Birjand University of technology

Faculty of Mechanical and Materials Engineering

In the Name of God

Subject: Automobile Engine(Alloy Selection and Manufacturing Processes)

Prepared by: Alireza Jokar

Student Number: 9713611113

Supervisor: Dr. Mohammad Khosravi

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Introduction

In the early years, attempts were made to utilize steam engines and electric motors; however, these efforts achieved limited success. During the twentieth century, the internal combustion engine (ICE) became the dominant type of engine used in automobiles. As of 2015, the internal combustion engine continued to be the most widely used power source in vehicles; nevertheless, the renewed utilization of electric power appeared increasingly plausible due to growing concerns regarding exhaust emissions produced by internal combustion engines.

Until 2017, the majority of vehicles in the United States were powered by gasoline fuel. In the early 1900s, internal combustion engines competed with steam engines and electric motors. At that time, internal combustion engines primarily operated using gasoline. The fundamental operating principle of internal combustion engines is based on a piston that is compressed and set into motion through a controlled and confined combustion process. This combustion burns the hydrocarbon fuel present in the engine cylinder head.

Among all vehicles manufactured during that period, only about one quarter were recognized as being powered by internal combustion engines; however, over subsequent years, the internal combustion engine became the most popular type of automotive engine. In the nineteenth century, Rudolf Diesel developed a new type of internal combustion engine that generated power by injecting liquid fuel into air that had been heated solely through compression. This engine, invented by Rudolf Diesel, is considered the predecessor of modern diesel engines used in automobiles, particularly in heavy-duty vehicles such as trucks.

The technologies employed in automobile powertrains have undergone numerous changes throughout the history of the automotive industry; however, one of the most enduring systems in this field has been the internal combustion engine. Despite the passage of time and the development of external combustion engines, internal combustion vehicles are still produced on a mass scale. The origin of internal combustion engines can be regarded as a fundamental cornerstone in the development of modern automotive propulsion systems.

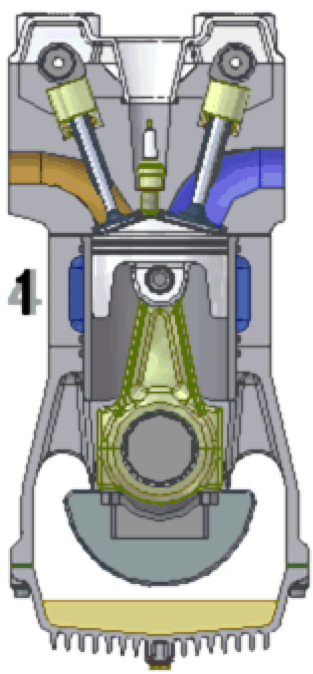
Nikolaus Otto is known to have invented the first practical internal combustion engine in 1876. According to this German engineer, the operating mechanism of the internal combustion engine was inspired by James Watt's steam engine. The engine designed by Otto was capable of continuously performing four stages: intake, compression, combustion (power), and exhaust. However, at that time, internal combustion engines were not yet suitable for automotive applications, because with an increase in fuel quantity, the combustion process tended to turn into uncontrolled explosions, which rapidly led to engine overheating and damage.

1. Four-Stroke Engine

In four-stroke engines, four distinct stages—intake, compression, combustion, and exhaust—must be completed for each power generation cycle (conversion of fuel energy into mechanical energy). Each stage corresponds to half a revolution, or 180 degrees, of the crankshaft. Consequently, a complete cycle in a four-stroke engine requires two full revolutions, equivalent to 720 degrees of crankshaft rotation.

2. Two-Stroke Engine

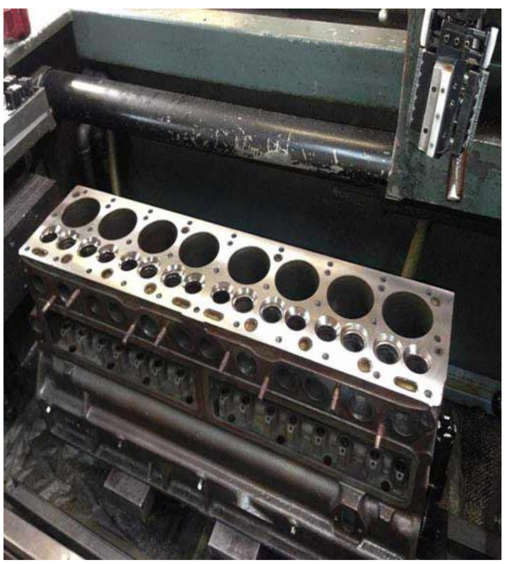
In two-stroke engines, one combustion event occurs during each crankshaft revolution. This is achieved by combining the intake and combustion processes into a single stage, and merging the exhaust and compression processes into the subsequent stage



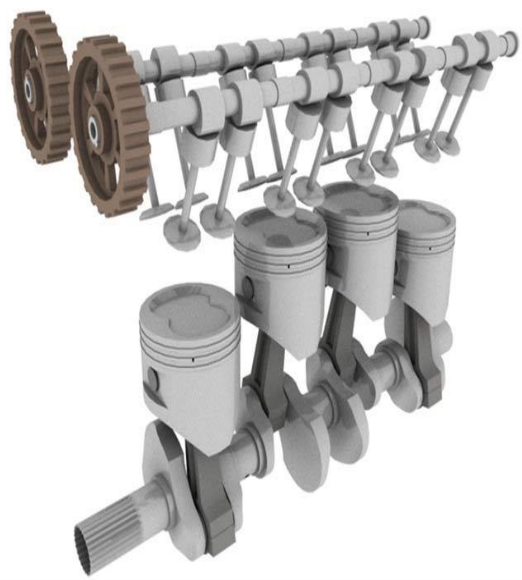
Types of Automobile Engines

Automobile engines can be classified based on the number and arrangement of cylinders. One of the most common configurations is the inline (straight) engine, in which all cylinders are arranged in a single row along the crankshaft axis. The most widely used types of inline automobile engines are as follows:

- **Inline Three-Cylinder Engine**
- **Inline Four-Cylinder Engine**
- **Inline Five-Cylinder Engine**
- **Inline Six-Cylinder Engine**
- **Inline Eight-Cylinder Engine**



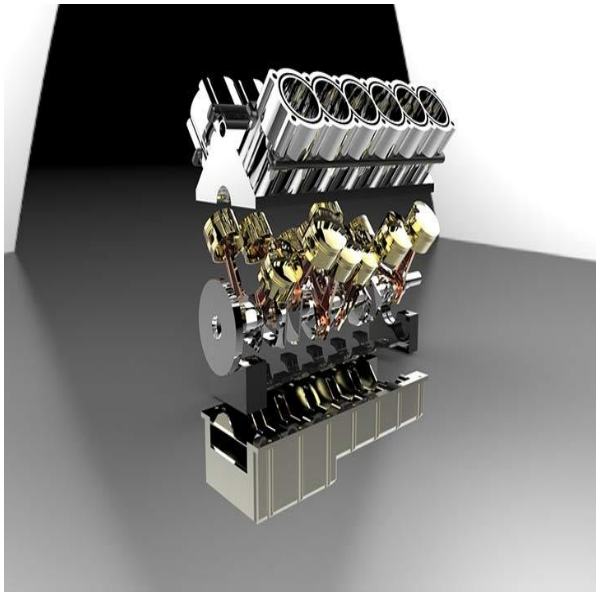
Inline Eight-Cylinder Engine



Inline Four-Cylinder Engine

V-Type Engines

V-type engines consist of cylinders arranged in two banks forming a V shape. These engines are available in configurations with **two, four, five, six, eight, ten, twelve, and sixteen cylinders**.



V-Type Twelve-Cylinder Engine (V12)

V-Type Four-Cylinder Engine (V4)

W-Type Engines

W-type engines consist of multiple cylinder banks arranged in a compact W-shaped configuration. These engines are manufactured with **eight, twelve, sixteen, and eighteen cylinders** and are mainly used in high-performance and luxury vehicles due to their high power density and compact design.

The W-type twelve-cylinder engine consists of twelve cylinders arranged in multiple banks forming a W-shaped configuration. This engine is mainly used in high-performance and luxury vehicles due to its compact design and high power output.

The W-type eight-cylinder engine consists of eight cylinders arranged in multiple banks forming a W-shaped configuration. This engine offers a compact structure and relatively high power output and is used in limited automotive applications.

