Thermal analysis in the light alloys foundry

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Abstract
An increasingly strict control of production parameters is required to make the best choice and use of alloys in the light alloys foundry. This paper relates information gathered by means of thermal analysis to foundry characteristics; it describes the set-up and introduction of a thermal analyzer as a " routine " production device to check the eutectic Si modification and grain refinement.
Experimental data on foundry alloys for current use are reported.

Riassunto
L'ottimizzazione nella scelta e utilizzazione delle leghe nella fonderia di leghe leggere richiede un sempre più attento controllo dei parametri produttivi. Questa memoria mette in correlazione le informazioni deducibili mediante analisi termica e proprietà di fonderia; illustra la messa a punto e introduzione come controllo di « routine » in produzione di un analizzatore termico per verificare lo stato di modifica del Si eutettico e del grado di affinazione del grano. Vengono riportati dati sperimentali relativi ad alcune leghe di uso comune in fonderia.

Introduction

The present energy crisis has urged the automotive industry to find means of reducing fuel consumption; making lighter vehicles is very helpful to this end, and has become one of the industry's main aims.
As a consequence, the light alloys foundry has been urged to extend its production range further by making products which were unthought of up to a few years ago, and is thus facing considerable problems regarding the feasibility, the quality and distinctiveness of alloys.
The foundry has always stressed the need to restrict its range of alloys in order to reduce costs, this being in contrast with the great variety of castings produced, each with precise requirements: brake calipers, pistons, wheels, boxes, cylinder heads for petrol and diesel engines, aircraft landing gear, etc. For each product there is an alloy, of which the technician must know the mechanical characteristics and casting properties: castability, shrinkage tendency, solidification range, gas sensitivity, etc. By means of thermal analysis (which is widely used throughout the ferrous metals foundry) useful information can be obtained on these and other properties (which are not easily found in the literature, being closely connected with the chemical analysis of the examined alloy) by using simple equipment, cheaply and in a very short time (1), (2).

Solidification of Al-Si alloys

Both hypoeutectic and eutectic or hypereutectic Al-Si alloys are widely used: the first for structural works which require high mechanical strength; the second when wear and high-temperature resistance is required.
The mechanical characteristics of Al-Si binary alloys are, as a rule, satisfactory, but can be further improved by addition of copper and magnesium besides iron, chromium, manganese, etc.
The eutectic solidification structure is further modified by adding small quantities of such elements as sodium, strontium, antimony, rare earth metals, etc., thus obtaining considerable improvements, especially as far as the material ductility is concerned. It is necessary to refine not only the eutectic structure but also the primary structural solidification constituents (Al-high contents phase α for hypoeutectic alloys and Si-high contents phase for hypereutectic alloys) by adding such elements as titanium and boron for hypoeutectic alloys and phosphorus for hypereutectic ones. The presence of a refined structure generally brings well-known advantages to the alloy's mechanical behaviour. Moreover, in this specific case, a refined primary structure prevents ternary inter-metallic compounds (β type - Al Fe Si) from taking a coarse site and the growth of big grains from interfering with the self-feeding of the liquidus during solidification in the mould, and causing microporosity due to microshrinkage.
During cooling of an Al-Si hypoeutectic alloy from the liquid state, at first primary phase-α nucleation takes place, followed by crystal growth with a dendritic structure. According to well-known solidification theories, nucleation requires undercooling, which is more notable in the case of pure alloys (homogeneous nucleation) but which decreases considerably in the presence of certain impurities and inoculating agents (heterogeneous nucleation). The latter, by multiplying the solidification nuclei, have a strong refining effect on

the structure; therefore undercooling and refinement can be related.
As mentioned above, in Al alloys the refining effect is obtained by adding titanium and boron. Two theories help in explaining this phenomenon: one (peritectic theory) ascribes the titanium effect to the formation of a peritectic phase with $TiAl_3$ aluminium. This phase develops from a peritectic reaction between the two metals in the form of small acicular crystals, which disintegrate into even finer crystallites and act as nuclei for the subsequent α-phase solidification. The second theory postulates the presence of carbon in the system and ascribes the titanium effect to the formation of TiC nuclei; in the presence of boron also AlB_2 and TiB_2 nuclei might appear.
As the cooling process continues and the α-phase quantity increases through dendritic growth, the liquidus composition increases its Si content till the right conditions for the formation of the eutectic are established, with Si phase nucleation being mainly due to AlP particles.
There is no relationship between the phases of the Al-Si system eutectic (anomalous eutectic). The Si phase has a certain degree of inter-connection, since the eutectic Si acicular or plate structure, as it appears through the microscope (because of cooling in sand moulds without modifying agents) is due to the cross-section of irregular plates interconnected and branched.
The Al-Si eutectic can be classified among the types with or without facets: as a matter of fact, the Si phase has a high entropy of fusion and, therefore, tends to solidify with a smooth surface (with facets), while the α-phase has a low entropy of fusion and tends to solidify with an uneven surface (without facets).
The resulting eutectic is therefore irregular, as it grows with few connections between the two phases and without a common growth surface.
The undercooling of the liquidus in front of the solidus-liquidus interface provides the driving force necessary for the solidification to continue. The Si phase with facets grows rapidly and goes from the interface into the liquids with a plate morphology. The α-phase without facets follows, enclosing the Si plate almost completely but for the top, and leaves some liquidus behind the solidus structure. Subsequently, the liquidus solidifies at a higher undercooling rate and at a finer structure.
The metallographic structure of the eutectic is thus made of big Si particles (acicular), surrounded by α-phase, provided that operations take place at the undercooling speed of castings poured into sand moulds.
The addition of sodium causes changes in the Si phase morphology of the eutectic. According to confirmed theories, such morphology depends on the growth temperature of the Si phase, the structure of which changes from acicular to lamellar and globular, as the growth temperature is set at increasingly lower rates (3). The eutectic Si morphology given by the modification with sodium is similar to that due to rapid cooling.
It has been supposed that sodium neutralizes the AlP particles on which, as a rule, the eutectic Si nucleates, so that crystallization takes place at a lower temperature. Nucleation originates from the primary α-phase dendrites and the structural morphology is characteristic of the lower temperature at which the Si phase of the eutectic grows.
In spite of the difference of opinions in the literature, it is accepted that the eutectic Si phase is interconnected, even in the case of modified eutectic. This means the refusal of the hypothesis that, in the presence of sodium, the Si eutectic particles are surpassed, during their growth, by the growth of α-phase and isolated from the liquidus, so that another nucleation must take place for further crystallization, with prevention of recalescence. On the contrary, it must be supposed that the eutectic Si, nucleated from the primary α-phase, grows together and in close connection with the eutectic phase, so as to form a continuous eutectic, with a common growth surface for both phases. The temperature remains constant at the solidus-liquidus interface, and the liquidus composition changes to equalize the growth rate of the two phases, so that no local recalescence takes place.

Experimental part

After setting up, interpreting and preparing the datum curves, a thermal analyzer was installed in the furnace department of the ALUTEK Works, as a routine inspection device. The way it works has been described in some previous literature (1), (2). However, it was necessary to overcome problems regarding the time necessary to carry out the analysis and the cost of a non-recoverable crucible with a thermocouple.
An up-to-date foundry must be equipped, therefore, with an analysis system that is fast but also accurate and economic, and which can be operated by personnel not always qualified, but reliable enough to perform both the checking and all necessary corrections.
The crucibles usually used in foundries for thermal analysis are made of a glass core with a phenolic shell moulding, with a chromel-alumel thermocouple showing in the measurement zone (quite often the wires are not welded but just twisted together) and

