Evolution of HSLA Steels Production in Brazil - An Influencing Factor in the Increasing Consumption of Special Ferro-Alloys.

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The objective of this paper is to present the evolution of development and production of high strength low alloy (HSLA) microalloyed steels in Brazil.

The development of HSLA microalloyed steels, in Brazil, was initiated in 1964 but it was during the seventies, and parallel to the expansion and modernization of the steel industry, that production in large scale gained significance.

In the late seventies and early eighties the quality of Brazilian steels improved and microalloyed steels meeting strict property requirements could be developed.

The stage reached in the production of HSLA steels could not have been possible without a modern integrated steel industry. Therefore, the expansion of the Brazilian steel industry is also discussed.

INTRODUCTION

Fifteen years ago crude steel production in Brazil amounted to about five million tons per year. At that time high strength low alloy (HSLA) steel production was not of great significance. Steel internal quality (content of P;S and shape of inclusions) and existing facilities would not allow the development of steels requiring superior characteristics of formability, toughness and welbability.

In the early seventies the Brazilian Government started a massive investment to modernize and expand the existing national steel industry. In addition, new steel plants were built and, as a result, present crude steel production capacity is over twenty million tons per year.

Not only has steel production increased in Brazil but a significant upgrading of steel products has occurred. Intensive research and development work on HSLA steels, also referred as microalloyed steels, by the three major integrated steel producers was initiated in the early seventies. Initially, due to plant equipment limitations, the characteristics of the consuming market and lack of experience in the new technology, HSLA steel development generally concentrated on relatively thin gage flat products, sections and rails. In recent years numerous developments have occurred and production of HSLA steels has gained momentun. Steel plant equipment and availability of qualified and experienced metallurgists are no longer inhibiting factors.

A large variety of HSLA steels has been developed and these are now produced under normal commercial conditions. The steels include plates for pipelines up to Grade API X70 and plates for offshore platforms (BS 4360), HIC resistant steels as well as heat-treated plates for pressure vessel and other applications. Thin gage formable HSLA hot and cold rolled sheets are produced for consumption by the automobile industry. In the long products area, besides sections and rails, microalloying technology has also been applied to reinforcing bars and engineering steels. For the latter, the production of as forged (without application of heat treatment) microalloyed automobile parts is an established practice.

The present production of microalloyed steels under equivalent quality standards to many products from developed steel making countries, coupled with the large availability of raw materials and relatively low labor cost, has consolidated the participation of Brazil as an exporting country for HSLA steels. Steel mill HSLA products such as sheets and plates, fabricated or manufactured items, e.g. X-70 line pipe, as-forged crankshafts and automobiles, are exported to several countries around the world.

The production of HSLA steels to meet strict metallurgical requirements depends on the development of the steel industry, starting from the early stages of the process of hot metal making in the blast furnace. Thus, before microalloyed products are discussed a brief review on the development of the Brazilian steel industry is given.

AN OVERVIEW OF THE BRAZILIAN STEEL INDUSTRY

EVOLUTION OF STEEL PRODUCTION

In the early 30's it was recognized by Government leaders that integrated and consistent economic development could not proceed without the establishment of steel production on a large scale in Brazil. Thus, in 1931 the National Iron and Steelmaking Comission was created to study the complex subject of installing an integrated steelworks utilizing mineral coal, in a country where most of the required infrastructure for such a project was not available at that time (e.g. adequate transportation systems). In 1941, the government decree law nº 3002 authorized construction of Companhia Siderurgica Nacional (CSN) - an integrated steel works to produce 295,000 t of finished products in 1945. Since the construction period took place during Workd War II, delays occurred but the project was not interrupted and in 1946 the first heat was produced (1). In addition to flat products CSN was designed to produce sections, bars and rails.

During the fifties and as a result of acceleration on the industrial development process, two other important integrated steel mill projects emerged Usinas Siderúrgicas de Minas Gerais (Usiminas) and Companhia Siderúrgica Paulista (Cosipa). Usiminas started operation in 1962 and Cosipa in 1963, both companies having at that time, production capacity of 500,000 t per year. In contrast to CSN which started producing steel through the open hearth process, Usiminas and Cosipa have been operating BOF vessels since their start-up and their product mix is limited to flat products.