W-Type Twelve-Cylinder Engine (W12)

W-Type Eight-Cylinder Engine (W8)

H-Type Engines

H-type engines consist of two flat (horizontally opposed) engine blocks coupled together, forming an H-shaped configuration. These engines are manufactured with **two, four, eight, twelve, and sixteen cylinders** and are mainly used in high-power and specialized applications.

H-Type Four-Cylinder Engine

The H-type four-cylinder engine consists of two horizontally opposed two-cylinder units arranged in an H-shaped configuration. This layout provides good balance and low vibration, but its complexity limits widespread automotive use.

Main Components of an Engine

1-Cylinder Block	10-Crankcase
2-Cylinder	11-Valve
3-Cylinder Head	12-Camshaft
4-Cylinder Head Gasket	13-Spark Plug
5-Cylinder Liner	14-Timing Belt
6-Water Pump	15-Flywheel
7-Piston	16-Connecting Rod
8-Crankshaft	17-Valve Spring
9-Piston Ring	18-Oil Pump

Piston

Cylinder Head

Connecting Rod

Crankshaft

Valve

Spark Plug

Cylinder Head

The cylinder head is a critical structural component mounted atop the engine block, sealing the combustion chambers. It houses essential valvetrain components—including intake and exhaust valves, valve springs, and often the camshaft(s)—and provides passages for the air-fuel mixture, exhaust gases, and coolant. Manufactured typically from aluminum alloy or cast iron, it must withstand high thermal and mechanical stresses. Its design directly influences engine efficiency, emissions, and performance by managing airflow, heat dissipation, and combustion sealing.

Alloys Used in Cylinder Heads

Historically, cast iron and ferrous alloys were predominantly employed in cylinder-head production. Today, with technological advances and a deeper understanding of aluminum-alloy properties, a large proportion of engine components—including cylinder heads—are manufactured by casting aluminum alloys. The alloy selected for a cylinder head must possess two critical characteristics:

1. **Resistance to deformation and stress** arising from combustion forces and mechanical loads, which prevents gas leakage.
2. **High-temperature toughness** to avoid crack formation in the region between the intake and exhaust valves exposed to combustion.

Cast aluminum alloys are among the most widely used casting alloys and exhibit superior castability compared to other alloy systems. Desirable properties of these alloys include:

- Excellent fluidity for filling thin sections,
- A relatively low melting point compared to other metals,
- Rapid heat transfer from the molten aluminum to the mold, thereby shortening each casting cycle,
- Ease of hydrogen-dissolution control through degassing methods, and others.

In addition to strengthening elements, a cast aluminum alloy must contain sufficient amounts of eutectic-forming elements (typically silicon) to provide the necessary fluidity for compensating solidification shrinkage.

The alloy commonly used for cylinder heads is an **aluminum-copper-silicon** system. Aluminum, silicon, and $CuAl_2$ constitute a ternary system. The solid solubility of copper in aluminum is not significantly altered by the presence of a third element. Copper enhances strength, while silicon improves castability and reduces high-temperature brittleness.

Iron and manganese are the most important impurities in these alloys and appear as structural constituents that form a series of solid solutions. These structural constituents appear in microscopic structures in shapes such as fishbone or printed text.

Alloys with more than 3–4% copper can be heat-treated, but heat treatment is usually applied when they contain some magnesium, because magnesium improves the heat-treatability of the alloy. Alloys with medium silicon content (5–7% Si) possess good toughness and are mainly used in cylinder heads. Alloys with higher silicon content (above 10%) have a low thermal expansion coefficient, which is an advantage for components operating at high temperatures.

The alloy used for a cylinder head must have high strength and toughness. Strength and toughness are opposing properties, so a balance must be struck between these two characteristics in the alloy selected for the cylinder head. The strength of aluminum alloys can be increased by adding other elements. For example, adding Sc to Al-Si alloys and even to other aluminum alloys can enhance the alloy's thermal resistance and toughness. Researchers have studied the effect of adding various elements to aluminum alloys on Young's modulus and found that lithium has the greatest effect on improving Young's modulus.

In another study, three different alloys—AlSi7MgCu0.5, AlSi6Cu4, and AlMg3SiScZr—were investigated for cylinder-head casting. The first two alloys are widely used for cylinder-head production, while the AlMg3SiScZr alloy has recently been adopted for this purpose. Under similar casting conditions, all three alloys exhibit approximately the same tensile strength. The mechanical properties of the AlMg3SiScZr alloy are superior to the others, but it has a greater tendency toward hot cracking. The addition of The addition of Sc and Zr to the AlMg3Si alloy resulted in positive effects on its mechanical properties; however, it also led to an increase in alloy cost. The good tensile properties, fluidity, and resistance to hot cracking of the AlSi6Cu4 and AlSi7MgCu0.5 alloys have allowed them to remain suitable choices for the production of aluminum cylinder heads.

The **thermal and mechanical properties** of **AlMg3Si1, AlSi7Mg, AlSi5Cu3**, and **AlMg3Si1 alloys containing Sc and Zr** were investigated in order to evaluate their resistance to **thermomechanical fracture**. The results showed that **the AlSi7Mg alloy exhibited the best overall performance** among the studied materials. This alloy is regarded as **the most commonly used material for the production of aluminum cylinder heads in diesel engines**, due to its favorable combination of mechanical properties, thermal stability, and resistance to thermomechanical loading.

In addition to AlSi7Mg, other alloys used for cylinder head casting include **AlSi5Cu3Mg (AS5U3G)** and **AlSi7Cu3Mg (AS7U3G)**. These alloys are widely employed in the automotive industry, particularly by **Peugeot and Citroën**, owing to their good castability and sufficient mechanical strength at elevated temperatures.

Cylinder Head Casting Methods

Various casting methods are used for the production of **aluminum cylinder heads**, and their differences can be classified into the following three main aspects:

1. **The driving force responsible for filling the mold**
2. **The mold material**
3. **The gating system**

One of the most commonly used casting methods for manufacturing aluminum cylinder heads is **gravity casting**, in which the molten metal fills the mold solely under the action of its own weight. This process can be carried out using **three types of molds: sand molds, permanent molds, and semi-permanent molds**.

Molten metal is injected into the mold shell. Another method is **low-pressure die casting**, in which the molten metal enters the metallic mold from the bottom under applied pressure. One of the most important factors affecting the quality of cast components is the **design of the gating system**. If the gating system is not properly designed, turbulent flow may occur during mold filling, which adversely affects the quality of the casting. The flow characteristics of molten metal as it is poured from the ladle into the gating system play a significant role in the formation of oxides and defects, including **leakage defects in cylinder heads**.

One of the most influential factors in the quality of cast components is the **mold filling process**. This factor is particularly critical in cast cylinder heads. In one study, the effect of **three different gating systems** on the gravity casting of cylinder heads (as shown in Figure 2) was investigated.

The use of a **top gating system** provides improved cooling conditions in the combustion chamber region of the cylinder head and, by promoting **directional solidification**, results in better mechanical properties in this area of the component. Another advantage of this method is the prevention of surface turbulence.

One of the advantages of a **bottom gating system** is the creation of a smooth and calm flow of molten metal within the mold. However, a major drawback of this system is the limited cooling conditions in the combustion chamber, which leads to reduced mechanical properties in this region. The restricted directional solidification in this area can also result in the formation of **shrinkage cavities**.

In a **two-sided gating system**, all the advantages of the top gating system are retained, and due to the overall slope of the system during mold filling, the level of turbulent flow is significantly reduced.

Common Defects in Cylinder Head Casting

One of the most common defects in the production of cylinder heads is **leakage**. This defect originates from the presence of **gas porosity and shrinkage cavities** within the casting, which are most often revealed during the **machining process**.

The main factors contributing to the formation of these cavities include:

1. **Hydrogen absorption** in the molten metal
2. **Shrinkage during the solidification process**
3. **Reactions between the mold and the molten metal**
4. **High-temperature oxidation**
5. **Blisters**, which are typically spherical in shape and are formed due to the entrapment of gas during solidification

According to previous studies, several factors have been identified as major causes of these defects, including:

1. **Disturbance of the mold thermal regime**
2. **Low melt density**
3. **Improper control of melt temperature and the use of burners on the holding furnace**
4. **Turbulence in the molten metal**
5. **Insufficient mold sealing**
6. **6. Use of Consumable Resin Binders in Cores**

Common defects in **cylinder head castings** include **gas porosity, shrinkage cavities, leakage-related defects, and solidification cracks**, which are largely attributed to the complex geometry and the presence of thin sections and internal cooling passages. Gas porosity primarily arises from entrapped gases in the molten metal and gas evolution from sand cores during the pouring process. Shrinkage cavities occur due to insufficient feeding and improper control of the solidification sequence in critical regions. Such defects adversely affect the mechanical integrity, sealing capability, and overall service performance of the cylinder head.

