

Aspects concerning the role of coatings in the production of iron castings by the "Policast" process

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Abstract

The "Policast" process is already in an advanced stage of industrialisation. However some interesting areas need further investigation in order to improve the effectiveness and consistency of the process.

Among them there are the problems concerning the coatings used to cover the patterns of Expanded Polystyrene (EPS).

In the present study, the porosity, the external appearance of the coating layers and the setting-up of the methodology and apparatus for permeability inspection are investigated. All these parameters are strictly interconnected, and they affect the success of the resultant castings, as demonstrated by systematic testing.

Riassunto

Alcuni aspetti circa il ruolo della vernice nella colata di getti in ghisa con il processo «Policast»

Il processo «Policast» ormai in fase avanzata di industrializzazione pone alcune problematiche importanti sul controllo e la previsione di sanità dei getti.

Tali aspetti sono fondamentalmente legati al comportamento ed al ruolo delle vernici utilizzate per ricoprire i modelli in PSE.

Nel presente studio sono state investigate la porosità, l'aspetto superficiale degli strati di vernice e messe a punto metodologie ed apparecchiature di esame della permeabilità. Tutti questi parametri risultano strettamente interconnessi e condizionanti la buona riuscita dei getti come evidenziato dalle prove sistematiche di produzione.

Introduction

The "Policast" process, already in an advanced stage of industrialisation at the Iron Foundry Division of Teksid S.p.A., was developed with the aim of making it suitable for large-scale series production.

Using established and simplified solutions, less costly than those of the traditional technologies, the new process permits the production of castings using expandable patterns of Expanded Polystyrene (EPS) in a form identical with that of the castings themselves, and unbound sand as material to contain the molten alloy which, in the act of casting, takes the place of the pattern, which evaporates.

Wide experimentation over the last few years has defined and codified every stage, and identified the specific material characteristics necessary to achieve castings having the prescribed geometric and metallurgical requisites.

A crucial point of the process is the role that the coating must play in the casting process, when the molten metal gasifies the polystyrene of the pattern and of the feed system, and occupies their exact volume.

The outflow of this gas is regulated by the permeability of the layer of pigment applied to the surface of the EPS, which is one of the chief characteristics of the coating.

The coating must in fact, keep the shape of the mould during the act of pouring, while the polystyrene retreats, but at the same time, allow the exit of the gas through it, limiting the degree of pyrolysis.

In the light of these considerations, a study of the technological characteristics of coating materials has been developed, and an instrument, suitable also for in process control, has been designed.

Dynamics of filling-up the mould

The pouring stage is extremely critical; two factors together contribute principally to its success: the characteristics of the coating and the configuration of the casting system. These two parameters are strictly interdependent since during the filling-up a back pressure develops.

Remember that, as a consequence of vaporising the polystyrene, a gaseous buffer is interposed between the advancing metallic front and the retreating EPS. The gases leave the system, filtering through the coating, partly to recondense on the surrounding sand and partly being liberated to the atmosphere.

The coating, therefore, constitutes an element in which the porosity causes a greater or lesser difficulty in evacuating the gases, and thus acts as a metallostatic barrier and a control section influencing the speed of pouring.

The pressure that the gases reach must, also, be held over an interval which guarantees the stability of the surrounding sand. The filling-up operation must be free from implosion, explosion and back-flow of gas through the sprue (1).

Obviously, the pressure of the evolving gases will depend, besides the metallostatic head, on the pouring temperature, and the quantity and density of the EPS at the time of destruction.

At this point, the problem can be seen in the proper terms: given a pattern with fixed geometry, the design engineer will have to calculate the system of pouring, considering the best method of evacuating the gas from the mould, on the basis of the permeability presented by the coating.

From all the above a new application emerges, of that

part of the methodology generally called "Mould Study". In fact, dimensioning of the pouring system would not be possible without considering what emerges from this study.

The coating, then, plays a leading role at the time of deciding on the spray and, as will be seen from what is to follow, it is an important element that contributes to different kinds of phenomena.

Mechanism of EPS pyrolysis

During pouring, the polystyrene gasifies, according to a mechanism of varied and complex nature (it cannot, in fact, be connected with combustion at all, because of the scarcity of oxygen in the pattern and its immediate surroundings). A schematic indication is given here, of how much of the volume is included between the retreating polystyrene, the advancing metal and the containing coating.

The destruction of the polystyrene begins basically with a heat-exchange mechanism that involves both metal radiation and the gases from pyrolysis of the polymer (convection and liminar propagation) (2).

The combination of the two mechanisms results in one part of the polystyrene subliming while the other fraction, more limited, passes to the vapour state through a higher-density liquid phase.

The reason for the above lies in the fact that EPS has a low thermal conductivity, so that the layers immediately following those in the process of sublimation are still at a relatively low temperature, which is also facilitated by the sublimation itself.

Moreover, among the sublimates of the products, there are also EPS solvents which contribute to the formation of the liquid phase.

Laboratory work has identified the products of polystyrene decomposition at various temperatures (3).

As shown graphically in Fig. 1, the degree of destruction of the polymer increases with the temperature, up to producing increasing amounts of elements such as hydrogen and carbon in the form of lustrons carbon (4). Fig. 2 shows the portion of space which we will call the "control volume", inside which let us suppose that the thermal-flow dynamic regime is constant; in this volume the characteristics of the gases present are connected with the temperatures, which, on average, they re-attain before leaving the system through the permeable lattice formed by the coating.

Nevertheless, it must be recognised that in the space containing metal and undecomposed polystyrene, the temperature changes continually, so that the composition of the interposed gases is modified in consequence; thus verifying that close to the liquid the percentage of carbon and hydrogen increases