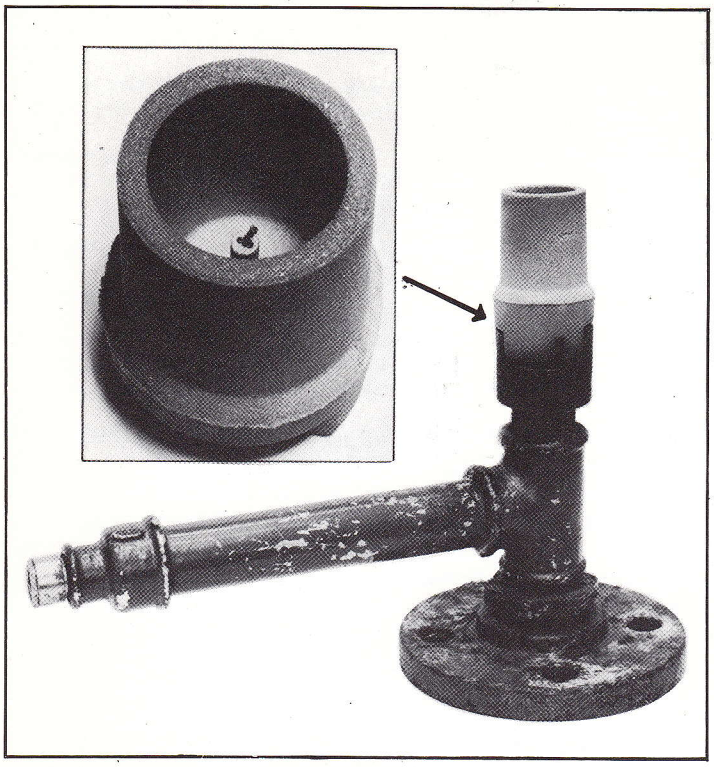
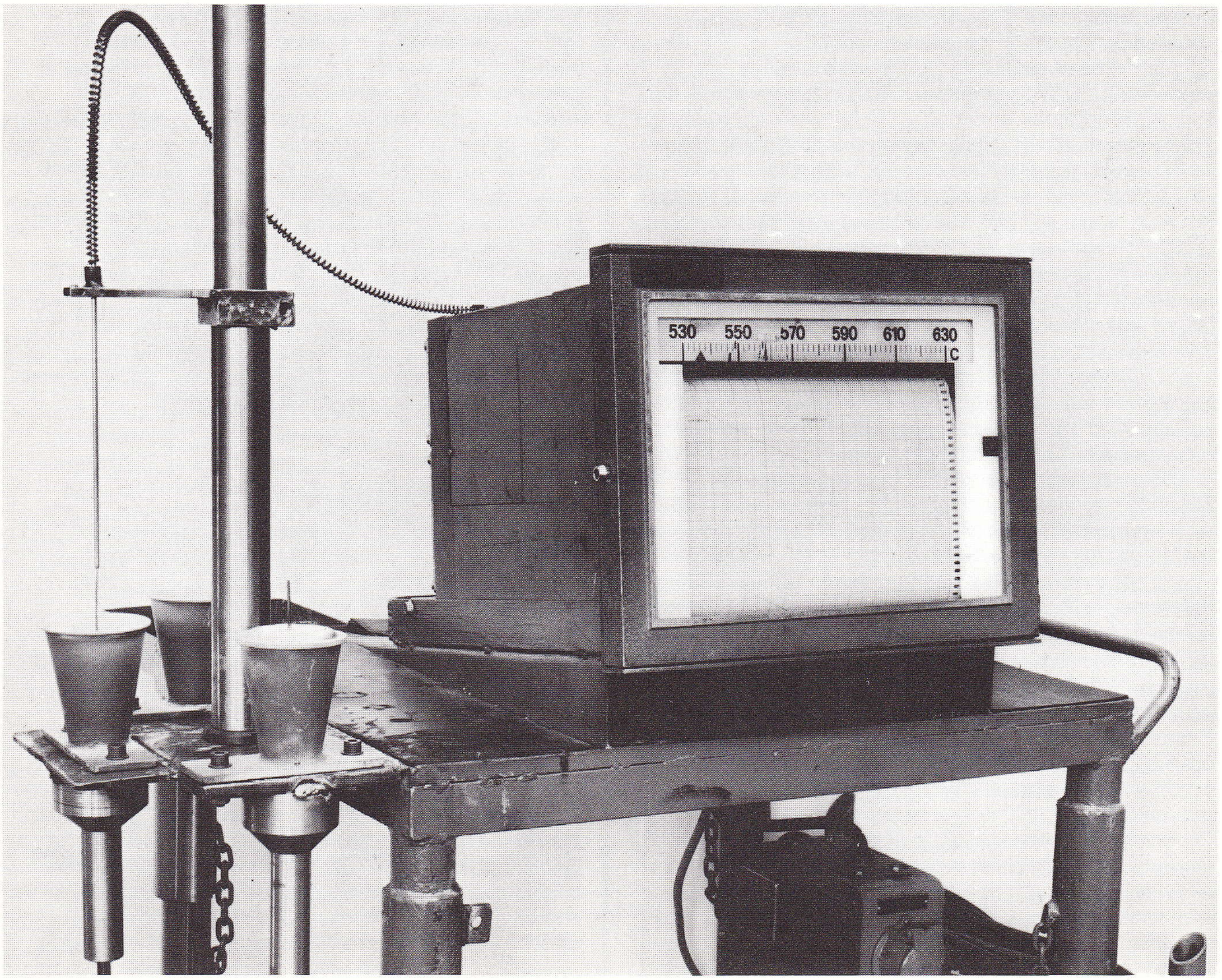


Fig. 1 - Non-recoverable crucible for thermal analysis.

encased in a refractory material tube with two holes allowing the passage and insulation of the filaments, locked at the bottom of the glass with silicate or other high flux material.
The time necessary to carry out the analysis varies between 2'30" and 4', according to the type of alloy. Because of the cost of the crucible shown in Fig. 1 (~ $ 0.4) and in view of the main analysis parameters described above, a system of thermal analysis has been set up with a permanent crucible that is spray painted with insulating coating and has precise thickness, volume and shape characteristics. The

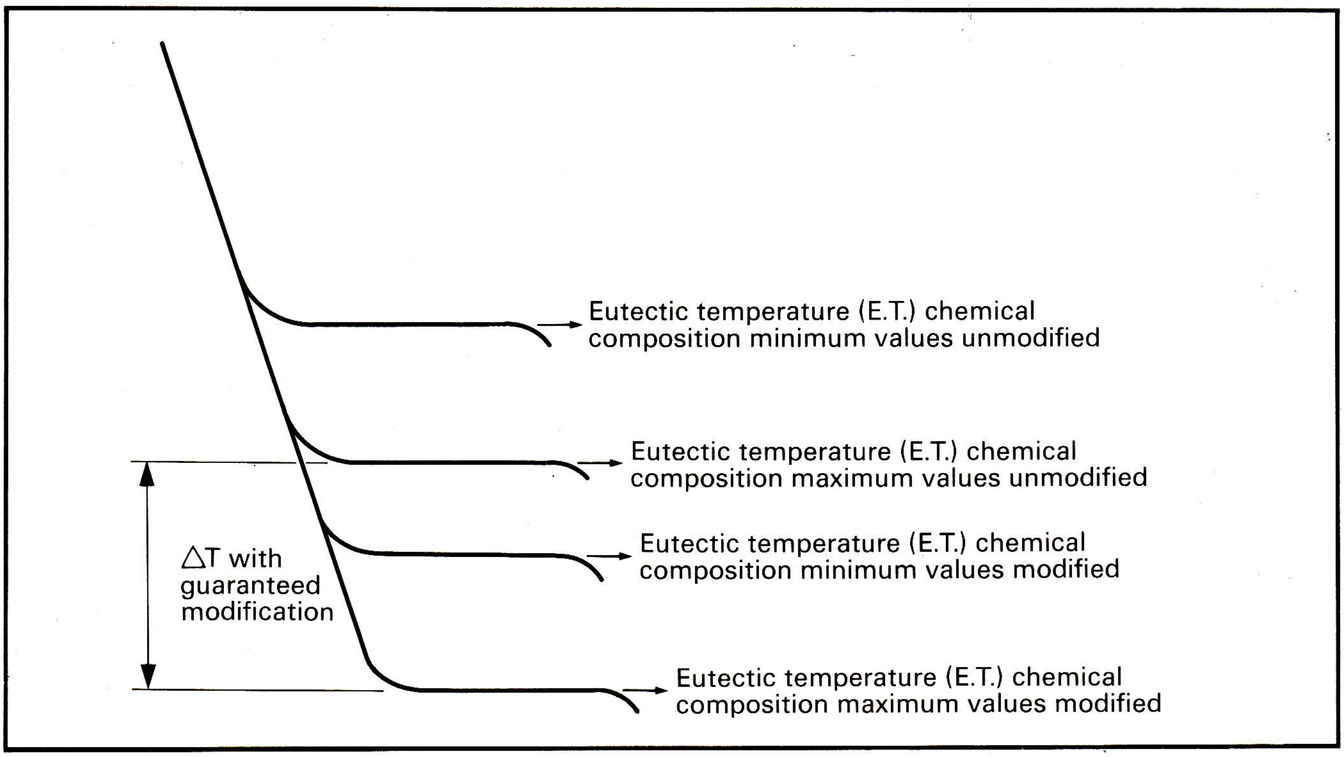
Fig. 2 - Permanent crucible for thermal analysis.



device is equipped with a system for vertical movement of the thermocouple, which is dipped in the metallic crucible in a certain position (thermal centre of gravity). The top of the thermocouple is covered with a metallic tube so as to be protected during measurement. The device is shown in Fig. 2. By means of it, thermal analysis curves have been drawn experimentally and studied, for the following alloys:
G - AlSi5 Cu3 Mg - SG - AlSi6 Cu2 - SG - AlSi7 Cu3 Mg
SG - AlSi9 Cu1 - G - AlSi9 Cu1 - GD - AlSi9 Cu3
In order to determine the eutectic temperature interval within which the optimum metallurgical state is guaranteed, without taking into consideration the percentage fluctuations as provided in the specifications, the eutectic temperatures have been determined for each alloy with chemical composition within the range considered and the structure present. Fig. 3 shows the above points schematically. The validity of the Δ T interval has been verified experimentally with statistical drawings.
As an example, the curves for SG-AlSi 7 Cu 3 Mg alloy are shown with minimum analytical values in both the modified and the unmodified state as well as the micrographs of the Si eutectic modification (Fig. 4).

The eutectic temperatures for the minimum and maximum values both modified and unmodified, and the Δ T useful for the examined alloys are shown in Table 1.
The variations in the horizontal path of the curve and in the eutectic temperature value point out the fact that silicon can take a different morphology according to the modification level, i.e. from coarse to fine globular (lamellar, acicular, modified). The crystalline aspect of the eutectic silicon originates various types of shrinkage:
— surface shrinkage in case of lamellar appearance;
— surface and internal shrinkage in case of acicular appearance;
— internal shrinkage in the barycentric zone in case of modified appearance.
If Δ T is known, it is possible therefore to foresee the morphology of both silicon and shrinkage, and to optimize the latter by means of the parameters that influence the former.
The curve also provides information about the grain size, in the initial solidification zone. If the alloy, in the liquid state, has few crystallization centres, a crystalline structure is obtained having few big grains.

Fig. 3 - Influence of structure and chemical composition on eutectic temperature.



