COMMISSION OF THE EUROPEAN COMMUNITIES

technical steel research

Technical and economic advantages of pig iron in the charges of cupolas or electric furnaces

1980

EUR 6439 EN

COMMISSION OF THE EUROPEAN COMMUNITIES

technical steel research

Technical and economic advantages of pig iron in the charges of cupolas or electric furnaces

Jean-Claude Margerie *

Chambre syndicale des producteurs de fontes brutes
Roheisenverband - Düsseldorf, C.S.M. - Rome
Arbed - Luxembourg

* Centre Technique des Industries de la Fonderie

Contract No 6210-87
(1.7.1972 - 31.12.1976)

SYNTHESIS REPORT

Published by the Directorate-General
Scientific and Technical Information and Information Management

1980

EUR 6439 EN

ZUSAMMENFASSUNG

1. - Aus Vorversuchen (Probenahmen in 20 französichen Giessereien) ist bekannt, dass bei gleicher chemischer Zusammensetzung die mechanischen Eigenschaften von Gusseisen (Festigkeit, Härte und Bearbeitbarkeit) je nach Schmelzaggregat und Aufbau der Ofeneinsätze etwas anders ausfallen.

2. - Die Inzidenz der Chargen-Zusammensetzung und insbesondere der Roheisen-Anteilsmenge konnte anhand systematisch in Frankreich und Italien durchgeführter Versuchsreihen erfasst werden (Grauguss mit mittleren Festigkeitswerten aus einigen ausgewählten Giessereien). Im Kupolofen und im Elektroofen führt ein höherer Roheisenanteil zu leicht geminderten Festigkeits- und Härtewerten, aber auch zu einer merklich verbesserten Bearbeitbarkeit. Die Wirkungsweise der Beschaffenheit von Roheisen ist im Vergleichswege nachgewiesen worden, wodurch Bedeutung und Problematik des Begriffs von der Vererblichkeit aufgezeigt werden konnten.

3. - Die technisch-wirtschaftliche Analyse basiert auf betriebstechnischen Aufzeichnungen aus etwa 30 französischen Unternehmen, wo Kalt- bzw. Heisswindkupolöfen, Indusktionsöfen oder Lichtbogenöfen gefahren werden. Die Fertigungsselbstkosten wurden in ihrer Gesamtheit jeweils erfasst und geprüft, was zur Feststellung betriebstechnisch bedingter Diskrepanzen Anlass gab.

4. - Aufgrund der Untersuchungsergebnisse lässt sich die Aussage vertreten, dass die Installierung moderner Kaltwindkupolöfen und die Verwendung gezielt ausgewählter Roheisensorten - selbst für die Beschickung von Elektroöfen - in zahlreichen Fällen vollauf gerechtfertigt sind.

ABSTRACT

1. Preliminary tests (samplings from 20 French foundries) have shown that cast irons having the same chemical composition differ slightly in mechanical properties (strength, hardness, and machinability) depending on the melting installation and the constitution of the charges.

2. Campaigns of systematic trials carried out in France and in Italy (grey cast iron of average mechanical quality produced in a few selected foundries) have made it possible to determine the specific influence of the composition of the charges and in particular the percentage of pig iron. In both the cupola and the electric furnace, increasing the percentage of pig iron slightly decreases strength and hardness but substantially improves machinability. The influence of the type of pig irons compared has been demonstrated, thus confirming the interest, but at the same time the difficulty, of the notion of heredity.

3. The technical-economic analysis was made on the basis of statements of operating conditions in about 30 French firms using cold- or hot-blast cupolas, induction furnaces, or arc furnaces. The overall cost prices of production in each case were examined and disparities resulting from the incidence of operating parameters were found.

4. The results show that the installation of modern cold-blast cupolas and the use, even in the electric furnace, of carefully selected pig irons are fully justified in many cases.

RESUME

1.- Des essais préliminaires (prélèvements d'éprouvettes dans 20 fonderies françaises) ont montré que pour une même composition chimique, les propriété mécaniques des fontes moulées (résistance, dureté et usinabilité), sont légèrement différentes selon l'engin de fusion et la constitution des charges.

2.- L'influence propre de la composition des charges et, particulièrement, du taux de fonte neuve a pu être dégagée en exploitant des campagnes d'essais systématiques menées en France et en Italie (fontes grises de qualité mécanique moyenne élaborées dans quelques fonderies choisies). Au cubilot comme au four électrique, l'augmentation du taux de fonte neuve diminue faiblement la résistance et la dureté, mais améliore sensiblement l'usinabilité. L'influence de la nature des fontes neuves comparées a été mise en évidence confirmant ainsi l'intérêt, mais aussi la difficulté, de la notion d'hérédité.

3.- L'analyse technico-économique a été conduite à partir des relevés des conditions d'exploitation dans une trentaine d'entreprises françaises utilisant des cubilots à vent froid ou à vent chaud, des fours à induction ou des fours à arc . On a examiné les prix de revient globaux d'élaboration dans chaque cas et on a constaté des disparités dues à l'incidence des paramètres de fonctionnement.

4.- Les résultats montrent que l'installation de cubilots à vent froid modernes et l'utilisation, même au four électrique, de fontes neuves bien choisies, sont pleinement justifiables dans de nombreux cas.

TABLE OF CONTENTS

LIST OF THE TABLES AND FIGURES

This final report is based essentially on the three partial documents prepared to report on Franco-Italian part B of the ECSC common research programme into cast irons, begun on 1st July 1972:

Final report No. 1

L'emploi des fontes neuves dans les charges des cubilots ou des fours électriques en vue d'améliorer les propriétés des fontes de moulage, by M. Charbonnier, Y. Brachet, and R. Sainte-Catherine of the Centre Technique des Industries de la Fonderie (Paris, September 1975).

Final report No. 2

Impiego delle ghise nuove nelle cariche dei cubilloti o dei forni electrici in vista di migliorare la lavorabilita dei getti di ghisa grigia, by G. Cola and A. Scaccia of the Centro Sperimentale Metallurgico (Rome, September 1975).

Final report No. 3 (not destinated for publication)

Etude technico-économique de l'élaboration de la fonte au cubilot et au four électrique, by M. Charbonnier, C. Farque and R. Sainte-Catherine of the Centre Technique des Industries de la Fonderie (Paris, September 1977).

1. INTRODUCTION

1.1. Objective of the study

The study has the following general objective: to determine the technical and economic advantages of the use of pig iron in charges remelted either in the cupola or in the electric furnace.

It has been found that the consumption of pig iron per tonne of castings produced by iron foundries has dropped significantly in all Community member countries in the last few years.

This decline seems to result primarily from the price difference between pig iron and scrap, which is encouraging foundries to accommodate to the latter, which is of course not as close to the iron to be produced, with the help of new melting and metallurgical testing techniques:

- electric furnace melting (precision and cleanness);

- holding and homogenization in electrically-heated mixers (flexibility of supply to casting shops);

- spectrographic inspection of chemical composition (speed of response allowing certain corrections to be made before casting);

- and complementary metallurgical treatments such as graphitizing inoculation (corrective action on structure of solidifed metal).

Judiciously used, these techniques, which are ceaselessly progressing and diversifying, do in fact make it possible to produce satisfactory castings from charges in which pig irons are more or less completely replaced by scrap; but we must ask ourselves if its generalized use is not abusive and attempt to define those cases in which the use of pig iron should reasonably be continued or even increased. For this purpose, it was judged worthwhile to undertake in-depth research to determine whether sufficient allowance is made for certain differences in quality (casting properties, machinability) - this is the technical aspect of the question - and to what extent a cost analysis including all expenses in conjunction with the production of the molten metal justifies the trend observed - this is the economic aspect of the question.

1.2. State of the question at the start of the work

1.2.1. Metallurgical research

It has often been said that iron produced in the cupola, with a high proportion of pig iron in the charges, has desirable properties that disappear with production in the electric furnace from scrap charges.

