THE HISTORY OF COMPONENTS

This section of the journal will deal with one of the metal components used in the automotive industry, recording the changes in its design. At the same time, the many ways in which the techniques and materials employed in its manufacture have developed will be described.
This approach will also serve to emphasize the vital role played by metal component manufacturers in developing the basic materials and working out production processes.
The article in this issue deals with the connecting rod.

The Connecting Rod

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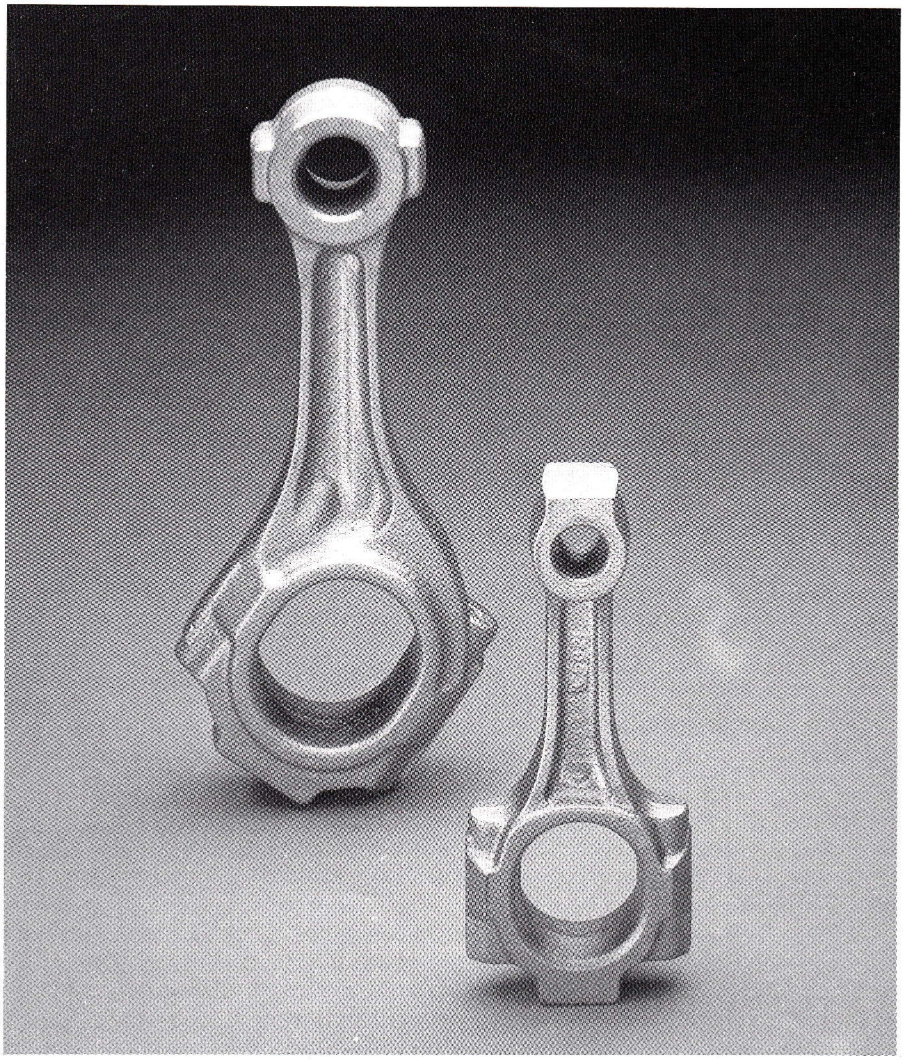
Abstract
Like all components of the internal combustion engine, the connecting rod has been the object of significant changes in design and manufacturing, due to its function of primary importance.
The article traces the evolution up to the present day of this metal component, examining the materials used and the latest innovations in manufacturing technologies.

Riassunto
La biella.
Come tutti i componenti dei motori a combustione interna, anche la biella, per la sua funzione di primaria importanza, è stata oggetto di significativi mutamenti in sede di fabbricazione.
L'articolo ripercorre la storia e l'evoluzione di questo componente, prendendo in esame i materiali utilizzati e le innovazioni intervenute nelle tecnologie di fabbricazione.

