5.0 CAMSHAFT

Introduction

Combustion gases in four-stroke engines are controlled by the valve mechanism, a complex structure, often referred to as a valve train, of which the camshaft is an integral part. The valve train determines overall engine performance. Figure 5.1 shows a photographic representation of a valve train. Table 5.1 lists the main parts of a valve train and the typical materials used in its construction. Most of these parts are produced from high carbon iron alloys.

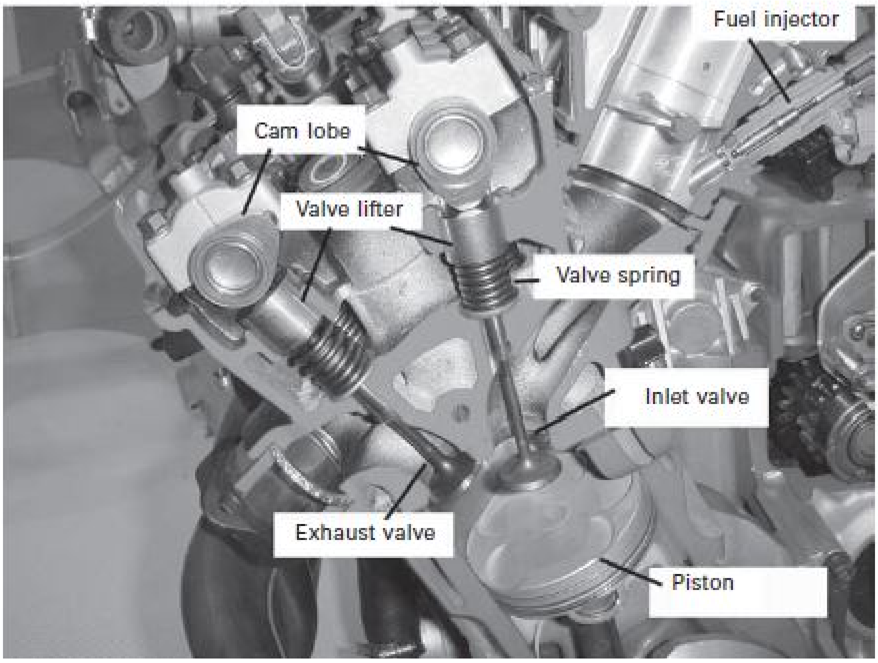

Figure 5.1: DOHC type valve system.

Table 5.1: Materials used in valve train

Part name	Material
Camshaft	Chilled cast iron, hardenable cast iron or JIS-SCM420 forging followed by carburizing
Valve lifter	JIS-SKD11 cold forging (quench-temper)
Rocker arm	JIS-SCM420 forging (carburizing) + Cr-plating or + wear-resistant sintered-material chip (brazing)
Inlet valve	Martensitic heat-resistant steel JIS-SUH3 forging
Exhaust valve	Austenitic heat-resistant steel JIS-SUH35 (crown) forging + JIS-SUH1 or SUH3 (shaft), friction welded. Stellite hardfacing on the valve face
Inlet valve sheet	Iron-base heat- & wear-resistant sintered-material (press-fit into the cylinder head)
Exhaust valve sheet	Iron-base heat- & wear-resistant sintered material (press-fit into the cylinder head)
Valve spring	Si-Cr steel oil-tempered wire + shot peening