Because of its practical importance, this opinion has been the object of critical examination by foundry specialists but the published conclusions are not always in agreement: some observers have found that the melting installation has no particular influence while others have reported differences (mechanical properties, casting properties) in favour of the cupola or of the electric furnace as the case may be.

Metallurgical research, using all the resources of modern metallography but generally working at laboratory scale, has clearly established that the structure and in consequence the properties of an iron sample solidified under well-defined conditions are significantly affected by the following factors:

- the nature and purity of the constituents of the charge;
- the complete thermal cycle followed by the molten iron (temperature/time curve);
- environmental factors that may react with the metal at high temperature (refractories, atmospheres, etc.).

The study of each of these factors is highly complex. For example, the charge cannot be represented only by the chemical composition (tracers included) of its various constituents; a Community research project has established that the overall concept of heredity must be kept to express the fact that certain structural characteristics of different comparable pig irons are partially transmitted to the samples by remelting under identical conditions[*].

[*] Agreement 6210-36/3/031 - Final report Eur 5152 f (part 2), August 1974

Moreover, knowledge of the relationships between the main properties and chemical composition of grey-iron castings has advanced considerably during the last twenty years.

Work by the Institut für Giessereitechnik (I.F.G.) in Dusseldorf on iron produced in Germany under a wide variety of conditions (in the cupola or in the electric furnace) has established correlations between tensile strength (the basis of the standardized classification of grey irons) and hardness (a property that is to some extent representative of machinability) and chemical composition. Further work under the sponsorship of the International Committee of Foundry Technical Associations (Commission 7a) has revealed that these correlations are modified by the influence of the materials constituting the charge (pig and scrap) and by the type of melting (cupola and electric furnace); in conclusion, it could already be anticipated that the long-standing practical experience according to which the cupola would give softer cast irons than the electric furnace could only be confirmed and understood through rational tests including systematic modification of the proportions of pig iron and steel in the charges and a comparison of irons produced in parallel in the cupola or in the electric furnace.

The ICFTA (Commission 7a) is also recommending new rapid tests to estimate the machinability of cast irons; given the increasing importance of this property, the use of several distinct methods based on tool-wear criteria in parallel with the hardness test could therefore be considered.

1.2.2. The economic aspect

No technical step can be considered on an industrial scale without allowance for economic factors.

For many years, the Centre Technique des Industries de la Fonderie (C.T.I.F., Paris) has been doing technical-economic work with a view to helping French foundries to use the resources of analytical accounting to know themselves, to keep track of how they change in time, and, most important of all, to refer to one another in the context of "intercompany comparisons". The collective experience so acquired has already revealed disparities in cost, man-hour productivity, and consumption between apparently similar shops engaged in the same speciality; the methods developed make it possible to measure the economic consequences of a de facto technical situation with satisfactory accuracy.

It was therefore proposed to make use of this experience and these methods for a comparative analysis of the production costs of iron in a group of foundries as large as possible producing iron ready for casting from a variety of charges using cupolas or electric furnaces.

2. OVERALL PROGRAMME (see diagram, fig. 1)

2.1. Breakdown of tests

It was thought judicious to follow a programme calling on the help of several countries in the Community, both to increase the means of execution and to include production techniques as diverse as possible.

While the I.F.G. was to deal in Germany and Luxembourg with perfecting and regularizing the operation of the cupola to combine its own advantages with those of pig iron, of which it is on the average a heavy consumer (part A), the C.T.I.F. for France and the C.S.M. for Italy were to coordinate their testing (part B) aimed at differentiating the influence of the nature of the charges from that of the type of melting, using statistical plans the principle of which will be explained later. To improve the reliability of tests of machinability, they were to be carried out jointly on the same cast irons, produced in France or in Italy, at the facilities of the C.S.M. and of the C.T.I.F., using the respective proven methods of each.

In addition, a large supplemental programme based on information already gathered in the four countries mentioned above was entrusted to the C.T.I.F., involving conducting and analysing an economic survey covering all techniques used in the Community; however, for obvious reasons (practicality of the survey, uniformity of the information), it was agreed that the foundries to be visited would be chosen from among those located in France.

The three detailed reports of the Franco-Italian tests are cited at the head of this report.

2.2. Experimental plans

2.2.1. Tests conducted in France by the C.T.I.F. (with the help of the C.S.M.)

The plan of tests conducted by the C.T.I.F. consists of two successive stages.

2.2.1.1. The preliminary stage consisted of studying a population of 253 samples (test bars 30 mm in diameter) taken in 20 French foundries without any change to their usual practice; their tensile strength, hardness, chemical composition (5 elements) and machinability ("Renault-Mathon" accelerated plane turning method) were statistically correlated with a distinction made between types of melting (cupola or electric furnace). The samples were of non-alloy grey cast iron of ISO classes 15 to 40 (tensile strength from 150 to 400 N/mm^2). Since cupola melting gives higher sulphur content and cupola charges generally contain more phosphorous (old cast iron), special observations were made of these two elements.

2.2.1.2. The main stage of the tests conducted by C.T.I.F. consisted of studying, separately, the effect of the percentage of pig iron (20, 30, 40, and 50%), of the percentage of steel (10, 20, 30, and 40%), and of the type of pig iron (4 origins, same commercial class) on the essential properties of cast irons produced in two foundries, one of which made available two (identical) conventional 3 tonne/hour cold-blast cupolas to the experimenters and the other an 0.8-tonne low-frequency crucible induction furnace (cold-charge melting with controlled heel).

For each type of melting, the operations were carried out in accordance with a "Latin square" statistical plan of which figure 2 gives a diagram; the charges were made up to 100% with ingots of a single iron cast in the cupola for the whole programme to simulate returns. In this way, with a total of 32 melt-downs, it was in theory possible to separate the effects of the factors cited above (independent variations) and that of the type of melting.

Adjustments were provided to result in all cases in a cast iron of the same strength class (ISO grade 25) by aiming, after a constant inoculation, at the same chemical composition except for sulphur.

The properties studied using appropriate test bars were the following: Tensile strength*
Brinell hardness*
Structure
Machinability* (three methods, two applied at Rome)
Chill depth* (standard shop test)
Liability to shrinkage.

A complete statistical analysis was made of the properties marked with an asterisk, with the necessary correction made to allow for the effects of differences in chemical composition resulting from experimental imperfections (carbon, primarily) and not to the actual melting principle (sulphur, nitrogen, etc.).

2.2.2. <u>Tests conducted in Italy by the C.S.M.</u> (with the help of the C.T.I.F.)

The Italian programme consisted, like the French programme, of producing the same grade of iron (ISO grade 25) in a conventional cold-blast cupola and in a low-frequency crucible induction furnace from charges containing more or less pig iron, but following a somewhat different statistical plan (factorial plan).

In this case, a 5.5-tonne/hour cupola and a 1.5-tonne furnace (cold charges on initial ingot) were used; the charges included the same fixed portion in all cases:

(30% returns (prepared in advance either in the cupola or in the electric
(furnace)
(20% hematite iron containing 4% carbon and 2% silicon.

The variable portion consisted of:

50% steel
or 50% iron containing 2.6% carbon (blast-iron furnace iron refined in electric furnace)
or 50% iron containing 2.7% carbon of another origin (synthetic iron produced from steel)
or 50% of the same containing 0.6% chromium.

Here again, the composition was in theory adjusted (percentage of coke or recarburization agent) to obtain, after constant inoculation, substantially the same percentages of the main element (except sulphur). The following properties were studied after the chemical composition had been checked:

Tensile strength

Brinell hardness

Structure

Machinability (3 methods, 1 applied at Paris).

A complete statistical analysis (analysis of variance) was made, separately for the cupola and electric-furnace irons, of the hardness and machinability measurements.

It should be added that the Italian programme, like the French programme, included all useful precautions possible in industrial surroundings to make the comparisons truly significant insofar as possible.

2.2.3. Economic study (C.T.I.F.)

The primary objective was to establish a plan defining the "work centres" unambiguously so as to make possible a clear classification of melting expenses from charge preparation to metallurgical testing* including items that are ancillary but nevertheless very important, such as normal or exceptional repairs, the removal of dust from smoke or from the environment, etc.).