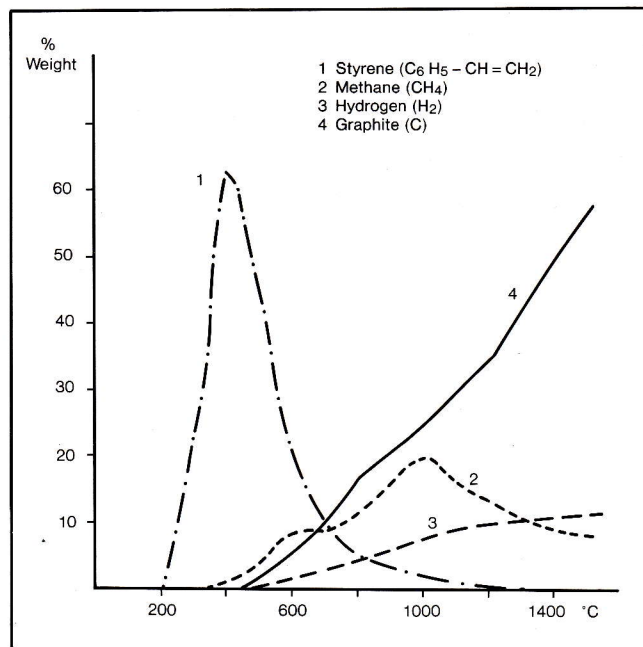
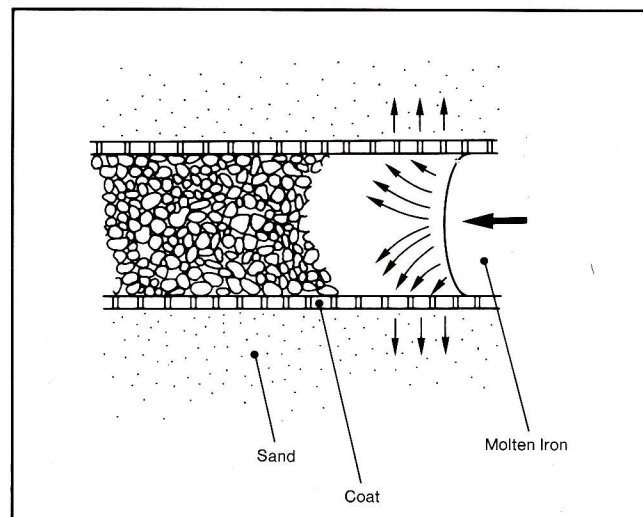


Fig. 1 - Products of decomposition of EPS at different temperatures.

Fig. 2 - Pattern of metal advance in parallel section duct.



considerably, while close to the EPS the percentages of monomer styrene and certain polymers of low molecular weight increase, combined with other components. Finally, in the intermediate zone, aliphatic hydrocarbons and short-chain molecules (1-3 atoms of C) prevail (Fig. 3), (5).

The degree of pyrolysis which the gases present in the control volume attain is, as said, directly connected with the time they stay in it.

It emerges, therefore, that the coating, by its

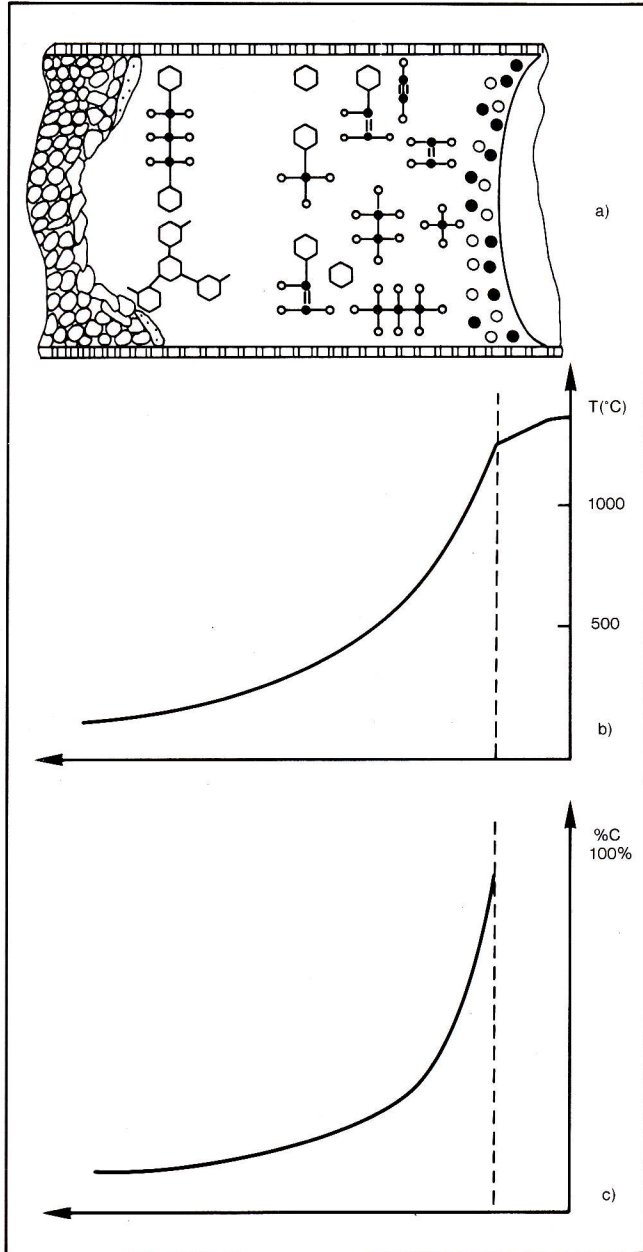


Fig. 3 - Pattern of pyrolysis of EPS.

characteristic of permeability, influences strictly, not only the flow-dynamics of the system, but also the physical-chemistry of the types of molecules present. In fact, under the same conditions of all the other parameters that influence the control volume, different atmospheres interposed between metal and EPS correspond to different coating permeabilities. Obviously such atmospheres are active with respect to the advancing metal front so that, also in relation to the

rheological characteristics of the alloy, implications of a metallurgical character can be important.

Metallurgical aspects

In the case of cast iron, it is possible to single out, immediately, certain characteristic facts:

- a reducing atmosphere allows us to limit the formation of oxide films, and therefore of slags;
- the presence of carbon, remembering that the gush of liquid arrives by rupturing of the doughy front, enables us to obtain a kind of inoculation, which contributes to grain refinement;
- in the case of high C.E. desulphurised iron, particularly after spheroidisation treatment, carbon can be a source of serious defects, above all in thin-walled castings.

In fact, remembering that for an iron of this type the surface tension (6) and viscosity values are elevated, and that the active carbon potential is lower, at the interface this can clusterise at a higher speed than that of diffusion in the boundary layer, or that of evacuation through the coating.

In this way, aggregates of moderate dimensions originate, which remain trapped by the liquid streams at the time of joining, as in the case illustrated in Fig. 4. Such a phenomenon can be exacerbated by the thickened polystyrene in the liquid phase, which captures the carbon present and promotes its agglomeration.

Conditions of this kind are enhanced by slow evacuation of the gas, and are therefore linked with poor coating permeability or with long-term exposure to radiation from the metal, as in the case presented in Fig. 5, in which, immediately the carbon residues correspond exactly to the original beads of the pattern, and are trapped at the metal/coating interface, through which they appear on the surface. In certain cases, moreover, the presence of liquid phases can induce in zones of castings, featuring critical geometry or conditions of filling, rate of cooling such as to promote the formation of carbides associated with voids of gaseous origin, as in Fig. 6.