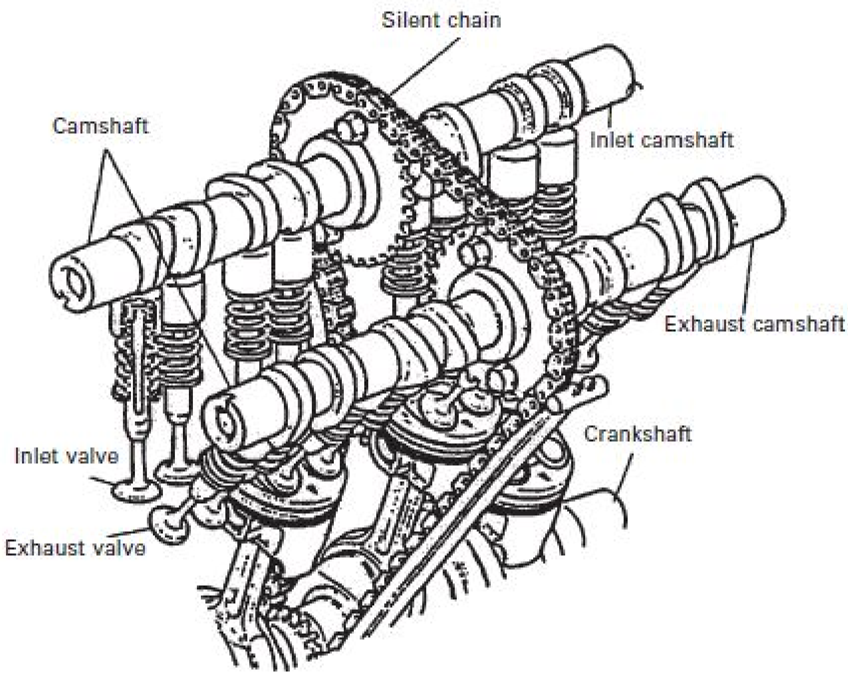

Figure 5.2: Schematic illustration of a valve train

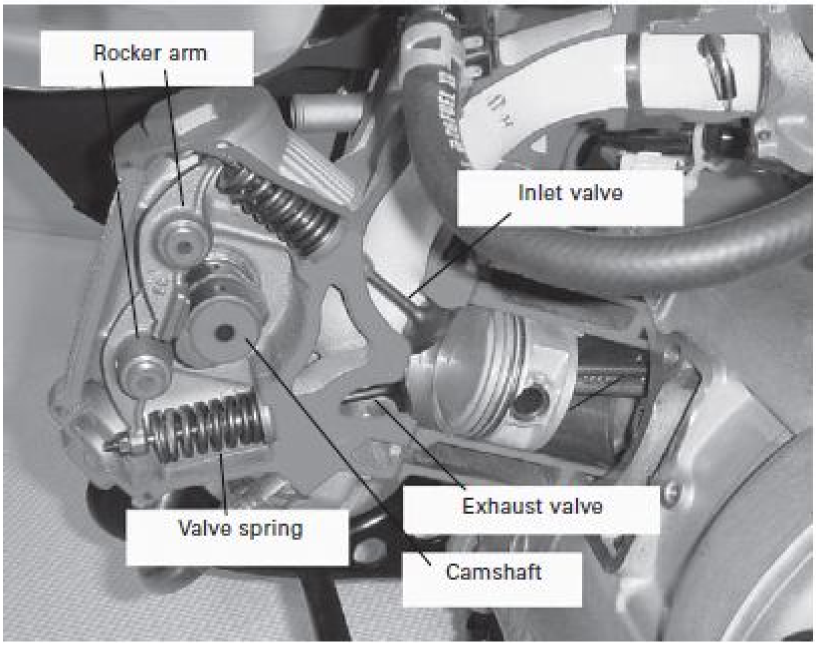

Figure 5.3: SOHC type valve system installing twin rocker arms.

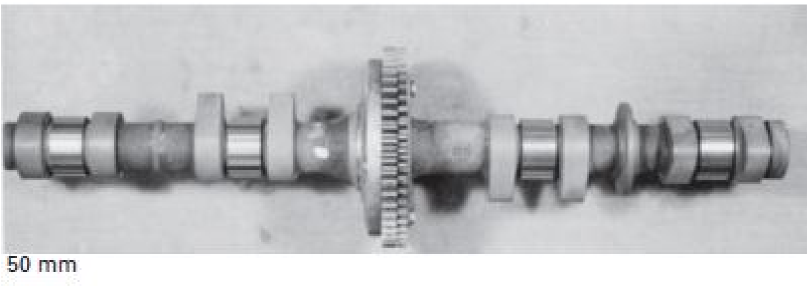

Figure 5.4: Camshaft installing a drive sprocket at the center

The valve train consists of a valve operating mechanism and a camshaft drive mechanism. The valve operating mechanism transforms rotation of the crankshaft into reciprocating motion in the valves. The valves protrude into the combustion chamber and are pushed back by the reactive force of the valve spring.