In addition, there was an accounting questionnaire intended to facilitate the recording (by C.T.I.F. employees working directly on site) of the physical data (hours of work, quantities of materials consumed) and their local unit cost.

Naturally, a very detailed analysis of the constitution of the charges would be required.

In particular, the quantity and true cost of the pig iron consumed, with the commercial class and origin noted, together with similar data for other metallic raw materials and the method used by the firm to assign a value to returns were to be noted for each type of iron produced.

*Subsequent experience showed that it was unfortunately impossible to isolate this item in most firms.

We then set up a sampling of foundries willing to participate in the survey in exchange for all key information, broken down by firm but with firm identities strictly protected, together with any remark essential to their interpretation, in accordance with the proven "interfirm comparisons" technique mentioned earlier (1.2.2.). In the end, we were able to study:

- 18 cold-blast cupola installations (one with two rows of tuyeres);
- 5 hot-blast cupola installations;
- 11 induction furnace installations used for single melting
- 7 induction furnace installations used for duplex processing
- 4 induction furnace installations used for hold
- 2 arc furnace installations.

The principal melting techniques used in the Community are thus represented by this sample, which also covers a very broad range of monthly outputs The survey covered the first half of 1975 (with a few duly-corrected exceptions).

For the analysis and interpretation of the quantitative data collected, it was necessary, finally, to choose a method of comparison in which the consequences of disparities external to the melting installation itself could be held to a minimum, either by subtracting their incidence or by transposing it to a mean value.

3. RESULTS OF THE TECHNICAL STUDY

We shall not here amplify the statistical analysis of the results obtained, since it is presented in the final reports together with all necessary details. We shall confine ourselves to emphasizing the conclusions to which they lead, with numerical illustrations that, outside of the test conditions, may indicate at least orders of magnitude or tendencies.

3.1. Remarks on the execution of the experimental programmes

The experimental plans, both Italian and French, were fully carried out in accordance with the agreed programmes. However, in particular in the case of melt-downs in the cupola, the efforts made to obtain the same carbon and silico contents in the resulting iron in spite of the substantial variations in the metal charged were not always perfectly effective; for example, the following mean values were found (cupola):

% Pig iron	Mean carbon content in %
20	3.05
30	3.18
40	3.20
50	3.21

% Steel	Mean silicon content in %
10	1.92
20	1.95
30	1.83
40	1.70

In the case of tensile strength, it was possible thanks to a good knowledge of statistical relationships with the chemical composition and hardness (Weis and Orths's formula) to calculate a correction making possible comparisons "at constant chemical composition"; it was then found that these corrections did not significantly alter the conclusions. We shall finally assume that, on the whole, the approximation obtained was sufficient with respect to the findings made. The mean chemical compositions are listed in table I for guidance. Significant differences in sulphur and nitrogen contents were of course found, related, naturally, to the type of melting.

3.2. Remarks on machinability tests

In view of the importance attached to machinability, the tests were carried out using three different methods. It is interesting to note that the results are in perfect agreement. By comparison with the conventional determination of the critical speed of tool wear in 60 min. (V_{60}), which is relatively long and consumes much material, it was found that the "Brandsma" method (plane turning of disc 240 mm in diameter) gave information that was very nearly as sensitive; the critical speeds (in m/min) are, moreover, correlated by the formula:

$$V_{C\ (60)} = 0.75\ V_{C\ (B)} - 6.65 \pm 5.3$$

(with the limitsof linked dispersion given here being to the 0.05 level).

The Renault-Mathon method, which uses even less material, is less accurate, and its limit of sensitivity was reached in this case, which involved comparing rather similar cast iron.

Moreover, it was clearly confirmed that evaluation of machinability by hardness is justified if, as was the case here, differences in chemical composition and structure are small.

3.3. Influence of percentages of steel and pig iron

3.3.1. The tests of the C.T.I.F. show the consequences of the percentage of steel in the charges as this percentage is gradually increased at the expense of scrap and returns, with the percentage of pig iron held constant.

Some degree of underestimation of carburization difficulties and silicon melting losses was revealed (in the cupola) by the fact that, in spite of an increase in the percentage of coke and the addition of ferrosilicon based on foundry experience and the literature, the carbon equivalent nevertheless steadily declined:

Steel	10%	20%	30%	40%
Ceq %	3.89	3.82	3.76	3.72

After correction, it may be calculated that if the carbon equivalent ($C + \frac{1}{3}[Si + P]$) had been held strictly constant, the mean increase in tensile strength would have been:

0.84 daN/mm^2 (or about 2.4%) per 10% additional steel. In reality, nearly the entire effect is already attained at 20% steel and it is no longer significant thereafter.

In the electric furnace, steel has no particular influence on this point. Moreover, the increase in tensile strength is accompanied by a strictly parallel increase in hardness, with a mean in the cupola of 3.7 HB per 10% additional steel.

In view of the correlation between hardness and machinability, even more marked in electric-furnace irons, we obtain, in the end, a mean decrease in critical cutting speed V_{60} estimated at:

(- 0.9 m/min. (or about 2%) per 10% additional steel in the cupola
(
(- 1.2 m/min. (or about 2.7%) per 10% additional steel in the electric furnace.

It may therefore be concluded on the whole that the slight increase in tensile strength obtained by these means is offset by a proportional increase in tool wear. Furthermore, the inhomogeneity of mechanical properties as a function of moulding thickness (section sensitivity) increases significantly, especially in the electric furnace (fig. 3).

A certain detrimental effect of steel on tendency to shrinkage was found in the case of cupola cast iron. In consequence, the increase in tensile strength may prove to be illusory unless a larger feeder system is accepted.

Finally, the nitrogen content increases quite significantly with the steel content and, in the case of the cupola, exceeds 100 ppm from 20% steel. It is well known that, if very massive parts are cast, such contents are almost sure to cause highly undesirable vermicular porosity.

In conclusion, replacing scrap and returns by steel results, based on the criteria chosen and at constant chemical composition, only in certain technical drawbacks (machinability, section sensitivity) in the case of electric melting; in the cupola, some increase in strength is accompanied by hardening, a decrease in machinability, and an increase in section sensitivity and liability to shrinkage.

3.3.2. We shall see, conversely, the effect of pig iron when the percentage of steel remains constant, again based on tests made by the C.T.I.F.

The contribution of carbon by pig iron in the cupola has been underestimated, as has been seen in §3.1. When the necessary corrections are made, we find a mean decrease in tensile strength of:

(- 1.1 daN/mm^2 (about 3.1%) per 10% additional pig iron (in the
(electric furnace);
(
(- 0.7 daN/mm^2 (about 2%) per 10% additional pig iron (in the
(cupola).

Here again, there is an exactly parallel change in hardness, a decline of 6.7 HB per 10% additional pig iron, and the expected corresponding improvement in machinability; the approximate improvement in critical speed V_{60} is 2 m/min. (about 4.7%) per 10% additional pig iron.

No effect on section sensitivity was found. On the other hand, the favourable effect of charges rich in pig iron on liability to shrinkage is quite marked in the cupola and may compensate for the undesirable effect of steel. Moreover, pig irons that themselve contain little nitrogen and are not nitrided during melting in the cupola reduce - albeit moderately - the final content and diminish the risk of vermicular porosity.

In short, increasing the percentage of pig iron in charges by replacing the ingots simulating scrap and returns, at constant chemical composition, softens the iron and improves its machinability while at the same time decreasing the liability to shrinkage in the case of cupola melting. The corresponding decrease in tensile strength remains quite small. It can therefore be seen that, on the whole, in the cupola as in the electric furnace, the effects of pig iron and scrap are of comparable amplitude and opposite sense.

3.3.3. The tests made in Italy do not show that replacing 50% steel by 50% pig iron results in a greater change in the tensile strength of the cast iron, whether in the cupola or in the electric furnace: melts with 50% steel: Ceq, 3.85%; TS, 26.9 daN/mm^2; melts without steel : Ceq, 3.79%; TS, 26.3.