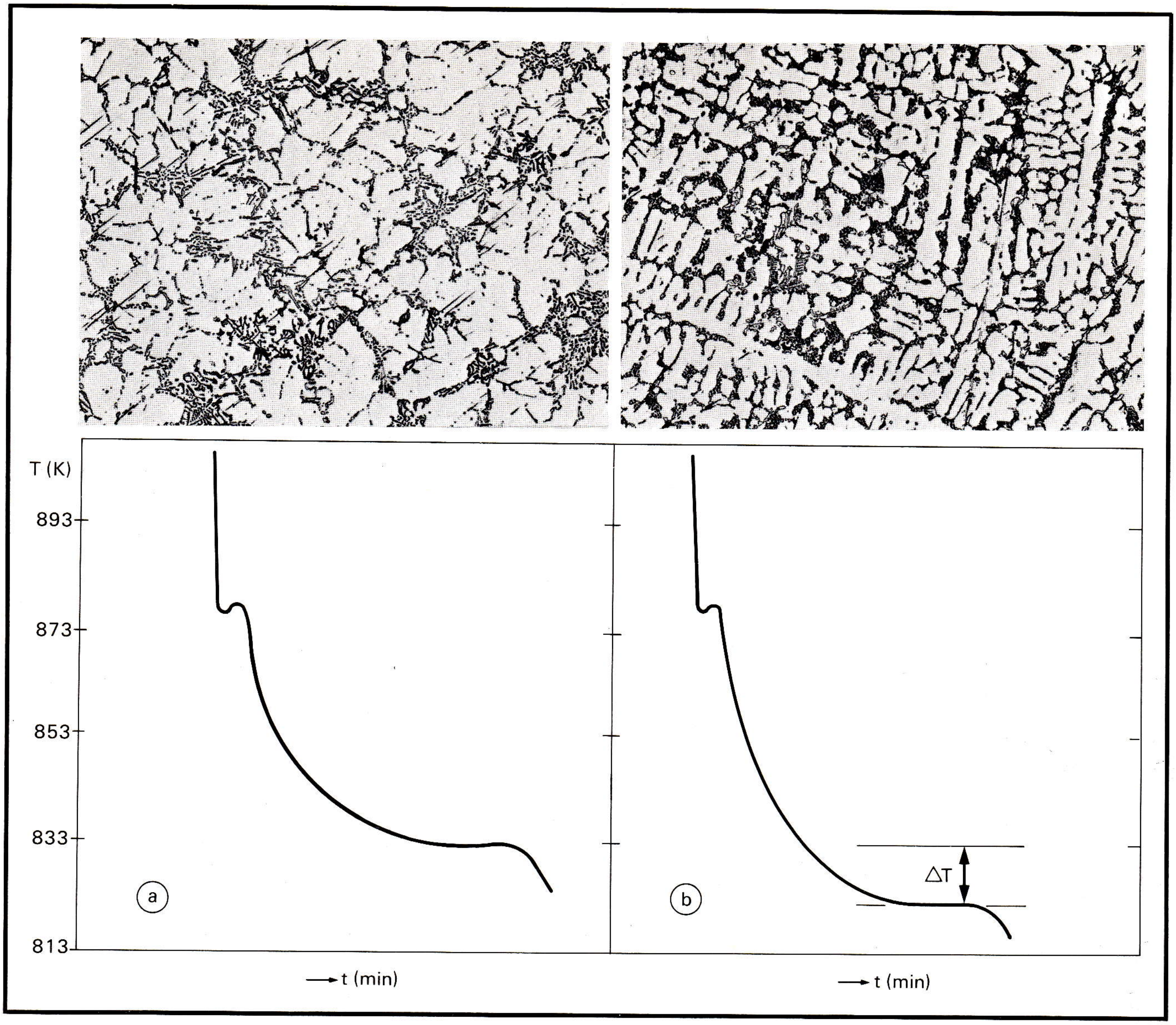
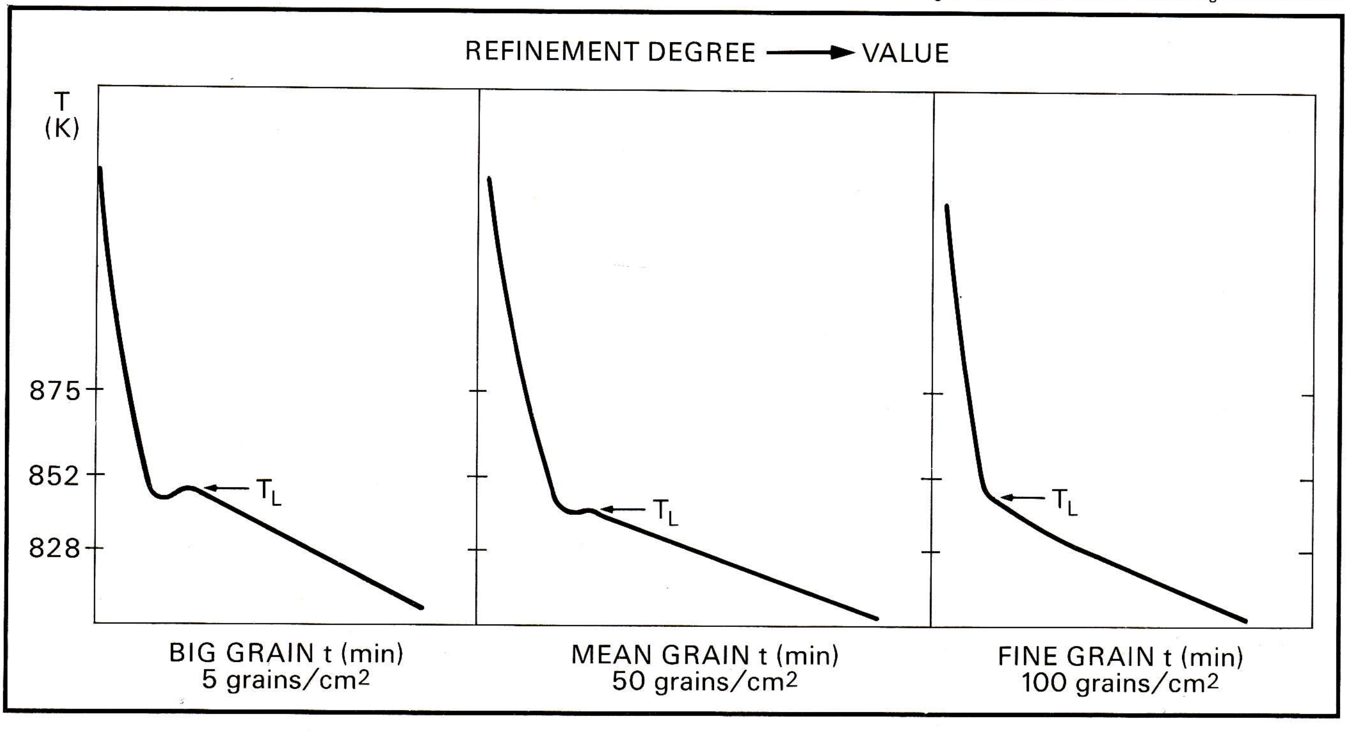


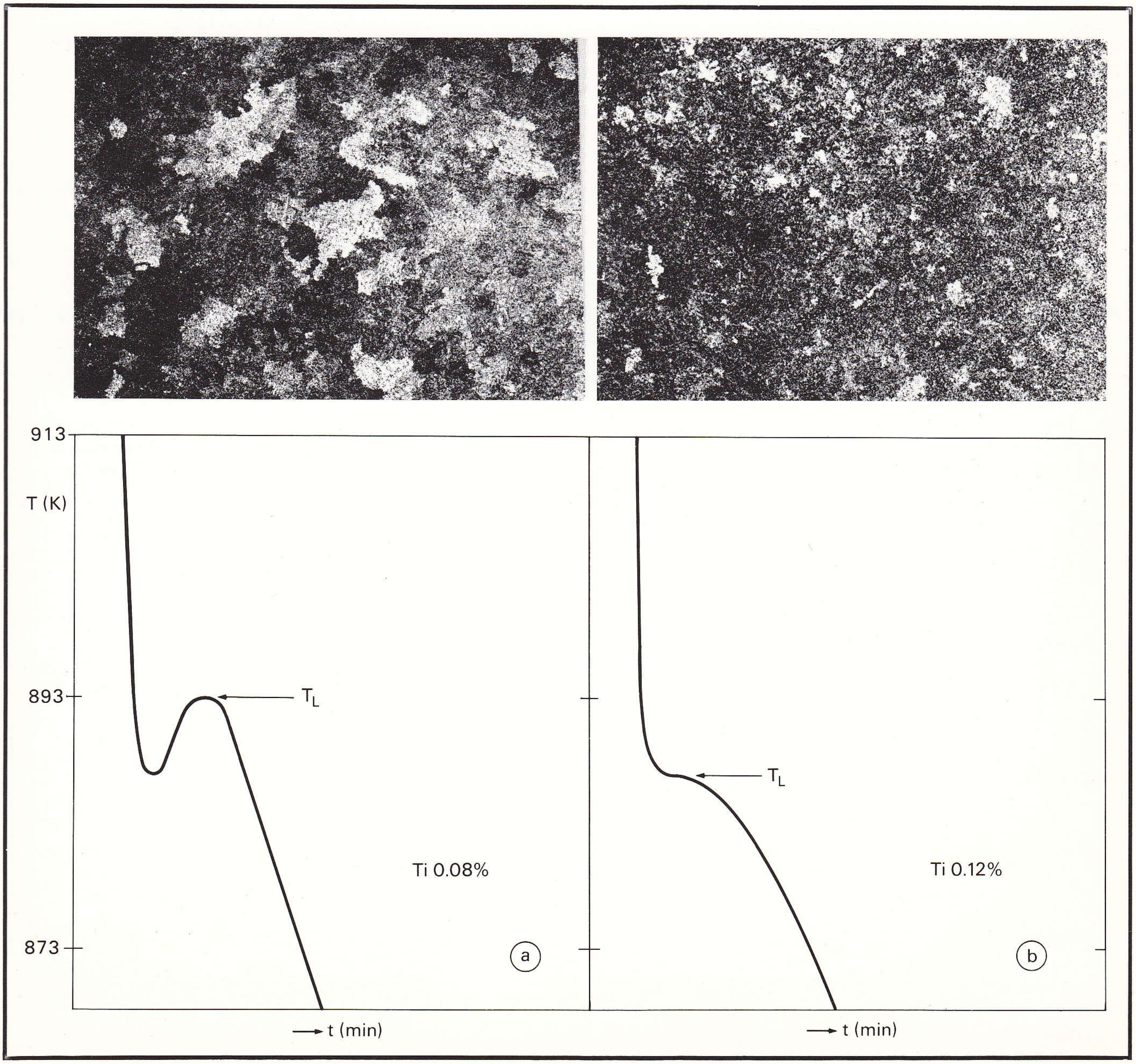
Fig. 4 - SG-ALSi 7 Cu 3 Mg Alloy; solidification curve and micrograph structure of a) unmodified alloy, b) modified alloy.