Alloys Used in Pistons

Pistons are manufactured from cast iron, cast steel, or aluminum alloys. Cast iron pistons have a larger and heavier structure and are mainly used in certain high-power diesel engines. In such pistons, the combustion chamber may be formed on the piston crown.

Nowadays, aluminum pistons are widely used in passenger vehicles and even diesel engines due to their low weight and superior heat transfer capability. These pistons are produced using either casting or forging processes. Although cast aluminum pistons are more common at present, forged aluminum pistons are preferred for heavy-duty and high-power engines.

Cast pistons generally exhibit a porous structure and are not suitable for operating speeds exceeding 5000 revolutions per minute (RPM). In contrast, forged pistons possess a dense and compact microstructure and are approximately 70% stronger than their cast counterparts.

The materials used in pistons consist of specially designed aluminum alloys combined with several metallic alloying elements. Through multiple processing stages and compliance with international standards such as ISO/TS 16949, these materials are converted into products suitable for OEM and aftermarket (AM) applications. The increasing power and acceleration requirements of modern engines impose high thermal loads and stresses on pistons. Moreover, designers of gasoline and diesel engines face challenges such as reducing air pollution, increasing compression ratios, and improving fuel and oil efficiency. Consequently, pistons used in such engines must exhibit maximum strength while maintaining minimum weight. The new generation of products manufactured by Iran Piston Manufacturing Company (IPMCo) is designed and produced in accordance with the current requirements of engine manufacturers.

Stages of Piston Manufacturing

Casting Process:

Pure aluminum ingots are first melted and alloyed with several metallic elements in pre-melting furnaces, induction furnaces, and electric holding furnaces to produce a special alloy suitable for casting raw pistons. Using modern and advanced equipment such as spectrometers (quantometers) with micron-level measurement capability, along with quality control laboratories and various tests including vacuum testing and thermal analysis, the molten material is refined and prepared for gravity casting in steel molds.

Finally, the cast raw piston undergoes heat treatment, ultrasonic inspection, hardness testing, and visual defect inspection. After full compliance with relevant standards, the piston is transferred to the machine shop for machining operations.

Machining (Machine Shop)

By employing modern automatic and semi-automatic CNC machines across multiple production lines, the capability to machine and manufacture various types of pistons with diameters of up to 150 mm has been established at Iran Piston Manufacturing Company (IPMCo). Fully automated part transfer, including robotic loading and unloading between different machining stations, has significantly improved dimensional accuracy, surface quality, production capacity, and manufacturing flexibility.

At this stage, different piston features and geometrical characteristics—including the skirt, crown, pin bore and circlip grooves, oil holes, ring grooves, combustion chamber, ovality profile, and valve recesses—are subjected to rough machining and finishing operations. Dimensional inspection and quality control are carried out at each machining stage using appropriate measuring equipment in conjunction with operator verification to ensure compliance with specified tolerances and technical requirements

Cleaning and Final Inspection

Cleaning:

To ensure the complete removal of residual particles generated during machining operations, a high-precision cleaning process is performed using ultrasonic and spray-based cleaning systems. This process is carried out under controlled temperature conditions and with appropriate cleaning agents to guarantee surface cleanliness and functional reliability.

Final Inspection:

All finished products undergo 100% dimensional and geometrical inspection to verify conformity with specified tolerances, technical drawings, and quality requirements.

Phosphating:

At this stage, the pistons are prepared for surface coating through a phosphating process, which provides an appropriate base layer to improve coating adhesion and surface performance.

Coating and Surface Treatment:

In order to reduce friction and enhance wear resistance, tin- and graphite-based coatings are applied to the piston surface. These coatings play a critical role in preventing sudden piston seizure under critical engine operating conditions. In the final stage of the manufacturing process, both gasoline and diesel pistons are coated with tin and graphite using spray coating or silkscreen printing techniques to ensure uniform coverage and consistent functional performance.

Crankshaft Manufacturing Methods

The main methods used for crankshaft production are as follows:

1. **Forging**
2. **Casting**
3. **Green Sand Casting**
4. **Shell Mold Casting**
5. **Lost Foam Casting**
6. **Billet Machining (Machining from Solid Stock)**

Forging Method

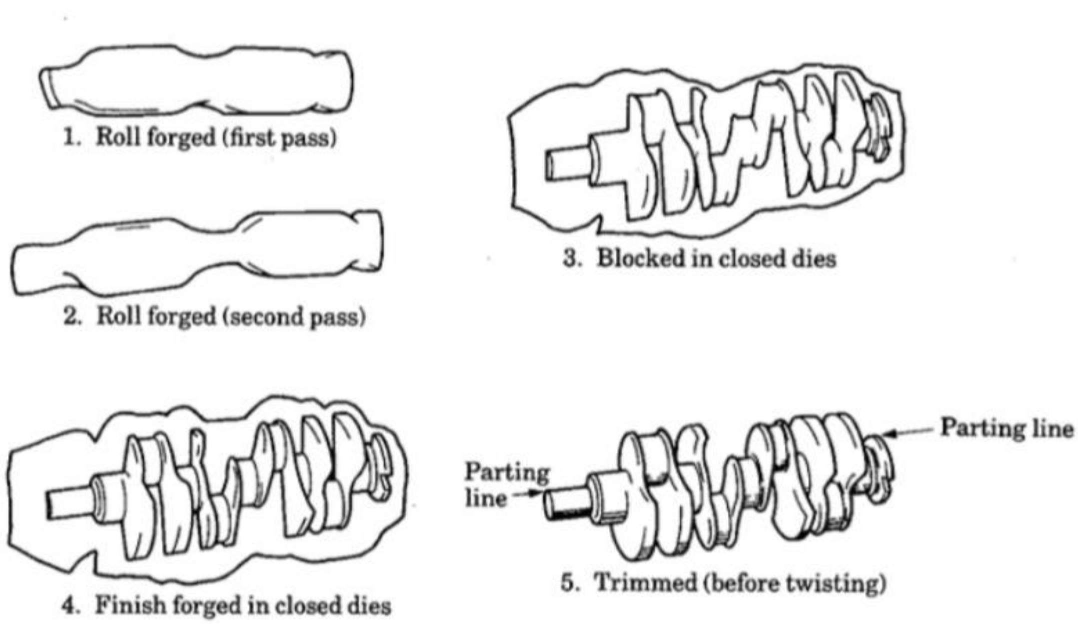
Forging is one of the most widely used and reliable methods for crankshaft manufacturing, particularly in high-performance and heavy-duty engines. In this process, a heated metal billet—typically made of carbon steel or alloy steel—is plastically deformed under high compressive forces using forging presses or hammers to achieve the desired crankshaft geometry.

The forging process results in a refined grain structure that follows the contour of the crankshaft, significantly enhancing mechanical properties such as strength, toughness, and fatigue resistance. Compared to cast crankshafts, forged crankshafts exhibit superior load-bearing capacity and improved resistance to cyclic stresses, making them highly suitable for engines operating under high speeds and severe service conditions.

Forging is one of the metal forming processes based on plastic deformation, in which the material is shaped by the application of compressive forces. This method encompasses various forming techniques commonly used for manufacturing components with high mechanical strength and structural integrity.

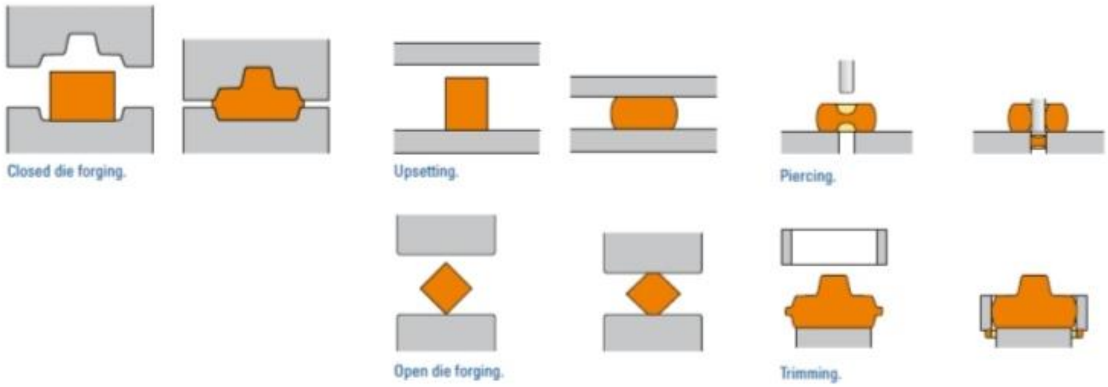
Due to the relatively large thickness of the crankshaft and the significant amount of deformation required, the **hot forging** process is employed for its production. In this process, a billet with an initial temperature of approximately **1100 °C** is placed into the lower die, and a forging press applies multiple strokes to deform the billet into the desired crankshaft geometry.

