MOTORCYCLE ENGINEERING—21

Head and Barrel Materials

Their effect upon design over the years

By PHIL IRVING

UNTIL recently, cylinder heads and barrels shared with lamp-posts the distinction of commonly being made from cast iron. This is one of the most versatile of materials; not only that, but it is also cheap, it can be cast into the most intricate shapes provided one possesses the necessary know-how, and it can be drilled, turned, bored and ground with little difficulty.

Furthermore, it is about the only metal that can be run against itself without seizure or rapid wear, even under conditions of great heat and scanty lubrication. A cast-iron piston will run satisfactorily for years in a cast-iron cylinder, but a mild steel piston would fail rapidly if run in a mild steel barrel.

Cast iron's major defects are low tensile strength and extreme brittleness. Even these deficiencies, however, have been largely overcome by metallurgical methods, so that irons with a high degree of ductility and shock resistance are commercially available; their applications include overhead rockers in car engines and crankshafts.

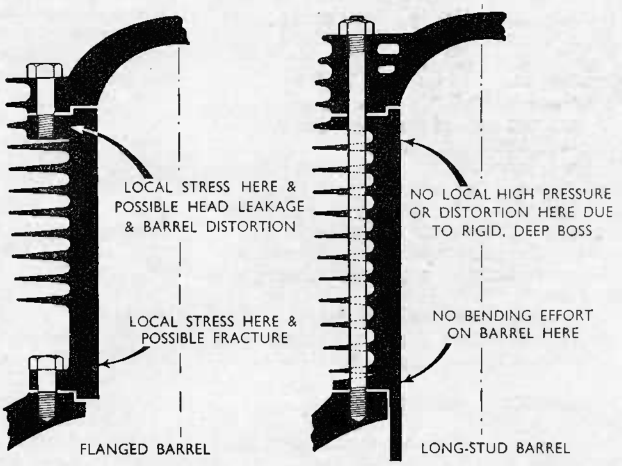
In any case, low tensile strength and brittleness are not of very serious consequence except in engines where light weight is an essential feature. The earliest cylinders and heads were made, usually integrally, from ordinary grey cast iron with a little phosphor added to give fluidity at pouring temperature and so assist the metal to flow into the narrow spaces in the mould which formed the fins.

Moulding technique was not very advanced at that time, the practice being to use wooden patterns, split into halves, and rammed up with "green" (i.e., damp) sand into moulding flasks. Extracting a pattern with a great number of deep, closely-pitched fins from the green sand was quite a problem and, hence, designers were forced to put up with inadequate fin area in order to simplify the work in the foundry.

Today the method is still somewhat the same, but for production work the patterns forming the outside shape, and the core-boxes in which the cores for the ports are made, are constructed of metal and the moulds are dried in ovens or hardened by injecting carbon dioxide into the sand before the iron is poured in. Filling and ramming the moulds is usually accomplished on machines in a fraction of the time taken by hand moulding, and in one way and another the process has been developed until there is now no difficulty in casting fins up to 2 in. deep and pitched $\frac{1}{8}$ in. apart.

With the advent of the detachable cylinder head, moulding became a little simpler, and it also became possible to use a different grade of iron, or an entirely different material, for this component.

The main quality desired in a cylinder iron is freedom from wear; some grades of iron are better in this respect than others, mainly on account of their differing grain structure. It was once thought that rapid wear was due to insufficient hardness, and one or two makers adopted irons which could be hardened by heat treatment after all machining operations, except final grinding or honing, had been performed.



Part-sections comparing a flange-type barrel with one secured by through-bolts. The second form is superior structurally but more expensive.

However, while a hardened barrel may have a lower rate of wear than a soft one under abrasive conditions—for example, when an engine is run in dusty surroundings minus an air cleaner—it is not necessarily any better, and may even be worse, than a softer iron of the correct analysis under the corrosive conditions which exist every time the engine is started up from cold.