Fig. 5 - Relation between undercooling and refinement.



Solidification, in this case, does not start at the theoretical temperature but at a lower temperature (undercooling) and then increases up to its normal value.
By adding refining elements, which increase the number of crystallization centres and the nucleation speed, a fine structure is obtained (a big quantity of small grains) and undercooling is avoided while there are no delays in the beginning of solidification thanks to active nuclei which favour the formation of the first crystals from the liquidus). Therefore, it is possible to relate undercooling with alloy refinement. Fig. 5 shows the trend of the cooling curves.
The effect of Ti - B (refining element) on the thermal

Fig. 6 - Effect of refining agent addition (Ti B) on the thermal analysis curve of G-AlSi 5 Cu 3 Mg alloy.



analysis curve for G-AlSi 5 Cu 3 Mg alloy has been studied. Fig. 6 shows the result of the study together with Ti percentage values and the macrographies of the two different grain sizes.

A refined structure gives superior qualities of isotropy and resistance to the metal; but it must be kept in mind that a high number of nuclei originates a tight lattice hindering both liquidus flow and feeding. It is therefore necessary to come to a compromise.

Intermetallic constituents are shown by inclination changes or by horizontal strokes (inflexions) on the cooling curve.

These peculiar points of the curve are mainly due to magnesium, copper and iron when we consider the group of Al-Si-Cu-Mg foundry alloys.

The main intermetallic constituents which form during the solidification of the alloys can be detected by correlating the solidification thermal analysis with the study of binary, ternary and quaternary diagrams and micrographic examination. It is also possible to correlate the mechanical characteristics with the presence of intermetallic constituents as some of them form lattices which not only hinder the liquidus flow between dendrites but also cause brittleness (4).

Conclusion

By using a systematic control, this type of analysis allows us to verify its importance in the production process as seen in its different stages:

- study and setting up of the pouring system of a casting;
- maintenance of the optimum metallurgical parameters;
- achievement of the required quality in the component;
- reduction or elimination of some traditional checks;
- improvement of the versatility of the production;
- cost reduction.

TABLE 1 - Variation of the eutectic temperature of foundry alloys for ordinary use

Alloy	Minimum analytical value (Cu - Mg - Fe)		Maximum analytical value (Cu - Mg - Fe)	
	Unmodified Si °C	Modified Si °C	Unmodified Si °C	Modified Si °C
G-AlSi 5 Cu 3 Mg	558	548	555	545
SG-AlSi 6 Cu 2	563	553	559	549
SG-AlSi 7 Cu 3 Mg	560	550	556	546
SG-AlSi 9 Cul	568	562	565	560
G-AlSi 9 Cul	570	563	566	559
GD-AlSi 9 Cu 3	568	559	564	557

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THE HISTORY OF COMPONENTS

This section of the journal will deal with the story of one of the metal components used in the automotive industry. An account will be given of changes in its design. At the same time, the way in which the techniques and materials employed in its fabrication have developed will be described.
This approach will also serve to bring out the decisive importance of the part played by metal component manufacturers in the elaboration of both the basic materials and the methods of production.
Our first article deals with the crankshaft, and the rivalry that still exists between the materials and techniques employed in its manufacture.

The Crankshaft

Giovanni Riccio

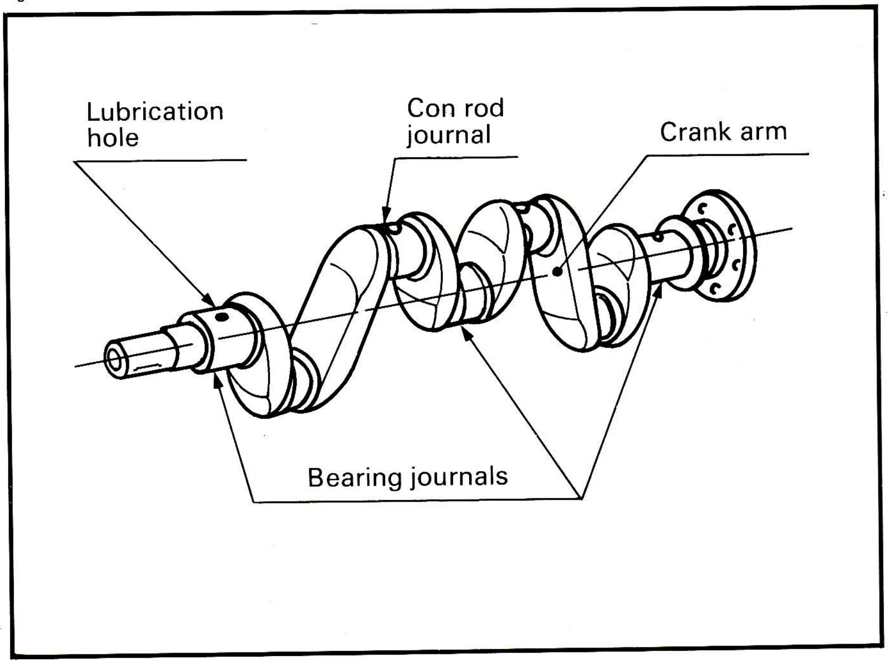
Abstract
This paper examines the crankshaft, which can be considered the heart of the internal combustion engine, and the component which most reflects the development of engines as regards planning and progress in the choice of material. Spheroidal cast-iron is increasingly favoured by the design engineer. The importance of the discovery of this material can be compared only with that of malleable cast-iron, during the last century.

Riassunto
Viene preso in esame il componente che può essere considerato come il cuore del motore a combustione interna. Questo componente è anche quello che rispecchia in maniera più evidente l'evoluzione dei motori dal punto di vista della progettazione e del progresso realizzato nel campo dei materiali. Nella scelta che può essere fatta dal progettista è tenuta sempre più in considerazione la ghisa sferoidale, il materiale che ha rappresentato nella fonderia un fatto paragonabile soltanto alla scoperta della ghisa malleabile, avvenuta oltre un secolo prima.

What we now refer to as an engine may be said to have first come upon the scene when extensive use began to be made of the combination of a crank and a connecting rod to transform reciprocating motion into continuous, rotary motion.
From the crank handle employed by knife-grinders in the late Middle Ages, this system has wended its way down to machines designed for an infinity of applications, and mechanical devices of every kind. The conversion of the backward and forward movement of a steam engine into the circular movement of a wheel was the striking feature of the improvements introduced (1).
The 19th century witnessed the birth of the internal combustion engine, at first complementary to, but eventually replacing the steam engine. This new system of propulsion continues to be the most widely employed. It has retained the crank and con-rod arrangement, and the crankshaft as its star performer (Fig. 1).
The crankshaft is one of the most important parts of the internal combustion engine and undergoes heavy duty. Therefore, it requires careful consideration when it comes to designing, choice of material, machining and finishing.

During the *design stage*, both the proportions and the strength of the crankshaft must be taken into account, that is, problems concerning systems of calculation and choice of material must be dealt with (2). These two aspects are linked, as calculation must be contained within the limits set by the material's specifications, while improved material specifications allow wider scope for calculations.
As we have said, the geometry of

Fig. 1 - Crankshaft.



the part must take account of the material of which it is made. It is also subject to the constraints imposed by the specifications of the engine. The bore and stroke will be determined by the power rating, the number of cylinders, and the thermodynamic cycle employed, whereas the centre distances will depend on the way the cylinders are arranged, the type of cooling, and various parameters connected with heat.
Once both reciprocating masses and the thermodynamic cycle are known, crankpin loads and their dimensions are determined. Then main journal loads and their dimensions are defined. Finally, tensile conditions due to static and dynamic loads are analyzed in order to establish the critical point of fatigue strength and safety (Fig. 2). These calculations are based on simplified hypotheses and subsequent experimental examinations.
The prototypes for crankshafts usually undergo both static and dynamic tests (fatigue tests). The former are meant for the examination of form factors and maximum stresses while, at the same time, helping the planning; the latter for the control of the technological production process and evaluation of the product's reliability (Fig. 3).
Major innovations have recently been introduced, with regard to both calculation systems and planning, and these are being adopted in industrial practice. A calculation system which is based on modal analysis and direct integration has been set up. Thanks to this system, dubious aspects are removed and very significant mock-up crankshafts can be produced as early as the planning stage (3). The well-known and most up-to-date CAD/CAM systems are also applied, thus obtaining the optimum design of the part and engineering its manufacture in the most rational way.
As for the *material* used for making crankshafts for the automotive industry, the following ferrous alloys are considered:
— forged and cast steel;
— grey cast-iron;
— blackheart malleable cast-iron

Fig. 2 - Block diagram of current analytical and experimental processes applied in the designing of crankshafts.