Otherwise, differences in hardness and machinability were found, but varied with the type of pig iron and type of melting: the elimination of steel had a significantly positive effect on machinability only in the cupola and only for one grade of pig iron.

Cupola - Melt with 50% steel: HB, 214; V_{60}, 34.4 m/min;
- Melt without steel (BC4 pig iron): HB, 198; V_{60}, 39.0 m/min.

The relative difference in machinability, 13.4%, is here quite large with respect to the difference in tensile strength (close to 1.5 daN/mm^2) or in carbon equivalent (0.13 points).

3.4. Effect of nature of pig iron

By "nature" of the pig iron, we refer to all of its properties, resulting not only from its class or commercial grade but also from the particular manner in which it was produced (origin).

3.4.1. The French tests covered four different blast-furnace pig irons:

- No. 1, French 2652 hematite pig iron, I* = 1.75;
- No. 2, Australian charcoal pig iron, = 0.84;
- No. 3, German special (ferritic) pig iron, = 1.35;
- No. 4, German special (perlitic) pig iron, = 3.35.

These pig irons have comparable carbon and silicon contents but the concentrations of manganese and impurities are quite different. They were characterized by the second melting test and impurities equivalent I previously defined by S. Parent and J.C. Margerie*.

The nature of the pig iron has an effect on the (corrected) tensile strength, and it can be seen that the classification by strength correlates with the impurity equivalents.

Cupola	TS (corrected)	Impurities
Iron No. 2	34.9 daN/mm^2	0.84
3	34.5	1.35
1	32.9	1.75
4	32.1	3.35

* For a definition of "impurity equivalent", see "Fonderie", No. 264, Feb. 1968, p. 61 (S. Parent and J.C. Margerie).

In the electric furnace, pig irons Nos. 1 and 4 also give lower strengths than irons Nos. 2 and 3.

But here, contrary to the cases examined earlier, the weakest irons are also the hardest, revealing some decline in engineering quality (according to W. Patterson and A. Collaud).

Moreover, the effect on machinability at constant hardness is even clearer, and there was a difference of 2.2 m/min. between the critical speeds V_{60} of pig irons No. 2 and No. 4, or 5.1% to the disadvantage of the latter (cupola); the differences are smaller in the electric furnace, but iron No. 4 remained relatively poorly placed in this respect.

Clear differences in liability to shrinkage appeared. Pig iron No. 2 (with charcoal) seems significantly to favour the production of sound castings and would therefore, offer, on the basis of the technical criteria chosen, the most advantages; pig iron No. 3, on the other hand, would give more shrinkage, with the remaining two origins falling between these extremes.

It should be added that the inclusion of pig iron does not result in substantial changes in structure after remelting (the cupola irons, in particular, were all completely perlitic), nor should it be thought that the differences between pig irons of different origins resulted merely from their contents of impurities. Earlier research has clearly shown that the concept of heredity is still necessary and cannot at this time be dismissed by simple considerations* (in particular, index I does not include lead, which seems in large measure responsible for the drawbacks of iron No. 4).

3.4.2. The Italian tests used an Italian blast-furnace hematite (the same percentage in all charges) and three low-carbon pig irons (2.6 to 2.7%) replacing 50% steel.

---

* See § 1.2.1. and reference cited.

BC4: Italian blast-furnace pig iron refined by dilution with steel in the electric furnace;

B2: British pig iron made in a reverberatory furnace from steel, refined in shaker ladle and arc furnace (Cu, 0.4; Cr, 0.15);

B3: Same origin as B2 but with additional chromium (Cu, 0.4; Cr, 0.6).

A first comparison of pig irons BC4 and B2 shows that the former is quite pure, whereas the latter contains much nickel, copper, and tin in addition to chromium (but no lead). The tensile strengths of the resulting cast irons were nevertheless close, but there was a significant difference in hardness and thus in machinability. This difference was further accentuated by the effect of the chromium (pig iron B3), but was accompanied in this case by a substantial increase in strength.

Finally, there were substantial differences in machinability (V_{60}) with respect to pig iron BC4:

Cupola - Pig iron B2:	- 7.8%	Electric furnace - Pig iron B2:	- 30%
- Pig iron B3:	- 23.8%	- Pig iron B3:	- 31%

In the electric furnace, pig irons B2 and B3 had rather similar effects, while pig iron BC4 was, on the other hand, much closer to steel.

The Italian and French tests both show that it is sometimes necessary to choose among pig irons on the basis of origin to obtain the desired properties.

3.5. Direct comparison of cupola and electric-furnace iron

The preliminary tests (see § 2.2.1.1.) have shown, on the basis of foundry samplings without any change in normal procedures, that the relationships among the chemical composition, hardness, and machinability of the irons produced depended on the type of melting: at tensile strengths below 24 daN/mm^2, iron produced in the electric furnace was found to have better machinability, but this would seem to result primarily from the fact that its phosphorous content was substantially lower (remelt iron is more frequently charged in the cupola than in the electric furnace).

We then saw, in sections 3.3 and 3.4, that systematic changes in charges compatible with the production of iron having a constant chemical composition did not always have the same effects in the cupola as in the electric furnace. What, now, are the results of direct, overall comparison of the iron produced by these two melting systems?

3.5.1. Table II (French tests) shows that electric-furnace irons are on average substantially less strong, less hard, and more machinable than cupola iron; this is found with all charges almost without exception, but the difference is small if there is less than 20% steel in the charges. It is important to note that this results from the appearance of some ferrite in electric-furnace irons (which have smaller nitrogen and sulphur contents - see fig. 4). This ferrite is detrimental to wear resistance. To avoid it, one may aim for a lower carbon and silicon content in the electric furnace than in the cupola (contrary to certain preconceived ideas), which generally entails casting properties that are not as good; another solution may be to reinforce the inoculation and the manganese content or to add alloy elements, which is expensive; the use of impure steel charges may introduce undesirable trace elements (lead).

This effect on the mechanical properties is confirmed in part by the results of the Italian tests.

Cupola melting in fact gave greater hardness and lower machinability than electric-furnace melting, except in the case of B2 pig iron, where the opposite occurred; this exception seems to be related to an anomaly of the electric melting that resulted in this case in a somewhat lower carbon equivalent and a relatively high tin content (0.08%).

As in France, the presence of ferrite in electric-furnace irons was confirmed, except in those that contained large amounts of impurities (B2 and B3).

While the Italian tests did not give differences as general, this probably results from the fact that hydrogen content remained moderate in the cupola, even with charges containing 50% steel, by contrast to what was found in French foundries. Scrap quality and the working of the cupola would seem therefore to play a role in this connection.

3.5.2. With the test bars chosen (plates with bosses, without risers), cupola and electric-furnace irons can be distinguished by the shape and extent of shrinkage defects. Electric-furnace iron has open shrinkage concentrated at the sensitive point of the test bars, whereas cupola iron has less-extensive, dispersed porosity, especially if the percentage of steel is small and the pig iron used is pure, as indicated above (3.3.1., 3.3.2., and 3.4.1.).

In short, it can be seen clearly that the differences between cupola and electric-furnace irons produced from the same charges do not always match the differences found in normal industrial practice, in which quite varied materials are used, mainly for economic reasons. Furthermore, it is not sufficient to consider only the commercial classification of the metallic raw materials to define the charge; account must be taken of empirical concepts of quality or origin, not only in the case of scrap materials but even in that of pig irons, because of so-called "heredity" effects.

4. RESULTS OF THE TECHNICO-ECONOMIC STUDY

We shall extract the information related most directly to the constitution of charges from the final report of the technico-economic study dealing with iron production in the cupola and in the electric furnace. Having noted the possible advantages of pig irons to improve casting quality, we must now examine the exact economic consequences on the basis of precise surveys conducted in accordance with a uniform method.

4.1. A few overall characteristics of the foundries surveyed

We have seen above (§ 2.2.3.) the breakdown by type of the melting installations studied. We shall now give some statistical data for each of the types in question.

