On the Bottom Blown Processes and the LD-AC Process

P. Coheur

IN FEBRUARY 1957, we had an opportunity to speak, in this country, in New Delhi, about the results of the research carried out by our Centre National de Recherches Metallurgiques in the field of steelmaking; to be more precise, in the field of blowing iron in a basic bottom-blown converter either with oxygen-enriched air or with an oxygen and steam mixture.

On that occasion, we also emphasised the results dealing with the industrial development of the new blowing processes that we formerly recommended.

From that time the industrial application of these methods still expanded and at the present time 10 steelworks have recourse to it. Let us point out the fact that two out of these works are located in Great-Britain and that a third steelworks will start running there within a few months.

BOTTOM BLOWN PROCESSES

In the first part of this report, we should like to summarize the main results obtained by the steel industry in the field of the botton blown processes.

For further details, we suggest the reader to refer to two quite recent publications which were the object of communications at the "Journees Internationales de Siderurgie" which were held in Liege in June 1958.

The first one is due to J. Daubersy and A. Decker and its title is: "Conversion de la Fonte par le Fond de la Cornue"; the second one was written by H. Kosmider, A Weyel and H. Neuhaus and entitled: "Uber das Frischen von Phosphorarmen Roheisen im Bodenblasenden Konverter".

The techniques

Let us first recall that the irons such as the steelmakers of Western Europe have to work are basic Bessemer iron containing on an average: Carbon 3·6–3·9%; Manganese 0·4–1·2%; Silicium 0·3–0·6%; Phosphorus 1·5–2·1%; Sulphur 0·04–0·08%.

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Nitrogen in steel

In order to blow that type of iron, the steelmakers generally utilise either atmospheric air, or oxygen-enriched air, or oxygen-steam mixture, or even oxygen and CO_2 mixtures. The choice of one or another method depends on the final nitrogen content they want to obtain in steels.

(*a*) *Atmospheric air*: This is the classical or orthodox technique which in most cases provides steels containing 0·007 to 0·0120% nitrogen. This amount is on the high side but we must hasten to add that this must not be regarded as an intrinsic defect of the process, but simply as a limitation of its field of application.

There is no doubt whatever that the use of steel produced by the conventional basic Bessemer process is excellent for e.g. structural steels, reinforcing rods for concrete, screw stock, magnetite sheet (transformer sheet), wires for special purposes. It even has properties which are specially valuable for certain applications, such as rails, plates, sleepers, springmaking wires.

It is thus quite certain that for numerous applications, there is no major advantage in modifying the steel obtained in the converter by the conventional method but, it is no less certain that for some applications requiring a high degree of ductility at room temperature, such as cold rolling, drawing, etc. the usual rimmed basic Bessemer steel is handicapped by its nitrogen content.

This is the very reason why new manufacturing processes have been developed over the last half century.

(*b*) *Enriched air*: The usual practice has recourse to mixtures containing about 30%, 35% and even 40% oxygen. This oxygen enrichment of the blast has a first advantage, an important increase in scrap consumption. Furthermore from the point of view of the nitrogen content, one can reach 0·0050 to 0·0060% if the temperature level is sufficiently low and this is realised by cooling the metal bath with additions of ore, limestone, or steam. This cooling and its control is fundamental if one wants to obtain regular results.

(*c*) *Oxygen-steam mixture*: This mixture must be used in the overheated phase in order to avoid the quick destruction of dolomite bottoms by water condensation. The range of the oxygen and steam proportion in the mixture is very narrow for if a sufficient amount of oxygen is necessary to obtain the temperature level, the excess of oxygen leads to the bottom destruction. In practice, the mixtures contain 37 to 40% steam in weight.

Several techniques are used :

Integral blowing with oxygen-steam mixtures. This of course is the method which gives the lowest nitrogen contents : $N_2 \leqslant 0{\cdot}0020\%$ using an oxygen supply of 95% purity only. This method only enables small scrap additions similar if not somewhat larger to the additions in the atmospheric air blowing. It is thus particularly interesting when steels with a very low nitrogen content are aimed, i.e. the most suitable grades for deep drawing steels.

Blowing in two phases, namely :

(1) Oxygen-enriched air during the first half of conversion.

(2) Oxygen-steam mixture during the second one.

This technique gives steels with a rather higher percentage of nitrogen: 0·0020 to 0·0030%. On the other hand, it is of an easier application as regards the bottom life and it allows a more important scrap consumption whilst using a smaller quantity of oxygen.

Phosphorus in steel

The use of oxygen in the blast has no direct influence on the phosphorus content of the steel. Hence, in order to reach the low phosphorus contents, one has to eliminate the first slag by tilting the converter and shape a new basic slag. This is thus a double slag process. Phosphorus is by this means in the range of 0·015 to 0·025%[1].

This operation requires of course a higher elaboration temperature to build the second slag and it consequently involves, when blowing with air, a certain nitruration in steel. But this nitruration does not occur in the case of blowing with an oxygen-steam mixture, because this mixture which does not contain nitrogen cannot give rise to nitruration whatever the temperature. Let us mention the fact that by keeping the temperature of the metal bath as low as possible, it is possible to obtain a very low phosphorus (0·006 to a maximum of 0·012%). This was realised by the oxygen-steam, double slag process, and characterised by a temperature of 1,620°—1,630° at the end of the blow.