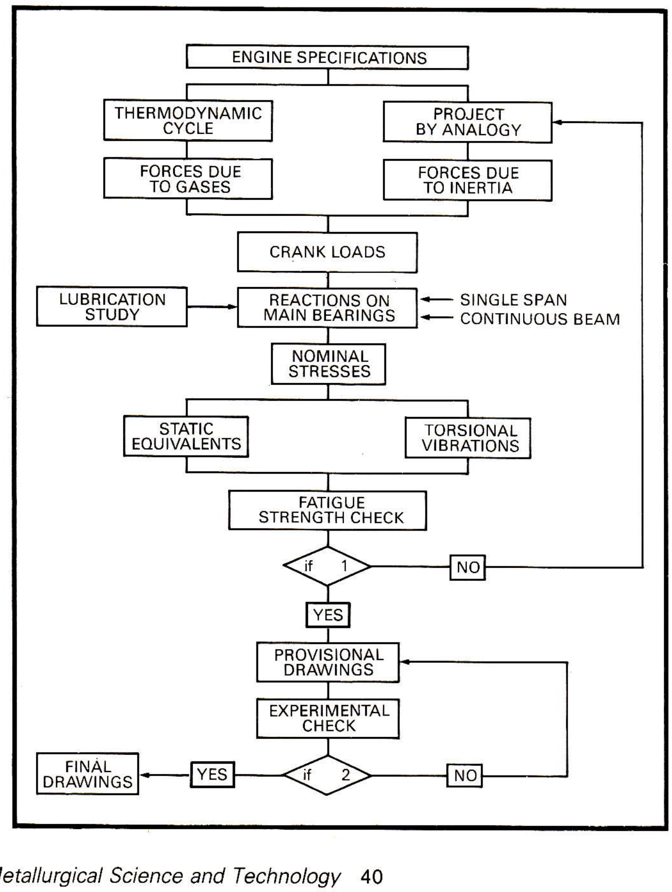
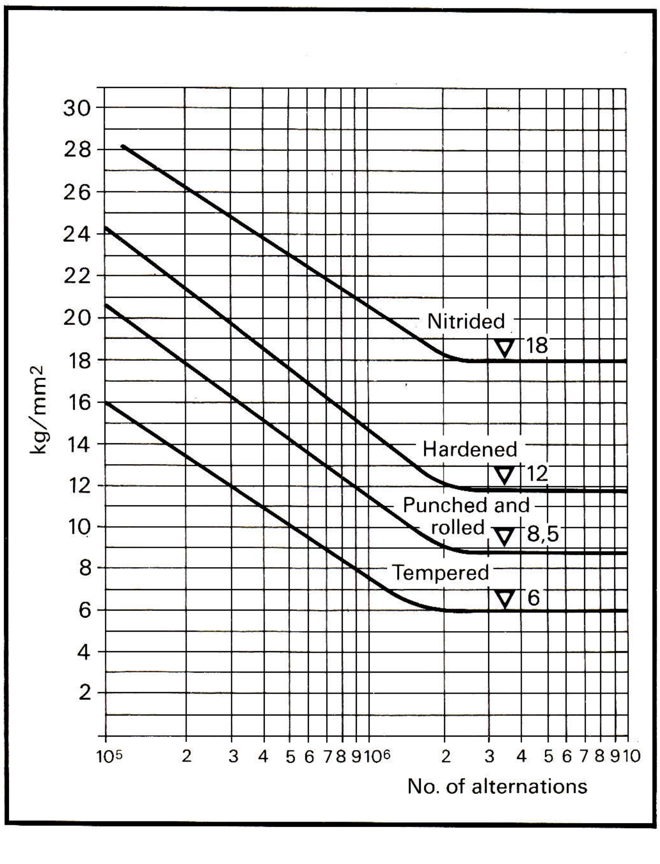


Fig. 3 - S-N curves for hardened crankshafts subjected to alternating torsion stresses. (Wöhler).



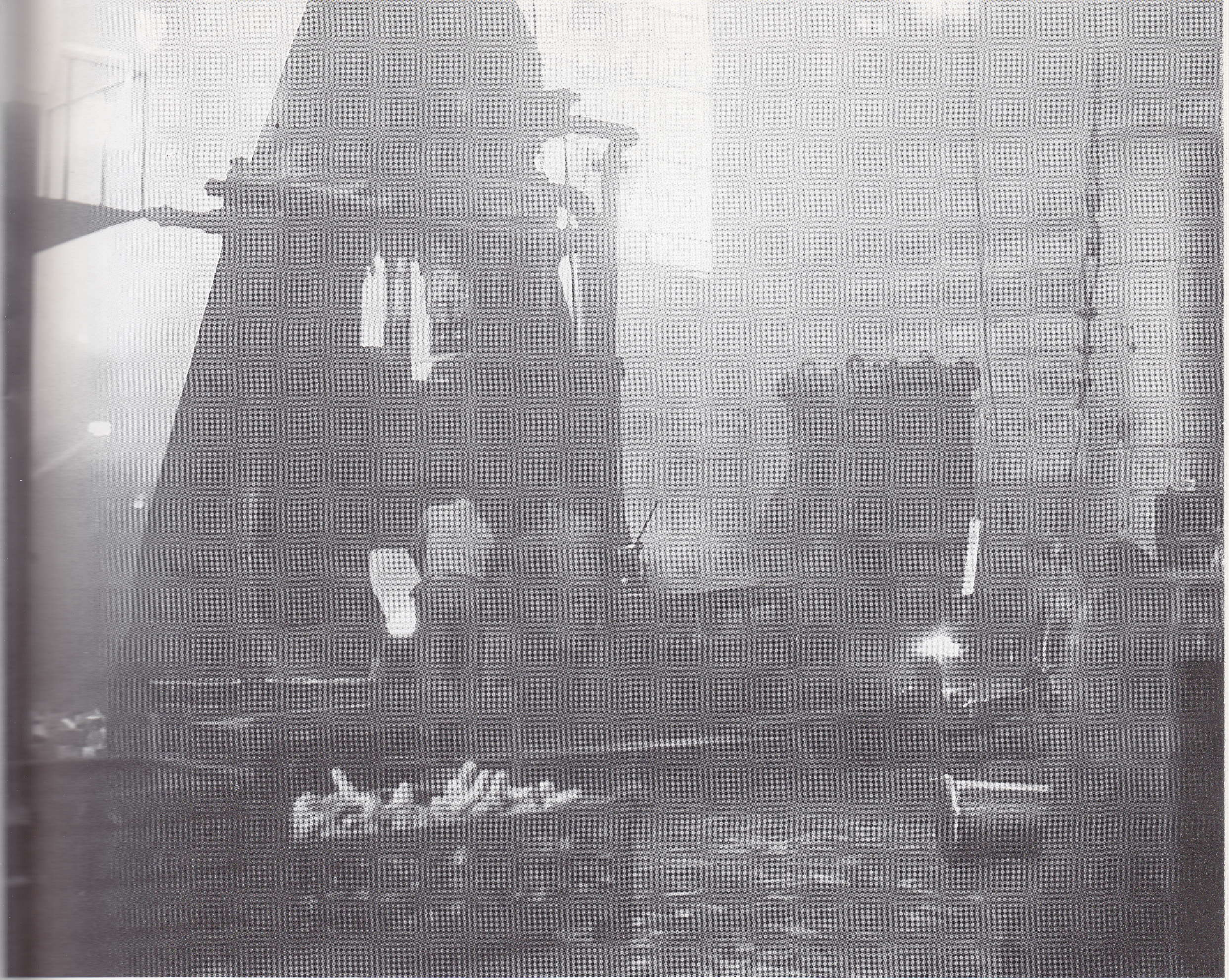
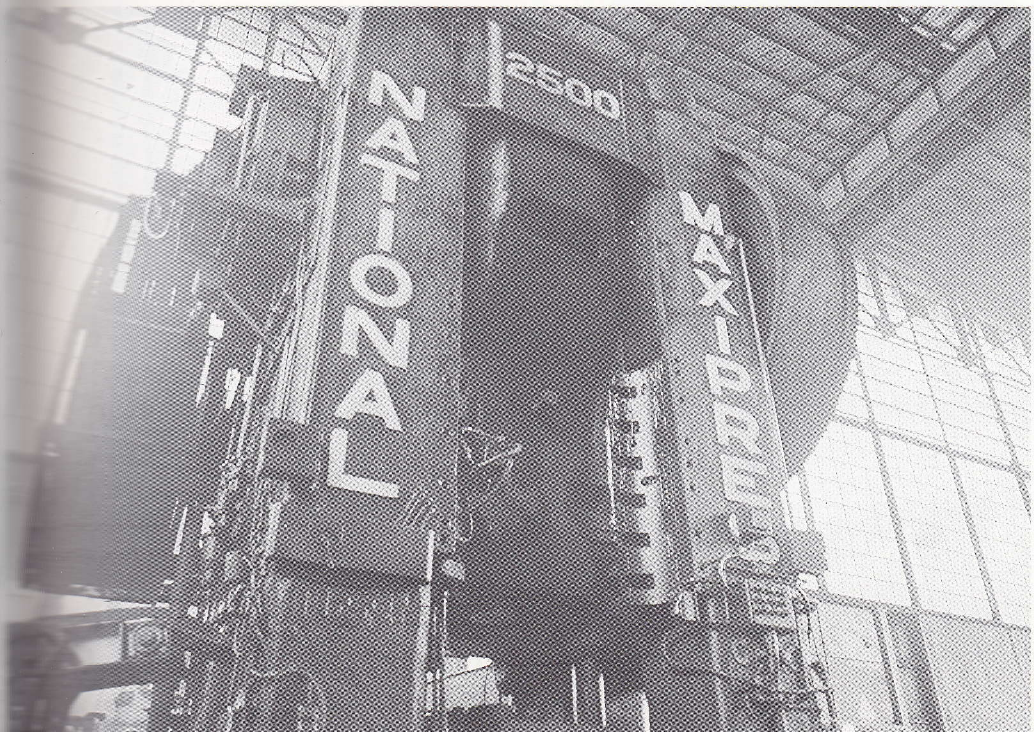


Fig. 4 - Hammer.