Several types of valve trains have been developed. The overhead camshaft is the most popular mechanism used in high-speed engines. There are two types, the double overhead camshaft (DOHC) and single overhead camshaft (SOHC). Figure 5.1 shows an example of the DOHC type, which uses five valves per cylinder (two exhaust and three inlet valves). This mechanism uses two camshafts, one camshaft drives the three inlet valves and the other drives two exhaust valves through the valve lifters. Figure 5.2 gives a schematic representation of a typical DOHC drive mechanism. The chain or timing belt transmits the rotation of the crankshaft to the camshaft, which is turned by the camshaft drive mechanism. Figure 5.3 shows the SOHC type. This mechanism uses one camshaft, which drives a pair of inlet and exhaust valves via the rocker arms. An example of a camshaft is shown in Figure 5.4. The functions of the camshaft are analyzed in Figure 5.5. The camshaft turns at half the rotational speed of the crankshaft, which is synchronized by the crankshaft rotation. If the number of revolutions is 12,000 rpm at the crankshaft, then the camshaft turns at 6,000 rpm, resulting in reciprocating motion of the valves at 6,000 times a minute.

The oval shape of the cam lobe determines the lift (displacement) of inlet and exhaust valves. The valve itself has an inertial mass. If the curved shape of the cam lobe surface is not designed appropriately, then the valve cannot accurately follow the contour and this will result in irregular motion. This is likely to occur at high revolutions. Lighter moving parts in the valve train will enable high-speed revolutions. Increasing the tension of the valve spring will increase reactive force, helping to prevent irregular motion of the valves.

However, the high reactive force will result in high contact pressure on the cam lobe, so the cam lobe should have high wear resistance. It is essential that adequate amounts of lubricating oil are supplied to the cam lobe. The contact between the curved surface of the cam lobe and the flat face of the valve lifter (bucket tappet) generates high stress, and therefore both parts require high wear resistance where contact occurs. In the DOHC mechanism, the cam lobe makes contact with the head of the valve lifter directly or via a thin round plate (pad or shim), which is positioned on the valve lifter head. The high contact pressure means a much harder material is needed for the shims. The SOHC mechanism uses rocker arms (Figure 5.3). The face that is in contact with the cam lobe also needs to have good wear resistance.

5.1 TRIBOLOGY OF THE CAMSHAFT AND VALVE LIFTER

The reactive force of the valve spring must be set high in order to maintain smooth motion and generate high revolutions, as discussed above. The maximum permissible surface pressure, usually regarded as the decisive parameter limiting cam lobe radius and the rate of flank-opening, currently lies between 600 and 750 MPa, depending on the materials used.

When the camshaft is operating at high revolutions, contact pressure is reduced by the inertia of the valve lifter. Under these conditions, the oil film on the running face is maintained most easily, providing hydrodynamic lubrication. Contact pressure is therefore highest and lubrication most challenging when the engine is idling. Figure 5.6 summarizes the basic relationships between the factors that influence the tribology of the camshaft and valve lifter, and which can therefore cause problems that result in wear at the point of contact.

Figure 5.7 shows an example of flaking at the head of a DOHC valve lifter. **Flaking** is caused by surface fatigue. The **Hertzian stress** reaches its highest value just under the contact surface, frequently resulting in fatigue cracks that then cause flaking.

