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Material Selection Report and GD&T Drawings

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1. Introduction

The selection of materials and manufacturing processes for critical components, such as those found in engine or suspension systems, is crucial for a vehicle's performance, durability, and cost-effectiveness. This technical report details the complex process of choosing the most appropriate material and manufacturing method for a modern vehicle's specific engine or suspension component. The selected component for this report will be a Crankshaft for a Porsche 911 Dakar (Figure 1).



Figure 1:Porsche 911 Dakar(Porsche 2024)

2. Component Design Specification

When drafting a component design specification, it is crucial to consider various factors that may impact the performance and usability of the component. These factors may include the intended environment of use, the expected maintenance requirements, the durability and reliability of the materials used, and the associated costs. By carefully considering these factors and incorporating them into the design specification, the resulting component is more likely to meet the desired performance standards and provide long-term value to its users. Aspects of design specification are listed below.

2.1 Functional Requirements

The purpose of a crankshaft is to convert the up-and-down motion of the pistons into rotational motion that drives the transmission and wheels of a vehicle (Philip Hubert Smith 1977). It must endure high rotational speeds and torque levels commonly found in high-performance engines (BMW 2024). Additionally, the crankshaft must maintain accurate alignment and balance to minimise vibrations and ensure smooth engine operation. When considering these aspects, forged (medium carbon steel) or billet steel would be the

optimum choice for selecting a material. Both forged and billet have exceptional strength, durability, and fatigue resistance, and both have a tensile strength of over 300 MPa (Wright 2020). Billet steel also provides dimensional accuracy, aiding in maintaining the alignment and balance of the engine.

2.2 Environmental Considerations

The crankshaft will undergo significant temperature changes, from high temperatures when the engine runs to ambient temperatures when it is stored or transported. It should resist corrosion, oxidation, and other types of degradation, particularly in challenging operating environments like the off-road terrain encountered in Dakar rally events (Fonte et al., 2013). Titanium alloy would be a reasonable environmental consideration as it has high tensile strength, corrosion resistance, and temperature stability. These are the main aspects when considering environmental conditions.

2.3 Material Requirements

The crankshaft material must be solid, fatigue-resistant, and durable to withstand the harsh conditions of high-performance driving and off-road use (Yamagata 2014). It should also have excellent machinability to ensure precise manufacturing processes and dimensional accuracy. Weight reduction should be considered without sacrificing structural integrity to improve engine responsiveness and overall vehicle performance. Considering various factors, Carbon Fiber Reinforced Polymer (CFRP) (Zheng et al. 2022) can be an appropriate material choice. Although relatively new, CFRP crankshafts are becoming increasingly popular in supercars due to their exceptional strength-to-weight ratio. Carbon fibre composites provide high stiffness, fatigue resistance, and reduced rotational inertia, enhancing engine performance (Saeed Asiri 2022).

2.4 Cost Considerations

The materials and manufacturing processes should balance performance and cost-effectiveness to align with production budgets and market competitiveness. Materials such as forged or billet steel are more feasible when considering costs than CFRP, which uses more expensive components.

2.5 Maintenance Requirements

When designing a crankshaft, it is essential to ensure that the design minimises the need for frequent maintenance interventions. This can be achieved by carefully considering the crankshaft's materials, shape, and size (Enzi and Asif 2022). Additionally, the design should be compatible with standard maintenance procedures and servicing schedules to make

maintaining and keeping it in good condition easier. Considering this, forged or billet steel would be the optimal choice as Porsche already uses these materials and is familiar with their maintenance.

2.6 Safety and Reliability

The crankshaft must meet safety standards for reliable operation and undergo rigorous testing and quality control to ensure structural integrity and consistency (Xu et al. 2023). Regarding safety, medium carbon steel is the best option as it has already been used in cars previously by Porsche and other manufacturers due to its high tensile strength, which ranges from 570-700 MPa (Steel Forging 2018), which means that it has already been shown to be a safe and reliable material to use for high-end car crankshafts.

3. Material Selection

Optimal performance and durability for high-performance crankshafts can be achieved using materials such as billet steel, titanium alloy, and medium carbon steel. Each of these materials offers unique properties ideally suited to the demanding requirements of the Porsche 911 Dakar.

3.1 Billet Steel

Billet steel crankshafts are crafted from a single piece of high-quality steel, providing exceptional durability, strength, and dimensional accuracy (Humkins 2007). This material is a popular choice for high-performance engines, as it possesses outstanding mechanical properties, including high tensile strength, yield strength, and hardness, ensuring reliability even under extreme conditions. Furthermore, billet steel offers excellent machinability, making it easier to manufacture precise components with tight tolerances and optimal performance characteristics. This gives billet steel more dimensional accuracy over forging because of how accurate a CNC machine is (JE Auto 2023).