Sulphur in steel

(*a*) Before entering the converter, the sulphur of the iron is generally reduced by a soda-ash treatment. For this treatment, let us point out especially the technique developed by ARBED[1] and used in two steel works. In this process (Fig. 1), one uses two teapot ladles. The slag of the mixer is eliminated at one side of the first teapot ladle, the soda carbonate addition takes place in the channel between the first and second teapot ladle. This procedure allows a saving of 50% soda or for the same soda consumption,

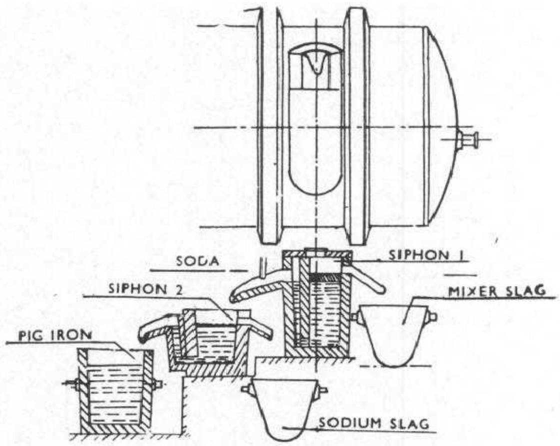

FIG. 1.

a better desulphurisation. For a 45-50% desulphurisation (from irons containing 0·020% S), 2·5 kg soda carbonate are sufficient per ton of iron.[2, 3]

(*b*) In the converter, the desulphurisation degree is around 30–40%. This desulphurisation is made considerably easier by using lime burnt in modern ovens which avoid the sulphur fixation of the fuel. With these limes, it is easy to obtain steels the sulphur content of which at the casting pit is practically lower than 0·020% and very often lower than 0·015% when starting with an iron containing 0·035%.

Exploitation summary

An exploitation summary covering the year 1957 and bearing on around 9,000,000 tons will be found in Table I.

All these results have been obtained in rather small converters (20–25t).

Let us notice that the dispersion of the chemical analyses of the heats is small. This is the consequence of a very thorough control of the operation which is realised by means of classical equipment of the modern technique (spectrochemical analysis, measurement of temperature, etc.).

Extension of the process to low-phosphorus irons

We previously said that the irons which the steelmakers of Western European countries are led to handle had the following average contents :

C: 3·6-3·9%; Mn: 0·4-1·2%; Si 0·3-0·6%; P: 1·5-2·1%; S: 0·04-0·08%,

and all the results we mentioned are relative to that type of iron.

It should not be concluded that the field of

1 P. Coheur—Revue Univ. des Mines, April 1952 p. 114.

2 M. Bosseler—Joint Metallurgical Societies in Europe, London 1956.

3 P. Coheur—2nd Metallurgical Congress of Latin America, Sao Paolo, 1955.

TABLE I

	Kg per ton of iron			O_2 Nm3/t	Steam Kg/t	total time in min.	Sec./t of iron
	Scraps	Lime	Soda-ash				
a) Atmospheric air	50 to 100	115 to 125	-	-	-	15 to 22	37 to 48
b) Enriched air	162	134	4.22	25.7	-	12.33	38.05
c) Oxygen-steam	39	153	8.47	55.64	48.3	11.43	32.70

	$N_2 . 10^{-4}\%$		$P.10^{-3}\%$		$S.10^{-3}\%$	
	Average	σ	Average	σ	Average	σ
a) Atmospheric air	90 to 120	25	45	12	35	7
b) 30%-enriched air						
1. Scraps..................	80	15	45	12	35	7.0
2. Scraps-ore-limestone...	60	12	35	7	25	5.0
3. Ore-limestone..........	50	10	25	6	20	5.0
c) Oxygen-steam						
Steelplant A................	24.0	3.0	20.8	4.5	18.3	4.0
Steelplant B................	20.0	5.5	24.0	5.0	21.0	3.5
Steelplant C................	20.0	4.0	27.0	-	22.0	-
Steelplant D................	28.3	2.4	17.2	4.4	20.7	3.8

application of the processes we are stressing here is strictly limited to that type of iron. In order to prove this point, we should like to mention two important series of experiments realised in the USA on one hand and in Germany on the other.

1. In the USA, Mr. Daubersy blowed in acid converters of 13·5 t of the Bessemer type. The iron analysis during those tests varied as follows: *

	Si	Mn	P	S	C	Temperature
Minimum	1·00	0·35	0·065	0·030	4·25	2,450°F
Maximum	1·40	0·45	0·070	0·035	4·35	2,550°F

Two techniques were successively utilised.

(*a*) *Operation in one oxygen-steam phase*: The time of blowing was 6-7 minutes. The percentage of steam was scheduled in order to involve a scrap consumption not exceeding 500 kg per blow. This was relying on 41% H_2O in weight in the mixture. The nitrogen content of the steels obtained by this procedure was comprised between 0·0008 and 0·0016%, which is a very low content.

(*b*) *Operation in two phases*: This second technique allowed a scrap consumption from 1,000 to 1,700 kg per blow.

Nitrogen in this case ranged between 0·0020% and 0·0030% and depends directly on the quantity of scraps charged into the converter.

(2) In Germany, the oxygen-steam processes extended themselves under the impulse of our friends Dr. Weyel and Dr. Kosmider and we are glad to mention that a close collaboration exists in this field between their company, Klockner-Huttenwerk Haspe AG, and our Centre.

At the Klockner-Huttenwerk Haspe steelplant, low-phosphorus irons of various analyses have been blown as well with O_2-enriched blast as with the oxygen-steam process.

They found out that for an iron temperature of 1,250°C and an oxygen-steam mixture of a 50 : 50 ratio, an iron containing for instance 0·15% P and 0·50% Si may be blown.

They also found out that for an oxygen-steam mixture of a 1 : 1·2 ratio, the time of blowing for a 22t heat varied from 6 to 8 minutes. The procedure of blowing was very quiet and the end of the heats could be observed easily. Heats of rimmed and killed steels were comparable to the best open-hearth steels, as well from the analytical as the mechanical point of view. The carbon contents varied from 0·035 to 0·10%. The phosphorous contents were ranging from 0·011 to 0·021%. And the nitrogen contents, from 0·002 to 0·005%.