Fig. 5 - Forging press.



(American malleable iron);
— spheroidal cast-iron.

Forged steel was the first solution to the problem of the material for crankshafts, and still accounts for a large part of today's production (4), (5).
The forging process was enhanced by the perfecting of the steam engine during the first half of the 19th century, and by the invention of the Bourdon hammer at Creusot and the Nasmyth hammer in England. The forging press came shortly after, and the " closed-die " forging process was established. Since then forging has rapidly developed, thanks to new machines and equipment, and to better metallurgical knowledge of steel and of the laws regulating steel flow in the die (Figg. 4 and 5).

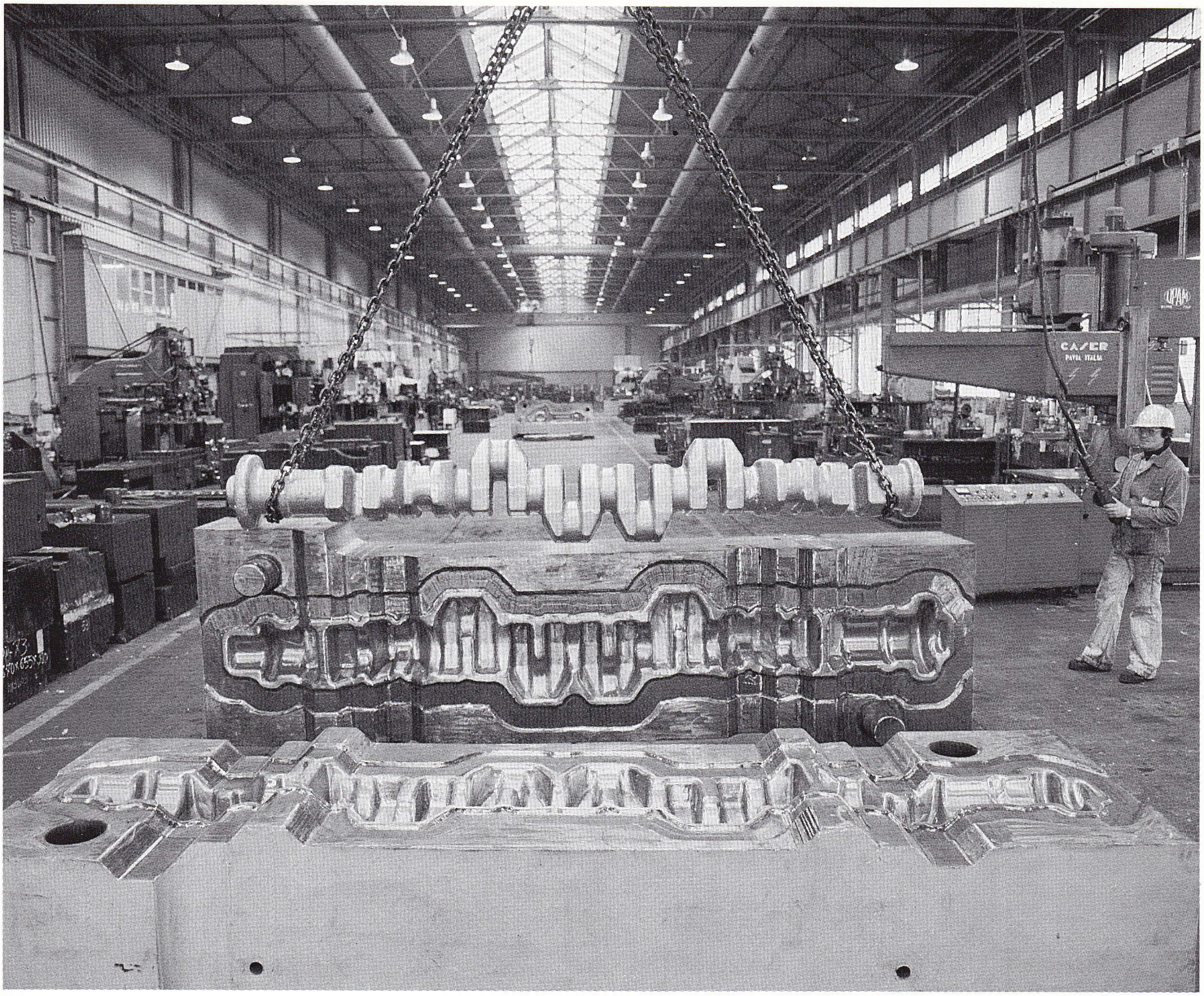
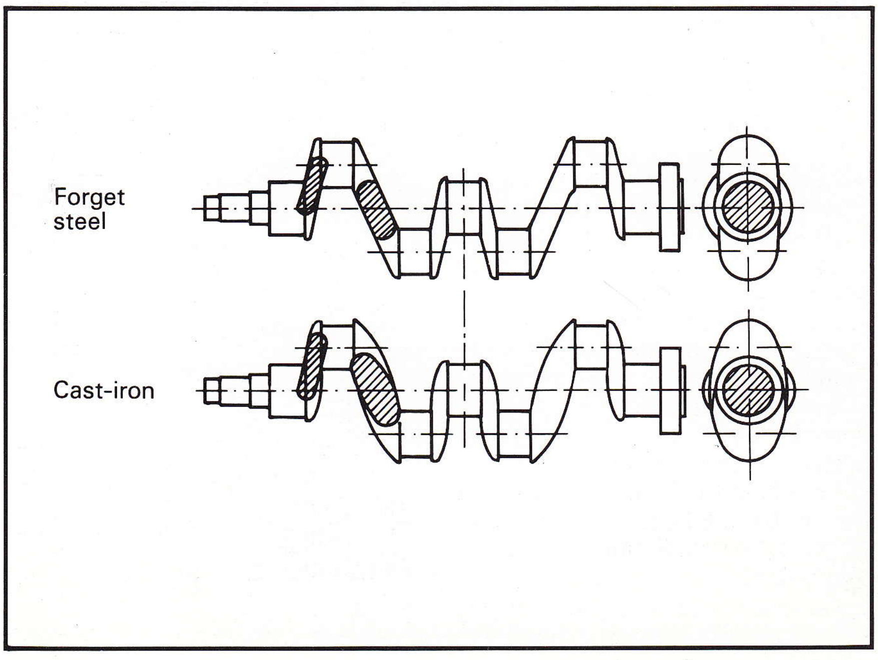


Fig. 6 - Die.

The closed-die forging process is used for crankshafts in the automotive industry. It confers the exact shape required on the steel once this has been heated to the point where it becomes plastic (Fig. 6). The forging blank (made of carbon or low-alloy steel) is cut to the length required to provide enough material to fill the die, plus an amount for the flashes, and (if necessary) a tail by which the piece can be held. Flashes represent the escape of surplus metal due to the pressure exerted inside the die. Quite complex and well-proportioned shapes can be obtained by means of " closed-die " forging which, combined with other processes, gives closer dimensional tolerances. Precision forging represents a recent improvement on the traditional process and gives very interesting results, especially as far as dimensions are concerned. The great variety of equipment available today for the forge shop

Fig. 7 - A forged and a cast version of the same crankshaft.



through hot-forging machines manufacturers, offers a wide choice of possibilities, so as to guarantee the right choice for production requirements.
Depending on their weight and design, crankshafts can be either drop-forged or pressed.
Alternatively a combined process can be employed. The die must allow for the stock that will be removed during machining of the piece, and for shrinkage when the part cools down to the ambient temperature after removal from the die. Provision must also be made for suitable draft angles, fillets, joints at the edges, flash holes, etc.
The highly refined technology of the forge was tested during the development of the motor car industry. Today it bears considerable weight and can compete with other technologies for the production of crankshafts.

Cast steel has always gone side by side with forged steel as a solution to the problem of the material for crankshafts (Fig. 7).
The initial modest importance of the foundry increased as foundrymen improved their casting technology. It is worth mentioning, in this connection, the cast-iron crankshaft shown at the Exhibition held by the American Society for Metals in the United States of America in 1934. The machine was mounted on an engine used in a mine, and had been in operation since 1898 without showing any drawback. Researches started in 1925 by Ford Motor Co. led to the use, for crankshafts, of a foundry alloy having characteristics intermediate between those of cast iron and steel, and with the following composition:
C = 1.35-1.60%, Si = 0.85-1.1%, Mn = 0.6-0.8%, Cu = 1.5-2.0%, Cr = 0.4-0.5%, P max 0.1%, S max 0.06%.
This metal was obtained by melting a charge of scrap steel and cast-iron returns in electric furnace.
Crankshafts for tractors were cast into sand moulds; those for motor cars into sand core moulds bound with oil. The castings were annealed, and their structure was made of globular pearlite and a certain amount of graphite. They presented the following characteristics:
HB = 280-320, Rt = 70-80 kg/ mm^2 and A% = 2.5-3%.
During the same years the so-called Esslinger Material was being developed in Germany. This material was made of cast-iron, melted in a cupola and subjected to a duplex process in an electric furnace; its carbon content was higher than that of the Ford material and it had small quantities of alloying elements.
Spheroidal cast-iron was already known when, at the end of the 'forties, the German metallurgist E. Piwowarsky considered heat-treated un-alloyed grey cast-iron to be the best suited material for crankshafts made in the foundry (6). But he also forsaw a future for Arma-Steel, i.e. American malleable iron with a pearlitic matrix, and for spheroidal cast-iron.
Of all foundry alloys, *cast steel* is the one with the best mechanical characteristics. It has a compact grain structure, high strength and toughness. Its impact strength is high and it can be bent and subjected to heavy loads before reaching its breaking point.
However, its melting point is high, and it can be melted and cast into complex shapes only with difficulty.