In Figure 5.7, the surface has peeled off to reveal the cavities underneath, a typical failure under high contact pressure. **Pitting** is another surface fatigue phenomenon. **Pitting** normally manifests itself as small holes and usually appears under high contact pressures. Figure 5.8 summarizes the main reasons why pitting occurs in the cam lobe and the factors that affect each of these reasons. The increased temperature at the running surface that results from increased friction lowers the viscosity of the lubricating oil, making it less efficient. Under these conditions, the mating metal surfaces lose their protective oil film and come into direct contact.

Wear can appear on either the tappet or the cam lobe. It is very important to choose an appropriate combination of materials. The function of the shaft itself is also very important. The torque from the crankshaft drives the camshaft, so the shaft portion is under high torque and therefore must have high torsional rigidity. Figure 5.9 shows a section taken at the journal-bearing portion (as indicated in Figure 5.5). The hole at the center runs along the entire length of the camshaft and supplies lubricating oil to the journal bearings.

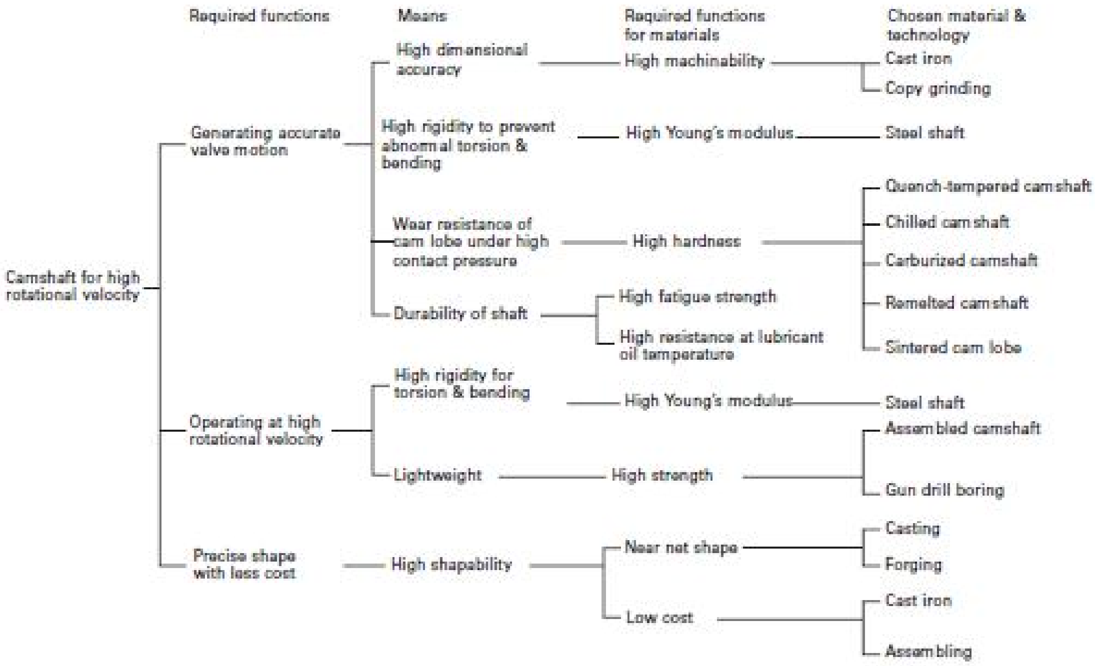

Figure 5.5: Functions of camshafts for high rotational velocity

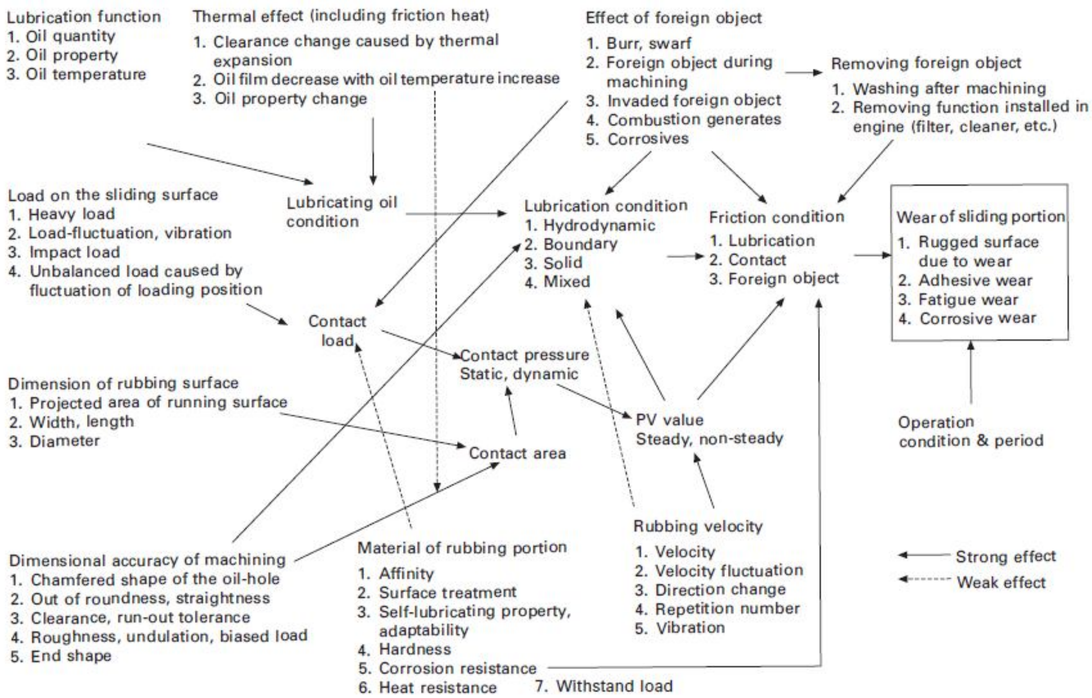

Figure 5.6: Tribology around the cam and valve lifter

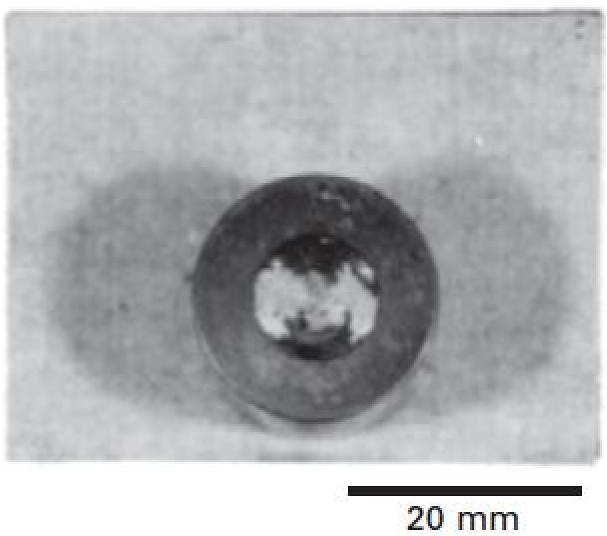

Figure 5.7: Flaking appearing in the valve lifter head.

5.2 IMPROVING WEAR RESISTANCE OF THE CAM LOBE

5.2.1 Chilled Cast Iron

The camshaft should combine a strong shaft with hard cam lobes. Table 5.2 lists five types of camshaft. Table 5.3 lists the chemical compositions of the various materials used. The most widely used material for camshafts at present is chilled cast iron (in Table 5.2), using a high-Cr cast iron. This type of camshaft is shown in Figure 5.4, and has hard cam lobes with a strong but soft shaft.