In 1970, Brazil produced 5.4 million ton of raw steel (2). The supply of flat products by the three companies was 2.55 million tons (3) and the ratio exports/imports reached a figure less than unity (0.84) (2). Over the subsequent five years, steel imports increased substantially. This situation was predicted in the late 60's indicating that Brazil had to expand and modernize the existing plants. In 1971, from the National Iron and Steel Making Program, three stages of expansion were planned for each of the three integrated plants (4). In 1978, another revised planning program - "Iron and Steel Making Master Plan" detailed sizes for two additional integrated (cokebased) steel works which in the early eighties gave origin to Companhia Siderúrgica de Tubarão (CST) and Aços Minas Gerais S.A. (Açominas). It was clear in the late 60's that the national steel industry would undergo substantial growth in the succeeding years indicating the necessity of creating government bodies to coordinate such a development. Thus, in 1968 the "Conselho de Não Ferrosos e de Siderurgia" (CONSIDER) was organized and entrusted with the objective of establishing strategies and directions for the development of the national steel industry as a whole. In 1973, another government entity, Siderurgia Brasileira S.A. (Sidebras) was created as a holding company for the state owned steel plants, mainly flat products oriented companies (4).

In the long products area also substantial growth occurred in the seventies with expansion of existing plants and installation of new ones. In that product area most companies are privately owned.

During the last ten years in order to execute the above-mentioned expansion programs the national steel industry has invested about 20 billion dollars. These investments have increased the production capacity to about 21 million ton/year of raw steel and the target of 26 million tons will be reached in the near future with the conclusion of projects at present under development.

The Brazilian steel industry complex comprises 41 steel works characterized as shown in table I.

TABLE I - CHARACTERIZATION OF BRAZILIAN STEEL COMPANIES

TYPE OF STEEL WORKS	NUMBER OF STEEL WORKS	RAW STEEL PROD. CAPACITY (10^3 tons)	STEEL PROD. 1985 (10^3 tons-%)
INTEGRATED AND BASED ON COKE	5	13,340	12,575 - 61
INTEGRATED AND BASED ON CHARCOAL	9	3,601	3,372 - 17
INTEGRATED AND BASED ON DIRECT REDUCTION	2	486	463 - 2
SEMI-INTEGRATED	25	4,746	4,045 - 20
TOTAL	41	22,173	20,456-100

The major integrated steel plants producing flat products are CSN (which also produces long products), Usiminas and Cosipa with production capacities of 4.6; 3.5 and 3.5 million ton of raw steel per year, respectively. Two other recently integrated steel plants, CST and Açominas, are in their first stage of operation producing semi finished products. Their raw steel production capacity, at this stage, is 3 and 2 million ton/year, respectively.

As a result of the massive investments in the steel industry, the situation of a potential steel importing country in the early 70's turned into a potential exporter in the early 80's, as illustrated in figure 1 (5-6-7-8).

In order to compensate for steel import restrictions imposed in recent years by some developed countries to protect their local industries, Brazil has adopted an aggressive program to diversify the destination of its exports. Brazil is now exporting steel to more than 50 countries (9).

The evolution of raw steel production for the period 1970 - 1985 is shown in figure 2 (5-6-7-8). Brazil improved its ranking in the world steel production from the 18th position in 1970 to the 7th major producer in 1985.