Developments in the design of internal-combustion engines, and in the methods and machine tools used for their mass production, have reached a high degree of sophistication in the past few decades. The automotive industry has also acquired much experience in regard to new materials and better fuels, along with a greater understanding of the phenomena involved. Two factors exerting an outstanding effect have been the determination to control exhaust emission and the emphasis on lower fuel consumption.
All motor vehicle components have undergone development to a greater or lesser extent, and the connecting rod is one of them (Fig. 1). This is the rod that carries the piston at one end and the the pin of the engine crankshaft at the other, to allow reciprocating motion to be transformed into rotary motion (Fig. 2).
The crank mechanism, dating back to the Middle Ages, is one of the most important mechanical inventions, and by its function the connecting rod is one of the most important features of engine design (Fig. 3). An engine's power, smoothness and life depend on proper dimensioning and positioning of the connecting rod. The dimensioning and consequently

Fig. 1 - Ductile iron connecting rods, for cars and trucks, produced by Teksid, Iron Foundry Division.



the shape of the rod are governed by features such as the cycle type (2-stroke or 4-stroke), the lubricating system (Figs. 4 and 5), the running speed, the number of cylinders and their layout, the distribution and connexion of the different parts of the engine, and assembly constraints.

Knowing the laws that govern the motion of the crank mechanism's component parts, and their weights, it is possible to calculate the forces generated by its movement. The parts having reciprocal motion are subject to inertial forces, and the parts connected to and rotating with the crankshaft are subject to centrifugal force.

With a good approximation the piston and its rings, the gudgeon pin and its accessories, the little end and two-thirds of the shaft of the connecting rod can be regarded as concentrated on the gudgeon pin's axis and having reciprocating motion. The crank pin, the big end and one-third of the shaft have rotary motion and are regarded as concentrated on the crank pin's axis, generating centrifugal forces, as also do the crank webs and any counterweights.

Fig. 3 - Computer plotting of connecting rod motion. Fiat's engine FIRE 1000.