Hot forging promotes favorable grain flow along the crankshaft profile, resulting in improved mechanical properties, particularly enhanced strength and fatigue resistance, which are critical for components subjected to cyclic loading in engine applications.



In the illustrated process, **Stages 1 and 2 correspond to rolling operations**, during which the billet is progressively deformed to achieve a preliminary shape. After completion of Stage 2, the billet is transferred to the forging press.

Stages 3 and 4 represent hot forging operations, where the billet undergoes substantial plastic deformation at elevated temperatures. During these stages, the formation of **flash** is clearly observed, indicating extensive material flow and effective die filling, which are characteristic features of the hot forging process.

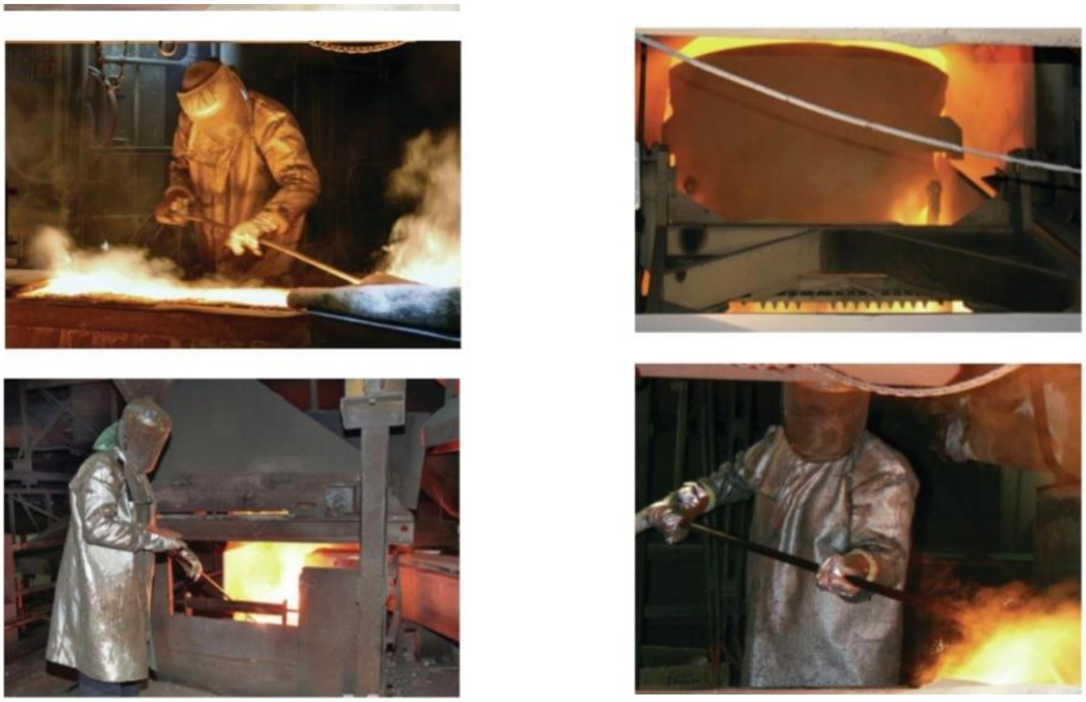


Forging Method

Green Sand Casting Method

Green sand casting is one of the conventional methods used for crankshaft manufacturing, particularly for low- to medium-load engine applications. In this process, molds are prepared using a mixture of silica sand, clay (as a binder), and water, which provides sufficient mold strength and permeability while maintaining reusability.

Molten metal, typically cast iron or alloyed iron, is poured into the sand mold cavity shaped according to the crankshaft geometry. After solidification and cooling, the mold is broken to remove the casting, followed by cleaning and machining operations. Green sand casting offers advantages such as low production cost, flexibility in mold design, and suitability for mass production. However, compared to forged crankshafts, components produced by this method generally exhibit lower mechanical strength and fatigue resistance due to the absence of grain flow control and the potential presence of casting defects.



Green Sand Casting Method

Casting Methods for Crankshaft Manufacturing

In crankshaft production, **ductile cast iron** is commonly selected as the base material due to its lower cost compared to alternative materials, while still providing acceptable mechanical properties for many engine applications. Based on practical experience, crankshafts made of ductile cast iron can be manufactured using three main casting methods: **green sand casting, shell mold casting, and lost foam casting**.

The selection of an appropriate casting method should be based on comprehensive information regarding the characteristics of each process, as well as the capability of the available equipment to produce the component with acceptable quality at a reasonable cost. If the decision is made solely on the basis of final production cost, without considering other influential parameters such as mechanical performance, dimensional accuracy, and defect sensitivity, the preference order of the casting methods can be expressed as follows:

1. **Green Sand Casting**
2. **Shell Mold Casting**
3. **Lost Foam Casting**

Alloys Used in Crankshaft Manufacturing

The alloys commonly used for crankshaft production include the following:

1. **Manganese–Molybdenum Steel**
2. **Chromium (1%)–Molybdenum Steel**
3. **Nickel (2.5%)–Chromium–Molybdenum Steel**
4. **Chromium (3%)–Molybdenum Steel or Chromium (1.5%)–Aluminum–Molybdenum Steel**
5. **Nodular (Ductile) Cast Irons**

Selection of Connecting Rod Alloys

In modern internal combustion engines, **connecting rods are most commonly manufactured from steel alloys**, owing to their high strength, excellent fatigue resistance, and reliability under severe cyclic loading conditions. However, alternative materials may also be employed depending on performance requirements and design priorities.

Aluminum alloys can be used in connecting rod applications where weight reduction is critical, as they offer low density along with a good ability to absorb high impact and dynamic loads during engine operation. Their favorable strength-to-weight ratio makes them suitable for specific high-speed or lightweight engine designs.

Titanium alloys represent another option, providing an exceptional combination of low weight and high strength. Despite their superior mechanical performance, the use of titanium alloys is generally limited to high-performance applications due to their significantly higher material and manufacturing costs.

In addition, **ductile cast iron** may also be utilized for connecting rod production in certain applications, offering a balance between cost-effectiveness, adequate mechanical strength, and good castability.

Methods of Connecting Rod Manufacturing

Connecting rods are commonly manufactured using the following methods:

1. **Forging Method**
2. **Powder Forging Method**

Forging Process for Connecting Rod Production

The manufacturing process of connecting rods by the forging method consists of the following steps:

1. **Cutting Operation**

   The steel bar is cut into predetermined lengths using a horizontal metal-cutting band saw to prepare billets suitable for the forging process.

2. **Preheating Operation**

   The cut billets are placed inside a recuperative preheating furnace for approximately one hour at a temperature range of **850–1050 °C**. This preheating stage is performed to ensure adequate plasticity and to facilitate subsequent forging operations.

3. **Forging Press Operation**

   For shaping the component, the heated billet is positioned within **four-stage forging dies** and subjected to deformation using a **64 kJ forging press**. During this stage, the billet undergoes significant plastic deformation to achieve the near-net shape of the connecting rod.

4. **Scale Removal and Inspection**

   To remove the oxide scale formed as a result of thermal exposure and to improve dimensional accuracy prior to trimming, the forged part is cleaned using wire brushing. The component then undergoes post-forging inspection to verify its quality and dimensional integrity.

5. **Flash Trimming**

   The excess material formed during the forging process is removed using a **400-ton hydraulic press**, ensuring proper geometry and dimensional conformity of the connecting rod.

6. **Stamping and Marking Operation**

   In order to create identification marks, reference symbols, and to ensure dimensional accuracy, a stamping operation is performed using a **600-ton hydraulic press**. This step contributes to traceability as well as improved dimensional consistency of the forged component.

7. **Heat Treatment Operations**

   Heat treatment processes, including **stress relieving, hardening, and tempering**, are carried out to eliminate residual stresses generated during the previous forming stages and to enhance the mechanical properties of the connecting rod.