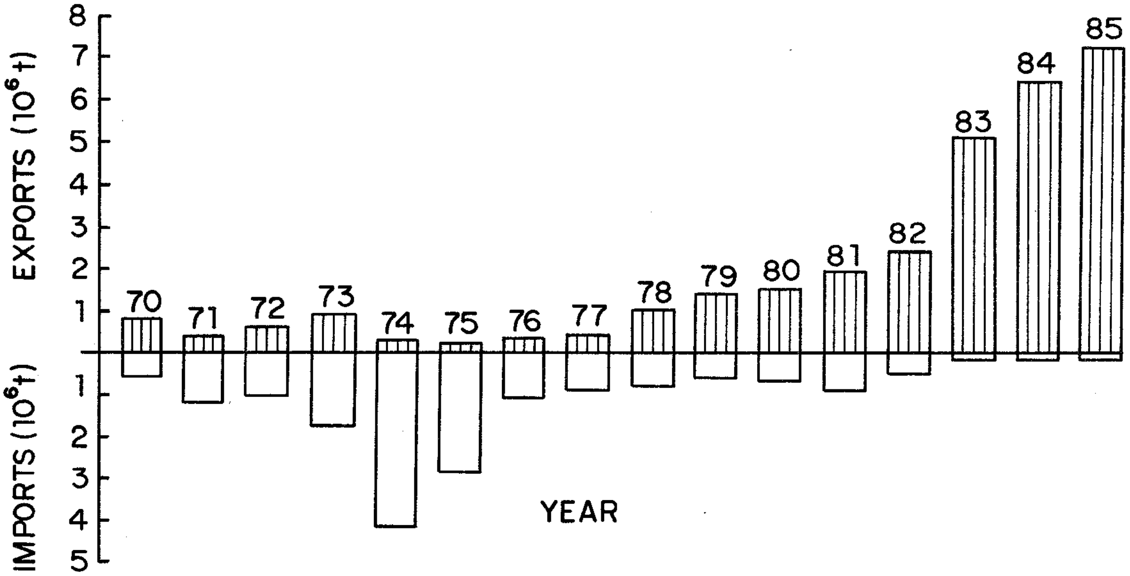

FIG. 1 - IMPORTS AND EXPORTS OF IRON AND STEEL PRODUCTS

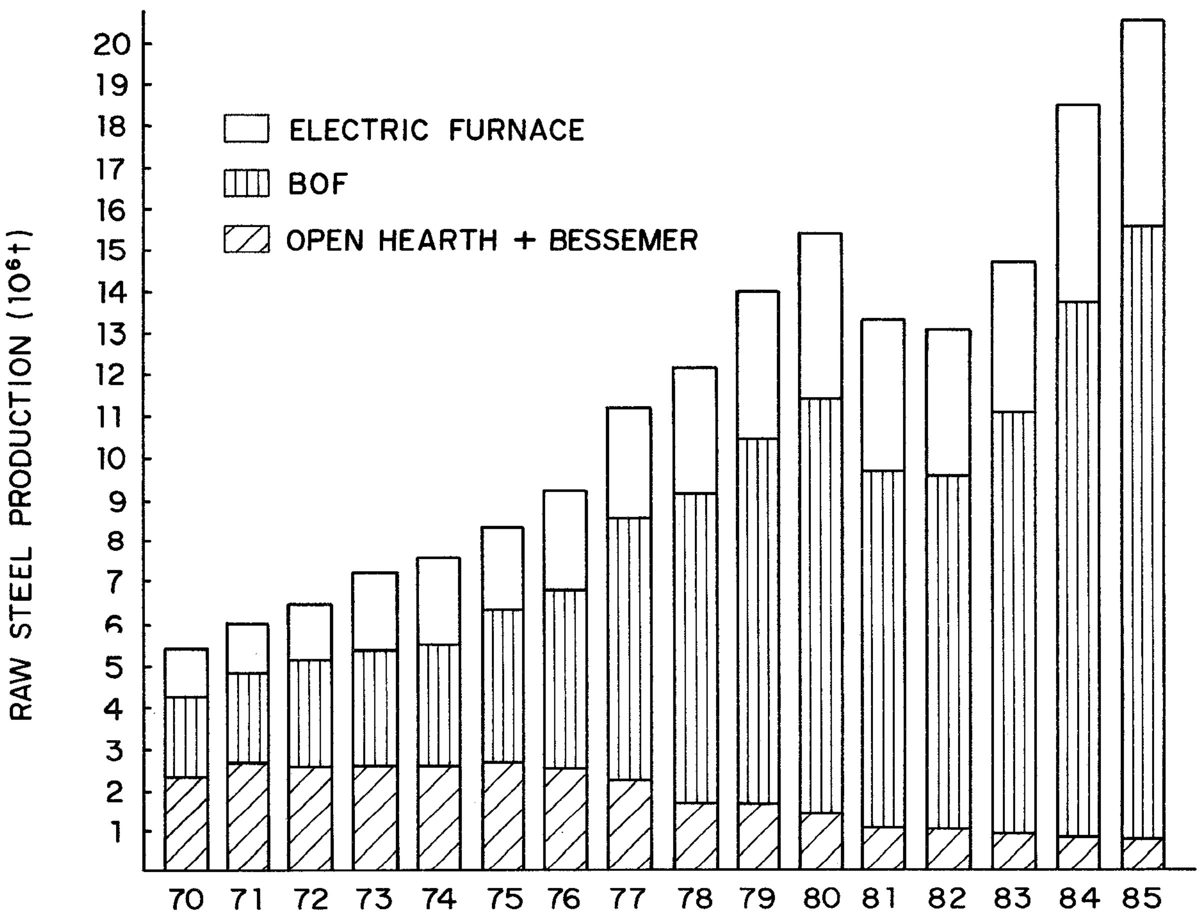

FIG. 2 - RAW STEEL PRODUCTION BY PROCESS

RECENT TECHNOLOGICAL TRENDS APPLIED IN STEEL PLANT UNITS

Not only has production capacity increased, but as the steel plants were being modernized parallel growth occurred in plant productivity, quality improvement and the upgrading of steel products.