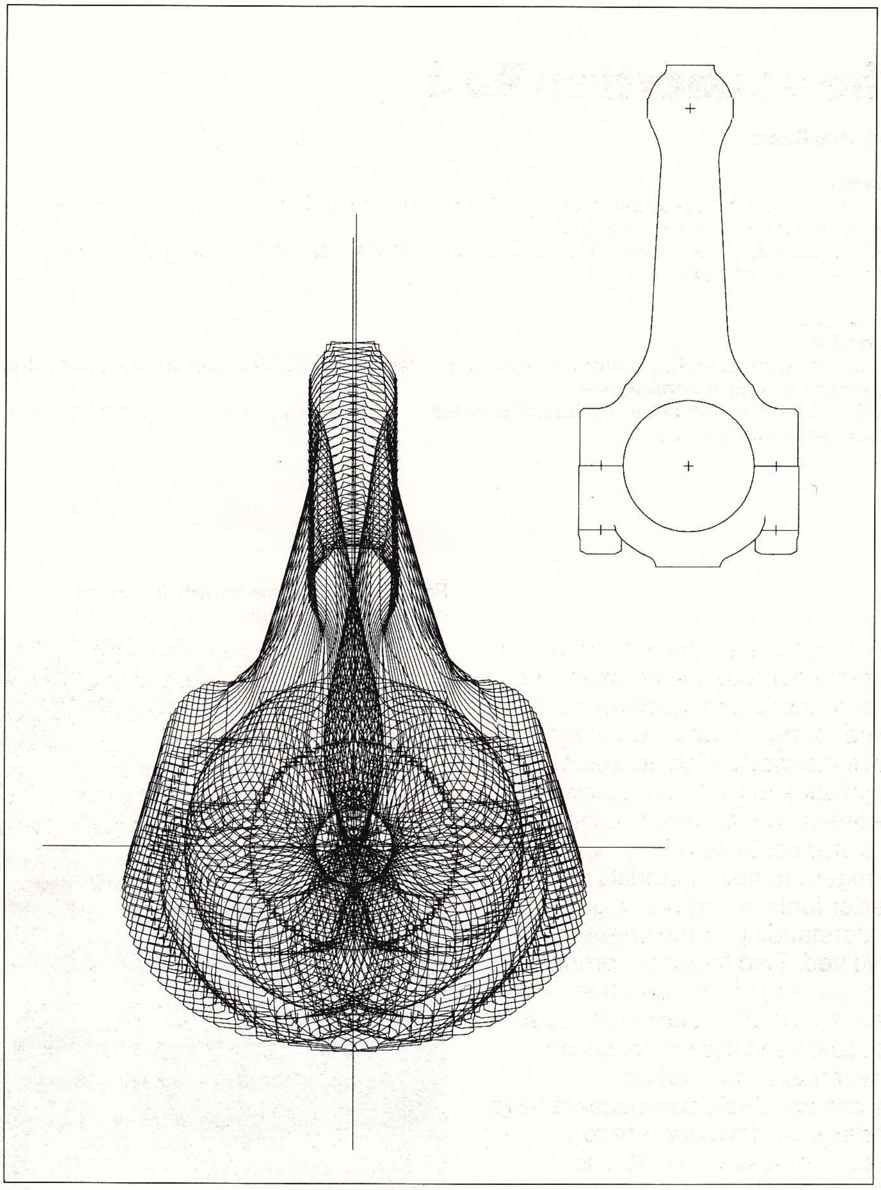


Fig. 2 - The crank mechanism.

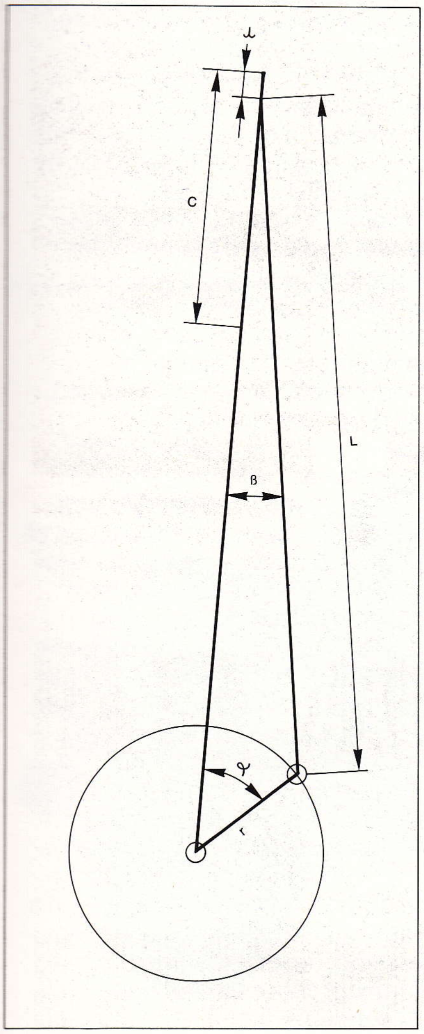


Fig. 4 - Big-end lubrication.

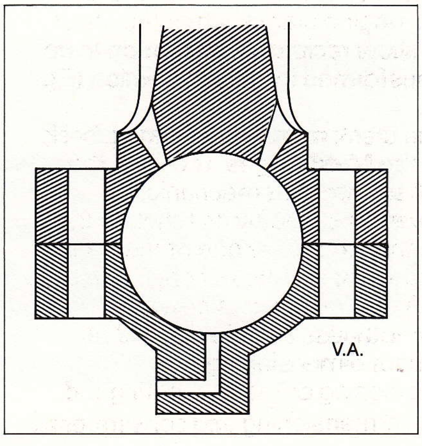
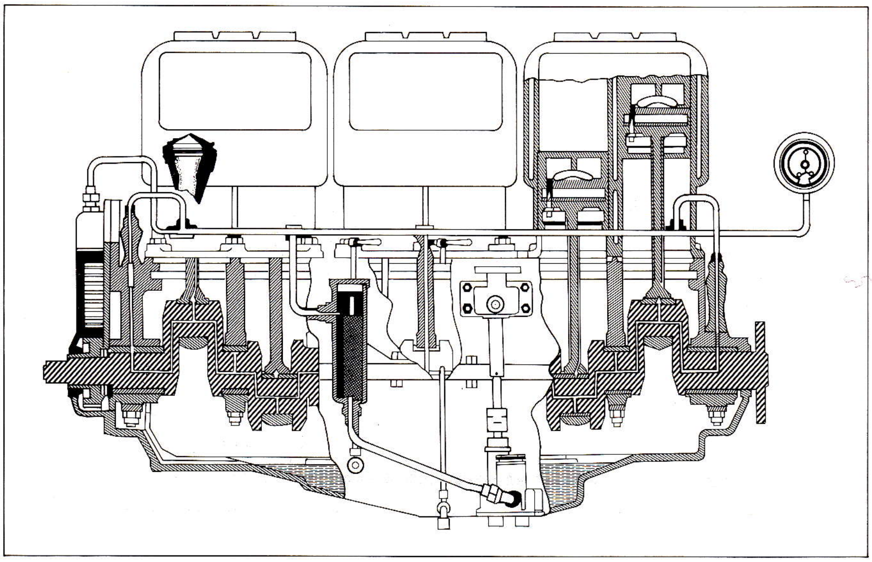


