threads are drilled into the part. Heat treatment is also carried out to produce increased material properties. These processes collectively produce the CR shown in Figure 1.

5 Conclusion

A CDS was completed, this researched vital aspects of the CR by researching into functional requirements, materials, testing etc. The CR is constantly in use throughout its life cycle, it withstands many forces. It was vital to ensure that the material and manufacturing process that was chosen could offer durability, reliability and strength whilst being lightweight. This is why an alloy steel was chosen. Alloy steel can be forged which provides advanced mechanical properties. Due to the reliability, it ensures that the components life cycle is long whilst provided performance. Alloy steel is mid-range cost compared to all the materials reviewed. This material is typically used to produce performance CR's. Close die forging minimises the post processes which reduces costs and production time. Post processing will involve heat treatment and then machining to ensure a smooth surface on the small and big end of part. Hardware will be sourced from a company and provided with the component.

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