In figure 2 the evolution of steel production per process is shown. Old fashioned steel making processes have practically been abandoned and substituted by large tonnage BOF vessels.

Production of steel by continuous casting has significantly increased in the late 70's and early eighties, as shown in figure 3.

In the early seventies, sheets or plates with 0.015%S could be considered low sulfur grades and sulfide shape control was in its first stage of development (10). Sheet and plate producing companies in Brazil are today equipped with facilities for hot metal treatment and secondary refining units using one or more of the following processes: RH degassing, Argon bubbling and Ca-Si injection. By applying hot metal treatment and secondary refining clean steels with sulfur contents as low as 0.001% have been produced, particularly in the product area of plates for pipes. For steel treatment with Ca-Si injection it is worthy of notice that COSIPA in collaboration with a local technological research institute (Instituto de Pesquisas Tecnológicas) has developed and constructed its own installation with no foreign assistance.

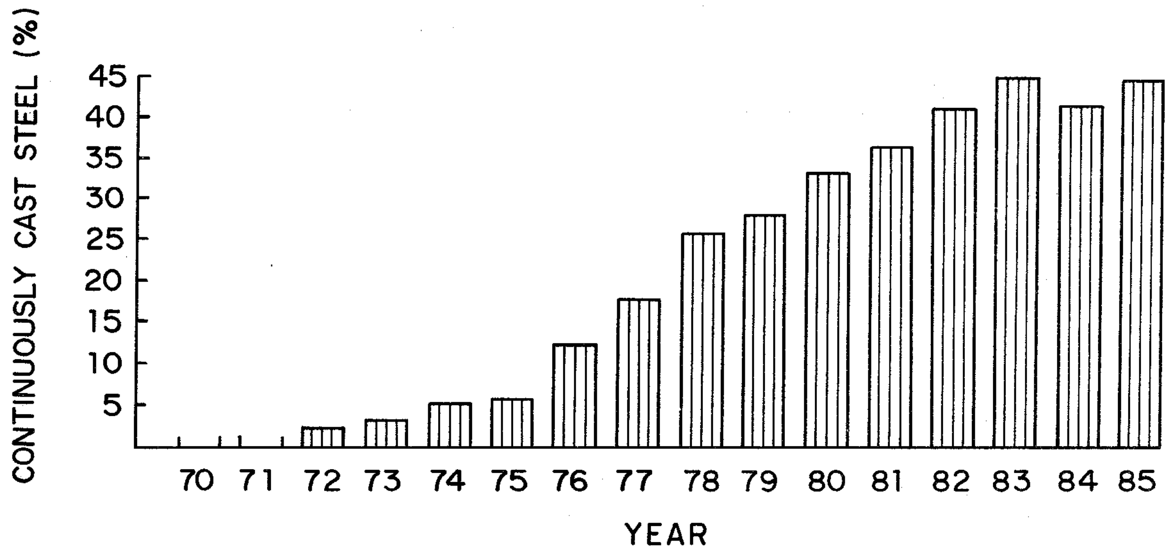

FIG. 3 - EVOLUTION OF STEEL PRODUCTION BY CONTINUOUS CASTING.

During the expansion programs, modern rolling mill lines have been installed and massive introduction of process control by computer has occurred. At CSN, the hot strip mill nº 2 can produce coils weighing up to 40t. The plate mills at Cosipa and Usiminas, with maximum separating forces of about 6,000 t, have well equipped finishing lines making it possible to produce high-quality controlled-rolled products in widths up to 4m. Heat treating lines for normalizing, quenching and tempering of plates are available at Usiminas and will start operation at Cosipa by the end of this year. Cosipa is also starting operation of its melting shop nº 2 and continuous casting plant.

For cold-rolled sheet products, the existing mills in the early 70's have been modernized and at CSN a continuous annealing line for sheets has been installed. HSLA steels are also produced as galvanized sheets and in Brazil, CSN is the only steel company producing coated products. For galvanized sheets this plant operates continuous galvanizing lines.

The large expansion of the Brazilian steel industry for flat products developed through three principal stages. During these stages a substantial increase in equipment nationalization index was verified. For instance, in stage II of the expansion of CSN, the average equipment nationalization index was 20%. In stage III that index increased to 70% and for some equipment, reached 100% (2). This is a consequence of a well-established strategy and the capability to absorb external know-how which has also been applied in the area of product development.