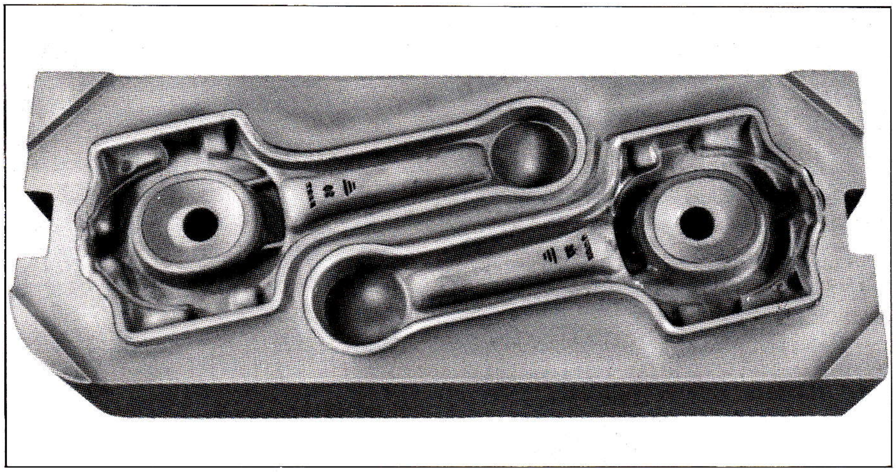
Fig. 5 - Pierce-Arrow "high-pressure" lubrication system of ca. 1912.



Inertial and centrifugal forces enter into the study of engine balacing, whose purpose is to reduce or eliminate engine vibration and its adverse consequences for components and casings.
Connecting rod design may take a variety of forms, depending on the intended purpose and essentially on the operating speed. A line is customarily drawn between low-speed rods, for locomotives, low-speed diesels, reciprocating power plants, compressors and so forth, and high-speed rods, for motor vehicle engines run at high revolutions.

Low-speed rods may be of heavier construction than high-speed rods, and made of less valuable materials, and may also be less carefully finished. For high-speed rods, on the other hand, lightness must be taken to the utmost limit allowed by the material used, so as to reduce the weight of the parts having reciprocating motion.
The shape of the rod's cross section also differs. In low-speed rods it is usually rectangular, sometimes lightened by machining. In high-speed rods it is practically always a double T, with the flanges lying in the plane of the crank mechanism.

Fig. 6 - Connecting-rod forging die. Teksid Hot Forging.



The connecting rod little end is usually integral with the shaft, and the big end is usually in two parts assembled by bolts or screws.
A connecting rod's characteristic parameter is its length, or the ratio of the crank throw to the rod's length. The lower this ratio is, the smaller is the angle made by the rod in its oscillating motion, thus reducing lateral thrust on the piston and allowing its skirt to be shorter. At the same time, however, the connecting rod is longer, and therefore heavier, for a given length of stroke, so a satisfactory compromise has to be found. In touring cars, for example, the ratio is between 0.22 and 0.23; it is higher in high-speed engines, and lower in low-speed engines.
Taking account of the connecting rod's characteristics, all of which are of the utmost importance, the greatest attention has been paid to the subject of its manufacture. This was the subject of a study made by D. A. Maynard, of the Chrysler Corporation, and published under the title "Selecting the optimum engine connecting-rod manufacturing process", which compares five processes: two forging methods, casting, hot powder metallurgy moulding, and cold precision forming.
Most connecting rods nowadays are produced by forging (Fig. 6). Casting is used considerably less, but is on the increase. Production of connecting-rods by the hot powder metallurgy method constitutes a very low percentage, but some long-term developments have now reached the stage of experimental production. Connecting-rods made by cold precision forming are not yet in production but are under development.
The forging process typically starts with a hot-rolled steel bar, which is cut to the required length, heated and drop forged or press forged in a series of operations, followed by trimming, heat treatment, stamping, shot-peening and inspection.