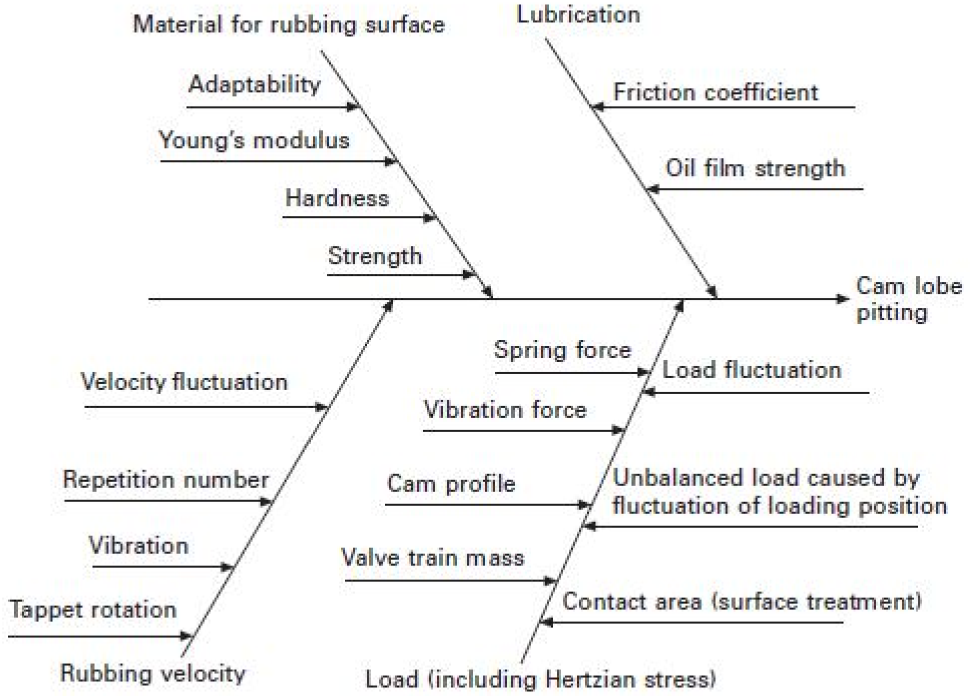

Figure 5.8: Reasons causing pitting.

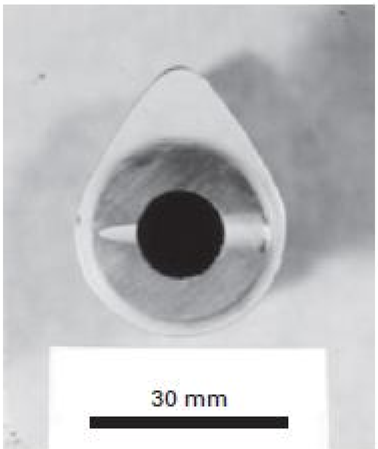

Figure 5.9: Camshaft cross-section at the position of an oil hole which is perpendicular to the central hole. The holes supply oil to the journal bearing.

Table 5.2: Various camshafts.

Type		Cam lobe portion	Shaft portion	Processing	Characteristics
(1)	Chilled cam	Chill	Flaky or spherical graphite cast iron	Sand casting combined with a chiller	Most general. Hardness control is difficult
(2)	Remelted cam	Chill	Flaky or spherical graphite cast iron	Remelting the cam lobe surface of the shaped material of gray cast iron	Increasing the hardness of the cam edge portion is difficult
(3)	Quench-tempered cam	Martensite	Quench-tempering or normalizing	Quench-hardening the cam lobe by induction or flame heating	Applicable to forged carbon steel, nodular cast iron or hardenable cast iron
(4)	Carburized cam	Martensite	Sorbite	Carburizing the forged part (SCM 420)	Strong shaft portion using a thin wall tube
(5)	Bonded cam	Wear-resistant sintered material Martensite	Steel tube	Brazing, diffusion bonding or mechanical joining of the cam lobe with the shaft	Flexible choice and combination of various materials

Table 5.3: Compositions of camshaft materials (%).