The above description is limited to the flat products integrated steel-producing companies and is not intended to cover the subject in detail. It does however indicate the extendt to which the Brazilian steel industry is prepared to accomodate world market requirements for high strength low alloy steels. The long products steel industry, representing today over 30% of the raw steel production, also experienced a substantial transformation period in the last ten years. Several existing plants were modernized and new plants were constructed. Nevertheless, this segment of steel producing companies will not be discussed in further detail in order to limit the length of this discussion of the Brazilian steel industry.

PRODUCTION OF MICROALLOYED STEELS IN BRAZIL

HISTORICAL PERSPECTIVE

In 1964, Eng.Mozart de Castro França, a Brazilian metallurgist working for the Research Department of CSN, conducted the first industrial investigation of microalloyed steels in Brazil. In his work - "Estudo sobre o Emprego de Ti e Nb na produção de Aço em Forno Elétrico Básico" (Study of the Use of Ti and Nb in Electric Arc Basic Furnace Steel Production) - França showed the superior grain refining effect of Nb as compared to Ti and suggested continuation of the studies aiming at the use of Nb in steels produced in Brazil (12). That work stimulated a number of developments in subsequent years. However, the first production of microalloyed HSLA steel in Brazil on a commercial scale,which occurred in 1966, was not a result of the above investigations. At that time, CSN was receiving technical assistance from United States Steel and as a natural consequence a license agreement was established to produce Cor-Ten steel - a weathering steel microalloyed with vanadium in its grades B and C. The first utilization of CSN Cor-Ten steel was also in 1966, in the construction of a viaduct in the city of Volta Redonda, where the CSN plant is located (13).

The year 1967 marks the beginning of the intensive development of microalloyed steels in Brazil. During that year the first experimental industrial heats designed in Brazil were produced for hot strip mill products at CSN and in 1968 a company brochure showed the characteristics of four niobium microalloyed grades which had been developed (14). Those grades were named NIOB-AR steels with minimum specified yield strengths from 320 to 420 MPa and their chemical composition specifications are shown in table II.

Research investigations to support the experimental developments in the plant were conducted at CSN research department and in 1968 França published a report on the effects of niobium in the first large scale industrial heat of niobium microalloyed steel produced in Brazil - Heat nº 72021 (figure 7 indicates the year of 1967) (15).

TABLE II - SPECIFIED CHEMICAL COMPOSITION FOR NIOB-AR GRADES

STEEL GRADE	CHEMICAL COMPOSITION WT %					
	C_{max}	Mn_{max}	P_{max}	S_{max}	Si_{max}	Nb_{min}
NIOB-AR - 32	0.21	0.90	0.03	0.05	0.30	0.008
NIOB-AR - 35	0.22	1.35	0.03	0.05	0.30	0.008
NIOB-AR - 39	0,23	1.35	0,03	0.05	0.30	0.008
NIOB-AR - 42	0,25	1.35	0.03	0.05	0.30	0.008

NOTE: Figures 32; 35; 39 and 42 indicate minimum yield strength in kgf/mm^2.

In the product area of plates Usiminas began the initial production of microalloyed steels in Brazil, which also occurred in the second half of the sixties. Usiminas, with the objective of following the Japanese technical development and diversifying its product mix, established an agreement for technical assistance with Yawata Iron and Steel Co. As one of the results from the above agreement, production of three HSLA microalloyed grades started, SAR-50, SAR-55 and SAC-50 (16). The first two grades are similar to the Japanese steels WEL-TEN 50 and WEL-TEN 55 from Yawata, with minimum tensile strengths of 50 and 55 kgf/mm^2 respectively, and meeting the requirements of DIN ST.52.3.These steels are microalloyed with vanadium and their specifications for chemical composition are shown in table III (17).The third grade,SAC 50,is an HSLA weathering steel equivalent to the Yawata product YAW-TEN-50. Carbon content is less than 0.16% and titanium is the microalloying element used. That steel meets the requirements from ASTM-A-242. Of course, not only plates were produced with above steel grades which were also processed in the hot strip mill.