Drop-forging tolerances are fairly wide, to allow for die mating error and die erosion caused by the high working temperature. Cold stamping does not do much to overcome these defects, and a suitable maching allowance has to be left to compensate for the size of the tolerances. Matters have been improved, however, by the use of press forging, in which the die mating error is smaller than in drop forging. In addition, if induction heating is used, decarburization, oxidation and burning can be reduced and a higher degree of automation is possible.
Next we come to casting, using ductile iron, in which the latest technology uses green sand moulding without flasks. In the

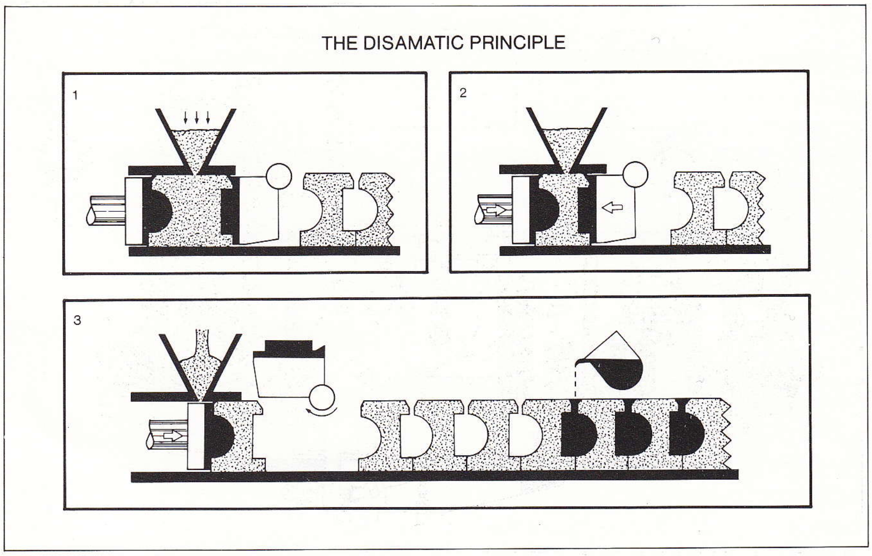
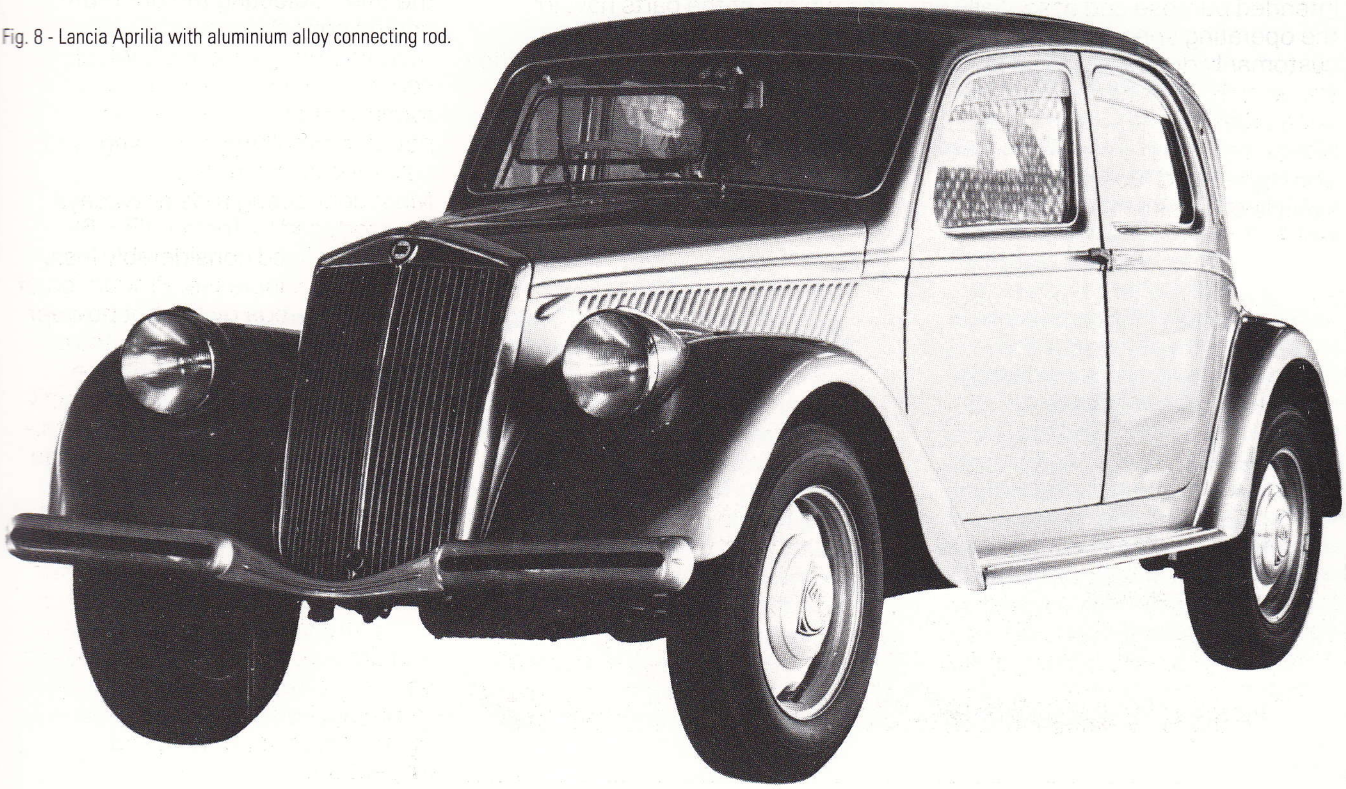