   Stress relieving is performed in an **electric muffle furnace** at a temperature of approximately **700 °C for 1 hour**. Subsequently, heat treatment for property enhancement is conducted to improve mechanical characteristics such as hardness. This includes **hardening at approximately 1000 °C**, followed by **tempering at 700 °C for 20–40 minutes**, both carried out in a muffle furnace.

8. **Surface Finishing (Shot Blasting)**

   Surface finishing is performed using a **shot blasting machine with steel shots** in order to improve surface quality, remove remaining scale, and prepare the component for subsequent machining operations.

9. **Broaching of Side Surfaces**

   The side surfaces of the connecting rod are machined using a **broaching machine equipped with flat broaching tools**, ensuring proper surface geometry and dimensional accuracy.

10. **Cutting Operation**

    A cutting process is carried out to separate the **upper and lower caps of the connecting rod**. This operation is performed using a **band saw machine**, providing precise and controlled separation.

11. **Broaching of the Gudgeon Pin Bore**

    The gudgeon (piston) pin bore is machined using a **broaching machine** to ensure correct alignment, straightness, and dimensional conformity of the bore.

12. **Milling Operations**

    Milling operations are performed on the **bolt seating areas and the mating surfaces of the two connecting rod caps**. These operations are carried out using **horizontal and**

vertical milling machines, employing face milling and end milling cutters to achieve the required surface flatness and assembly accuracy.

13. **Broaching of the Crankshaft Bearing Bore**

The crankshaft bearing bore is machined using a **broaching machine** to achieve the required dimensional accuracy, surface finish, and proper alignment for bearing installation.

Additionally, **drilling of the caps, chamfering, and auxiliary drilling operations** are carried out using an **MSB-20 drilling machine**.

14. **Pneumatic Measurement of Bores**

To ensure the correctness of drilling operations and to verify the diameter and geometry of the bores, **pneumatic measuring equipment** is employed. This inspection step plays a critical role in maintaining dimensional accuracy and assembly quality.

15. **Machining and Assembly Operations**

Machining of the **bearing shell locating grooves** is performed using a **horizontal slotting milling machine** specifically designed for bearing seat machining.

During the assembly stage, the **gudgeon pin bushing** is press-fitted into the connecting rod using a manual press. The assembled component then undergoes final inspection to ensure compliance with dimensional and quality requirements.

16. **Packaging and Storage**

The finished connecting rods are packaged in groups of **four pieces per cardboard box**, and subsequently, **100 boxes are placed into a larger container** for storage and transportation. The packaged components are stored on warehouse racks under controlled conditions.

Currently, approximately **6000 tons of these components are imported annually**, while the proposed optimal production capacity for domestic manufacturing is estimated at **400,000 connecting rods per year**.

Valve Materials

The **intake valves** are typically manufactured from **chromium–nickel steels, cobalt-based steels, or other suitable alloy steels**, which provide an appropriate combination of strength, corrosion resistance, and wear resistance under moderate thermal loading conditions.

In contrast, **exhaust valves** are produced from materials with **high resistance to elevated temperatures and thermal fatigue**, since significantly higher thermal loads act on the exhaust side of the engine. For this reason, **chromium–nickel steels and other heat-resistant alloys** are commonly used for exhaust valves, as they maintain their mechanical strength, oxidation resistance, and structural stability at high operating temperatures.

Valve Manufacturing Process

1. Cutting of Bar Material

In this stage, the raw steel material is cut to the required length using appropriate cutting equipment. This operation ensures dimensional consistency of the valve blanks prior to forming processes.

2. Upsetting and Forging

The cut bar material undergoes **upsetting**, followed by **forging operations**, during which the material is plastically deformed to form the **raw valve head**. This process improves material flow, grain orientation, and mechanical strength of the valve head region.

3. Cutting of Head Bar

After forging, excess height generated at the valve head during the forming process is removed. This trimming operation ensures dimensional accuracy and prepares the component for subsequent treatments.

4. Heat Treatment (Solution Annealing)

To eliminate the adverse effects induced by the forging process, the valve head is subjected to **solution annealing heat treatment** at a specified temperature and holding time. This step improves microstructural uniformity and reduces residual stresses.

5. Grinding of the Bar End

In this stage, the end of the valve stem is ground using a grinding machine to achieve a flat and smooth surface, ensuring proper alignment and preparation for subsequent processing steps.

6. Washing of the Valve Head

Prior to the welding process, the valve heads are thoroughly cleaned using an industrial washing system. This operation removes contaminants such as oil, scale, and particles to ensure high-quality welding.

7. Friction Welding

The valve head and valve stem are joined together using **friction welding**. This solid-state joining process provides a high-strength metallurgical bond with minimal heat-affected zone, making it particularly suitable for valves manufactured from dissimilar or heat-resistant alloys.

8. Heat Treatment (Normalizing)

Following friction welding, the valve undergoes **normalizing heat treatment** at a specified temperature and duration. This operation is performed to remove the detrimental effects of welding, refine the grain structure, and improve the mechanical properties of the valve.

9. **Straightening Operation**

In this process, the **valve head and valve stem are aligned coaxially** to ensure straightness and concentricity. This step is critical for proper valve seating and uniform load distribution during engine operation.

10. **Machine Grinding of Stem End**

The end of the valve stem is machined using a grinding operation to obtain a **flat, uniform, and smooth surface**, preparing the component for subsequent precision grinding stages.

11. **Stem Grinding – First Stage**

In this stage, the **initial grinding and polishing of the valve stem** is performed. This operation improves surface finish and removes surface irregularities generated during previous processes.

12. **Induction Hardening of Stem End**

The end of the valve stem is subjected to **induction hardening**, where it is rapidly heated by induced electric current and subsequently **quenched in oil**. This process significantly increases wear resistance of the stem tip, which is subjected to repeated contact with the valve train components.

13. **Deburring of Valve Head**

Burrs formed around the valve head during previous machining operations are removed using cutting tools. This step improves surface quality and prevents stress concentration.

14. **Removal of Stellite Welding Area (Seat Preparation)**

In this stage, the **stellite welding area on the valve seat is machined and removed using a grinding wheel with specified dimensions**, preparing the seat region for hard-facing.

15. **Washing of Seat-Prepared Valves**

The valves are thoroughly washed to remove grease, debris, and residual contaminants from the machined seat area, ensuring cleanliness prior to the hard-facing operation.

16. **Stellite Welding**

In this process, **stellite powder material** is welded onto the valve seat surface. This hard-facing layer significantly enhances **wear resistance, thermal stability, and resistance to hot corrosion**, particularly for exhaust valves operating under severe thermal conditions.

17. **Double Face Grinding**

During this stage, material is removed simultaneously from the **valve face and the stem end** using grinding stones, allowing the **final overall length and height of the valve** to be accurately achieved.

18. **Stem Grinding – Second Stage**

The second stage of stem grinding is performed to further improve **dimensional accuracy, surface finish, and cylindricity** of the valve stem.

19. **CNC Head Grinding and Groove Grinding**

In this operation, the **outer diameter of the valve head, the valve seat surface, and the groove geometry** are machined using **CNC grinding machines**. This step ensures that all critical dimensions reach their final specified tolerances.

20. **Stem Grinding – Third Stage**

In the final grinding stage, the valve stem undergoes **precision grinding** to achieve the required final diameter, surface roughness, and geometric accuracy.

21. **Hard Chromium Plating of the Valve Stem**

In this stage, the **valve stem is coated with hard chromium** through an electroplating process. This coating significantly improves **wear resistance, corrosion resistance, and surface hardness**, thereby increasing the service life of the valve during engine operation.

22. **Stem Grinding – Fourth Stage (Final Grinding)**

This stage represents the **final step of the valve manufacturing process**, in which the valve stem is ground to its **final specified diameter and surface finish**. This operation ensures high dimensional accuracy and compliance with strict tolerance requirements.

23. **Dimensional Inspection**

At this stage, **all valves undergo comprehensive dimensional inspection** using appropriate measuring instruments to verify conformity with design specifications and quality standards.

24. **Ultrasonic Testing**

Prior to packaging, the valves are subjected to **ultrasonic testing** in order to detect any **potential internal defects or cracks**, particularly in the **welded joint area**. This non-destructive testing method ensures the structural integrity and reliability of the valve.

25. **Oiling and Packaging**

In the final stage, the valves are **lightly oiled** to prevent corrosion during storage and transportation. Subsequently, they are **packaged and prepared for shipment** to the customer.