Analogous dynamics of destruction of the EPS can give rise to other categories of defects. In Fig. 7, for example, on a grain boundary, pinholes are observed in the metal matrix, which however, turn out to be free from carbides.

Fig. 8, on the other hand, shows a case of cold shut of the surface of a spheroidal iron casting, at a point where residues of irradiated EPS are not completely "englobed" by the metal.

In the light of the above, we can say that the coating

Fig. 4 - A) Inclusion of graphite in a spheroidal iron casting with a wall thickness of 5 mm. B) Detail.

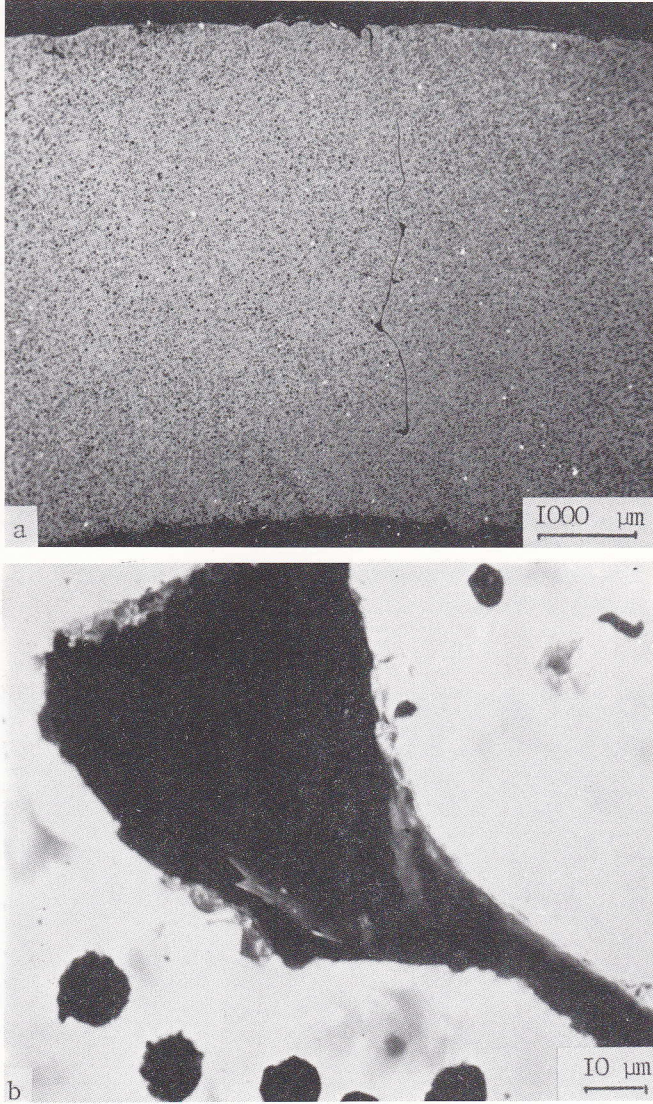


Fig. 5 - Effect of radiation on surface of a casting.

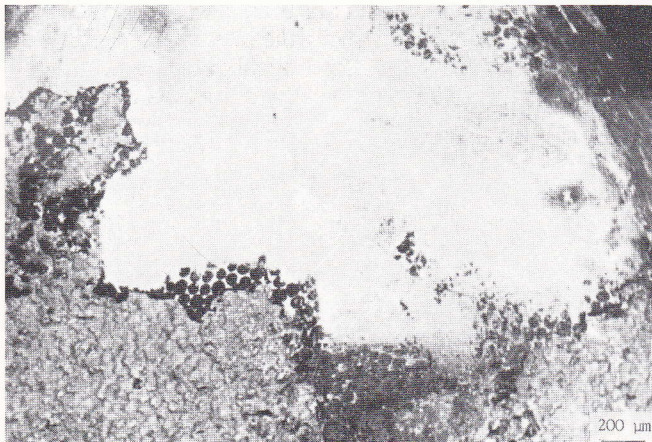


Fig. 6 - Carbides and micro-pinholes in the cortical zone of a spheroidal iron casting.

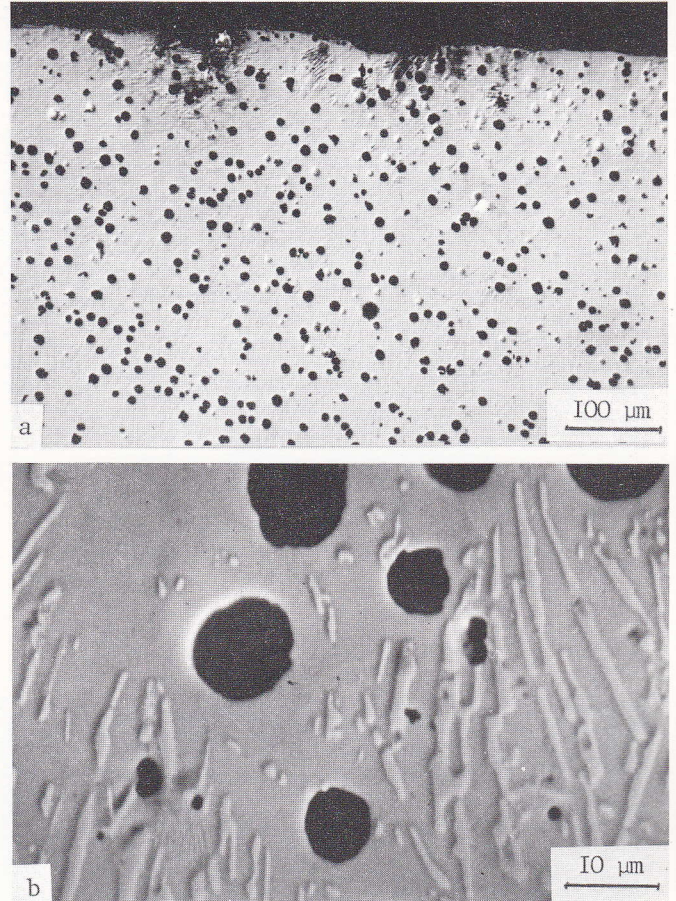
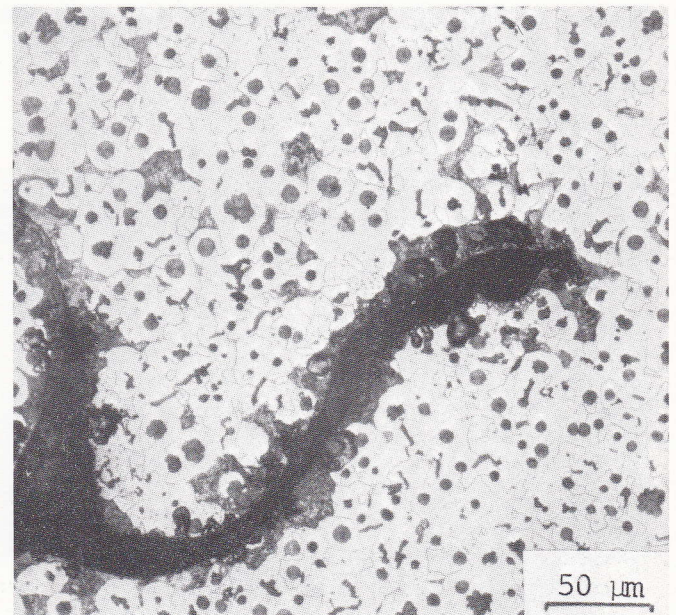