- Cold-blast cupolas (18 installations):

Mean total daily charges	3 to 160 tpd
Use factor [x]	0.4 to 1

- Hot-blast cupolas (5 installations):

Mean total daily charges	85 to 510 tpd
Use factor	0.6 to 0.7

- Induction melting with solid charges (11 installations):

Mean total daily charges	2.7 to 75 tpd
Furnace capacity	0.25 to 25 tonnes

- Arc-furnace melting (2 installations):

Mean total daily charges	43 and 110 tonnes
Furnace capacity	5 and 20 tonnes

We also noted the characteristics of seven electric-furnace installations, in duplex operation and four installations in holding operation. Altogether, all types of electric furnace are represented.

The majority of iron produced in the cupola (alone or in duplex) is non-alloy grey cast iron; this situation is reversed in the case of electric-furnace melting, used primarily but not exclusively to produce ductile iron or a variety of alloy cast irons. The total annual charges corresponding to the survey are estimated at 650,000 tonnes; in other words, the sample observed represents about 20% of French production of grey iron and ductile iron castings.

---

[x] Ratio of true mean output per hour of blowing to peak instantaneous output

4.2. Analysis and cost of charges

We shall first examine weighted mean charges by type of installation for all production. Table III shows that cold-blast cupolas are the main consumers of pig iron; electric furnaces consume primarily scrap, as do hot-blast cupolas.

Naturally, these mean figures cover a wide variety of situations. Thus, the extreme proportions of pig iron (refined, foundry, low-carbon, and others) in charges are as follows:

- Cold-blast cupolas	5 to 50%
- Hot-blast cupolas	0 to 24%
- Induction furnaces	0 to 50%
- Arc furnaces	0 and 2%

The differences result in part from the grade of iron to be produced, but also from factors external to the melting installation itself, such as the proportion of returns.

This has led us to narrow down the comparison by examining the proportions of purchased metallic material (returns excluded) for the production of non-alloy grey iron only. These are given are table IV, which clearly shows to what extent the retention of the conventional cold-blast cupola promotes the consumption of pig iron in the sample studied. Pig iron is most often used in the electric furnace only to produce alloy cast irons. Finally, pig-iron consumption is broken down as shown in figure 5, on which the hatch-marked areas are proportional to the quantities.

It is important to note at the same time the mean cost of the main materials charged during the reference period (first half of 1975), taking the value of foundry hematite iron as base:

- ordinary foundry hematite	100
- scrap	51
- remelt iron	71

This gives the relative costs of charges for the production of ordinary iron presented in table V. It can be seen that, in view of the necessary additions and inoculations, the mean saving in charge cost of induction furnaces with respect to cold-blast cupolas is in fact only about 25% (substantial fluctuations paralleling the price of scrap can be anticipated). It should however be noted that the unit prices of pig iron and scrap in 1977 are in the same ratio as during the reference period (first half of 1975).

Of course, the saving in charge cost is more or less offset by increases in other expenses, as is shown in detail in report No. 3. For example, in induction furnaces melting solid charges, the weighted mean energy cost is 20% higher than in cold-blast cupolas, with the necessary carburization graphite accounting, moreover, for 25% of the electrical power required for melting.

4.3. Incidence of percentage of steel on properties and operating costs

In the case of cold-blast cupolas, the gross percentages of coke noted ranged from 11 to 24%. If the effect of operating irregularities is eliminated, we obtain, for a constant use factor (0.7), a somewhat narrower range (12 to 22%) that is linked to the percentage of steel (0 to 38). On average, 10% additional steel corresponds to 1.3% additional coke.

Likewise, the consumption of refractories (20 to 60 kg per tonne charged) depends significantly on the percentage of steel in the charges: 10% additional steel corresponds to an additional 5.5 kg/t.

4.4. Total production costs of ordinary cast irons

Finally, we examined, in the sample in question, the distribution of production costs among the various melting installations. To make the comparison more rigorous, we considere only "ordinary" grey cast irons and allow for production (or rather for total daily charges).

The results, in francs per tonne charged, are given in schematic form by the diagram of figure 6.

It should be borne in mind that these costs include:

- the charges (including additions and inoculants)
- the direct cost of melting (wages and wage-related expenses; power; refractories; flux, etc.)
- other melting expenses (salaries; other expendable materials; motive power; equipment maintenance; technical depreciation).

The reader will refer to final report No. 3 for further information on how these expenses, some of which are standardized for the whole sample, are defined and calculated.

These results show that the production of molten iron in the induction furnace, in spite of the saving resulting from massive use of scrap in the charges, costs no less than production in a cold-blast cupola having the same output, allowance being made for dispersion. Hot-blast cupolas are shown to clear advantage, but the results apply only to outputs of more than 70 tpd, and it would be quite dangerous to extrapolate this finding to commoner outputs of 30 to 50 tpd.

Of course, in these expenses, the share represented by the charge varies; it accounts for 80% of the total cost in the case of cupolas and 70% of the total cost in that of electric furnaces.

5. OVERALL CONCLUSION

5.1. We have seen, thanks to the results of the technical study conducted jointly by the Centre Technique des Industries de la Fonderie and by the Centro Sperimentale Metallurgico, that, in the production of cast iron of a given mechanical quality, the composition of the metal charged was not without importance, whether melting be effected in the cold-blast cupola or in the induction furnace.

The addition of increasing percentages of steel scrap replacing iron scrap has certain drawbacks, while increasing the percentage of pig iron has significant technical advantages, especially in the cupola:

- softening of the resulting iron and corresponding improvement of its machinability;
- reduction in liability to shrinkage;
- limitation of nitrogen content and reduction of risk of vermicular porosity.

To be sure, these advantages are of modest scope (as shown by the figures given in the various reports) and are not without corresponding drawbacks, since softening, for example, is linked to a decrease in tensile strength. Furthermore, the extent of the effects depends on melting conditions, variable from one experiment to another: for example, the variations in nitrogen content found in France were not found in Italy. Nevertheless, it may be concluded that on the whole the Community-sponsored tests largely supported the arguments of foundry operators faithful to the use of high percentages of pig iron in the charges of cupolas.

5.2. The "quality" of the pig iron charged, that is, a certain metallurgical behaviour related to its origin, has a quite significant influence on certain properties of the cast irons.

The comparison of several batches of different origins but belonging approximately to the same commercial classes by chemical composition revealed substantial differences in strength, hardness, machinability, and even liability to shrinkage. Impurities, generally not tested, are partially responsible for sometimes undesirable effects. Here again, it was possible to determine the order of magnitude of the advantages enjoyed by the foundries still occasionally using pig iron produced with charcoal, the drawbacks of undesirable impurities such as lead, and the role of added elements such as chromium.

Although these effects are also of limited scope, it should be borne in mind that procurement choices should be made on the basis of technical and not merely economic criteria, even in the case of noble materials such as foundry hematites. These precautions are even more evident and better understood in the case of steel, scrap, and remelt iron.

5.3. The economic survey clearly confirmed that cold-blast cupolas naturally consume more pig iron than electric furnaces. To expand foundry consumption of pig iron, or at least stem the decline, any technical and economic advantages of melting in the traditional cupola should first be demonstrated, even if they are not decisive.

The tendency of electric-furnace irons to contain ferrite in their structures may lead to the use of materials that are less pure or slightly lower carbon equivalents: we have seen that this would entail some risks as regards casting properties and mechanical characteristics or some additional expenses for metallurgical correction.

It would be appropriate also to promote improvements of the cupola other than those aimed at increasing the replacement of pig iron by scrap (hot blast, oxygen, etc.). For example, work done towards the automation of slag removal and of the tapping of molten iron should be pursued with interest*. The entire German-Luxemburger portion of the Community-sponsored research will tend, moreover, in the same sense.

5.4. Finally, the survey conducted in France shows that the installation of electric furnaces is not a priori economically advantageous for the production of grey cast iron. The decrease in the cost of the metal charge is offset - if all cases are considered - by an increase in other costs. In particular, it will be noted that the cost of electric power for melting, even in the case of correctly operated furnaces, substantially exceeds the cost of coke in cupolas, which itself increases substantially with the percentage of steel in the charges.