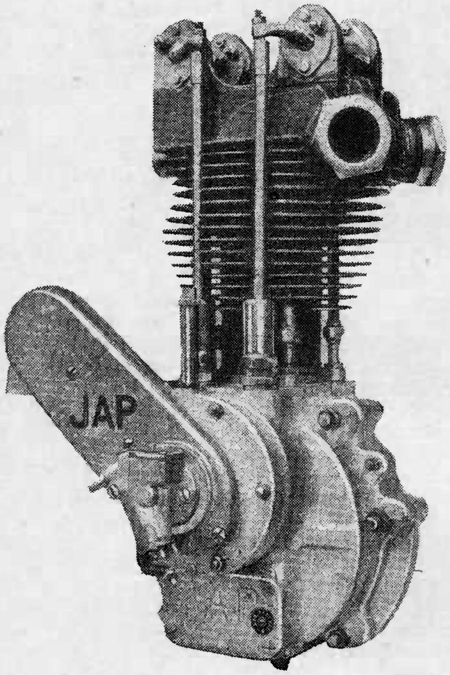
At such times the upper end of the cylinder wall is almost free from oil, and the fact that it is cold causes the water vapour, formed as part of the products of combustion, to condense thereon. Partly because of the cold conditions and partly because of the usual enrichment by flooding of the carburetter or closing the air slide, combustion of the mixture is not complete and this results in the formation of acids which are dissolved in the condensed water vapour and attack the cylinder walls.

Fortunately, air-cooled cylinders warm up so quickly, especially if the engine is allowed to run for a few moments before setting off, that corrosive wear is not so serious a matter as it is with water cooling. Cars used by doctors, or on short-distance work of the "stop and go" variety, can wear out their cylinders with astonishing rapidity unless precautions are taken to raise the temperature of the block quickly and to maintain it at the correct heat, whereas taxi engines, which rarely stop long enough to cool down, will accomplish very great mileages without serious wear.

Plating the cylinder with a deposit of hard chromium, which resists both corrosive and abrasive wear, is an attractive solution—with two drawbacks. One is that it is expensive, partly because chromium is dear stuff and partly because internal plating requires a specialized technique. The other reason is that oil does not "wet" a polished chrome surface.

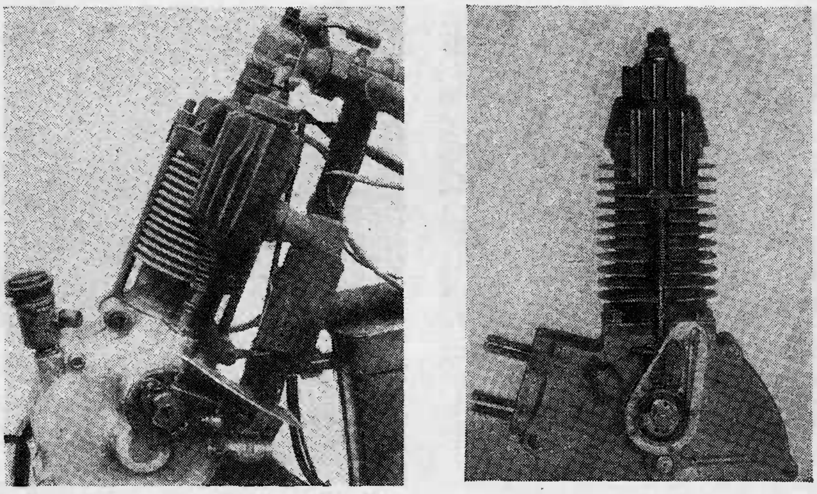
To overcome the latter trouble, it is necessary to provide microscopic oil reservoirs in the surface, either by making the deposit porous or by " back-etching " with a reverse flow of current towards a specially-formed cathode, which forms tiny depressions in the plating. Even if, as is possible, the plating is confined to the top one or two inches of the barrel, where the greatest wear occurs, the process is generally considered too " pricey " to be justified in commercial work. After all, provided that the grade of iron employed has been selected primarily for good wear-resistance and not on account of its low price or especially good " machineability," cylinder bore wear is not a serious problem—at least, when an efficient air cleaner is employed.