Fig. 7 - Pinholes in a ductile iron casting near a lustrous carbon inclusion.



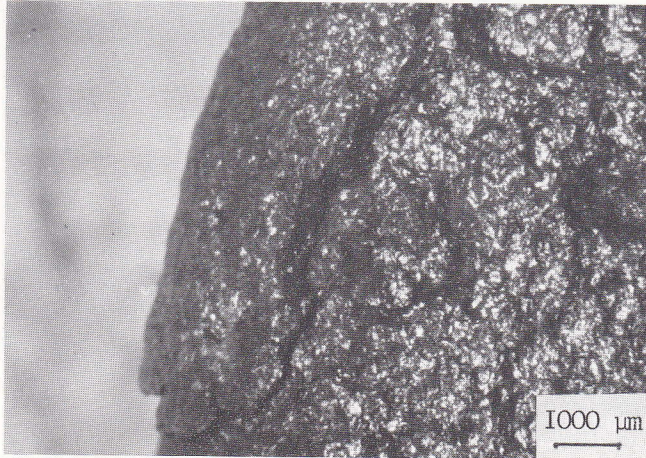


Fig. 8 - Stripping of surface in a casting of spheroidal cast iron.

assumes a new role, no longer being treated as just a permeable medium which permits filling-up at a more-or-less elevated speed, or as a system that, by its mechanical strength, gives the achievement of gas/sand equilibrium point by point, but also, and in some cases especially, as a "metallurgical agent" whose characteristic, in particular its permeability, can spell success or rejection of the casting.

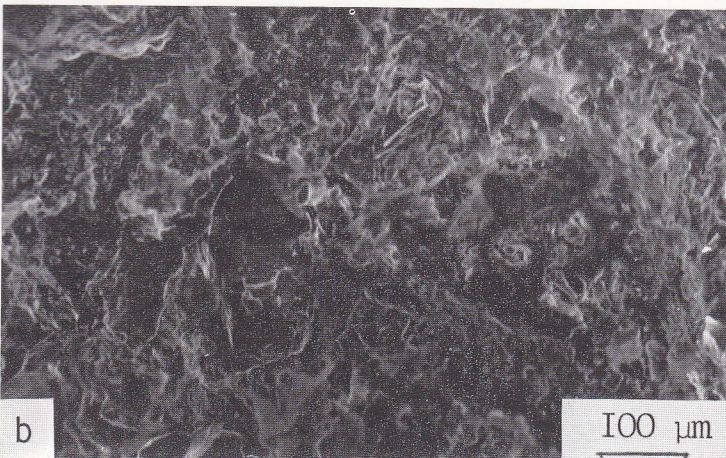
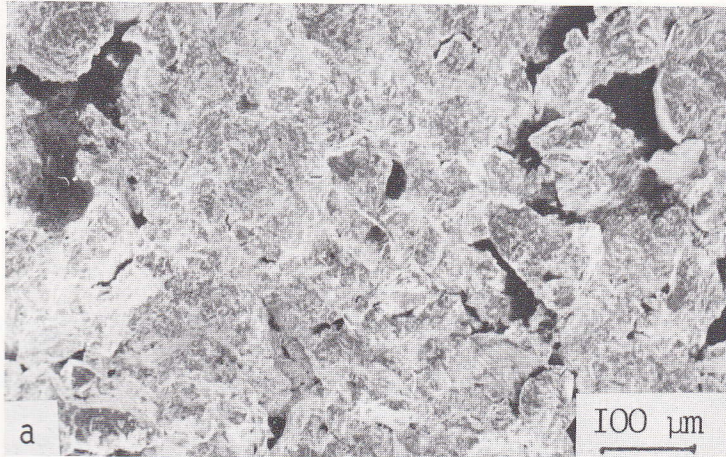
Characteristics of the examined coatings

The typology of these coatings is that of a refractory material used with different types of resin which have the function of a binder.

Most of the coatings studied are made of silica, together with silicate mixtures and other charge components.

The resins used range from modified phenolics to polyvinyl acetates, etc.

Fig. 9 - Surface appearance of Coating A.
a) Outside; b) Inside; c) Section.



At the time of application, it is possible to achieve on the patterns films of various thicknesses, controlled by the coating density, and to apply the desired number of layers by successive immersions so as to obtain the pre-decided permeability.

Experiments were conducted on a very large number of coatings, but the results reported here relate to three types which represent groups with different behaviour in the pouring of castings.

These types will be indicated as follows:

Type	Solvent	Basis	Binder	Density (Bé)
A	Alcohol	SiO ₂ Al ₂ O ₃	Vinyl Acetate	40
B	Alcohol	Silicate mix	Modified Phenolic	40
C	Alcohol	SiO ₂	Vinyl Acetate	40

In the SEM micrographs in Figs. 9, 10, 11, internal, external and cross-sectional appearances of coatings A, B and C are shown.