3.2 Titanium Alloy

Titanium alloy crankshafts are popular for being lightweight yet robust. They offer high tensile strength, corrosion resistance, and stable temperatures, making them suitable for high-performance applications where reducing weight is essential (Ajayi Oluwaseun et al. 2021). Titanium's exceptional strength-to-weight ratio makes it an attractive option for decreasing rotational inertia in the engine, which improves responsiveness and overall vehicle performance. Figure 2 compares titanium alloy to other materials, including medium

carbon steel, showing that titanium alloy has a higher tensile strength (Acta Materialia 2015). However, the limited availability of titanium and its higher production costs may pose challenges for its widespread use in automotive applications. The primary source of titanium is provided by the lack of raw materials like ilmenite and rutile, which are rare and only found in a limited number of countries. As a result, the global supply of titanium is restricted, and its price is elevated (Expert 2024).

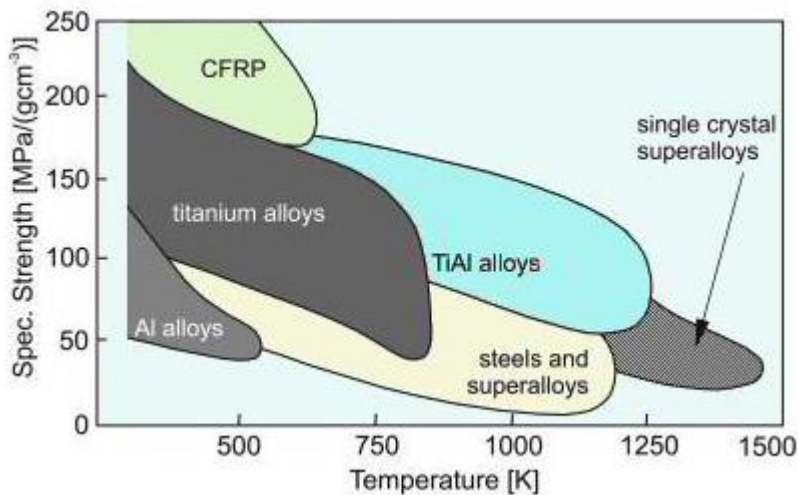


Figure 2: Tensile Strength Comparison of Titanium Alloy to Other Materials (Acta Materialia 2015)

3.3 Medium Carbon Steel

Due to its balanced strength, toughness, and cost-effectiveness, the crankshaft is typically made of medium carbon steel. A carbon content of 0.30% to 0.60% is commonly found in medium carbon steels (Singh 2016), providing excellent mechanical properties ideal for high-stress applications. Proper heat treatment can result in high tensile and yield strengths for medium carbon steel crankshafts, guaranteeing their durability in challenging operating conditions (Senthilkumar and Ajiboye 2012). Furthermore, medium carbon steel is widely available and has relatively low production costs, making it a cost-effective choice for mass production in the automotive industry. Table 1 shows the chemical composition of 1045 medium carbon steel, the most commonly used steel for manufacturing crankshafts. It shows the percentage of 0.45% of carbon in medium carbon steel.

Chemical	Percentage
Carbon	0.45%
Manganese	0.60-0.90%
Phosphorus	<= 0.040 %
Sulfur	<= 0.050 %
Iron	98.51 – 98.98 %

Table 1: Chemical Composition of 1045 Carbon Steel (Xometry 2023)

Tensile Properties		Raw Material		Annealed Material	
		Engineering	True	Engineering	True
Young's Modulus (GPa)		196	196	196	196
Yield Strength (MPa)		410	410	350	350
Ultimate Strength (MPa)		621	755	509	643
Poisson's Ratio		0.29	0.29	0.29	0.29
Fracture Strain		0.32587	-	0.37845	-
Work-Hardening	K	-	-	-	900
Law, $\bar{\sigma} = K\bar{\epsilon}^n$	n	-	-	-	0.225

Figure 3: Tensile Properties of 1045 Medium Carbon Steel (Ku 2020)

3.4 Material Conclusion

When selecting the material for a crankshaft, a thorough evaluation of various options is crucial, as it is a vital component of high-performance engines. After carefully assessing billet steel, titanium alloy, and medium carbon steel, the latter has emerged as the preferred choice. The mechanical properties of medium carbon steel make it an ideal material for the crankshaft, providing a perfect balance of strength, toughness, and cost-effectiveness. Figure 4 (Sotoodeh 2015) shows the balance of stress and strain of Medium Carbon Steel compared to other carbon steels.

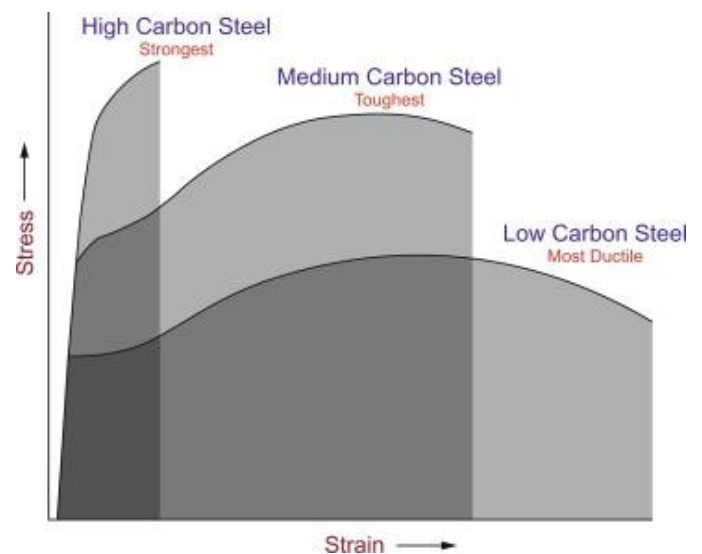


Figure 4: Stress/ Strain Comparison of High, Medium and Low Carbon Steel (Sotoodeh 2015)