Fig. 7 - Disamatic operating principle.

Fig. 8 - Lancia Aprilia with aluminium alloy connecting rod.



Disamatic process, for example, the mulled sand is supplied to the machine hopper continuously and the whole line of moulds is moved forward the width of one unit each time the machine feed is operated (Fig. 7). After the moulding zone come the casting, cooling, and knocking-out zones.
Connecting rods made of ductile iron are reckoned to be about twice as workable as steel connecting rods, but the cast iron rods for 6 or 8 cylinder engine weigh about one-sixth of a pound more than forged steel rods.
In the powder metallurgy process the alloy powder, mixed with graphite and lubricant, is briquetted into a blank of suitable size for the connecting rod to be produced. The blank is then heated and brought to its final density. Connecting-rod blanks produced by this method are more accurate and lighter than forgings. Oxides are present in considerable amounts, but workability can be kept at the same level as that of forged steel by adding sulphur.
Cold precision forming starts with a bar of smaller diameter than that used for conventional forging. The bar is raised to 980°C by induction heating, instead of the 1200°C used in conventional forging, and formed on a multi-station press to give a flash-free connecting rod with only a small bar hold, which is parted at the final press station, where the rod is stamped to the required size. Decarburization of the part and erosion of the die are considerably less in this process than in conventional forging, and the tolerances are closer.
Maynard's study concludes with the choice of the most suitable method for meeting all the technical and economic requirements relating to connecting rods. Using the Kepner-Tregoe method, it was found that ductile iron casting was the best method. Other possible materials are pearlitic malleable cast iron, aluminium-magnesium alloys, and the so-called composites.