It would be vain to deny that in certain cases the use of inexpensive metallic materials and the installation of electric melting or holding furnaces may be fully justified both economically and technically, but it nevertheless remains true that on the basis of the results of this research as a whole, there is as a general rule no drawback to installing

---

* L. Chaze and R. Sanz, "Cubilot à fonctionnement automatique", 44th International Foundry Congress, Florence, September 1977, No. 26

modern cold-blast cupolas and using large proportions of carefully-selected pig iron, even in the electric furnace.

Figure 1 - ORGANIZATION CHART OF COMMUNITY-SPONSORED RESEARCH ON FOUNDRY PIG IRON

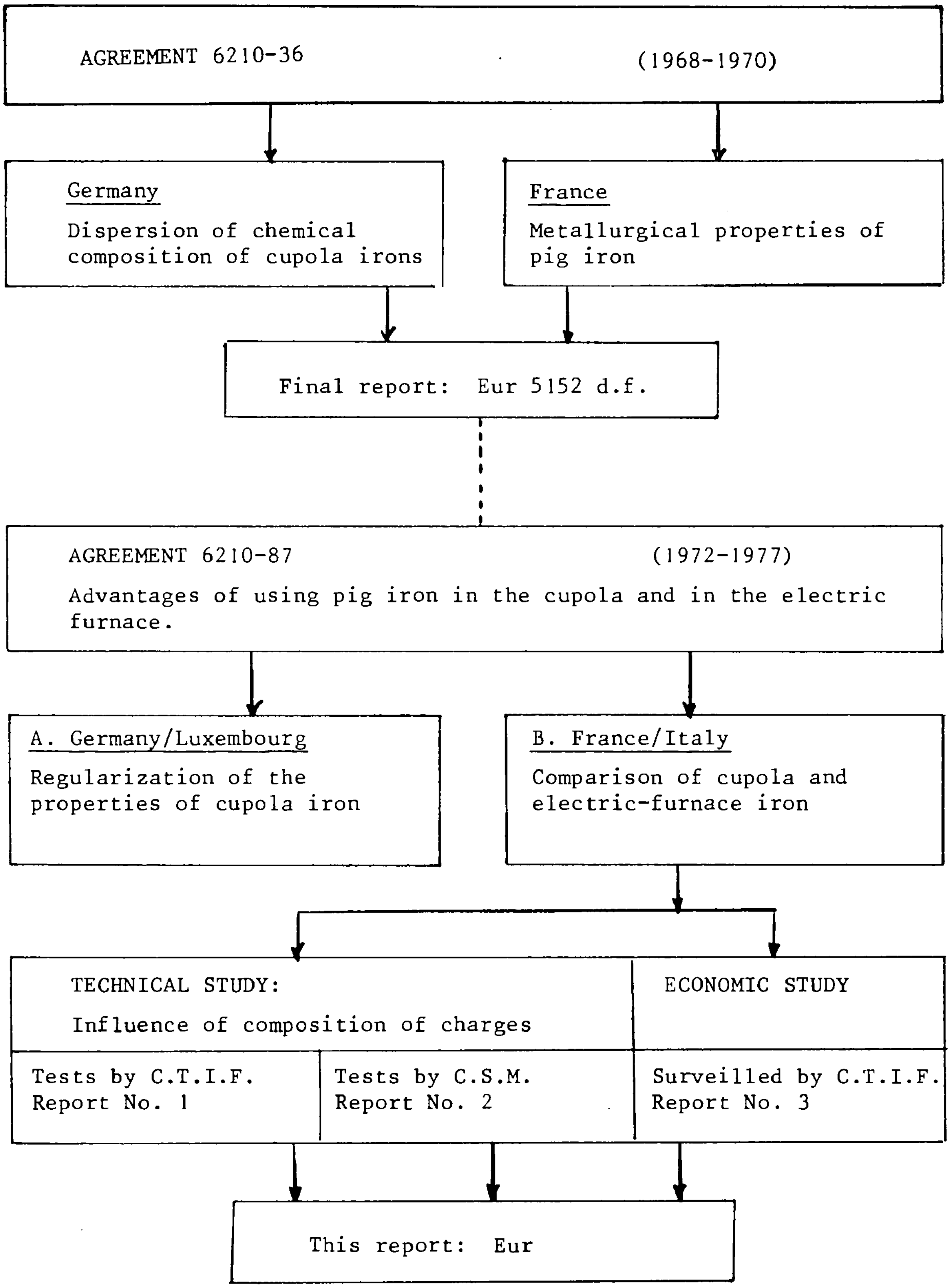

Figure 2 - EXPERIMENTAL PLAN IN FORM OF LATIN SQUARE (French tests)

Percentage of pig iron \ Percentage of steel	10	20	30	40
20	FN 3	FN 4	FN 2	FN 1
30	FN 2	FN 1	FN 3	FN 4
40	FN 1	FN 2	FN 4	FN 3
50	FN 4	FN 3	FN 1	FN 2

FN 1, 2, 3, and 4: indicates the origin of the pig iron used in each combination of percentages of steel and pig iron.