As described above CSN and Usiminas were the steel companies which started production of microalloyed steel in Brazil in the second half of the sixties. Two approaches for that production had been utilized - imported technology (COR-TEN, SAR and SAC steels) and in house development

(NIOB-AR Steels). Technical assistance from United States and Japan played an important role in helping Brazilian metallurgists better assimilate the technology of microalloyed steels so that

TABLE III - SPECIFIED CHEMICAL COMPOSITION FOR SAR GRADES

STEEL GRADE	CHEMICAL COMPOSITION WT %					
	C	Mn	P_{max}	S_{max}	Si	V
SAR 50	0.13-0.18	1.10-1.40	0.020	0.025	0.25-0.40	0.04-0.06
SAR 55	0.15-0.18	1.35-1.50	0.030	0.030	0.40-0.55	0.02-0.04

they could proceed with in-house developments. In this section mention has not been made of COSIPA because, as a younger company, it had no production of HSLA steels in the late sixties.

During the seventies, as previously mentioned, major changes occurred in the Brazilian steel industry. The steel plants production capacity had been expanded and modernization of existing units had occurred. Similarly, large improvements took place in the area of HSLA microalloyed steels. Several new grades were developed and product quality was significantly improved. In the section which follows, the evolution of HSLA steels in development and production from the seventies to the present day is discussed.

EVOLUTION OF HSLA MICROALLOYED STEELS PRODUCTION FROM THE SEVENTIES TO THE PRESENT DAY

In parallel to the modernization and expansion of steel plants in Brazil during the first half of the seventies, significant progress occurred in the development of microalloyed steels. By that time, Brazilian metallurgists were sufficiently familiar with the production and processing of these steels so that all products which were created had their developments "in house" in contrast to the case of steel grades Cor-Ten; SAR and SAC in the late sixties.

In 1973 CSN, for instance, was normally producing 12 grades of HSLA microalloyed steels, not including COR-Ten (18). Those steels were produced as hot strip or plate from the hot strip mill and among typical applications were longitudinal girders for the truck and buses industries and gas cylinders. Chemical compositions for the mentioned grades comprised carbon and manganese contents in the ranges of 0.07 - 0.20% and 0.40 - 1.20% , respectively. The tolerances for sulfur ($\leq$0.03) were relatively higer as installations for hot metal or steel treatment were not available at that time.

The microalloying technology at CSN was also successfully extended to high carbon steel. Pioneering the industrial utilization of niobium in rail steels, a development by CSN during 1973 and 1974 led to a high strength and wear resistant rail NIOBRAS - 200 - which is still being produced and used in Brazilian railways, some of them characterized by heavy and intense iron-ore traffic. Although the metallurgy of Nb in high carbon steels is yet to be further clarified, the rail steel developed by CSN demonstrated similar in-service performance to other high strength alloyed rails and superior weldability characteristics, eliminating the need for post weld heat treatment (19 - 20). It is interesting to note that the advantages of niobium additions to heat-treated and alloyed rail have recently been shown by a Japanese steel company (21). Typical chemical composition and mechanical properties of Niobras 200 rail steel are shown in table IV.

As previously mentioned, CSN became a licensee of USS to produce COR-TEN steel. In 1973 Ramos et al (22) conducted a study of the substitution of V by Nb in the above steel and concluded that a significant cost reduction would result based on the following factors:

- To produce COR-TEN CSN had to pay royalties to USS.
- Nb strengthening effect is twice as effective in low carbon structural steel. Less alloy addition would therefore be necessary.
- V is more expensive than Nb in Brazil because it is imported.

The consequence of Ramos et al. study was the development of NIOCOR steels 1 and 2 which are grades equivalent to COR-TEN A and B, respectively. After extensive development investigations through experimental heats during 1974 and 75 (23 - 24), NIOCOR steel was put in normal commercial production in 1976. By 1980 it was applied, in the form of plates, sheets and sections, in several bridges, viaducts, railroad wagons, silos and longitudinal girders for buses (25). Subsequently, CSN

ceased production of COR-TEN steel.
At Usiminas, as was the case for CSN, several HSLA microalloyed steels were developed in the early seventies. In 1972, the following standards started to be met by Usiminas products: ASTM A 572 grade 50;ABNT EB 593 LNE 38; AH 32 and 36 and DH 32 and 36. In 1974 grade 60 was developed for SAR steels (also microalloyed with vanadium) and ASTM A 583 - grade B (26). As will be discussed later, participation of COSIPA in the subject area of HSLA microalloyed steels gained significance in the second half of the seventies. In the first part of that decade, production of HSLA was concentrated on ASTM 242, a product similar to CSN NIOCOR steel

TABLE IV - CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF NIOBRAS 200 RAIL STEEL