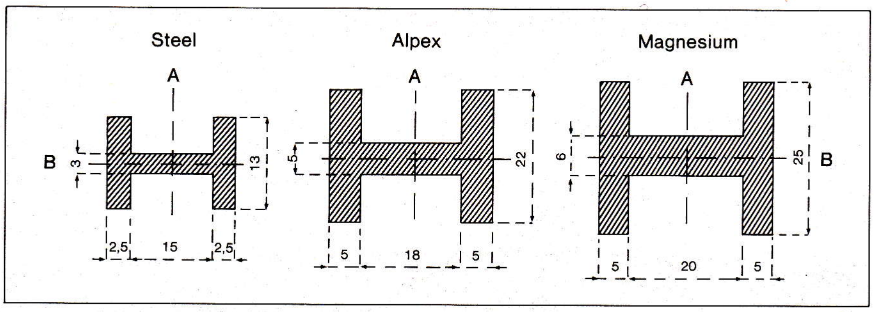
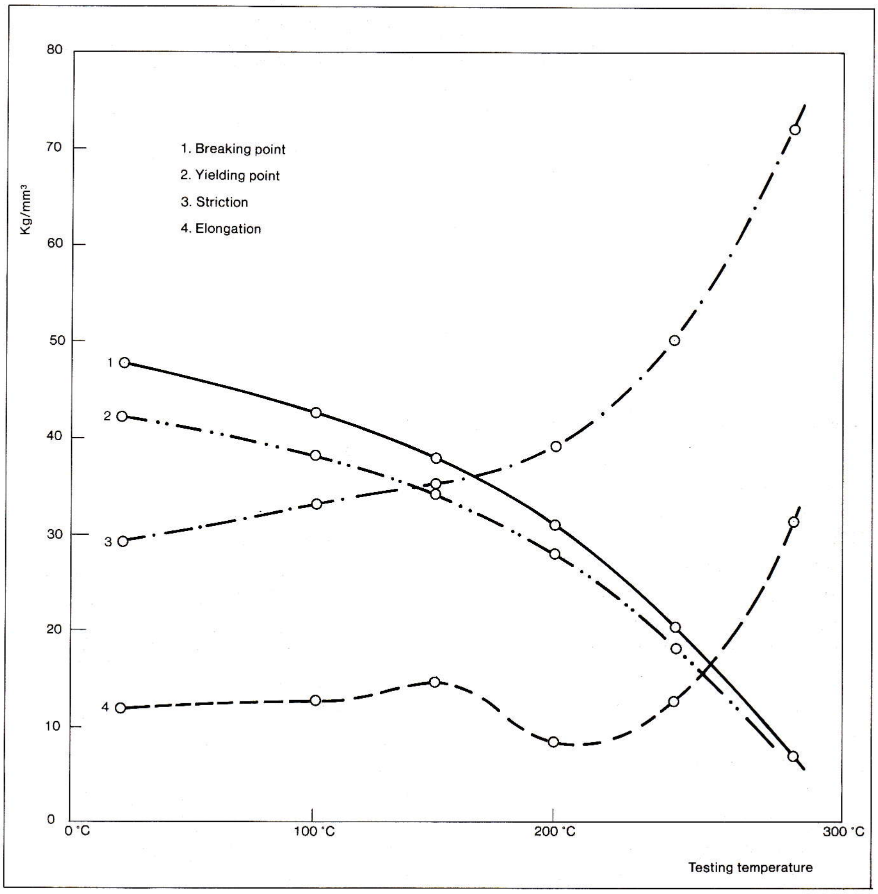


Fig. 9 - Cross section of steel, alpax and magnesium connecting rods.

Pearlitic malleable cast iron opened the way to large-scale production of cast connecting-rods. The material has given excellent results when used on both cars and trucks. The advent of ductile iron has in many cases tipped the balance in favour of the new arrival.
Aluminium alloy connecting rods have outstanding history (Fig. 8). Duralumin connecting rods were produced and fitted in quantity by the Hupmobile and Franklin car companies in America in the 1920s. After heat treatment duralumin has properties not unlike mild steel. In this case the connecting rods are obtained by forging. Experiments

Fig. 10 - Properties of duralumin 681 b. Dürene Metallwerke.