Spark Plug Manufacturing Process

Manufacturing of the Metallic Shell and Body of the Spark Plug

The **metallic shell of the spark plug** can be manufactured using different methods depending on the available level of technology and production capabilities. Initially, a **steel wire rod** is prepared and processed through **cold rolling or hot extrusion** to achieve the desired geometry and dimensions, forming an appropriate **hollow structure** for the metallic shell.

Subsequently, the steel body undergoes **six sequential machining operations**, including **turning, drilling, and thread cutting**, through which the component gradually attains its **final shape and dimensional accuracy**. These machining steps ensure the required mechanical strength, precise geometry, and proper interface with the engine cylinder head.

Welding of the Ground (Side) Electrode

The **ground (side) electrode** is manufactured from a **nickel-based alloy wire**, selected for its excellent electrical conductivity and resistance to thermal and chemical degradation. After being fed into the **electric welding machine**, the side electrode is **directly welded to the metallic shell** of the spark plug.

Following the welding operation, the electrode is **cut to the specified length** and subsequently **formed using a shaping die**, where it is bent toward the center of the metallic shell. In the final assembly stage, the **electrode gap between the ground electrode and the central electrode is precisely calibrated**, ensuring optimal ignition performance and consistent spark generation during engine operation.

Electroplating of the Metallic Shell

Prior to the electroplating process, the **metallic shell of the spark plug** is subjected to a **cleaning and surface preparation treatment**, during which it is immersed in solutions containing **acids, salts, or alkaline compounds** to remove surface contaminants, oxides, and residual impurities. After drying, the component undergoes an **electrolytic plating process**, in which a **permanent and protective silver-colored metallic layer** is deposited onto the surface through the passage of electric current through the electrolyte solution.

Electroplating produces a **thin, uniform metallic coating** that is evenly applied over the entire surface of the spark plug shell. This coating improves **corrosion resistance, surface durability, and long-term stability** of the metallic body under operating conditions.

Manufacturing of the Ceramic Insulator Body

The production of the **ceramic insulator body** begins with the preparation of a **ceramic slurry**, which is processed using **ball mills, grinders, and mixers** to achieve a homogeneous and controlled composition. The liquid ceramic material is then **poured into rubber molds**, where **hydraulic pressure** is applied to form the desired geometry of the insulator.

After removal from the mold, the shaped ceramic insulator undergoes **grinding and finishing operations** to improve surface quality and dimensional accuracy. The component is subsequently fired in a **tunnel kiln at temperatures exceeding 2700°F**, during which it is **sintered, densified, and strengthened**. This high-temperature firing process provides the ceramic insulator with excellent **resistance to moisture, high temperatures, and mechanical impact**.

Following the initial firing, the ceramic insulator is **labeled and coated with a glaze**, and then subjected to a **secondary thermal treatment** in a furnace to complete the **final firing process**. This step enhances surface smoothness, electrical insulation performance, and long-term durability of the ceramic component.

Preparation of the Central Electrode

The **central electrode** is manufactured using **nickel-based alloys**, selected for their suitable electrical conductivity and resistance to thermal and chemical degradation. The alloy wire is **joined to a steel terminal head and the current-supplying wire of the ignition system**, forming the electrical connection required for spark generation.

Subsequently, the assembled central electrode is **pressed into the ceramic insulator under high compressive force**, ensuring proper alignment and mechanical stability. The central cavity of the ceramic insulator is then completed by introducing **conductive glass powder and an electrode pin**, followed by the installation of sealing washers. This process provides effective **electrical insulation, mechanical fixation, and gas sealing**, preparing the component for final assembly.

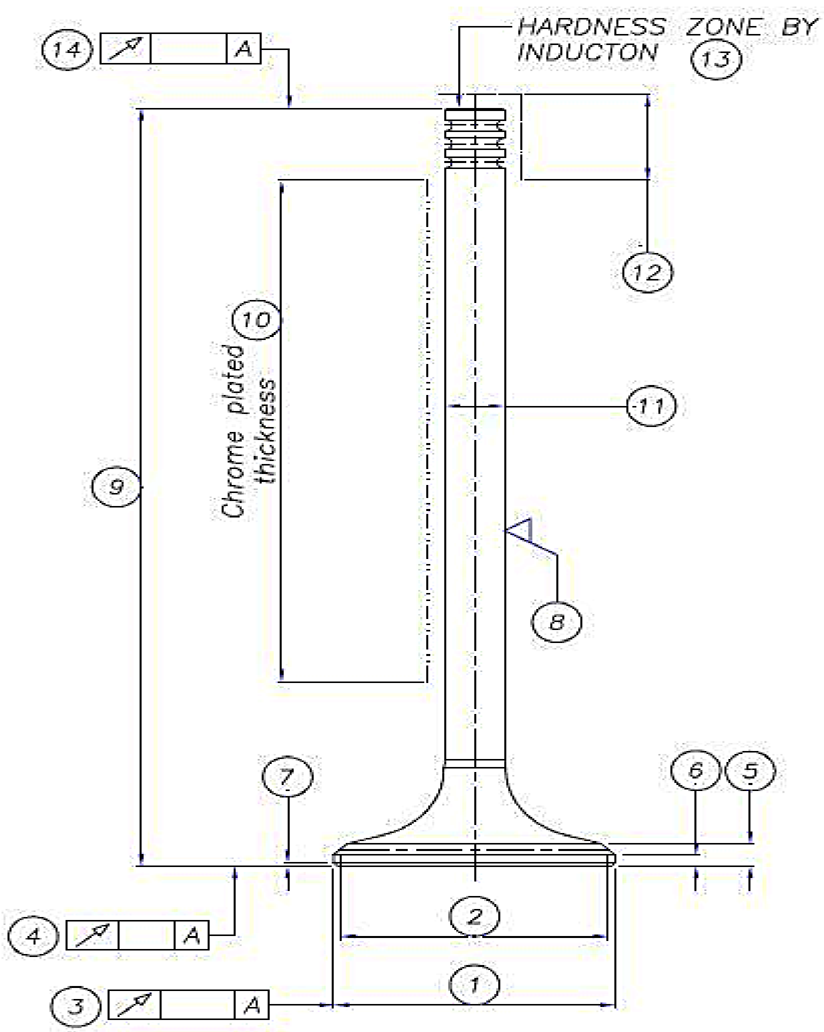
Final Assembly of the Spark Plug

During the **final assembly stage**, the **ceramic insulator body containing the central electrode** is assembled with the **threaded and electroplated metallic shell**, which already incorporates the **ground (side) electrode**. After the installation of the external sealing washer, the components are securely fastened to form the complete spark plug structure.

In the final step, the **gap between the central electrode and the ground electrode is precisely calibrated** to meet the specified ignition requirements. At the end of the production line, in accordance with the relevant product standards, the assembled spark plugs are **prepared for final testing and packaging**.