The quantity of scraps that can be added depends in a direct way on the phosphorus and silicium contents in iron. To make a comparison, the conditions of refining by means of 32% exygen-enriched blast and those of the LD process are given in Fig. 3.

Mechanical properties

The new grades obtained by means of the oxygen-

* results unpublished

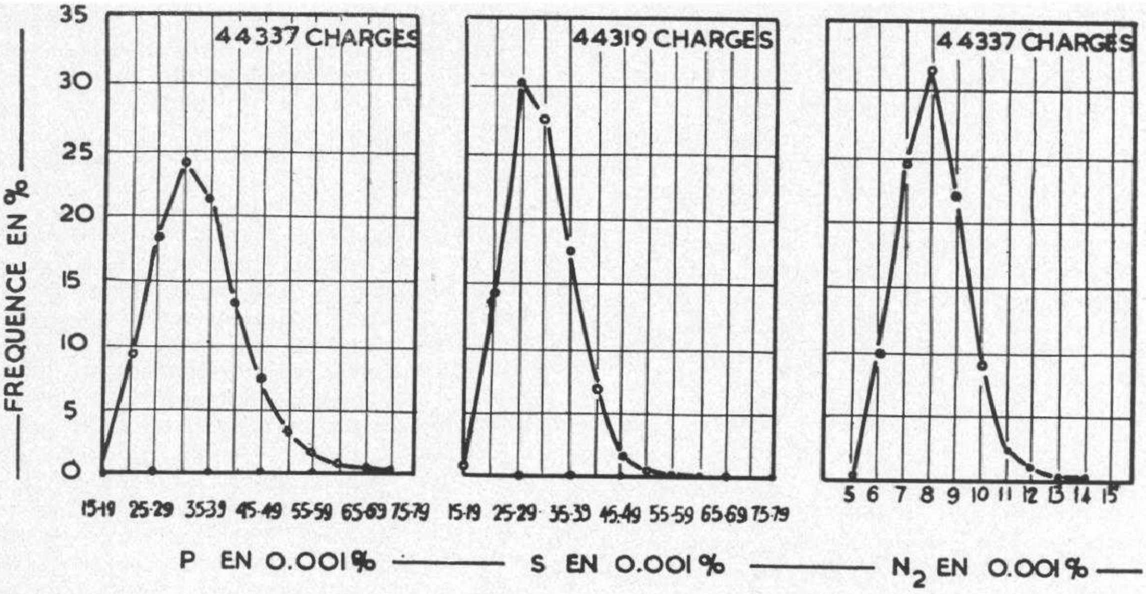

Fig. 2.

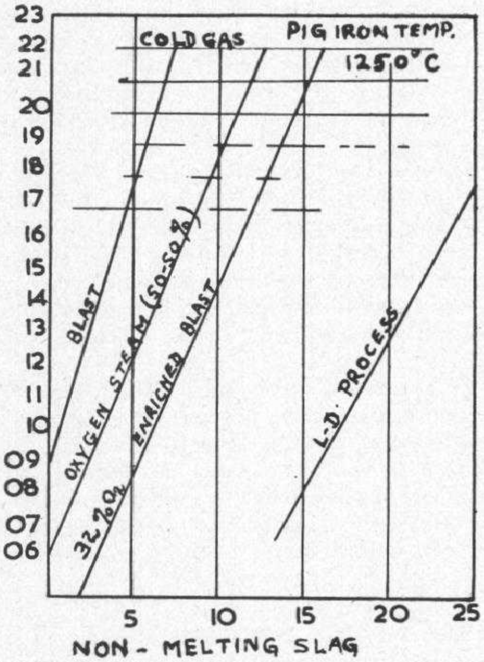

FIG. 3: QUANTITY OF SCRAP ADDED IN TERMS OF THE IRON COMPOSITION (% P.+1. 1 % Si.) AND FOR DIFFERENT PROCESSES

enriched air and particularly of oxygen-steam mixtures are particularly suitable for the application requiring a high ductility at room temperature.

As it is well known, the ductility of the flat products depends not only on the rolling and annealing conditions, but also on all the elements present in the steel such as for instance N_2, P, S, Cu, Sn, Cr and C.

The importance of the Strohmeyer index : $P+5N$ is well known[4,5,6,7].

The analyses show that the steels obtained by oxygen-steam blowing are in a particularly good position. For if their phosphorus content is somewhat higher than the best open-hearth steels, they are of a greater purity than the latter as regards all the other impurities, namely nitrogen, sulphur, carbon, or other elements introduced by the scrap.

The remarkably low nitrogen level obtained with the oxygen-steam process is particularly interesting if one considers that nitrogen is the most active element as regards the ageing properties at room temperature. The industrial experience confirmed this fact as well in the wire as in the sheet industry. Wherever we established systematic comparisons, the oxygen-steam steel have been favourably compared to open-hearth steels. Such comparisons were made in Belgium, in France, in Great-Britain and in the U.S.A. It is useful to notice that probably because of their low carbon content, the oxygen-steam steels often gave best results at the drawing shop than it could be expected from the laboratory tests. It was for instance what occurred at the Cleveland Works, General Motors, where trials were carried out on particularly difficult motor-car bodies.

4 M. Nepper and L. D'Or—Revue Universelle des Mines, 93 (1950), p. 331.
5 R. Langers, H. Herbiet and F. Montbrun—Revue Univ. des Mines, 95 (1952), 438.
6 A. Desoer, F. Vandestrick and J. Wurth—Blast Furnace and Steel Plant, 94 (1955) 45.
7 J. Wurth—L'Ossature metallique, 19 (1954), 205.