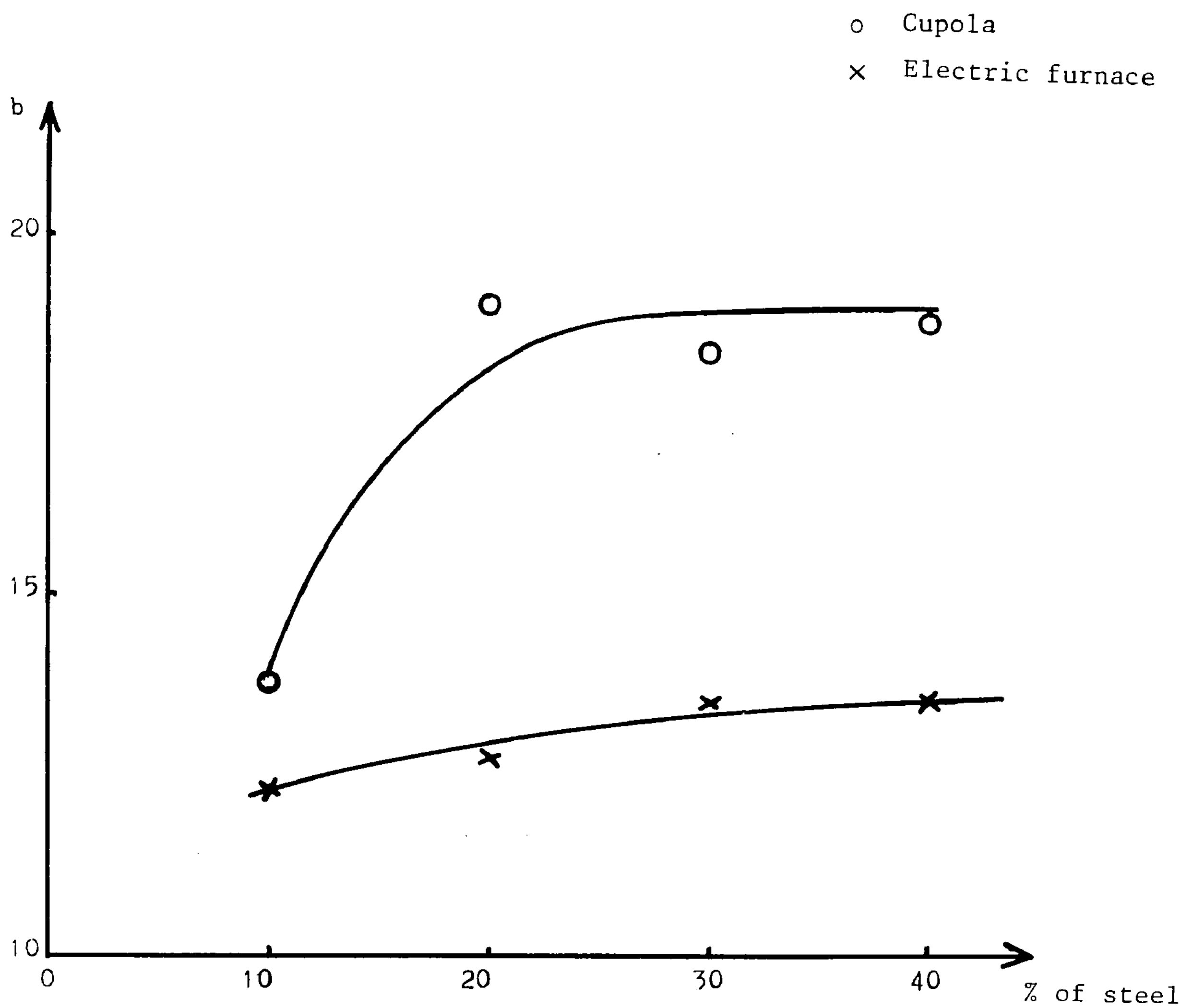

Figure 3 - INFLUENCE OF PERCENTAGE OF STEEL IN CHARGES ON SECTION SENSITIVITY

$$TS\ (daN/mm^2) = a - b \log \emptyset\ (mm)$$

b: section sensitivity coefficient

Ø: diameter of unfinished test bar

Figure 4 - MICROSTRUCTURE OF ELECTRIC-FURNACE IRON (presence of ferrite)