Engineering Drawings

1-Valve



1- **Valve Head Diameter**

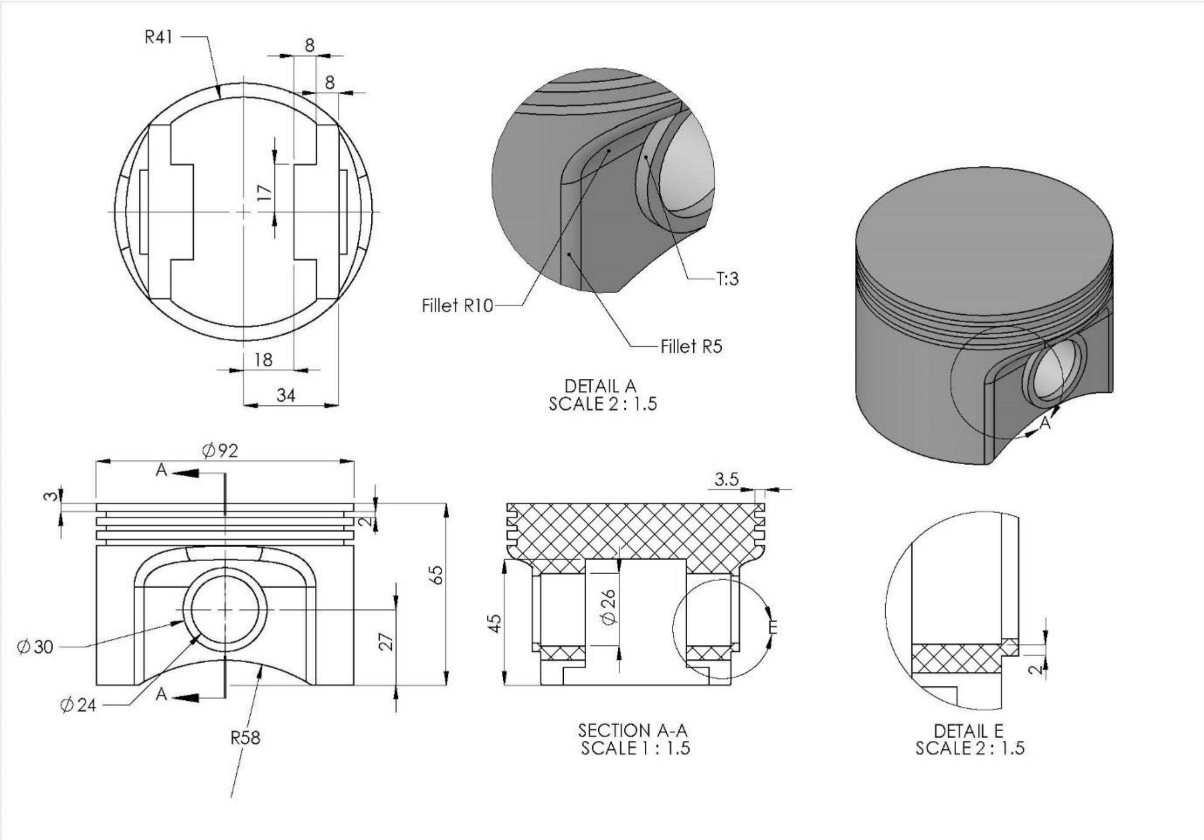
2- **Gauge Line Diameter**

3- **Head Face Runout**
4- **Seat Face Runout**
5- **Overall Face Width (Full Face Width)**
6- **Neck Height (Waist Height)**
7- **Chamfer Height at Valve Tip**
8- **Stem Surface Roughness**
9- **Overall Valve Length**
10- **Stem Plating Length**
11- **Stem Diameter**

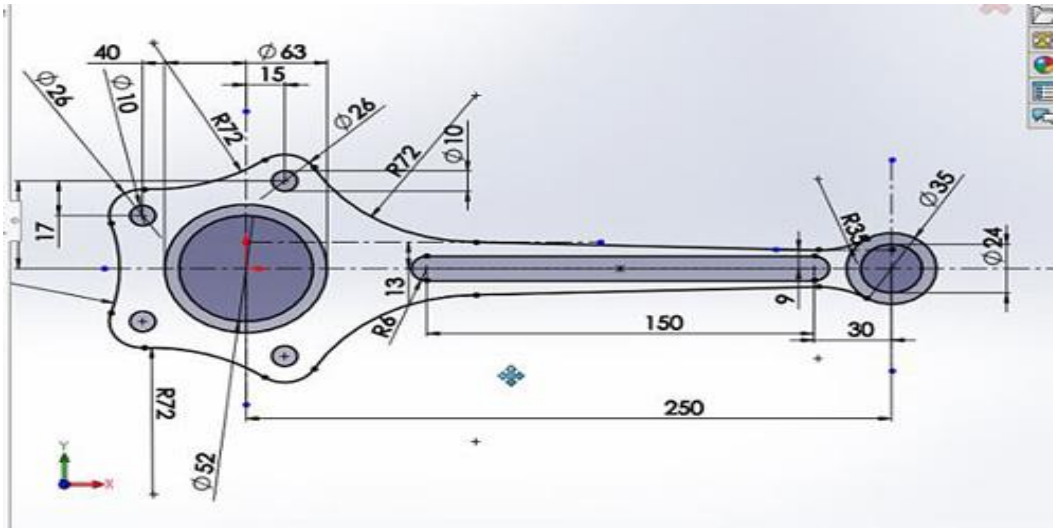
12- **Hardened Tip Length**
13- **Valve Tip Hardness**