High-grade cylinder irons usually have small percentages of nickel or chromium added, as these elements refine the grain, distribute the graphite more evenly and in smaller flakes and increase the tensile strength. The microstructure of the material is then referred to as " pearlitic," but there is another type of iron, containing more nickel and also copper as alloying elements, which is known as " austenitic."



Large-area fins, drilled for fixing studs, on a two-port o.h.v. J.A.P. of 1928.

Austenitic iron differs in being non-magnetic and highly resistant to corrosion. It also work-hardens with use—that is to say, it develops a hard skin under the rubbing action of the rings and piston skirt. This would seem to make it a highly desirable barrel material, but it is costly and does not lend itself well to being cast into intricate fin shapes; also, there is some reason to think that it is not such a good material as pearlitic iron from the lubrication aspect. Some years ago, a famous racing factory ceased to use it after experiencing trouble through excessive smoking at high r.p.m. with pistons and rings which ran perfectly in standard cylinders.



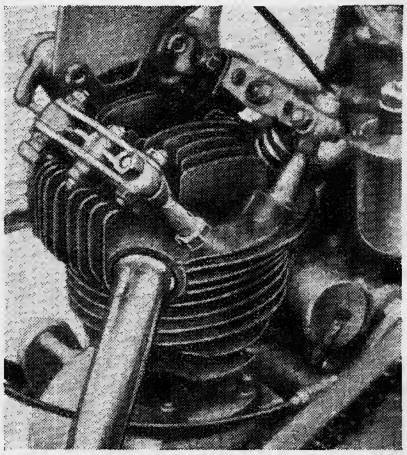
Meagre barrel finning on two early engines—the 1¼ h.p. French-built Werner of 1899 (left) and a 1901 Minerva; both have automatic inlet valves.

Some makers have, however, used austenitic iron for liners in aluminium jackets because of its high coefficient of thermal expansion—0.00019 in. per degree Centrigrade, as compared with 0.00012 in. for ordinary cast iron. There is obviously less tendency for the jacket to lose contact with the liner when the high-expansion iron is employed.

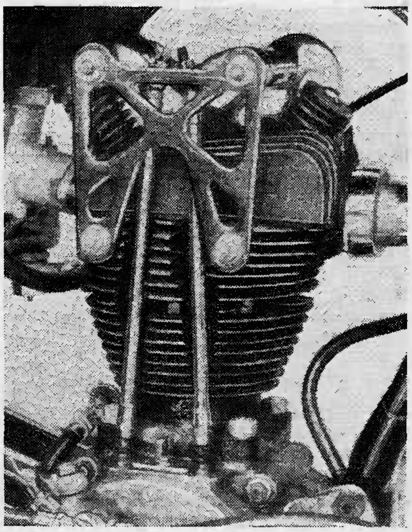
Because of cast iron's low tensile stress and lack of ductility, barrels which are retained by a base flange and four or six studs have, on occasion, broken off just above the flange. This distressing occurrence is most likely when the flange is located close to the bottom of the cylinder, and may be aggravated by a combination of a flexible crankcase and a rigid head-steady (as described in the article on torque reactions).