No. 71 708

4% Nital 250 x

No. 71 709

4% Nital 250 x

Burdens

50% No. 3 pig iron
20% steel

50% No. 1 pig iron
30% steel

Figure 5 - BREAKDOWN OF PIG IRON CHARGED BY APPARATUS AND CATEGORY

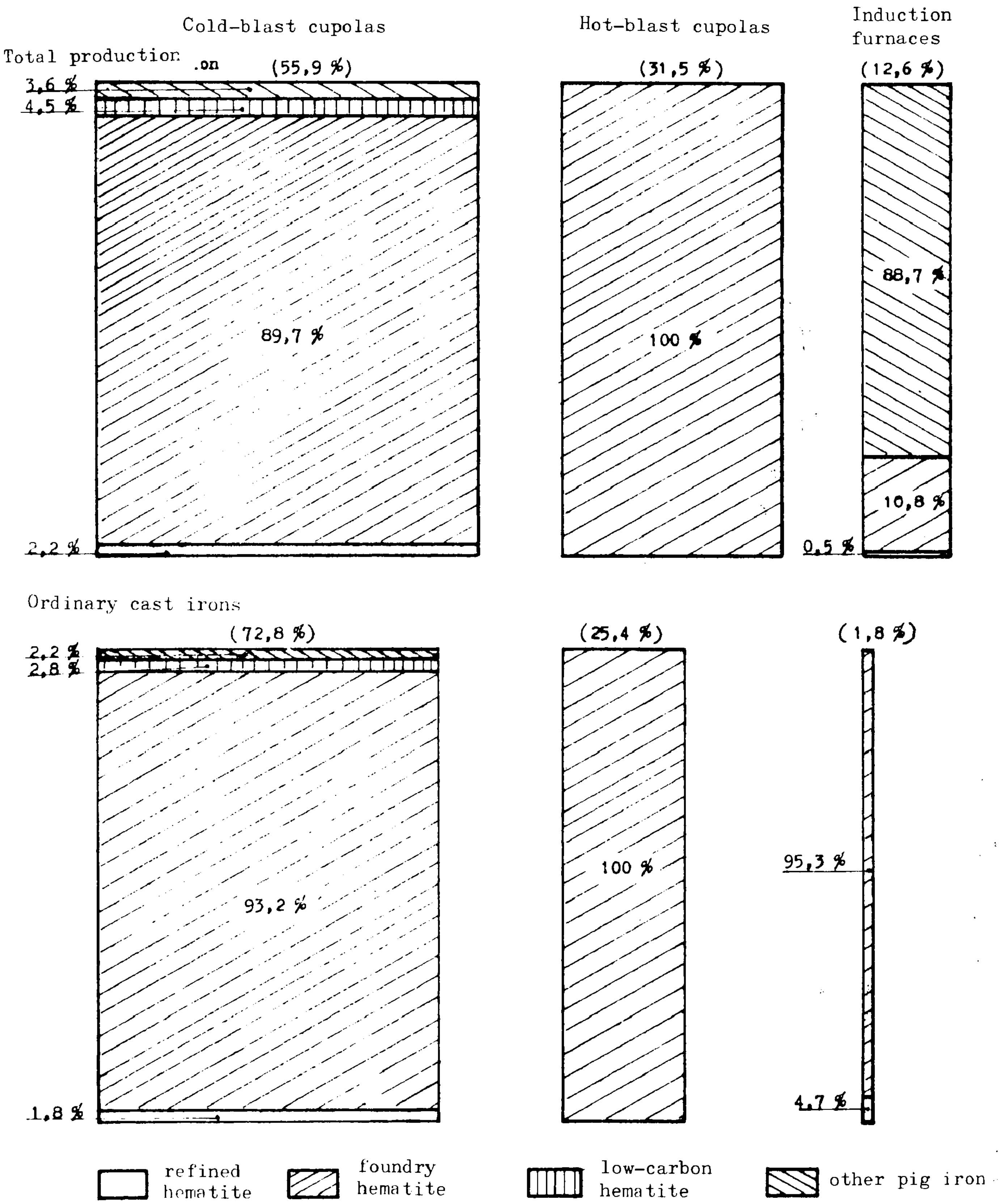

Figure 6 - COST OF PRODUCTION OF ORDINARY CAST IRON AS FUNCTION OF MEAN TOTAL DAILY CHARGES

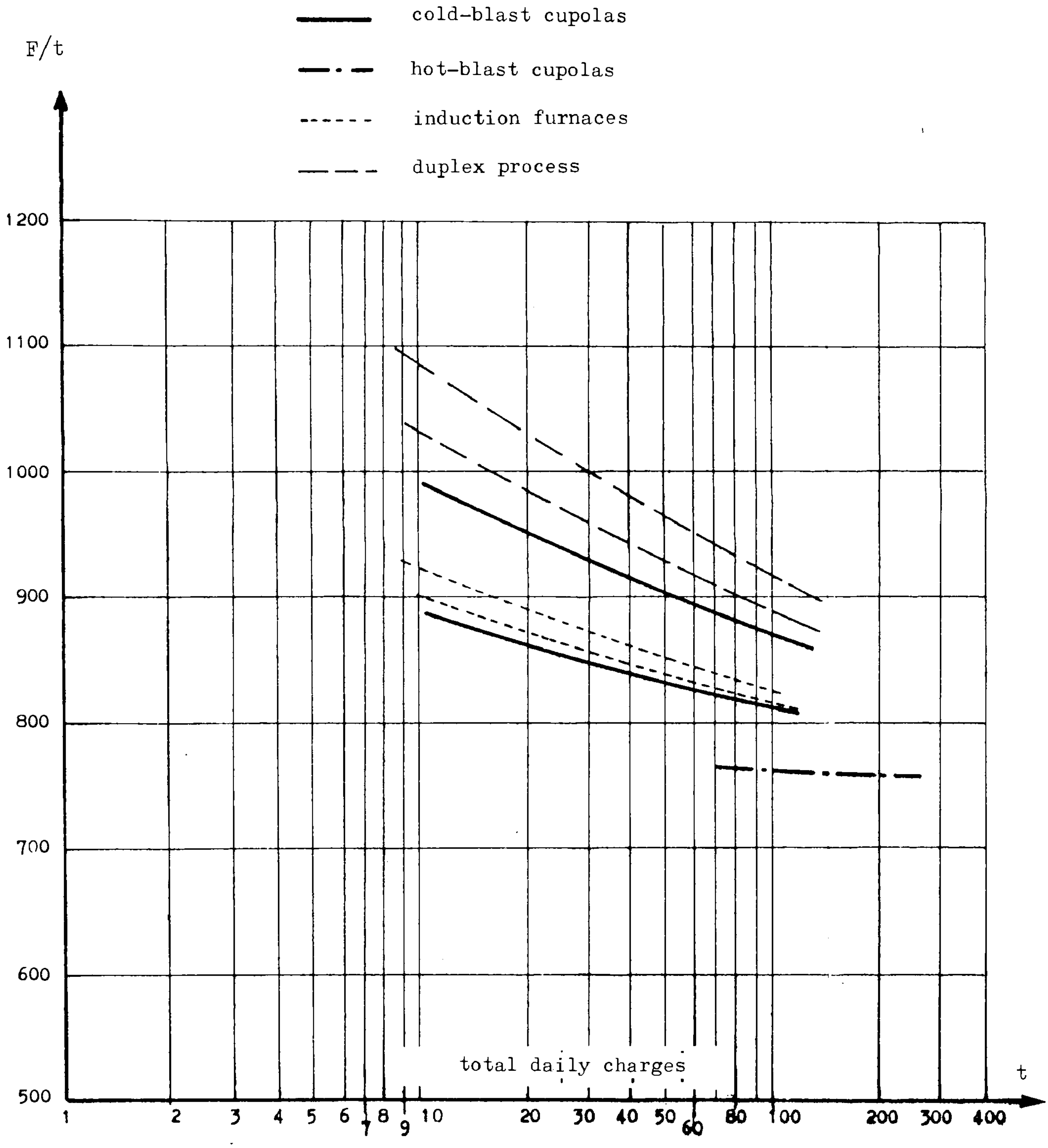

TABLE I

COMPARATIVE MEAN CHEMICAL COMPOSITIONS OF THE IRONS

	C.T.I.F. tests (France)		C.S.M. tests (Italy)	
	Cupola	Electric furnace	Cupola	Electric furnace
C%	3.16	3.22	3.16	3.03
Si	1.85	1.92	2.02	2.13
Mn	0.76	0.78	0.71	0.85
S	0.099	0.054	0.079	0.036
P	0.06	0.06	0.10	0.05
Nitrogen	0.014	0.0060	0.0081	0.0079
Ceq*	3.80	3.87	3.87	3.76

* Carbon equivalent: $C + \frac{1}{3}(Si + P)$

TABLE II

OVERALL COMPARISON OF CUPOLA AND ELECTRIC-FURNACE IRON (French tests)

	Cupola	Electric furnace
Carbon equivalent %	3.80	3.87
Nitrogen content (ppm)	104	61
TS (daN/mm^2)	34.8	29.7
Corrected TS (daN/mm^2)	33.6	29.3
Brinell hardness (runners 30 mm in dia.)	225	215
" " (Brandsma discs)	220	204
" " (V_{60} sleeves)	211	190
Brandsma machinability (m/min.)	58.6	62.1
V_{60} machinability (m/min.)	37.3	43.2

TABLE III

WEIGHTED MEAN CHARGES BY TYPE OF APPARATUS

All production

Type of apparatus	Pig iron %	Remelt iron %	Steel %	Returns %
Total charge				
Cold-blast cupolas	30	17	20	33
Hot-blast cupolas	9	24	37	30
Induction furnaces	8	2	46	44
Arc furnaces	0.5	5.5*	39	55

* Iron chips

TABLE IV

WEIGHTED MEAN CHARGES BY TYPE OF APPARATUS (returns excluded)

Ordinary cast iron

Type of apparatus	Pig iron %	Remelt iron %	Steel %
Cold-blast cupolas	47	25	28
Hot-blast cupolas	14	6	80
Induction furnaces	4	8	88
Arc furnaces	0	15*	85

* Iron chips

TABLE V

RELATIVE VALUES OF COST OF CHARGES FOR PRODUCTION OF ORDINARY CAST IRON WITH RESPECT TO UNIT PRICE OF PIG IRON

Base 100

Unit price of foundry hematite

Cold-blast cupolas	75 to 90
Hot-blast cupolas	66 to 77
Induction furnaces	59 to 69
Duplex process: cold-blast cupola/induction furnace and arc furnace/induction furnace	66 to 77
Arc furnaces	62 to 69

Salgs- og abonnementskontorer · Vertriebsbüros · Sales Offices
Bureaux de vente · Uffici di vendita · Verkoopkantoren

Belgique - België

Moniteur belge — Belgisch Staatsblad

Rue de Louvain 40-42 —
Leuvensestraat 40-42
1000 Bruxelles — 1000 Brussel
Tél. 512 00 26
CCP 000-2005502-27
Postrekening 000-2005502-27

Sous-dépôts — Agentschappen:

Librairie européenne — Europese Boekhandel
Rue de la Loi 244 — Wetstraat 244
1040 Bruxelles — 1040 Brussel

CREDOC

Rue de la Montagne 34 - Bte 11 —
Bergstraat 34 · Bus 11
1000 Bruxelles 1000 Brussel

Danmark

J.H. Schultz Boghandel

Møntergade 19
1116 København K
Tlf. (01) 14 11 95
Girokonto 200 1195

Underagentur:

Europa Bøger
Gammel Torv 6
Postbox 137
1004 København K
Tlf. (01) 15 62 73

BR Deutschland

Verlag Bundesanzeiger

Breite Straße — Postfach 10 80 06
5000 Köln 1
Tel. (0221) 21 03 48
(Fernschreiber: Anzeiger Bonn 8 882 595)
Postscheckkonto 834 00 Köln

France

Service de vente en France des publications des Communautés européennes

Journal officiel

26, rue Desaix
75732 Paris Cedex 15
Tél. (1) 578 61 39 — CCP Paris 23-96

Service de documentation

D.E.P.P.
Maison de l'Europe
37, rue des Francs-Bourgeois
75004 Paris
Tél. 887 96 50

Ireland

Government Publications

Sales Office
G.P.O. Arcade
Dublin 1

or by post from

Stationery Office

Dublin 4
Tel. 78 96 44

Italia

Libreria dello Stato

Piazza G. Verdi 10
00198 Roma — Tel. (6) 8508
Telex 62008
CCP 387001

Agenzia

Via XX Settembre
(Palazzo Ministero del tesoro)
00187 Roma

Grand-Duché de Luxembourg

Office des publications officielles des Communautés européennes

5, rue du Commerce
Boîte postale 1003 — Luxembourg
Tél. 49 00 81 — CCP 19190-81
Compte courant bancaire:
BIL 8-109/6003/300

Nederland

Staatsdrukkerij- en uitgeverijbedrijf

Christoffel Plantijnstraat, 's-Gravenhage
Postbus 20014
2500EA s'-Gravenhage
Tel. (070) 78 99 11
Postgiro 42 53 00

United Kingdom

H.M. Stationery Office

P.O. Box 569
London SE1 9NH
Tel. (01) 928 69 77, ext. 365
National Giro Account 582-1002

United States of America

European Community Information Service

2100 M Street, N.W.
Suite 707
Washington, D.C. 20 037
Tel. (202) 862 95 00

Schweiz - Suisse - Svizzera

Librairie Payot

6, rue Grenus
1211 Genève
Tél. 31 89 50
CCP 12-236 Genève

Sverige

Librairie C.E. Fritze

2, Fredsgatan
Stockholm 16
Postgiro 193, Bankgiro 73/4015

España

Libreria Mundi-Prensa

Castelló 37
Madrid 1
Tel. 275 46 55

Andre lande · Andere Länder · Other countries · Autres pays · Altri paesi · Andere landen

Kontoret for De europæiske Fællesskabers officielle Publikationer · Amt für amtliche Veröffentlichungen der Europäischen Gemeinschaften · Office for Official Publications of the European Communities · Office des publications officielles des Communautés européennes · Ufficio delle pubblicazioni ufficiali delle Comunità europee · Bureau voor officiële publikaties der Europese Gemeenschappen

Luxembourg 5, rue du Commerce Boîte postale 1003 Tél. 49 00 81 · CCP 19 190-81 Compte courant bancaire BIL 8-109/6003/300

OFFICE FOR OFFICIAL PUBLICATIONS
OF THE EUROPEAN COMMUNITIES

Boîte postale 1003 — Luxembourg

CDNA06439ENC