Material	C	Si	Mn	Cr	Mo	Cu	V	W	Fe
High-Cr cast iron	3.2	2.0	0.8	0.8	0.2	–	–	–	Balance
Hardenable cast iron	3.2	2.0	0.8	1.2	0.6	–	–	–	Balance
Cr-Mo steel JIS-SCM420	0.2	0.3	0.8	1.0	0.2	–	–	–	Balance
Sintered metal for cam lobe	0.9	0.2	0.4	4.5	5.0	3.0	2.0	6.0	Balance

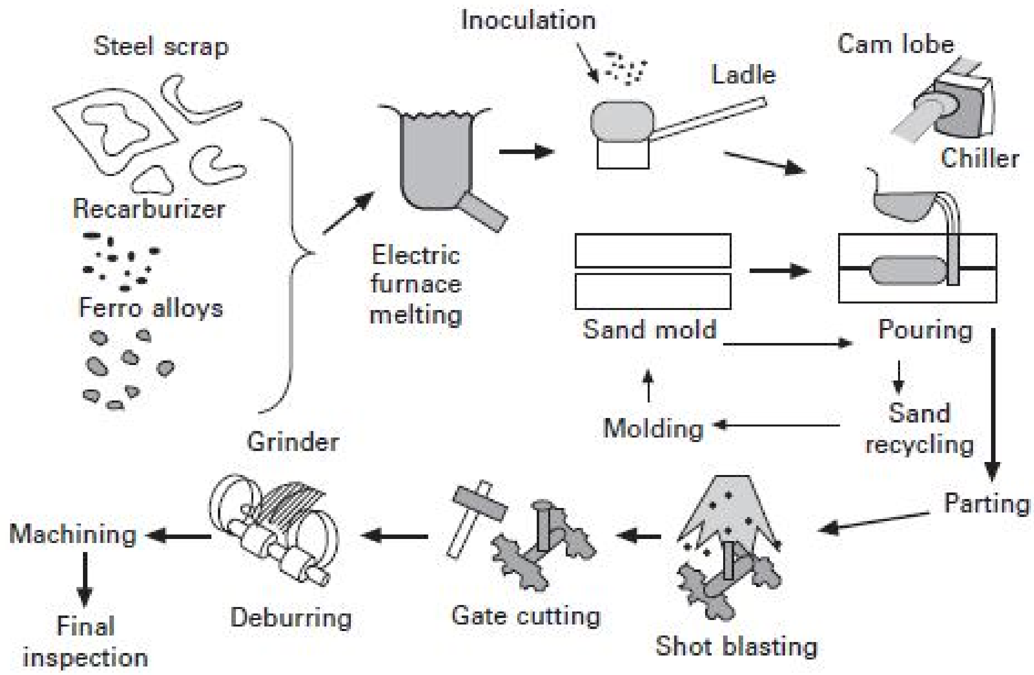

Figure 5.10: Casting process.

5.3 FINISHING – BORING AND GRINDING

The camshaft needs a continuous, longitudinal central hole (Figure 5.7) for the passage of oil. This also serves to reduce the weight. The hole is made using a gun drill (Figure 5.11), which was originally developed for boring guns. The drill consists of a long pipe shaft with a cutting bit at the end. Machining oil is transmitted through the pipe to the bit during the drilling process. If hard chill has occurred in the central portion of the camshaft, this prevents the drill from boring effectively. It is possible to eliminate the boring process by making the hole in the camshaft during the initial casting process. Figure 5.12 shows an example in cross-section. Excess metal is cut away using a long shell core. The shape of the cam lobe has a direct influence on engine performance.

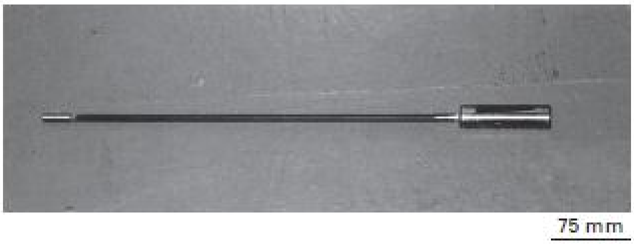

Figure 5.11: Gun drill. The right-hand end is a grip.