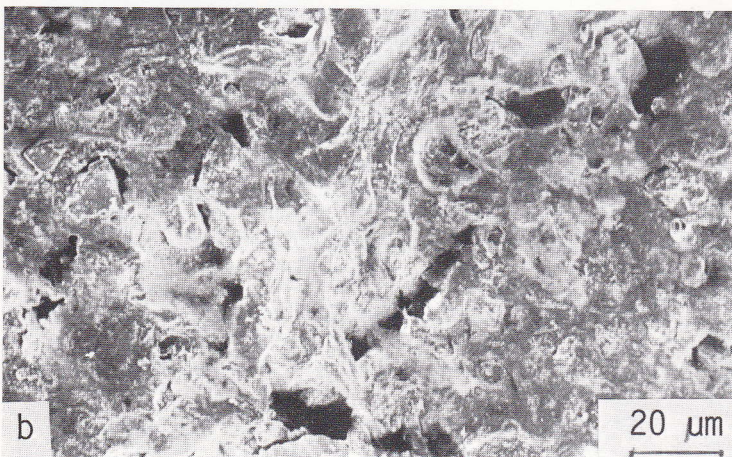
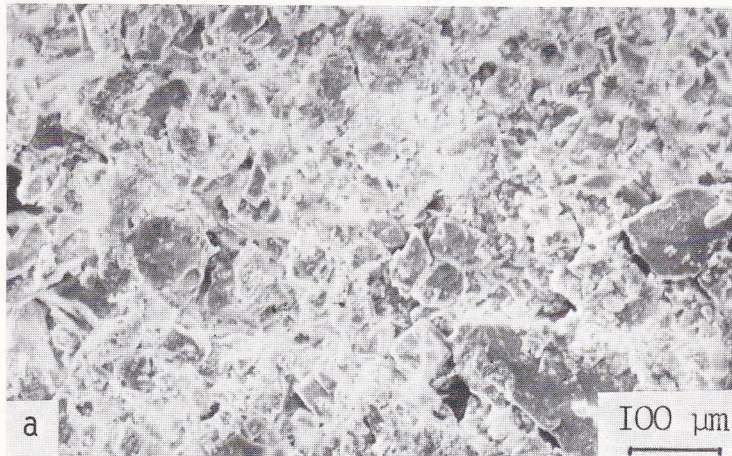
Types A and C have similar appearances, with the presence of large pores with crooked paths, Type B has a layered structure with porosity distributed over an ample spectrum of dimensions.

However, the average coating thickness obtained

varies with identical immersion conditions, being precisely: 307 μ for A, 300 μ for B and 430 μ for C. The layer of coating examined after pouring demonstrates a marked porosity at the grain boundaries, with occlusion or choking of the pores by the action of bright carbon (Fig. 12).

We have also noticed a different behaviour of the coating Types A and C which, after pouring, retain a

Fig. 10 - Surface appearance of Coating B.
a) Outside; b) Inside; c) Section.



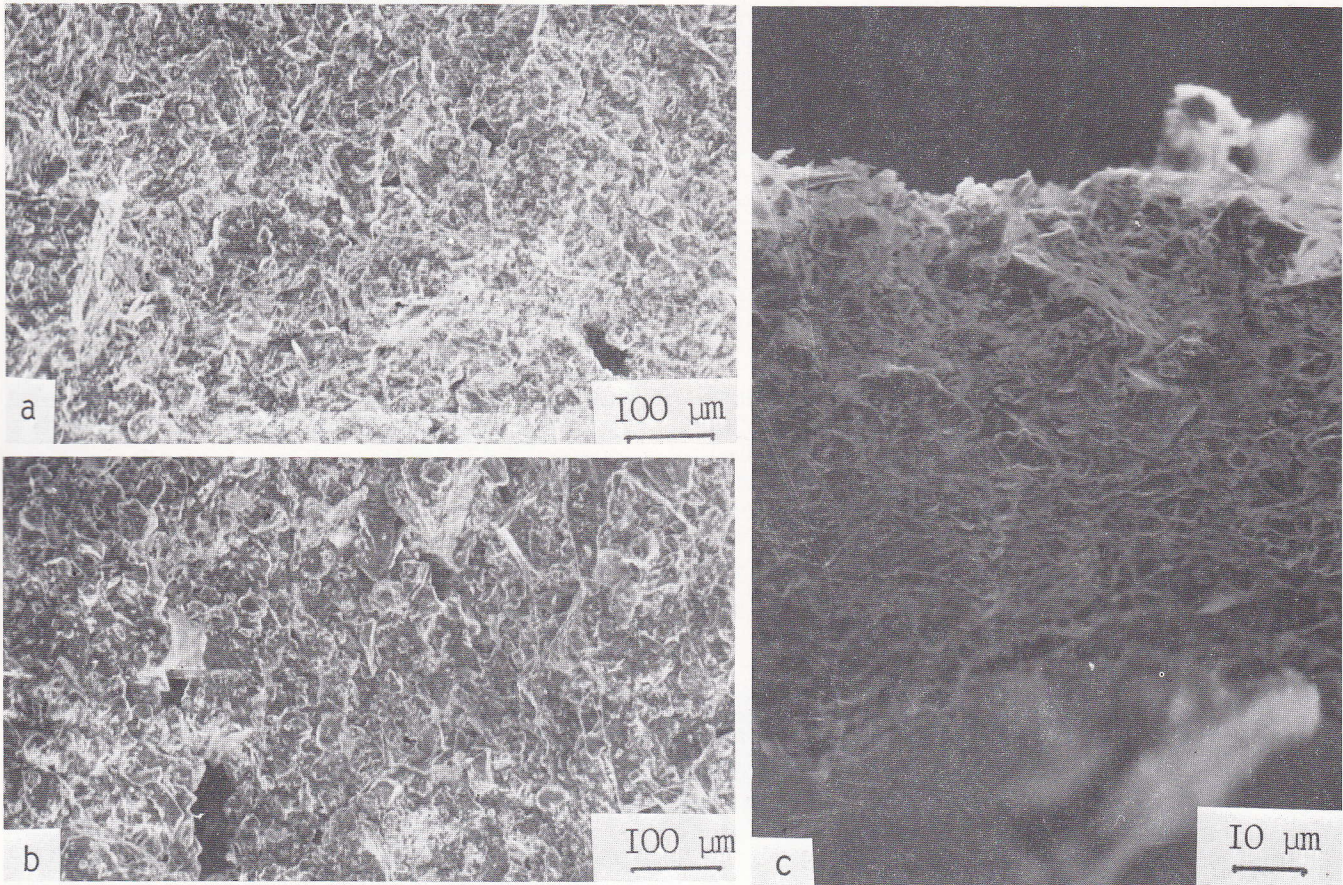


Fig. 11 - Surface appearance of Coating C.
a) Outside; b) Inside; c) Section.

Fig. 12 - Appearance of a coating flake after casting.