THE LD-AC PROCESS

In this second part of our report, we should like to say a few words about a new process of steel-making developed by ARBED in narrow collaboration with our CNRM and with the financial support of IRSIA.

We have in mind the injection of pure oxygen and pulverized lime over the surface of the metal bath and by means of a lance.

We think it useful to recall the circumstances of this new development and those which have led our specialists to propose it.

Historics

In order to increase the quantity of scraps in the bottom blown process, and to modify the metallurgical development of the operations, our experts first proposed to blow simultaneously through the top and through the bottom of the converter.

In fact, they proposed to inject pure oxygen over the surface of the metal bath by means of a lance, and from the top of the converter. At the same time, they proposed to blow through the bottom either air or oxygen-enriched air or still an oxygen-steam mixture.

The experiments carried out in this manner in 1955 at Esperance-Longdoz with a lance having a maximum flow of 20 cu.m/min at a pressure of 3 kg/sq.cm, have shown that the oxygen blown in through the converter top had a considerable thermal action, which made posisble to include in the charge from 10 to 12 kg of additional scrap per cu.m. of top-blown oxygen.

These experiments were not carried out, because the installations used were not sufficiently flexible, particularly as regards the oxygen flow and pressures ranges and the depth of penetration of the lance into the converter. In addition the lance was often charged with projections.

As to the modifications of the metallurgical development, we had in mind to build a liquid slag as soon as possible, in order to hasten the elimination of the phosphorus from the metal bath into the slag.

The interest of this had already been pointed out by Lellep[8] in 1941.

Unhappily our simultaneous blowings did not allow to reach this objective.

Mr. Metz[8a] proposed then to inject over the surface and with a lance, pure oxygen containing some powdered lime, he took as a basis of his proposal the high reaction temperature at the impact of the CaO-O_2 flow with the metal bath.

In order to achieve this programme, the specialists in the works connected with the CNRM suggested in 1956 the building of a new industrial installation having a particularly high flexibility. The purpose of this would be, in particular, to make it possible to introduce all the refining oxygen and, possibly also all the lime powder with the oxygen flow. This proposal was achieved at ARBED-Dudelange.

This research has resulted in a new process of steel making which was called OCP, these three letters meaning Oxygen-CaO in Powder. We wanted to characterize by this sigla our process in order to differenciate it from the previous experiments carried out with an oxygen lance and lime added into the converter in the ordinary way.

We think it may be of interest to recall that the idea of injecting pulverized products into a metal bath in order to refine it had already been suggested by Bessemer himself, over 100 years ago[9]. And among the many research workers who have studied this question, we would like to recall more particularly the writings of the specialists of Hadir[10] (1925) and of Ougree-Marihaye[11] (1947), for these two steel works are affiliated to the CNRM and their research workers take an active part in the work of the Centre.

Small-scale tests in the blowing in of pure oxygen for the refining of hematite irons have been carried out by K. W. Schwarz[12] and by R. Durrer and H. Hellbrugge[13].

As regards the practical tests in blowing pure oxygen into a converter by means of a lance, but without the addition of powdered substances which have been carried out during the past few years, one must first of all refer to the very well-known LD-process which has produced remarkable results on the industrial level, in the refining of hematite iron[14, 15, 16, 17].

Our OCP-process and the LD-process both utilise an oxygen lance. Our process is characterised by the fact that we add powder lime to that O_2.

In order to avoid wastes in time, and to make the best of the experience of both institutions, our CNRM and the Austrian works, owners of the LD-process, had decided two months ago to join their

IRSIA; Institut Pour L'Encouragement De La Recherche Scientifique Dans L' Industrie et L' Agriculture.

8 O. Lellep—Bericht uber die Versuche zur Stahlerstellung im Herdofen und Konverter unter Benutzung von konzentriertem Sauerstoff, March 1941.

8(a) P. Metz—Pat. 551 945, 19.10.56.

9 H. Bessemer—Pat, 2768, 7 Dec. 1855, p. 18.

10 Hadir—Pat. 325, 897, May, 1925.

11 Ougree-Marihaye—Pat. 475, 607, 22 Aug. 1947.

12 K. V. Schwarz—Stahl und Eisen, 72 (1952), 26, p. 1642–1649.

13 R. Durrer and H. Hellbrugge—Stahl und Eisen, 70 (1950), 26, p. 1208–1211.

14 H. Trenkler—Revue Universelle des Mines, Aug. 1953, p. 645–557.

15 K. Rosner—Stahl und Eisen 72 (1952), p. 997–1004.

16 O. Cuscoleca—Stahl und Eisen, 72 (1952) p. 989–992.

17 Drei Jahre Ld Stahl voest 1956.

efforts and to work in collaboration.

In order to stress this collaboration, it was among others decided to modify the sigla of our process. In the future, it will be called "LD-AC", A for ARBED and C for CNRM.

Technical results

This being said, we will now summarise the main results obtained at ARBED-Dudelange by Mr. Metz referring to the communication he submitted at the *Journees Internationales De Siderurgie*, June 1958 and those of the last 300 heats he elaborated recently.

Let us first precise that the experiments were carried out in an industrial converter of 25 t, with a plain bottom, and in which 25 t iron were poured, having the following analysis:

C : 3·3–4·1% ; Mn : 0·3–0·6% ; Si : 0·1–0·6% ; P : 1·7–2% ; S : 0 03–0·06%.

By carrying out a peculiar procedure of oxygen and lime injection, provoking a controlled foaming of the slag, the development of the metallurgical operation was the expected one. This is illustrated in Fig. 4.

Some data concerning the industrial exploitation of the process are to be found in Table II hereunder, which will allow the determination of its economic value.