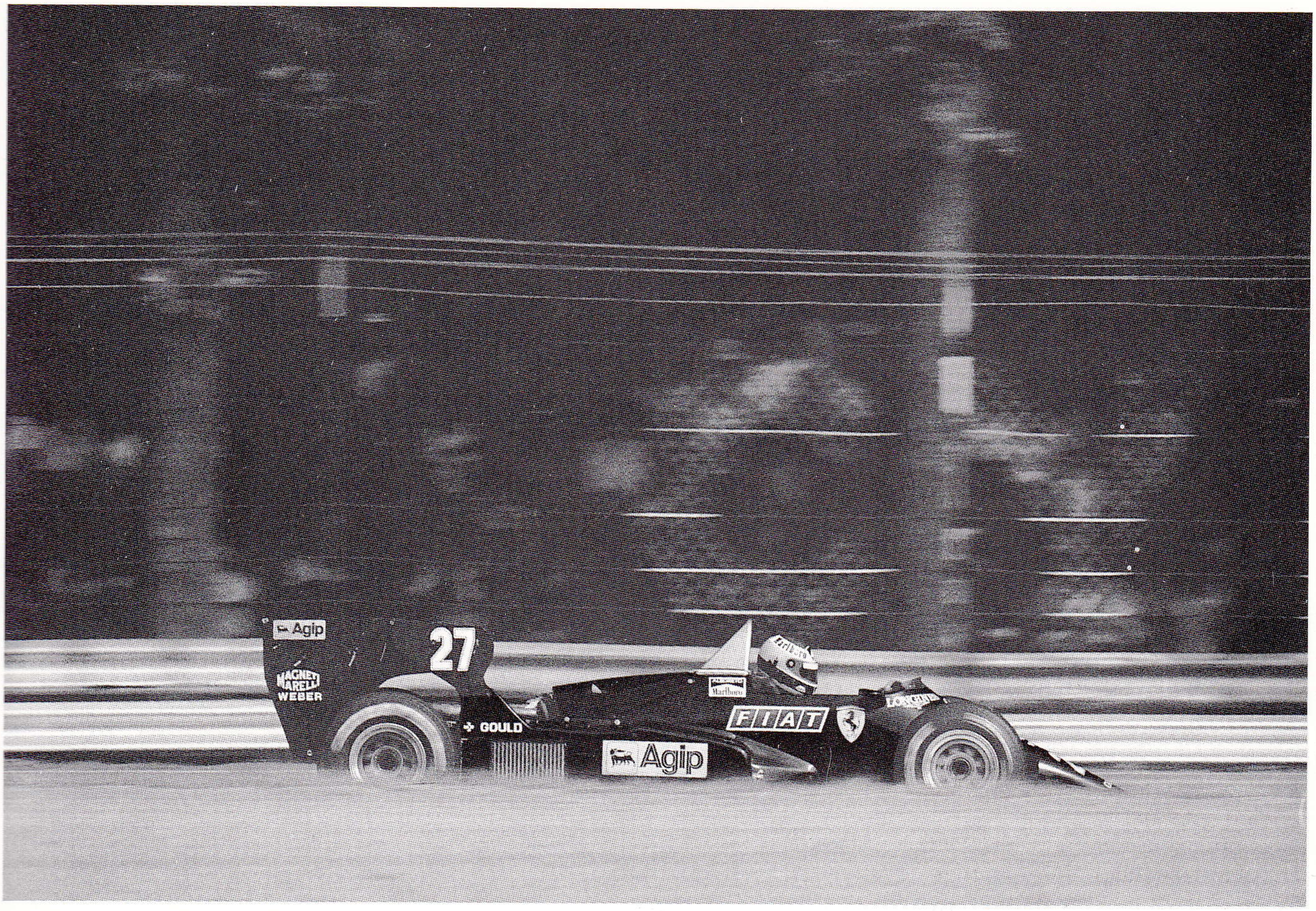


Fig. 11 - Ferrari F. 1 racing car with titanium alloy connecting rod.

were also made with Alpax casting alloy and Elektron magnesium alloy (Figs. 9 and 10).
The aim of lightening the moving parts of an engine is to increase its power and speed. Comparisons were made on the SPA Type 6A aero engine, using in turn pistons and connecting rods made of cast-iron/steel, aluminium/steel, magnesium/steel and magnesium/magnesium (Lepto alloy).
Even today, the use of aluminium for connecting rods is still given consideration in many cases and they are regarded favourably in comparison with steel both for their fatigue strength and for the possibility of avoiding the use of bearings.
The composites are among the latest materials that may be usable for connecting-rod manufacture with good chances of success, and their capabilities are spurring much research to that end. The Toyota Motor Corporation has used an experimental ceramic fibre (Du Pont's FP, an aluminium oxide polycrystalline fibre) to reinforce aluminium connecting-rods fitted to an experimental high-performance engine in the FX-1 sports car. Aluminium connecting rods reinforced with FP fibre are 35% lighter than the steel rods they replace. Titanium alloy connecting rods are used by Ferrari on its F.1 racing cars (Fig. 11).
Meanwhile, however, efforts are under way to reduce the cost of forged steel motor engine components by research into component geometry and the materials used. For example, medium-carbon micro-alloyed steels with a small percentage of vanadium or niobium, or both, harden by precipitation of carbides and carbonitrides after the forging operation. That means there can be

a substantial reduction in the cost of heat treatment as compared with manufacture using conventional steels. The results in regard to production possibilities and connecting-rod life are encouraging. There are also proposals for less expensive steels with improved workability.

Lastly, considering the function of the connecting rod, and its economic weight in the internal combustion engine as a whole, the importance of quality assurance should be emphasized. There is careful control during manufacture and upon completion. In addition to visual inspection, measurement and weighing there is ultrasonic, magnaflux and X-ray testing. Technologies tend to become increasingly refined in the motor industry, as a result of competition in a market where there is no foreseeable trend to growth.

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