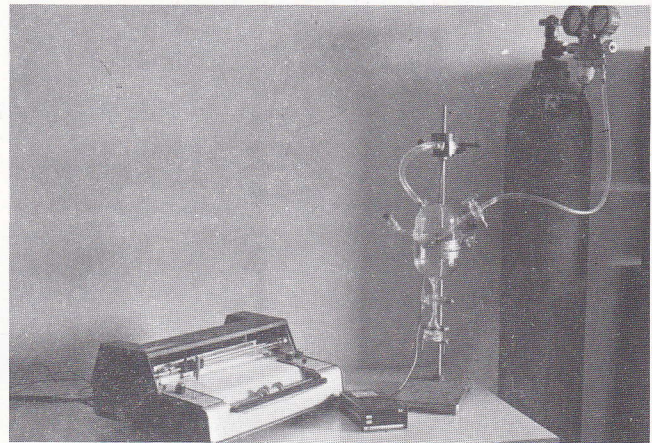
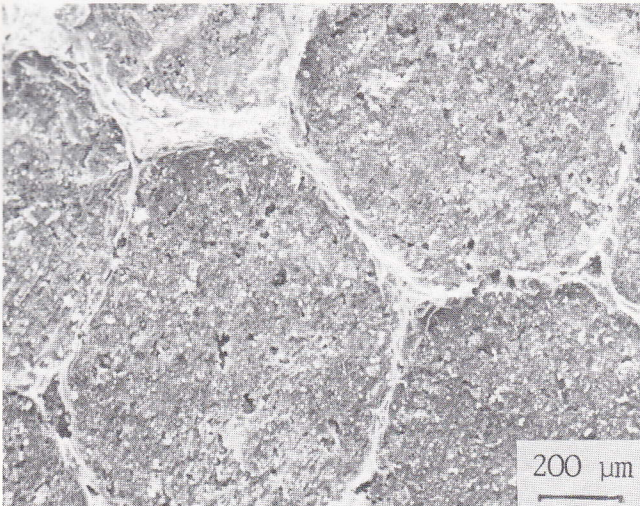


Fig. 13 - Equipment for the permeability test.

mechanical strength such as to allow flakes breaking-off easily from the casting, while Type B has a minimum mechanical strength, breaking-off only in powdery form.

The products of pyrolysis of the EPS are carried towards the outside through the layer of coating which

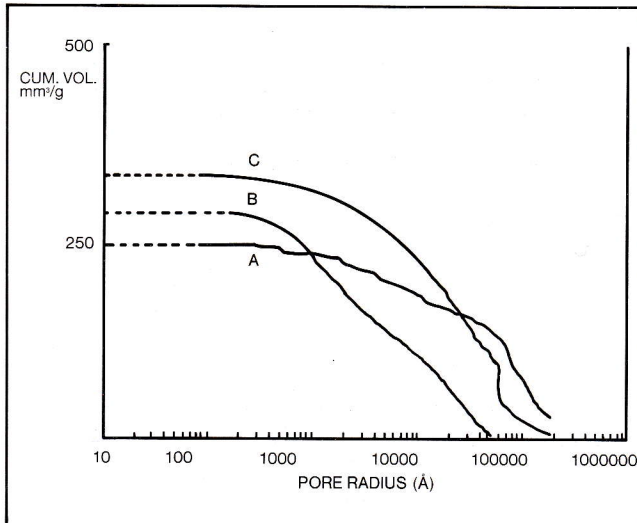


Fig. 14 - Course of porosimetry curve.

thus conditions the speed and quantity of products expelled from the casting zone.

Simulation of such a mechanism is particularly important for evaluating the coating's performance, verifying its consistency in the time, setting up a methodology of acceptance of the coating itself. To this end, after a series of preliminary tests, standard samples of polystyrene were coated, from which coating flakes were separated and subjected to permeability tests.

The equipment employed, shown in Fig. 13, was suitably set up and planned for this purpose.

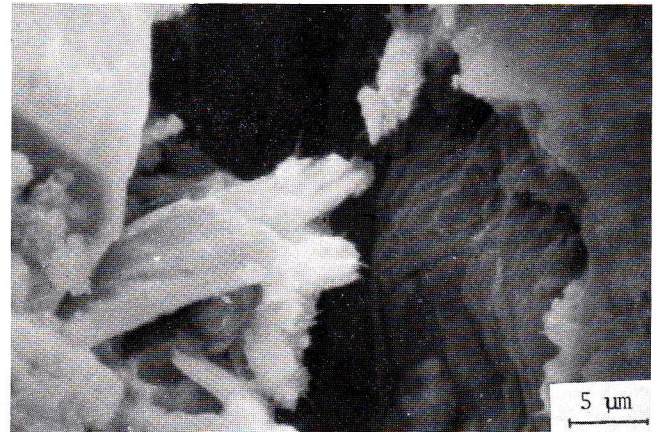


Fig. 15 - Carbon cluster inside a pore (Coating A).

It consists of a vessel of known volume, from which the test gas, at ambient temperature, flows out through a flake of coating mounted at the end of a calibrated orifice, for the time necessary to achieve balance between the initial inside pressure and that of the atmosphere.

The outflow of gas is followed with the help of a pressure transducer and a recording instrument. In particular, attention must be paid to safeguarding the integrity of the coating flakes, the calibration of the orifice, and the sealing of the system.

The reproducibility of the tests is such as to guarantee a measurement error within $\pm 5\%$.

By means of the equipment described, tests were made of permeability, measuring the times of outflow

TABLE 1 - Permeability of coatings compared (time of flow)

Type	Pressure 1.5 – 0 bar	Pressure 0.3 – 0 bar
A	21s	10s
B	43s	25s
C	102s	42s

TABLE 2 - Permeability of coatings after pouring

Type	Pressure 1.5 – 0 bar	Pressure 0.3 – 0 bar
A	56s	36s
B	—	—
C	200s	137s

of different gases through the coating layer under different pressures.

Table 1 summarises the results relating to the use of nitrogen, for the three coatings.

Permeability tests were conducted on samples both with flow from the inside (polystyrene/coating face) and from the outside (coating/sand face), not obtaining any significant differences in the compared values.

The same tests were also carried out on flakes detached from the castings. In this case it was not possible to experiment with coating B, because of the difficulty already mentioned. The results can be seen in Table 2.

Samples were then prepared of coating removed from polystyrene testpieces with dimensions $15 \times 20 \times 70$ mm, and mercury porosity meter tests were carried out with the aim of obtaining the dimensions of the pores, and their distribution.