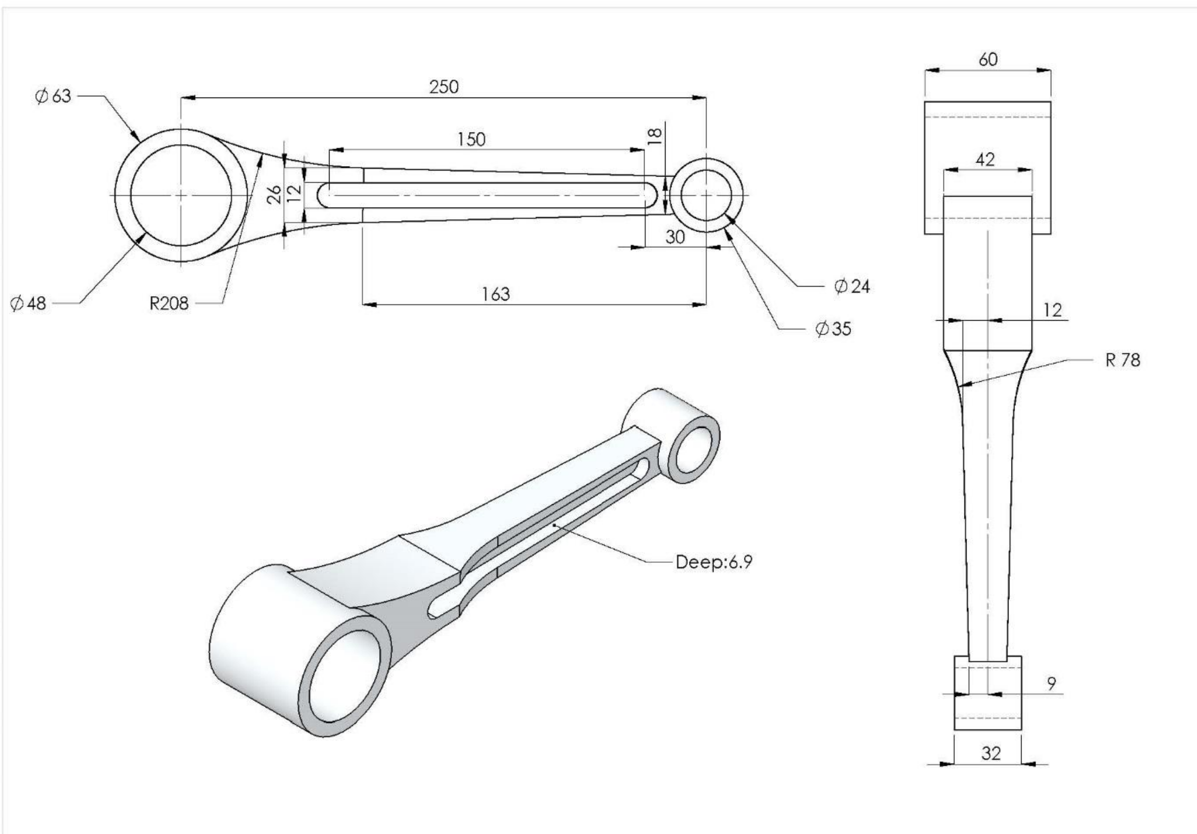
14- **Valve Tip Runout**

2-Piston

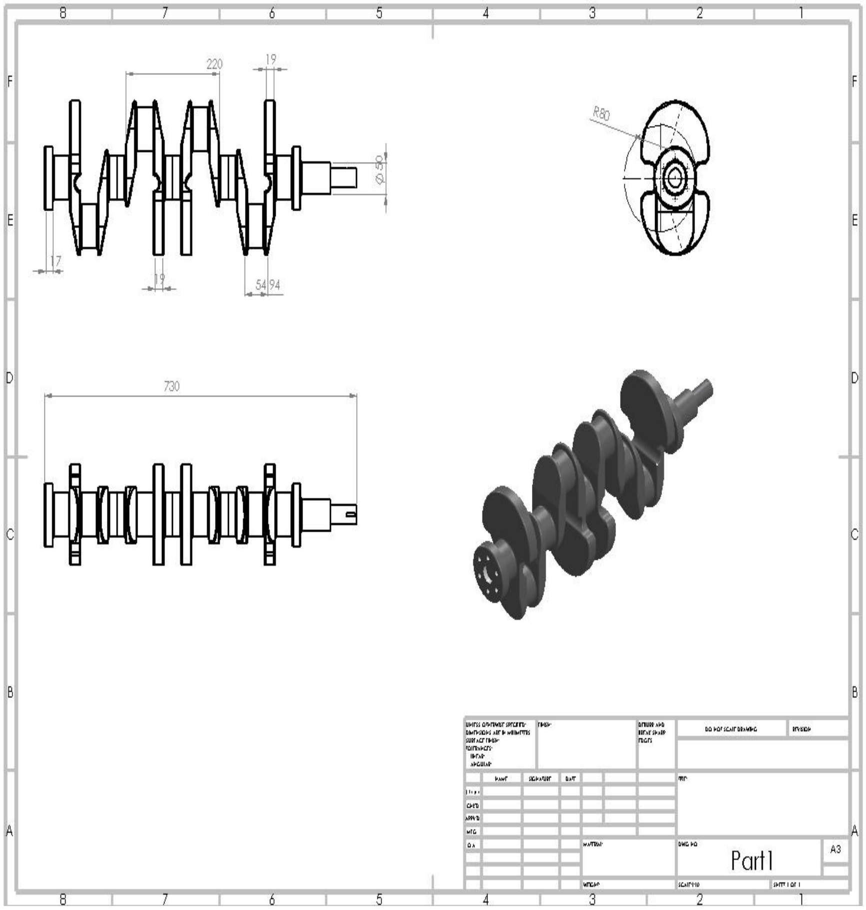


3-Connecting Rod

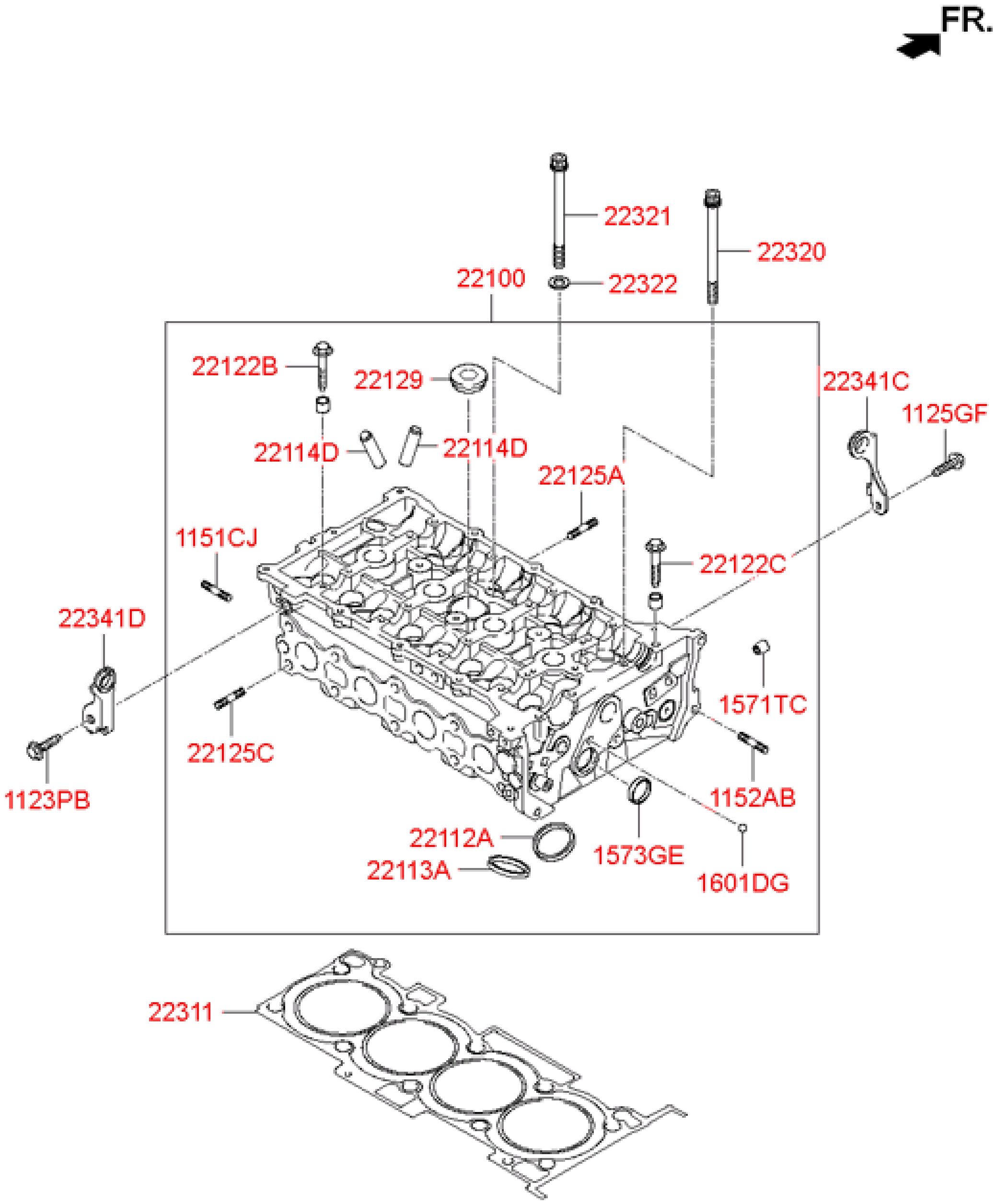


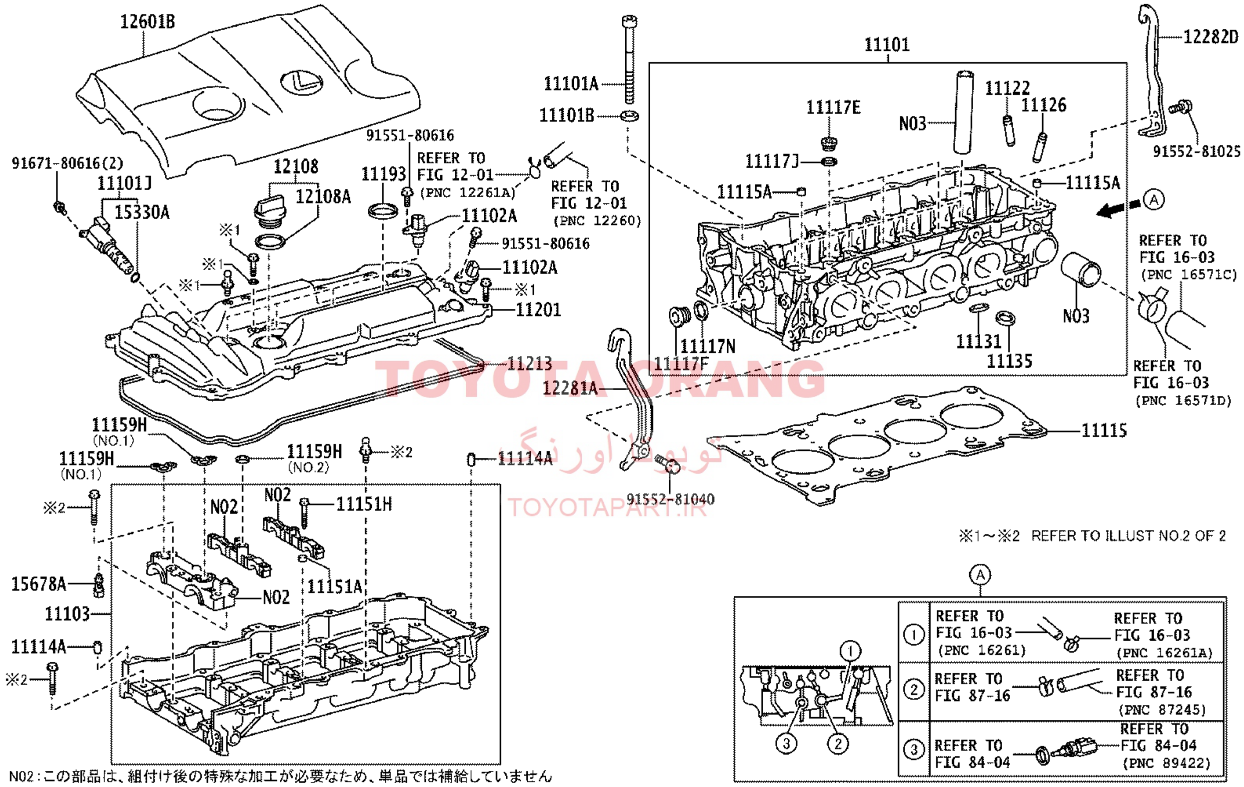


4-Crankshaft



5-Cylinder Head





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