CHEMICAL COMPOSITION WT %						MECHANICAL PROPERTIES			
C	Mn	P	S	Si	Nb	Rp MPa	Rm MPa	$A_{2''}$ (%)	BHN
0.74	1.35	0.024	0.027	0.81	0.03	625	1091	11	307

In the long products area, and for the period under consideration, mention should be made of concrete reinforcing bars. Cold deformation was the means of obtaining high strength product in the sixties. In 1970, following the utilization of niobium in rebar by North American steel industries, two steel plants in Brazil (Companhia Siderúrgica de Mogi das Cruzes and Siderúrgica Belgo Mineira) started adding niobium to their reinforcing bar products. After detailed investigations by research institutes in Brazil, the product was put into normal commercial production (27). With the addition of niobium minimum yield strength of 490 MPa was guaranteed, mainteining the elongation and bending requirements. Subsequently, all rebar-producing companies adopted this strengthening route and cold deformation was abandoned.

The second half of the seventies and early eighties can be classified as the period for upgrading quality of existing HSLA microalloyed steels and development of high strength products to meet strict property requirements such as toughness and formability. This was made possible by the start of operation of modern mills and installation of units for hot metal and steel treatment, degassing, continuous casting and heat treating of steel plates. As the HSLA microalloyed product mix significantly increased in that period, the section which follows gives a separate discussion for each type of product.

PLATES FOR PIPES

The application of plates for the production of large diameter pipes is one of the major uses for HSLA microalloyed steels. In addition, the development of microalloying, can, by and large, be attributed to that application where strict requirements of strength, toughness and weldability are imposed.

In Brazil, production of plates for pipes on a commercial scale and meeting standard API 5LX was started in 1978 by the two steel plants equipped with plate mills - Usiminas and Cosipa. Steel grades developed by that time were X 52 and X60. Typical X60 grade alloy design comprised 0.15%C; 1.24%Mn; 0.22%Si; 0.010%P; 0.010%S ; 0.035%Nb and 0.055%V for plates produced at Usiminas (28). Similar steel was being produced by Cosipa. Exports of API steels started in 1979 when CONFAB (a Brazilian SAW pipe producer) produced 43 thousand tons of X52 pipes for Mexico. The plates were provided by Usiminas.

The development and production of these two grades marked the beginning of the application of controlled rolling practices in Brazil. These practices had been assimilated through technical training and the visits of Brazilian metallurgists to steel plants in Japan and Europe.

Also in 1978, production of microalloyed steels by continuous casting started. Usiminas, after having conducted extensive studies of the quality of continuously cast steel (29 - 30), produced since 1976, started casting SAR 50 grade (V microalloyed) (31). The experience gained in these studies,and by being alert to the necessary measures recommended for continuous casting of microalloyed steels, resulted in good quality indices for SAR 50 continuously cast slab. At about the same time production of X52 and X60 grades by continuous casting was initiated (32), and this also maintained good quality indices.

In addition to the application of controlled rolling and continuous casting to microalloyed API steels in 1978, an important point was the success of efforts in the direction of low sulfur steels. Although 0.010%S is the typical figure mentioned above for X60 steel sulfur contents of 0.005% - 0.008% were being obtained by Usiminas and Cosipa. (32 - 33).

During subsequent years, production of API steels at Usiminas and Cosipa increased substantially. Considering that API steel is one major consumer of microalloys in the product mix of Usiminas, the above statement can be illustrated by figure 4 where the evolution of special ferroalloys consumption during the period 1978 - 1985 is shown (28 - 34). Figure 4 also shows the total orders of FeNb in Brazil since 1978. This is a good indication of the increase in production, not only of line pipe steels, but also of HSLA microalloyed steels in general.