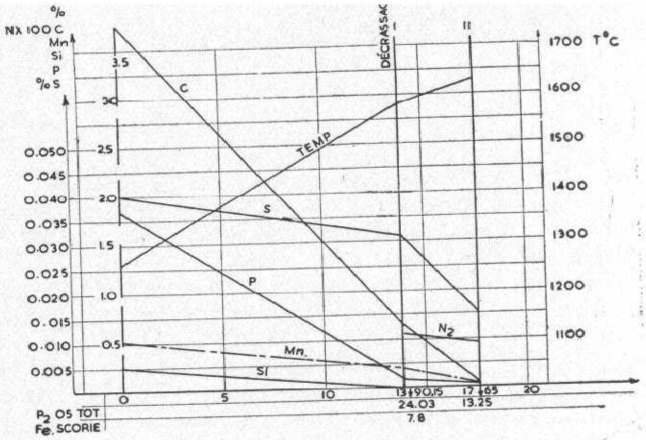

FIG 4.

TABLE II

The LD-AC process

Kg per ton of iron		O_2 Nm³/t	Total time in min.	Sec./t of iron	−4% N_2. 10	−3% P. 10	−3% S. 10
Scraps	Lime						
215	95	55·0	16 to 20	35 to 45	44·0	22·0	15·0

Let us point out in particular the following points:

(1) High consumption of scrap (215 kg/ton steel).

(2) Low consumption of oxygen (54 to 58 standard cubic meters) (1,900 to 2,050 cft.) per metric ton pig iron, and of lime (186 lb/ton steel).

(3) Great speed of refining (35 to 45 sec/metric ton steel in a 26 t converter).

(4) Nitrogen content in steel depending on the degree of purity of the oxygen used in refining: with 96·5% pure oxygen, the average nitrogen level is 0·0044%, with 99·5% oxygen the level drops below 0·003%.

(5) Easy dephosphorisation with high final carbon contents.

(6) High degree of desulphurisation (60%).

(7) Easy production of low sulphur (<0·02%) and low phosphorus (<0·020%) steels.

Moreover, the metallic yield of the operation is very high.

It must be noted also that the consumption of dolomite refractory is not higher, and perhaps even lower, than in the classical basic Bessemer process.

It follows that this is a very economical process.

Mechanical properties

The metallurgical development of the reactions taking place in the LD-AC process is quite similar to that which can be observed in the LD-process.

Let us particularly notice that for both processes, the phosphorus is eliminated before the carbon and the steelmaker may thus end the elaboration with a relatively high carbon contents. The chemical analysis of the obtained steel is similar for these two processes and the numerous mechnical tests we had recourse to, showed that the quality of both steels was as expected, similar and equal to that of open hearth steels.

This is the very reason why the steel obtained according to the LD-AC process will also be called "LD-steel".

Conclusions

Although it is still very young, the LD-AC process attracted the very special attention of a large number of foreign steelmakers (British, French, German, etc.) and we have the satisfaction to point out that already Belgian, British, French and Luxemburgian plants not only consider its application, but are already planning its application in their plants. We are convinced that it will have a very rapid extension and this is the reason which led us to deal with this subject today.

Dr. Ing. H. Hauttmann, Linz/Donau, Austria:
Comparing tests on mild LD-steel made of pig iron with 1% phosphorus and on mild open hearth steel molten of scrap and 50% stahleisen.

In their report on the LD-process with regard to the use of different types of pig iron with higher contents of phosphorus (Stahl und Eisen, 1958, p. 883–888) up to about 1·5%, H. Trenkler and R. Rinesch stressed the high quality of the LD-steel produced according to this manner.

The principle of the method consists in carrying out the operations with 2 slags and in using the second slag for the first part of the next cast. In the first step of the process the phosphorus content is reduced below 0·5% maximum, the C content of the bath being about 2%. After 10 minutes' blowing time, fine ore is added before the converter is tipped. After slag-off fresh quantities of lime and fluxes are added. A pouring hole is provided in the converter wall to separate slag and steel.

As a supplement to the paper mentioned, comparative tests with rimming open hearth steel of best quality and LD-steel made of pig iron containing 1% phosphorus were carried out in order to mark the properties of the LD-steel. The open hearth steel to be compared was molten with special care. Plates of about 0·5, 0·8, 1·6 and 4 in. in thickness were rolled from 15 t ingots of the two melts.

The *chemical composition* and mechanical properties of the normalised plates of 1·6 and 4 in. in thickness are given in Fig. 1. The chemical compositions are within narrow limits except the percentage to sulphur which is extremely low in the LD-steel.

For judging the *influence of cold deformation drawing*, tests were carried out on specimens taken from 4 in. plates. The test results of the steels as-rolled (Fig. 2) do not show important differences between the two steels compared. In normalised condition a small difference can be stated in favour of the LD-steel.

Notched bar impact tests were carried out on plates normalised and cooled in still air. The notch toughness (Charpy-V-notch) of the LD-steel is in general superior to open hearth steel.

In order to compare the aging properties of the two casts, test pieces were taken from 1·6 in. plates and were cooled from normalising temperature in water, oil and still air, respectively. The values of the aging impact tests carried out with the DVM-specimens are given in Fig. 3, right, while the left side shows the curve for the unaged specimens.

It can be seen that the LD-steel is at least equal to comparable open hearth steel but in most cases the LD-steel is considerably better.

LD - steel (pig iron with 1% P)					OH - steel (pig iron with 0,2% P)				
chemical composition									
%C	%Mn	%P	%S	$\%N_2$	%C	%Mn	%P	%S	$\%N_2$
0,09	0,35	0,019	0,005	0,004	0,09	0,40	0,023	0,024	0,004

mechanical properties (normalized)				
40	100 [1]	plate thickness, mm	40	100
20,8	20,7	yield point σ_S, kg/mm²	23,5	17,5
33,5	33,2	tensile strength σ_B, kg/mm²	36,3	31,4
35,9	42,6	elongation δ_5, %	31,1	42,0
66	71	reduction of area ψ, %	49	77

[1] in the case of 100 mm plates specimens from the rim zone

Fig. 1.
Rimming LD—(pig iron with 1% phosphorus) and open hearth steel, plates of 1, 6 and 4 in. in thickness, chemical composition and mechanical properties.