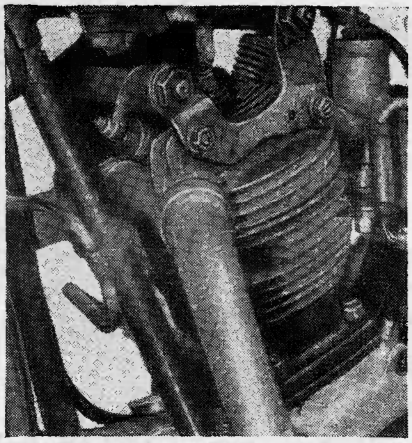
Forming the barrel with a long skirt projecting into the crankcase, and thereby raising the flange into a position much closer to that occupied by the gudgeon pin when the rod is at its maximum angularity, reduces the bending moment on the barrel very considerably; but, of course, the tensile stress due to gas pressure loading is still present. The best solution is therefore to use long studs which extend right through the barrel and head and hold the whole lot together, so relieving the barrel of tensile stress and the inevitable local loading at the flange studs which is a possible source of distortion under load.

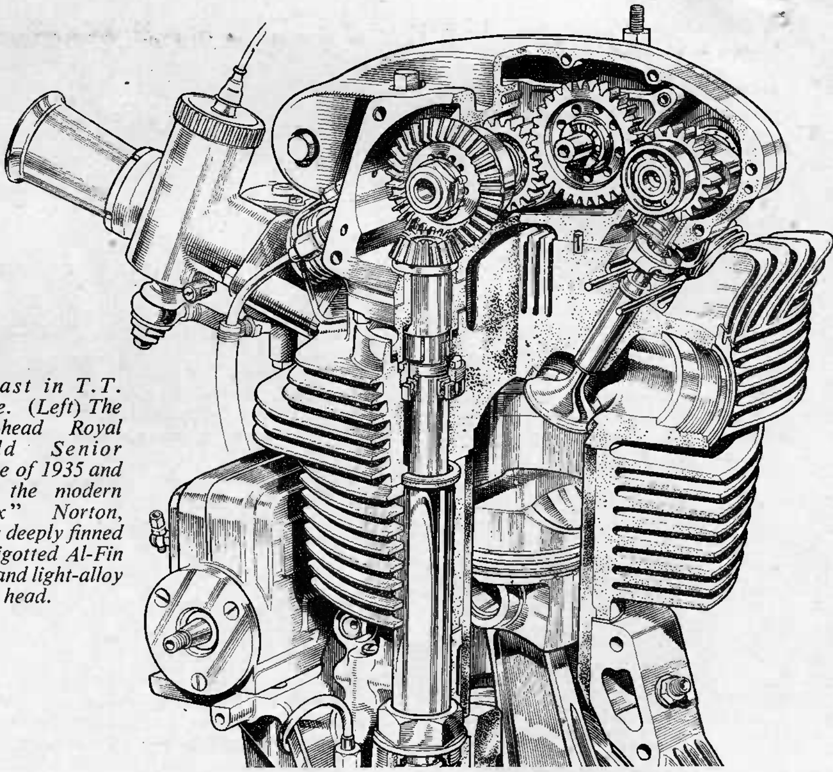
This construction is more expensive because, in addition to the use of longer studs, it entails drilling through all the fins (casting the fins with slots to clear the studs, as has been done sometimes, is prone to make the cylinder go " square " under running conditions). However, it opens the way to using bi-metal barrels, formed of aluminium jackets and thin liners, with perfect structural safety, even on big singles. The position with vertical twins is not so critical, because the area of the flange, embracing, as it were, both cylinders, is



Exposed valve gear meant relatively free airflow over the head, whether pillar-mounted as on this 250 c.c. four-valve Rudge (above) or with side-plates on the 1931 T.T. Raleigh (below).







Contrast in T.T. practice. (Left) The bronze-head Royal Enfield Senior machine of 1935 and (right) the modern "Manx" Norton, with its deeply finned and spigotted Al-Fin barrel and light-alloy head.

twice as large in relation to the piston thrust as in the case of the single.

For a time it was fashionable racing-engine practice to cast a finned aluminium jacket onto an iron cylinder, more in the interests of lightness than for better cooling. In fact, as it was difficult to guarantee close contact between the surfaces at all temperatures, there was little if any reduction in temperature of the liner, but this position has been altered by the development of the "Al-Fin" process by which liner and jacket are metallurgically bonded together.