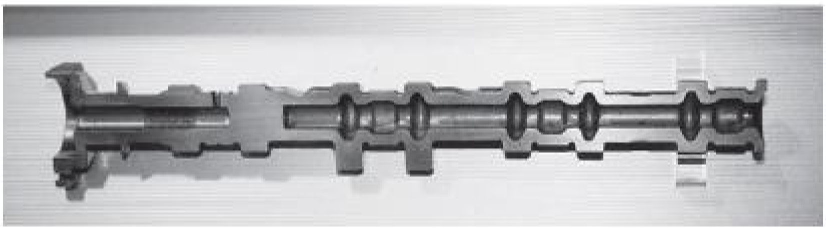

Figure 5.12: Chilled camshaft having a long hole as cast. To decrease the weight, the excess metal at the cam lobes is also removed.

A copy-grinding machine is used to finish the cam lobe. The grindstone traces a predetermined master cam. The hard chill means that each cam lobe has to be ground in small stages. Machine finishing is often followed by gas nitriding or manganese-phosphate conversion coating. These improve how the cam lobe adapts to the rocker arms during the running-in period. As an alternative to chilled camshafts, a cam lobe with a microstructure of carbide and martensite (Table 5.2) has also been proposed. In this case, the camshaft is made from hardenable cast iron (Table 5.3). After machining, induction hardening on the cam lobe portion generates hard martensite, which gives a hardness of around 52 HRC. It has been reported that tough martensite is more resistant to pitting than the chill microstructure.

5.4 COMPOSITE STRUCTURES

Camshafts can also be forged from Cr-Mo steel (Table 5.3). The entire camshaft is carburized and quench-tempered (Table 5.2). The multivalve engine employs a greater number of valves, and the gap between these valves is consequently narrow, particularly in the small-bore-diameter engine, requiring short intervals between cam lobes. Chill hardening cannot be used where the gap between the cam lobes is narrow because of the difficulty in using the chiller, so forged camshafts are used. Assembled camshafts (Table 5.2) consist of a hollow shaft and cam lobe pieces as shown in Figure 5.13. The cam lobe piece shown in Figure 5.13 is made from a wear-resistant sintered material (Table 5.3) or hardened high carbon steel. The shaft portion is a steel tube.

Figure 5.13: Assembled camshaft using mechanical joining (hydroforming)

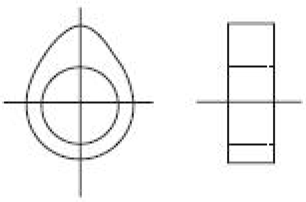

Figure 5.14: A cam lobe piece for assembled camshaft.

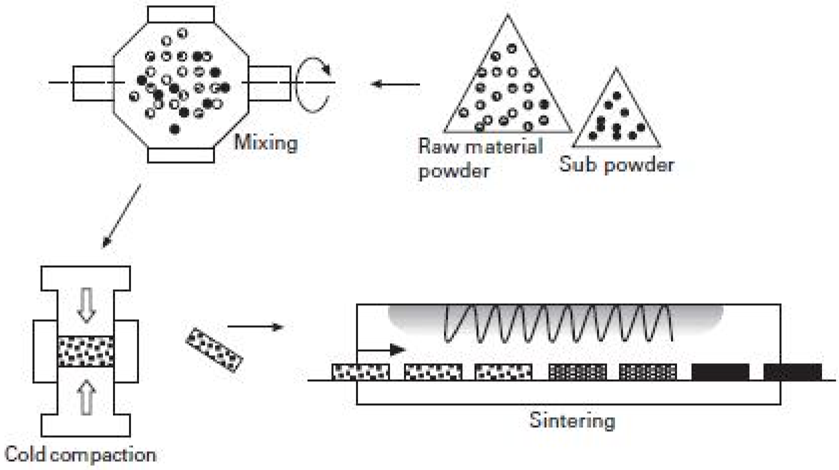

Figure 5.15: Powder metallurgical process.