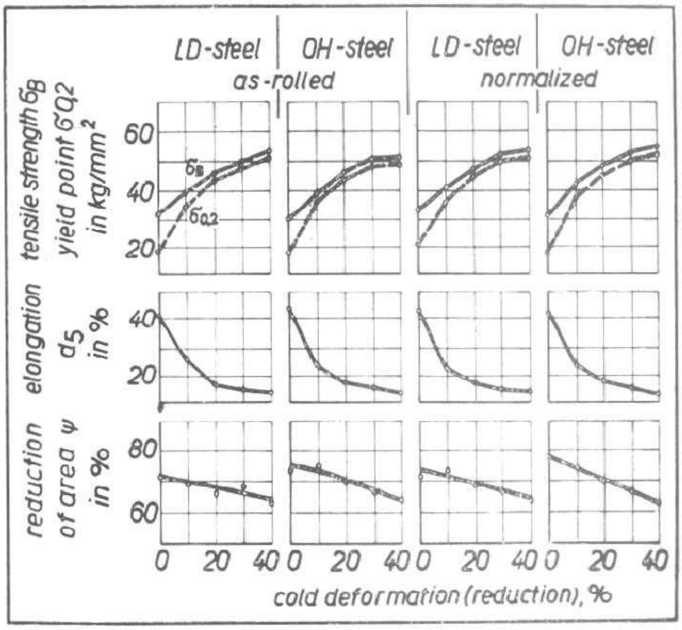

Fig. 2.
Rimming LD—(pig iron with 1% phosphorus) and open hearth steel, plate of 4 in., mechanical properties after cold deformation when drawn (aged for 10 days).

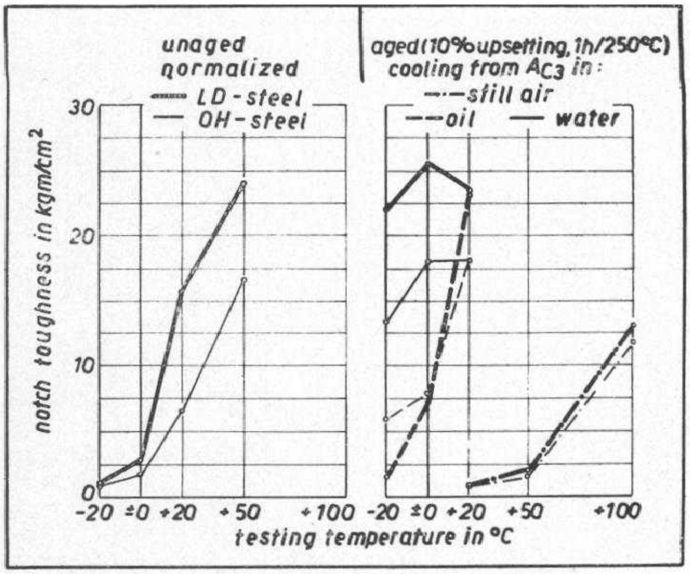

Fig. 3.
Rimming LD-(pig iron with 1% phosphorus) and open hearth steel, plate of 1·6 in., notch toughness of aged and unaged DVM-specimens.

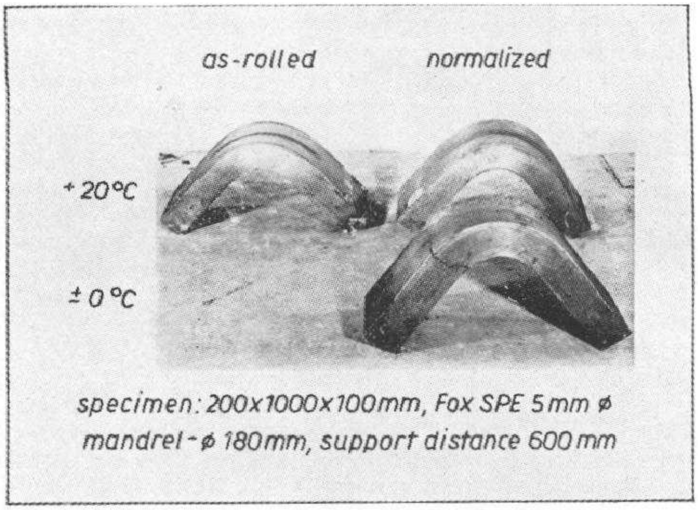

Fig. 4.
Rimming LD-steel (pig iron with 1% phosphorus) plate of 4 in. in thickness, weld bead bend test.

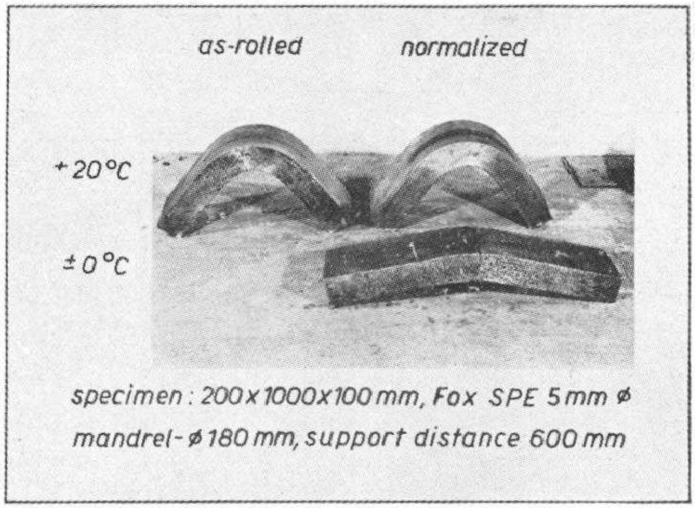

Fig. 5.
Rimming open hearth steel, plate of 4 in. in thickness, weld bead bend test.