In this process, which is the subject of patents and took a long while to perfect, the iron components are first "tinned" in a bath of almost pure aluminium, which has a great affinity for iron, and, while still hot, are transferred to a mould into which the aluminium is poured. There is thus no heat-break between the two metals such as exists between two unbonded parts, and very efficient cooling at an overall weight about half that of an equivalent iron barrel is obtained.

The resulting component, however, is not altogether perfect. On cooling down after pouring, the aluminium contracts and so subjects the iron barrel to a high compression stress. When the cylinder is at working temperature on the engine, the greater thermal expansion of the light metal relieves this compression and the barrel, if originally machined truly cylindrically, then expands at the upper end and becomes tapered. The effect may be serious in large-bore engines, but is less so in small ones, and may be guarded against to some degree by proportioning the fin area so that the barrel temperatures are as nearly as possible equal from top to bottom.

We come now to the more interesting part of the assembly, the cylinder head. The design of this was also influenced very largely in the early days by what could be accomplished in the foundry, and what little finning existed was often placed in the way which was easiest to make, rather than where it would provide the best cooling. Nevertheless, the overall effect, as compared with some later designs with enclosed valve gear, was reasonably good, as it was the usual practice to mount the rockers either between sheet-steel side-plates or on separate brackets, so permitting a good evacuation of air over the centre of the head.

Some of the methods employed for bolting the head on were not so happy, however, and blown head gaskets and leaking joints were not unknown.

The big-port A.J.S. was one of the designs exempt from these troubles, as its head was retained by a U-bolt which fitted into a slot cast in the vertically placed fins, so providing an equal distribution of pressure over the small-section copper-and-asbestos washer which formed the gasket. Slotting the fins formed a heat break between the hot exhaust side and the cool inlet—a very desirable feature, the value of which was, apparently, not recognized, because in later models the U-bolt was discarded and replaced by a strong steel bridge-piece which bore on a single button right in the centre of the head. This would appear to be an ideal arrangement, but was not, because the intense local pressure was sufficient to distort the head and cause the valves to leak.

This illustrates the cardinal importance of locating head studs so as to avoid local high stresses. Such stresses can also be generated by head studs screwed into flanges of insufficient thickness, so creating areas of alternate high and low pressure on the head joint, with a resultant liability to joint-blowing or head-distortion.

The best method is undoubtedly to use equally spaced studs which run right through substantial bosses to a height somewhat above the top of the combustion chamber. Although the pressure at each of the nuts is high, the load is well distributed down at the joint face, and if the head is of aluminium a gasket is not strictly necessary.

Whatever its good properties may be, cast iron has one shortcoming—low thermal conductivity. This means that it is likely to develop internal hot-spots; also, the exhaust valve has difficulty in getting rid of heat through its seat and stem. Therefore the use of cast iron places a limit on the compression ratio employable on petrol without trouble through detonation or early self-ignition.

The first attempt to overcome this limitation was to employ an aluminium-bronze alloy, composed of copper alloyed with about 10% of aluminium, which could be cast to the same proportions and with the same pattern equipment as for iron. This development took place rather later than it might have done—Ricardo had already pointed the way by using this material for the heads of the racing three-litre Vauxhall he designed in the early 'twenties—but it rapidly became standard practice for racing machines and a number of sports models.

Aluminium-bronze permitted an increase in compression of about one ratio due to its higher conductivity. It was, however, far from popular in the machine shop, because it is an awkward material to work, especially when drilling long holes; it is also about one-eighth as heavy again as cast iron, as well as more expensive. Another defect found in road machines was a tendency towards rapid wear of the inlet valve seats. All things considered, the bronze head had little to recommend it except the increase in power of perhaps 5% or 8% which it conferred.

The next step was to investigate the possibilities of aluminium as a head material. The steps which led to development of the light-metal head as we know it today will form the subject of the next article in this series.