Medium carbon steel has a tensile strength between 570-700 MPa, significantly higher than low carbon steel. Its toughness, ductility, and fatigue resistance make it ideal for high-stress

applications like crankshafts. Moreover, it is cost-effective, a significant advantage for the automotive industry.

Automotive engineers can ensure that supercars deliver a superior driving experience by opting for medium carbon steel for the crankshaft. Medium carbon steel offers high reliability, longevity, and cost-effectiveness, which is crucial for high-performance engines. Using medium carbon steel in the crankshaft ensures the engine can handle higher loads without compromising performance and durability.

4. Manufacturing Process

Crankshafts made of medium carbon steel are commonly manufactured using forging or machining. These offer precise control over the crankshaft's shape, dimensions, and material properties, ensuring high-quality components suitable for demanding automotive applications.

4.1 Forging

Forging is a commonly used manufacturing process for creating medium carbon steel crankshafts (Montazersadgh and Fatemi 2008). The process involves heating medium carbon steel billets to a specific temperature and shaping them under high pressure using dies to achieve the desired crankshaft shape. The forging process offers multiple advantages. It improves the mechanical properties of medium carbon steel, including strength, toughness, and fatigue resistance. The process creates a refined grain structure, resulting in superior material integrity. Although the initial tooling costs may be high, forging offers cost savings in the long run by reducing material waste and improving material properties, leading to longer component life and reduced maintenance requirements.

4.2 Machining from Bar Stock (CNC)

Machining from bar stock is a commonly used method for manufacturing medium carbon steel crankshafts. This process involves precision-machining medium carbon steel bars using CNC milling or turning machines to create the final crankshaft shape. Machining from bar stock has several benefits. It allows for producing custom designs and complex geometries tailored to specific engine requirements or performance goals. CNC machining delivers excellent dimensional accuracy and surface finish, ensuring high-quality components with tight tolerances (Universal Technical Institute 2020). However, there are some drawbacks to this process. Operating and programming CNC machines require specialised skills and training. Skilled CNC operators and programmers are crucial for maximising machine productivity, minimising errors and ensuring optimal performance. The need for skilled labour can result in higher costs and training expenses. CNC machines offer high precision and repeatability but may have limitations regarding part size, complexity, or material

compatibility. Large or irregularly shaped parts may require specialised equipment or multiple setups, increasing production time and costs.

Moreover, certain materials may pose challenges for CNC machining due to their hardness, brittleness, or thermal properties. These disadvantages may not align with the component design specification. Using a CNC could demand more cost and time consumption than needed, while the forging method provides a lower price and more practical method.

4.3 Material Selection

Forging is the ideal manufacturing process for producing medium carbon steel crankshafts for several compelling reasons. Forged crankshafts exhibit uniform material properties and dimensional accuracy across production batches, reducing variations and ensuring consistent performance in automotive engines. This is particularly important when considering the 911 Dakar. Even though the initial tooling costs for forging may be higher than other methods, the process offers significant cost savings in the long run, especially for the mass production of crankshafts. Reduced material waste, improved material properties, and streamlined production processes contribute to cost-effectiveness. This is well aligned with the component design specification.

In conclusion, the selection of forging as the manufacturing process for producing the medium carbon steel crankshaft is justified by its ability to deliver components with superior material properties, enhanced durability, precision, and cost-effectiveness. By harnessing the strengths of forging, manufacturers can ensure the production of high-quality crankshafts capable of meeting the stringent performance and reliability requirements of the 911 Dakar.

5. Conclusion

This report examines the selection of materials and manufacturing processes for the high-performance Porsche 911 Dakar's crankshaft. Factors like functional requirements, environmental considerations, material properties, cost, maintenance, safety, and reliability are considered. The component design specification analysis emphasises the importance of selecting materials and manufacturing processes that correspond with the functional requirements of the crankshaft.

After thoroughly considering material options, including billet steel, titanium alloy, and medium carbon steel, medium carbon steel was chosen as the best option for the crankshaft of the Porsche 911 Dakar. Medium carbon steel provides a balanced combination of strength, toughness, and cost-effectiveness, making it well-suited to handle the demanding requirements of high-performance driving and off-road use. Its proven reliability and widespread availability further reinforce its suitability for mass production in the automotive industry.

In manufacturing, forging was identified as the preferred method for producing medium carbon steel crankshafts. The forging process offers distinct advantages regarding material

properties, dimensional accuracy, durability, and cost-effectiveness, aligning seamlessly with the functional requirements and cost considerations outlined in the component design specification.

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