Fig. 14 gives the diagrams obtained.

Results

The porosimetric tests on the coating used showed a different size, total porosity and pore distribution for the types examined.

Coating A showed a total porosity of 36% with a maximum frequency of distribution of diameter of the pores around a value of 10μ .

From this it is derived that such a type is characterised by constant enough pore diameters.

Coating B had a total porosity of 32% and revealed pore diameters between 0.05 and 6.0μ . The pore diameters of this type of coating spread over a wide range, almost with the same frequency, while the total porosity was comparable with the one of coating A.

Coating C had a total porosity of 58%, and revealed pore diameters between 0.1 and 30μ .

This coating is characterised by the presence of a fair percentage of pores of large size, together with others of smaller dimensions distributed over a wide interval.

The permeability tests indicated a behaviour of the coatings which can also appear inconsistent with the porosimetric data.

An analogous trend of the outflow is noted whether starting with a pressure of 1.5 or of 0.5 bar.

For Coating A we had the minimum times of outflow correlated either to different dimensions of pores or to a different coating structure.

Coating B showed outflow times about twice as long as the ones of coating A: this can be attributed to both the different average pore size and the different texture of the coating.

Coating C, on the other hand, showed the lowest permeability. This behaviour, not being justified by the porosimetric data, is supported by the presence of non-transmitting pores. A tendency was also noticed to

form greater thicknesses during coating.

The tests carried out on coating layers after pouring finally revealed, in both cases A and C, a very noticeable increase in the respective times of gas outflow.

This variation can be correlated with the partial occlusion of the porosity present, by the lustrous carbon.

Fig. 15 records the presence of a carbon "cluster" inside a pore of Coating A, after pouring.

For both Coatings A and C the presence of a uniform accumulation of carbon along the coating thickness and at the casting/coating interface was proved; in the case of Type B, on the other hand, the carbon thickens in the outside layers, (Fig. 16).

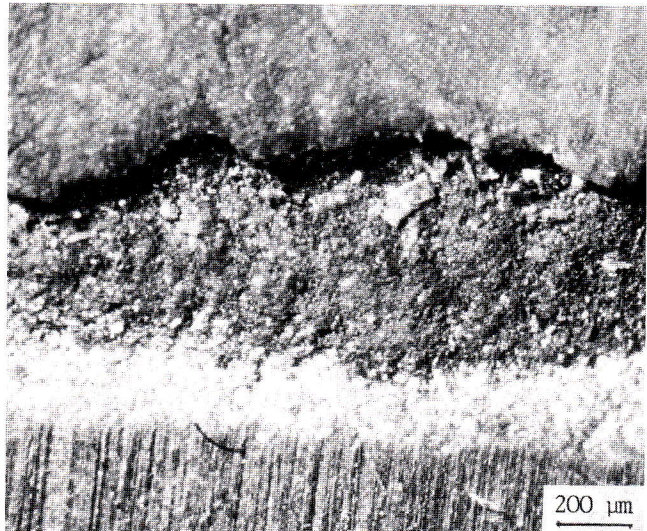


Fig. 16 - Section of a coating flake after casting (Coating B).

For all the products examined, it was verified that part of the carbon gets through the coating layer, depositing itself on the surrounding sand grains, as shown in Fig. 17.

Systematic pouring tests were carried out in order to confirm the indications from the investigations carried out in the laboratory; for this purpose, EPS patterns were used, with a uniform thickness of 5 mm, coated and dried according to a standardised method, and assembled in batches as shown in Fig. 18.

Casting was conducted using both gray iron and spheroidal graphite iron obtained by the "sandwich" method.

After casting, research into lustrous carbon defects was undertaken with the aid of a Magnaflux apparatus. The results of this work are schematically presented in Table 3, where the percentages of defective castings are given, based on 480 castings for each test.

The nature of defects discovered with an extension almost equal to the wall thickness of the casting, is of

Fig. 17 - Appearance of a sand grain.
a) - b) New sand; c) - d) Sand after 1000 casting cycles.