In Austria the *sensitivity of steel against brittleness* caused by local influence of a welded bead is tested by the *weld bead bend test* which is standardised in ONORM M 3052. Length and width of the test pieces are chosen according to the plate thickness. The specimens tested in the original thickness of 4 in. had a width of 8 in. and a length of 40 inches. A semi-circular groove of 0·16 in. radius was cut along the axis of the test piece and filled with deposited material from a coated electrode as used for mild steel. The specimens were bent in flat position with the filled groove in the tension zone. High bending angles prove the ability of stopping cracks originating in the deposited material and influenced zone. Thickness of the test piece and testing temperatures have great influence on the results.

Ordinary rimming mild open hearth steel usually shows brittle behaviour if the thickness of the normalised test piece exceeds 1·5 in. It is a sign of extraordinary quality if mild rimming steels in normalised condition show ductile behaviour though the thickness ranges at about 4 in.

Figs. 4 and 5 show the results of the weld bead bend tests at 68°F carried out on LD- and open open hearth steel.

The test results of weld bead bend tests at 32°F show a certain difference between LD- and open hearth steel. Using open hearth steel a brittle fracture occurred at a bending angle of 25° whereas the LD-steel specimens allowed a deformation up to 90° before the crack occurred.

Impact cupping tests similar to the Pellini test were carried out on plates in thicknesses of 0·5 in. In the centre of the specimen (16 by 16 in.) two welded beads are applied in the form of a cross using a soft electrode (FOX SPE) or a hard electrode (FOX DUR 200, with a Brinell hardness of 200 HB). The test pieces were put on a die with a circular hole of 9·8 in. in diameter and tested with the welded cross in the tension zone by a drop hammer. The weight of the round shaped hammer was 900 lb and the dropping height was 13 feet.

Fig. 6 shows the results for plates of 0·5 in. in thickness from the open hearth steel in question in as-rolled condition. The critical temperatures for the open hearth steel specimens welded with the soft and the hard electrodes ranged at about —22°F and 50°F, respectively.

The specimens of LD-steel (Fig. 7) welded with the soft electrode FOX SPE were still deformable without cracks at—40°F and the critical temperature of the specimens welded with the hard electrode FOX DUR 200 may be found at about +14°F. The tests carried out proved the LD-steel to be superior to open hearth steel.

In order to study the behaviour of steels for welded constructions we use *blowing bursting tests* on welded tubes. This severe test is marked by a very high deformation rate. 1% elongation occurs within 1/10·000 of a second. The blowing bursting test (Fig. 8) is carried out on tubes of about 30 in. in diameter and 60 in. in length, welded together by a circumferential seam from 2 equal sections stress free annealed after welding. The circumferential seam remains untreated after welding.

For testing, the tube is put in an upright position on a solid support and filled with water up to the upper edge. Then a blowing charge of Donarit

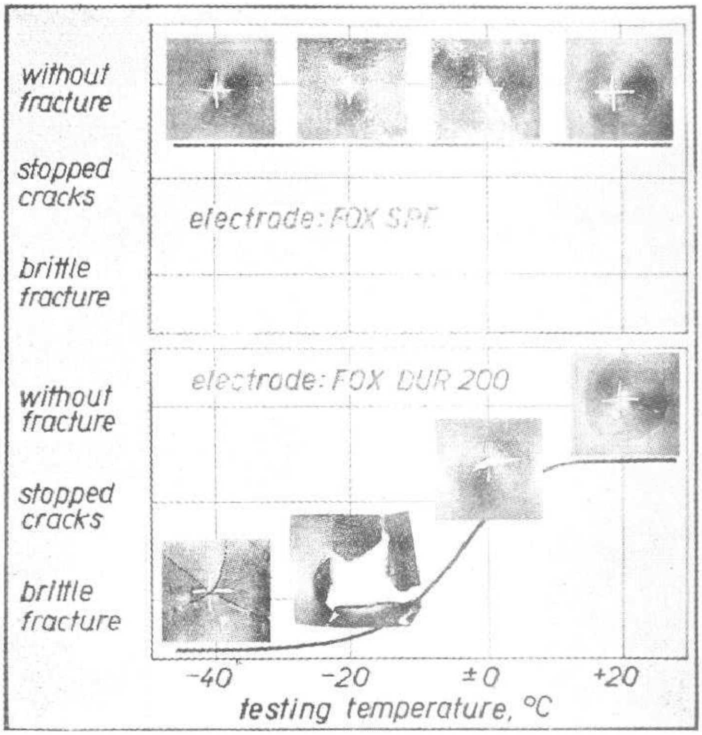

Fig. 7.

Rimming LD-steel, St 33, as-rolled, 0·5 in., impact cupping test, drop energy about 7,000 ft. lb.