Grey cast-iron (Fig. 8) has a relatively low melting point and can be melted

Fig. 8 - Microphoto of flaked graphite grey iron (x 500).

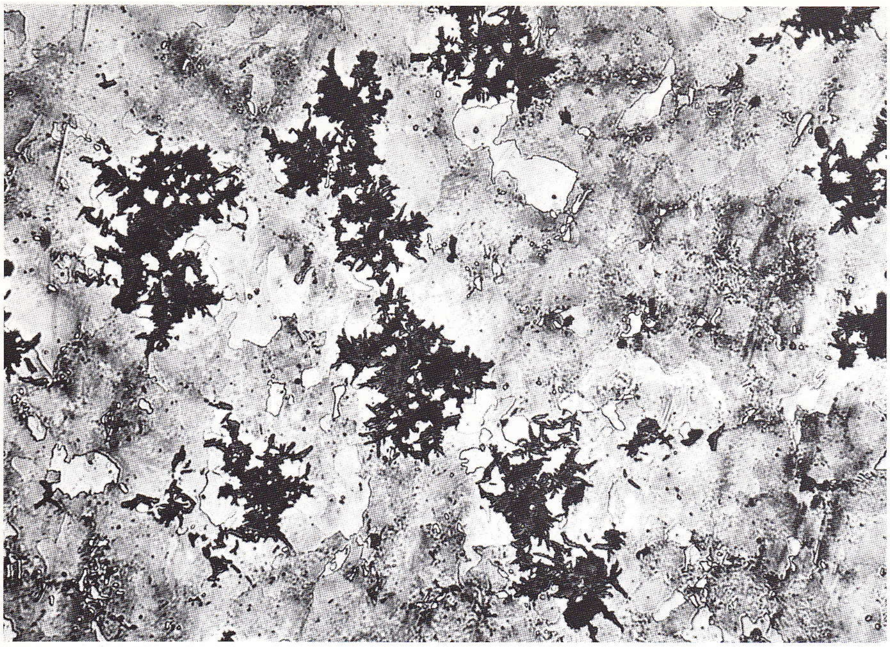


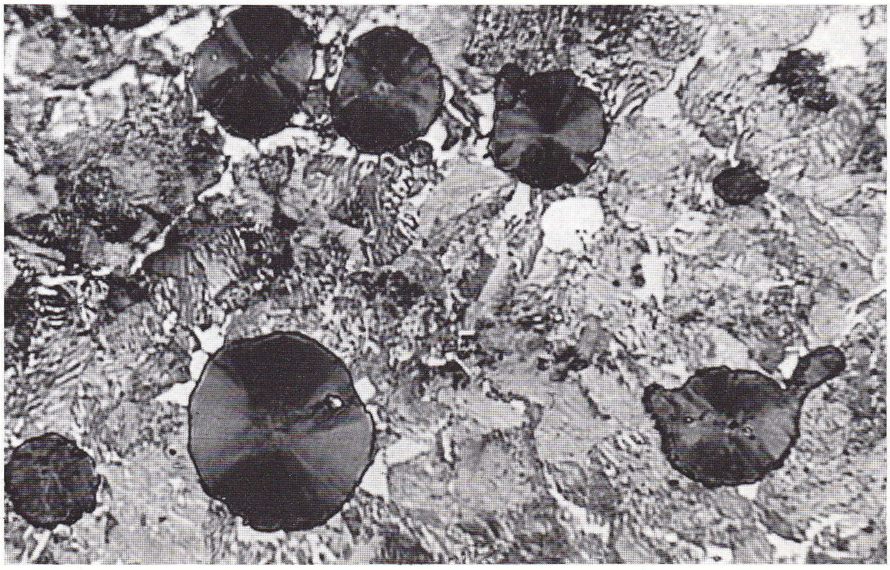
Fig. 9 - Microphoto of blackheart or American malleable cast iron (x 250).

and cast more easily than steel. The considerable carbon content of grey cast-iron (3-4%) causes the melting point to drop. During solidification, however, most of the carbon content splits as flaked graphite, thus breaking the continuity of the structure. Grey cast-iron is relatively brittle, and can be used only in the absence of heavy impact stresses.
Malleable and spheroidal cast-iron present different features. The first *malleable cast-iron* was obtained in 1722 by the well-known French physicist Réaumur, and it was the source of the so-called whiteheart malleable cast-iron which is still produced in Europe.
White malleable cast-iron is prepared by melting a charge with a carbon content of 2.5-3%, i.e. half-way between that of grey iron and casting steel. After pouring, this solidifies to form what is known as a " white " structure, in other words, a hard, brittle material that can be made malleable by high-temperature decarburisation.
This process was a major improvement in iron metallurgy because it used the carbon content in the liquid state to obtain fluidity, and then eliminated most of it during the subsequent heating treatment, so that the final product had features similar to those of steel.

Black-heart malleable cast-iron, invented in the United States of America around 1820 by S. Boyden, is more important (7), (Fig. 9). In an attempt to reproduce Réaumur's malleable cast-iron, Boyden used similar mixtures with intermediate carbon content, and obtained " white " structure castings with complex shape, which were subsequently annealed. With this process, however, the carbon was not eliminated, but precipitated into the metallic matrix in the form of dispersed flakes. The treatment was shorter than that for white-heart cast-iron. Both types of malleable cast-iron are tough and can be impact stressed, but they require long treatments and present difficulties when manufacturing very thick parts.

Spheroidal cast-iron was discovered in 1948 and is a kind of malleable cast-iron without treatment (8).

Fig. 10 - Microphoto of spheroidal cast iron (x 250).



The addition of caesium and/or magnesium to liquid cast-iron results in an alloy which solidifies to form a spheroidal graphite which reduces continuity problems to a minimum, so much so that the tensile properties of the spheroidal iron thus obtained are only about 15% different from those of steel, including ultimate loads of 40 to over 100 k/mm^2, and elongations of 5 to 20% (Fig. 10).
The fatigue limit of spheroidal cast-iron is on a par with that of carbon steels. Its good wear resistance and high mechanical properties are points in its favour that are particularly appreciated by manufacturers of crankshafts.

Crankshafts followed the changes taking place in the manufacture of *vehicle engines* which have adjusted to the requirements of the market and the needs of the recent crisis (oil, raw materials, ecology, economy, politics).
For some time, during the development of the motor car industry, forged steel was the most used material in the manufacture of crankshafts.

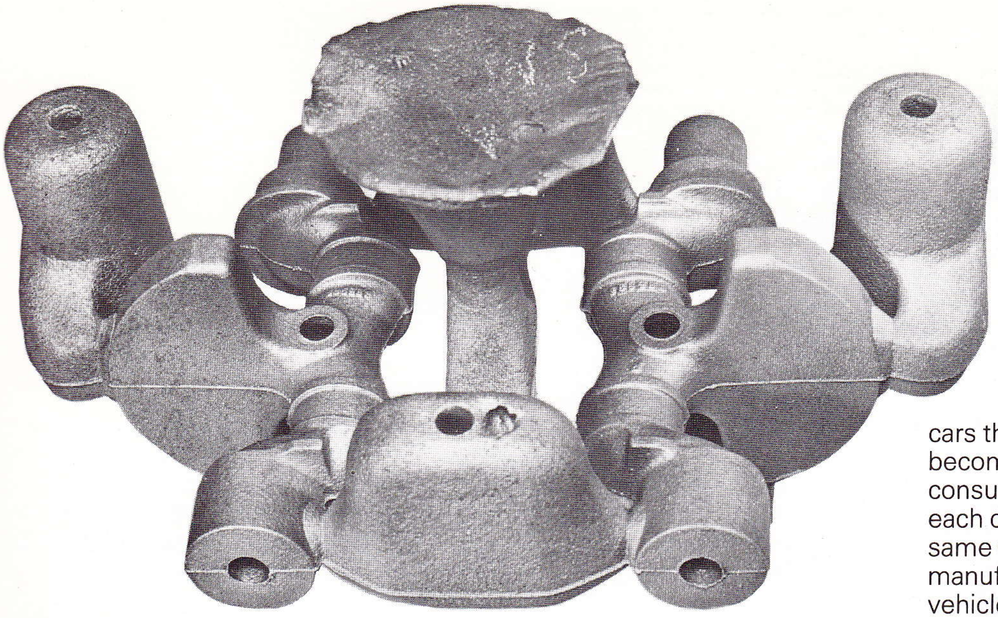
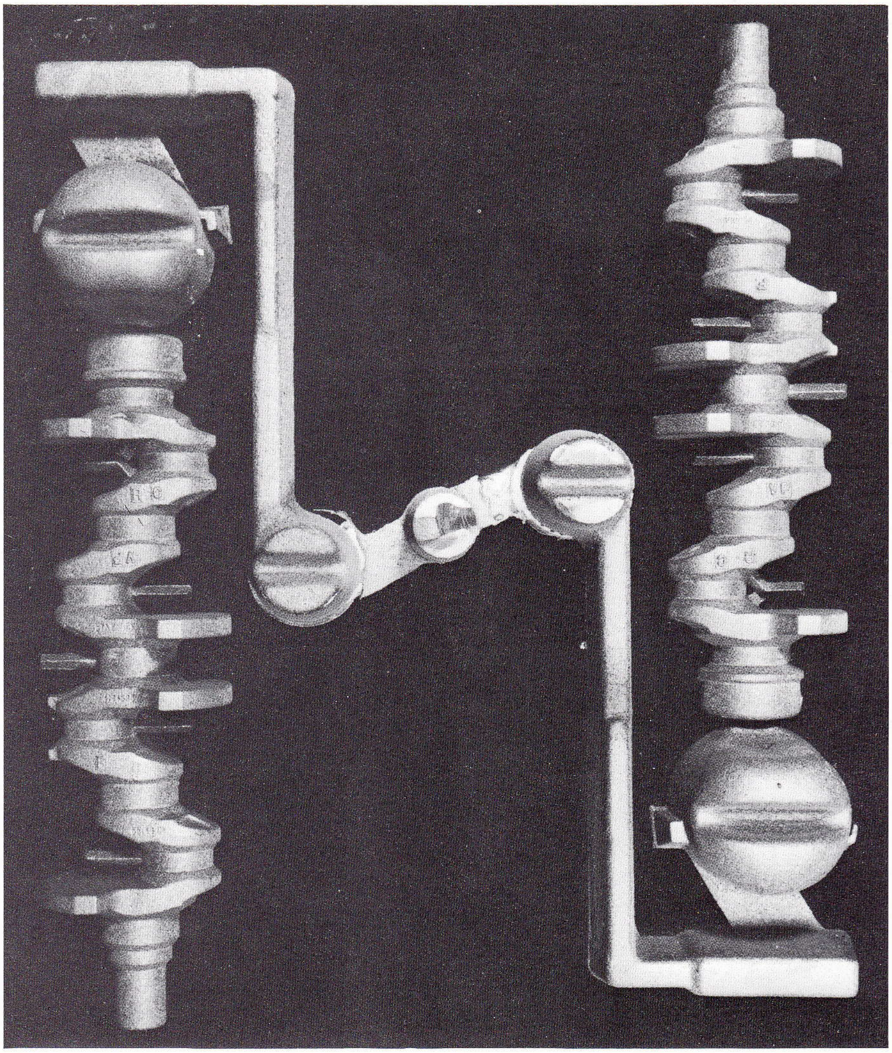