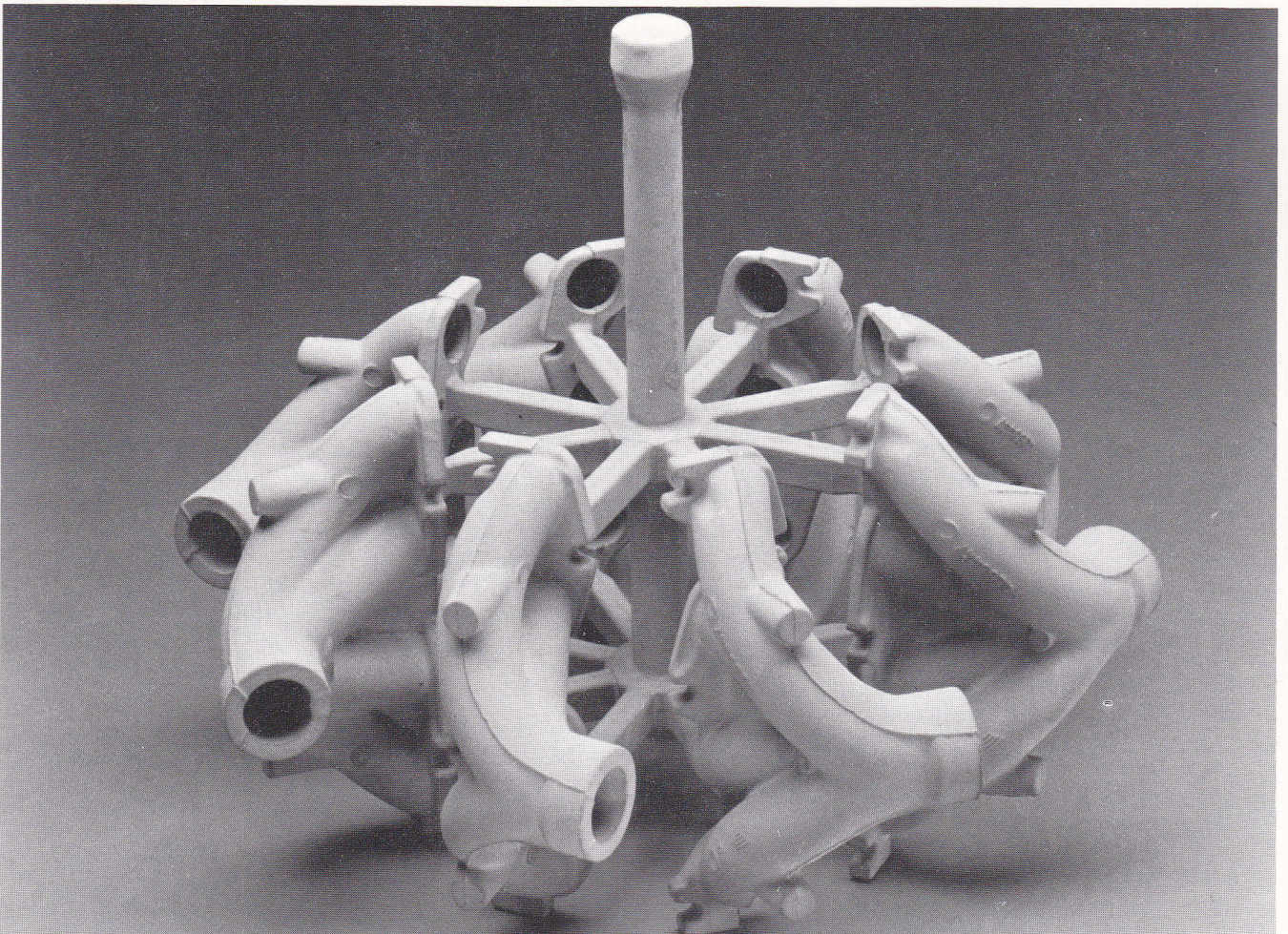
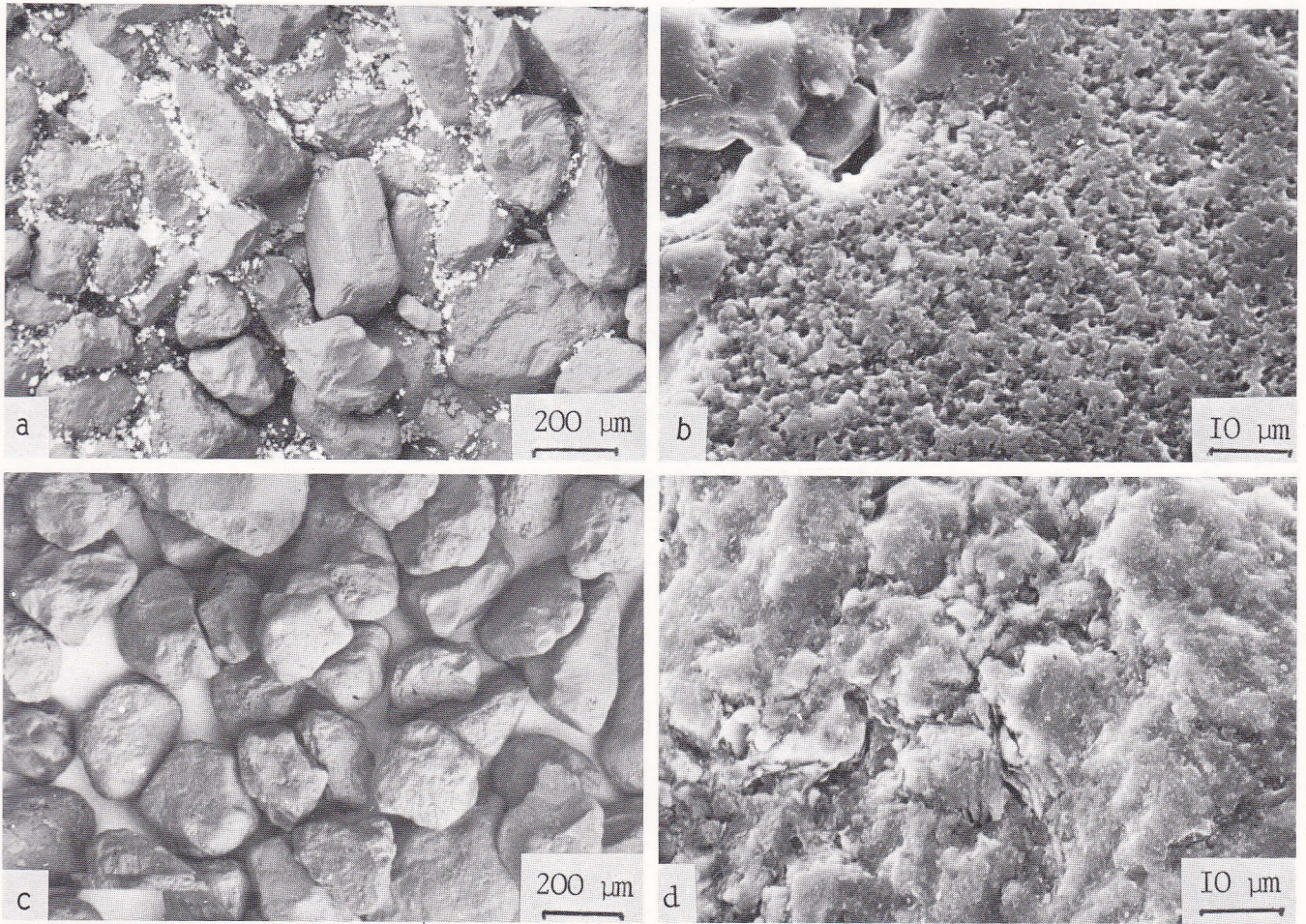


Fig. 18 - Cluster of patterns for exhaust manifolds.

TABLE 3 - Amount of defective castings

	Grey iron	Spheroidal graphite iron
Coating A	2%	40%
Coating C	15%	90%

the type shown in Fig. 4.

Type B coating does not appear in the tables because an equally significant number of castings could not be poured. Nevertheless, observations on a narrower basis of tests still indicate a percentage of defectiveness in the castings, potentially inferior to that of the other coatings.

Comparison of the results suggests a different high temperature behaviour of the applied layer, probably justifiable in view of its different structural morphology.

Conclusions

The indications so far emerging in the course of the experiment give a positive evaluation of the methodology adopted for characterisation of the coatings, which however, does not exhaust every aspect of the problem.

In fact, a good agreement results between determination of the flakes' permeability, obtained with standard samples, and percentages of defective castings when pouring; it is noted, nevertheless, that a study of permeability cannot fail to take account of the statistical distribution of the pores, and the structural morphology of the layer applied, with the aim of correctly interpreting the complex mechanisms that develop during casting.

To research the subject thoroughly, relative to this last argument, we envisage a further stage of experimentation, with particular reference to the high temperature behaviour of coatings.

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