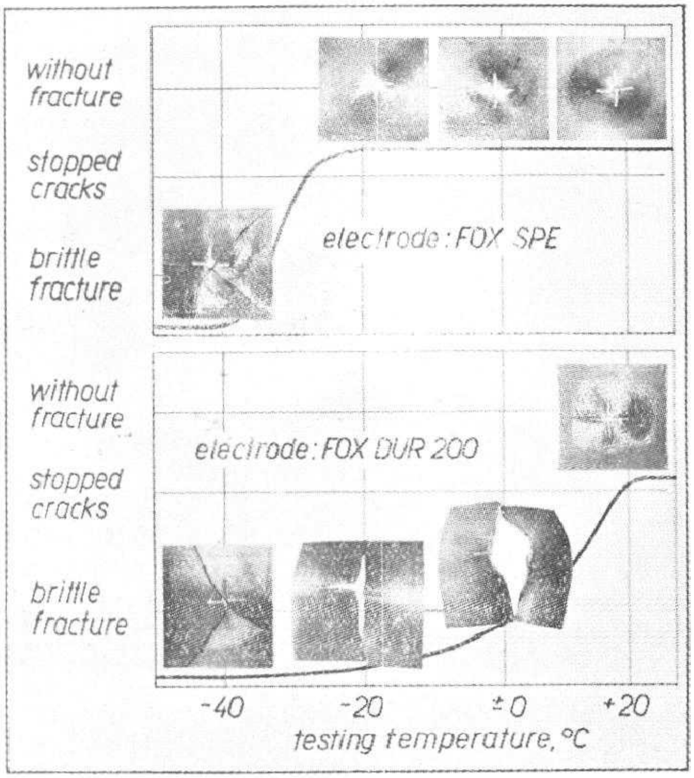

Fig. 6

Rimming open hearth steel, St 33, as-rolled, 0·5. in., impact cupping test, drop energy about 7,000 ft. lb.

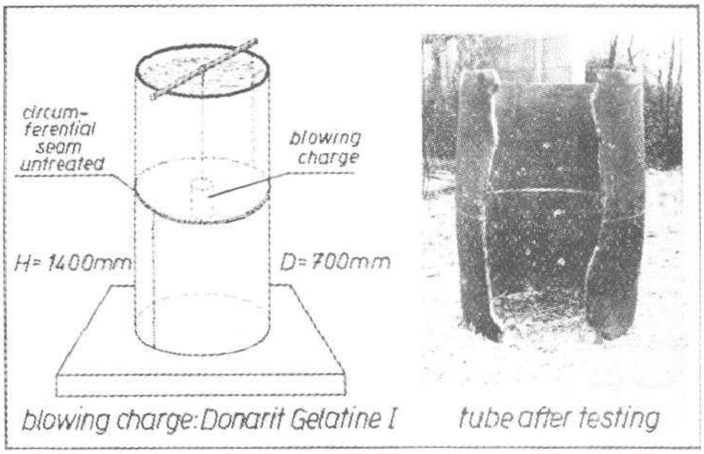

Fig. 8.

Blowing bursting test on welded tubes.

Gelatine I is blown up at the level of the circumferential seam. The weights of the single charges were measured thus that each blow causes a widening of about 5% at the circumferential seam.

An LD- and an open hearth steel tube each of 0·8 in. in wall thickness were welded from plates in as-rolled condition. The LD-steel tube was tested under more severe conditions (naturally aged during 3 months, after a widening of 13·9%). A final circumferential elongation of 17·6% in total was reached (Fig. 9).

The tube of open hearth steel in rolling condition was widened by blows within one hour's time and the fracture occurred at a circumferential elongation of 21·9%. Although these test results of the two mentioned tubes are not directly comparable we may speak, however, of an excellent behaviour of the LD-steel.

Tubes of the same size were welded also from normalised plates of the two steels. In both cases a widening up to 24·8% shows no fracture. These results are excellent.

Tubes of 1·6 in. in wall thickness of both steels showed a brittle fracture after the first blow. An elongation of 1% was measured in both cases.

The wall thickness of these tubes is beyond the critical range concerning the outstanding high deformation rate. The tests carried out proved mild rimming LD-steel made of high phosphorus hot metal to be equal or even superior to comparable open hearth steel of the best quality.

steel	heat treatment	plate thickness mm	tensile test [1] σ_s kg/mm²	σ_B kg/mm²	d_5 %	DVM aged [2] +20°C kgm/cm²	circumferential seam: electrode, annealing	month year	circumferential elongation %
LD [5]	a.r. [3]	20	21,6	35,2	31,8	0,9	Fox SPE untreated	6.58 9.58	13,9 17,6
LD [5]	n. [4]	20	22,9	34,9	38,2	1,1	Fox SPE untreated	9.58	24,8
LD [5]	n. [4]	40	20,4	33,4	36,2	0,8	Fox SPE untreated	9.58	1
OH	a.r. [3]	20	22,7	36,9	32,3	0,7	Fox SPE untreated	6.58	21,9
OH	n. [4]	20	22,2	36,0	36,7	1,0	Fox SPE untreated	9.58	24,8
OH	n. [4]	40	22,4	36,3	32,6	0,8	Fox SPE untreated	9.58	1

1) transverse 2) 10% upsetting, 1h/250°C 3) a.r. = as rolled
4) n = normalized 5) from pig iron with 1% P

Fig. 9.

Blowing bursting tests on tubes welded from rimming LD- and open hearth steel, St 33, inside diameter approx. 30 in., length approx. 60 in.

Mr. B. S. Sharma, Mysore Iron and Steel Works: Referring to the removal of P from pig iron to manufacture steel, I think the the problem in India has been that P is neither low enough for acid Bessemer process nor high enough to suit basic Bessemer for Thomas Iron. May I ask Mr. Coheur if it would be very uneconomical in the case of such medium P irons, to add P in the blast furnace and proceed to the manufacture of Thomas Steel? We could also get a good fertiliser slag out of it and I think this would be cheaper than Duplexing or Triplexing.

Mr. P. Coheur (Author): In some steel plants in Europe, basic Bessemer slag is added in the blast furnace to slightly raise the P content of the iron; this is done in Italy for example. However we now prefer, on economic grounds, to leave the phosphorus as it is and blow with O_2 enriched air or from the top.