Fig. 11 - Cluster of spheroidal iron crankshafts for the Fiat 500.

Cast steel was adopted following the hard work of foundrymen who re-studied the preparation of the metal and its characteristics, shaping and finishing processes, testing, and, above all, production costs.
Towards the end of the 'fifties, black-heart malleable and spheroidal cast-iron were given special attention by those concerned with engine design because of the great scope they offered as regards design, machinability and savings achieved when casting crankshafts.
FIAT showed the way with the spheroidal cast-iron crankshaft of its well-known Fiat 500 manufactured at its Mirafiori and Carmagnola Works (Fig. 11). This was followed by crankshafts made of pearlitic malleable cast-iron installed in cars and trucks. Then spheroidal cast-iron replaced malleable cast-iron (Fig. 12).
The great number of inspections carried out during manufacture and the performance of millions of vehicles on the road, has confirmed the use of cast-iron (9), (10), (Fig. 13).
Further rapid changes have been brought about in the engine manufacturing industry by the latest crisis and its related problems. In particular, the motor car industry has aimed at reducing both weights and costs, thus affecting both the foundry and the forge.
More particularly, the reduction in dimensions and machining tolerances, improved machining, the reduction or elimination of heat-treatment, and reduced machining of blanks are worth mentioning.
Engines for cars tend to be increasingly smaller and highly stressed. By manufacturing lighter cars the power to weight ratio becomes more favourable and fuel consumption is reduced. However, each component is optimised. The same objectives are pursued by the manufacturers of commercial vehicles, that is, reduction of weight and consumption, etc. Engines must be lighter, more reliable and less noisy.
With these objects in view, the designing of crankshafts for cars and major sectors of industrial vehicles tends towards foundry

Fig. 12 - Spheroidal iron crankshafts for the Fiat 128.

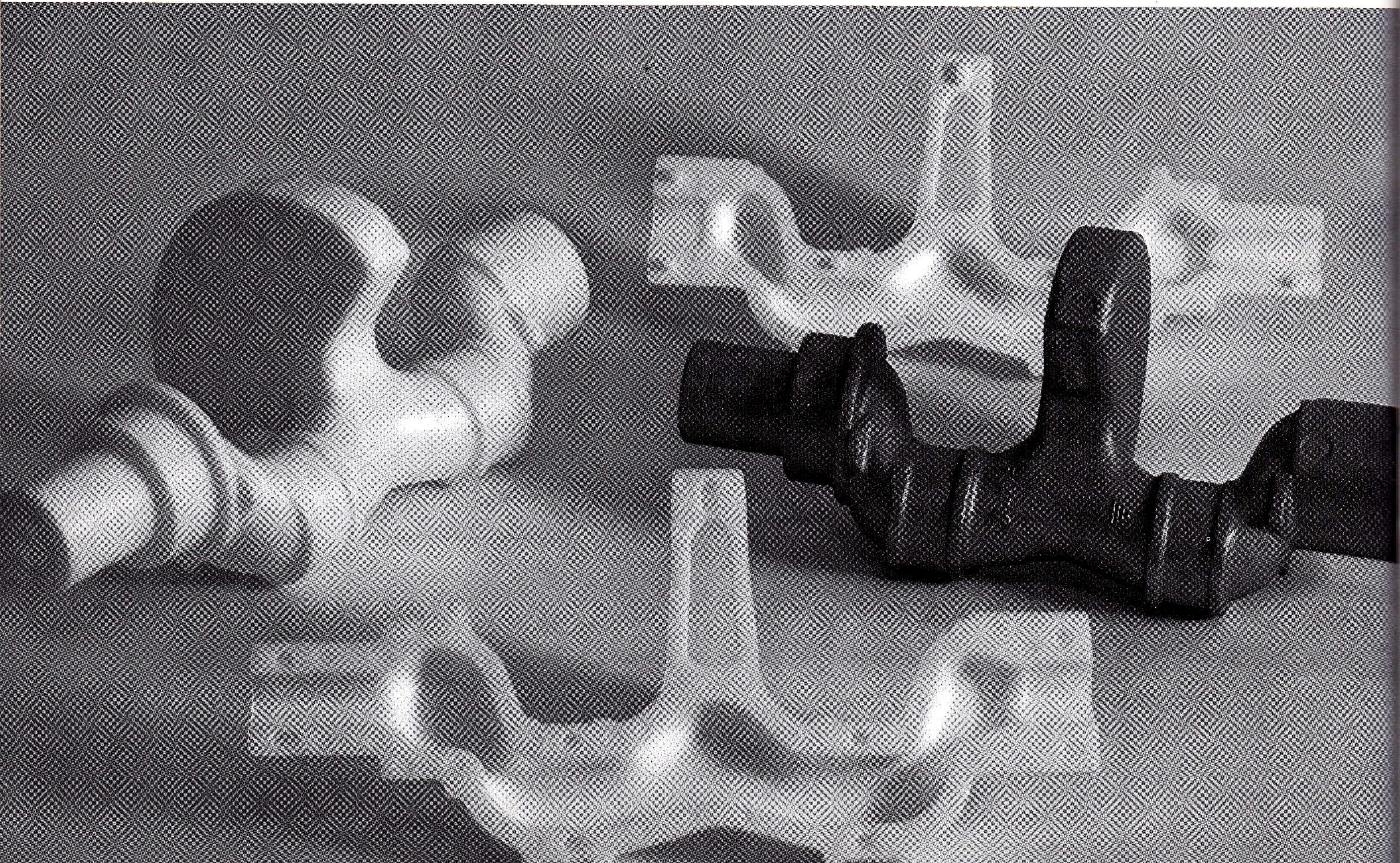


Crankshaft N°	Cycles N°	F (kg/mm²)	HB
1	5.652.000	8,1	283
2	5.598.000	8,05	282
3	5.400.000	8	285
4	5.400.000	8	239
5	5.148.000	7,9	285
6	4.860.000	7,8	269
7	4.500.000	7,7	285
8	3.960.000	7,55	270
9	3.850.000	7,5	286
10	3.240.000	7,25	270
11	3.240.000	7,25	235
12	3.000.000	7,15	281
13	2.812.000	7,05	294
14	2.774.000	7	285
15	2.700.000	6,95	285
16	2.700.000	6,95	269
17	2.700.000	6,95	243
18	2.500.000	6,85	268
19	2.420.000	6,8	285
20	2.420.000	6,8	271
21	2.268.000	6,7	285
22	2.160.000	6,6	288
23	1.980.000	6,4	285
24	1.700.000	6,3	286
25	1.600.000	6,2	291
26	1.400.000	6	288
27	1.400.000	6	229
28	1.260.000	5,90	269
29	720.000	5,05	207
30	572.000	4,75	207

Fig. 13 - Endurance, fatigue strength and Brinell hardness ratings of experimental crankshafts for the Fiat 500.

solutions using spheroidal cast-iron. The main factors affecting the choice of cast-iron are the great flexibility allowed by the process as regards design, the wide possibility of reducing the weight and better stress distribution in the component (by using hollow shafts), the better machinability of the material and the potential production of big foundries, with up-to-date equipment and the ability to control the various technologies perfectly. As a matter of fact, spheroidal cast-iron is making constant progress in Italy and all over the world (Japan excluded) as far as the car manufacture is concerned, while gaining a good position in the

Fig. 14 - Hollow spheroidal iron crankshafts produced by the Policast process.



manufacture of commercial vehicles.

The Policast process (evaporable-pattern casting), which Teksid set up only very recently at its Carmagnola foundries, is bound to be a further technical and economic reason for choosing cast-iron in the future (Fig. 14).
At the same time, it must be mentioned that noteworthy progress has been made in the forge by exploiting the superior qualities of steel and achieving weights and sizes which can well compete with the foundry products. The various factors already mentioned, that is production cost, material machinability (bearing in mind that forged steels are either resulphurized or have improved machinability), crankshaft weight given the same engine performances, and the availability of an industrial structure which can comply with the chosen solution, are to be taken into account when choosing between cast-iron and forged steel or between foundry and forge. At any rate, the wide choice of possibilities offered by both the foundry and the forge can meet all the requirements of motor car engines planning as regards the production of crankshafts.

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