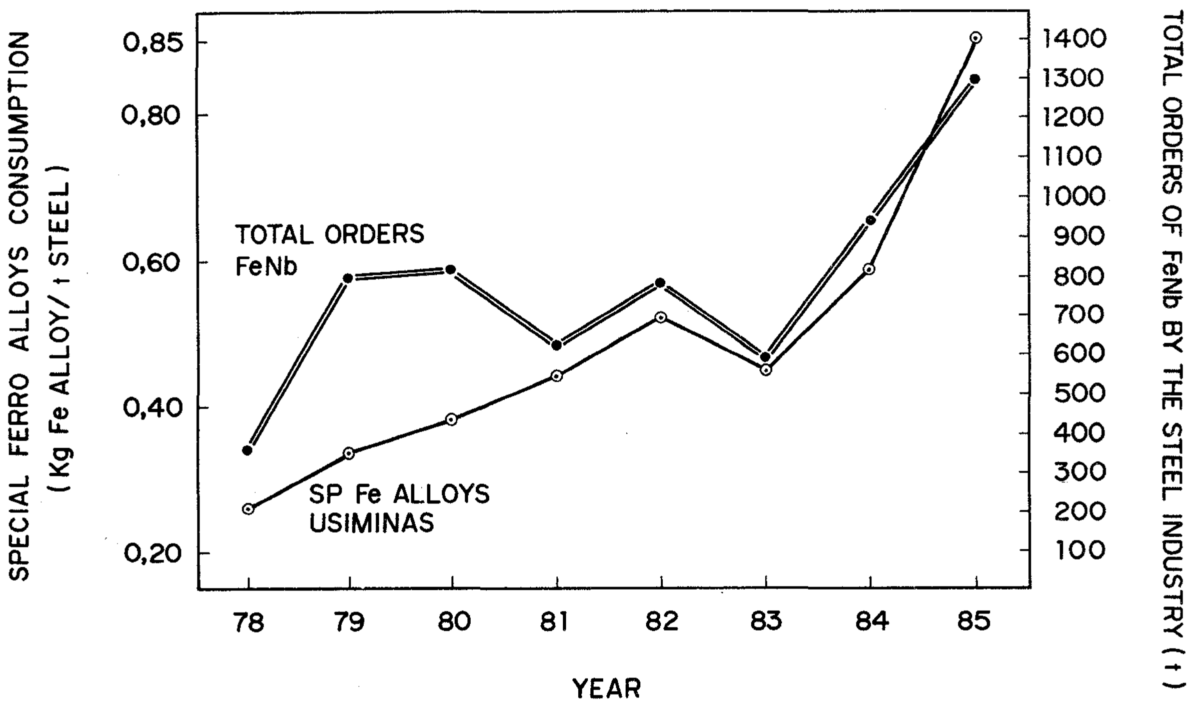

FIG. 4 - EVOLUTION OF SPECIAL FERROALLOYS CONSUMPTION AT USIMINAS

(FeNb, FeV, FeTi AND FeCr) AND TOTAL ORDERS OF FeNb BY THE STEEL INDUSTRY.

Contemporaneously with the increase in production, quality improvement occurred with the installation of units for sulfide shape control at Usiminas and Cosipa. The ladle injection system at Cosipa began operation in 1980 and, as previously mentioned, the system was developed by Cosipa and a local research institute. At present, two of those units are in operation at Cosipa.

The experience accumulated in the production of API steels in the late seventies accelerated the development of grades X65 and X70. Since 1981 those grades have been in normal production at Cosipa (26). Usiminas started producing X65 grade in 1980 and X70 in 1983 (26). These API steels have alloy designs based on the standard combination of niobium and vanadium, and exhibit fine ferrite-pearlite microstructures . Typical chemical compositions and mechanical properties are given in table V.

Recently, CSN has put into operation a modern hot strip mill which can produce 3.2 million tons per year of hot rolled products in widths and thickness up to 1575 mm and 12.7 mm, respectively. Development of API steels up to X60 grade has been carryed out (35). API plate steels resistant to hydrogen-induced cracking are the more recent development at Usiminas (36) and Cosipa. Grades up to X65 with these characteristics, under BP conditions, are already available.

A further step in the evolution of API steels in Brazil will be the production of steels with microstructures comprising lower temperature transformation products, at present being developed by Usiminas (26).

The production of API steels meeting strict quality requirements has added Brazil to the list of the few countries which export such products. For instance, Cosipa X70 steel, either in the form of plates or pipes, has been exported to

TABLE V - TYPICAL CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF API 5LX-X65,X70; BS 4360 - 50D and COS-AR-55 STEELS (1)

STEEL	CHEMICAL COMPOSITION Wt %											MECHANICAL PROPERTIES (6)					
															CVN		DWTT - 20ºC
	C	Mn	P	S	Si	Al	Cu	Ni	Nb	V	Ti	Rp (MPa)	Rm (MPa)	A (%)	E(J)	%F.F.	%F.F.
X 65 (2)	0.12	0.85	0.015	0.001 *	0.24	0.021	0.30	0.15	0.036	0.032	0.011	550	599	35	75	100 AT-20ºC	100
X 70 (3)	0.10	1.58	0.015	0.004 *	0.27	0.022	-	-	0.033	0.072	-	610	696	32	101 AT-20ºC	100 AT-20ºC	100
BS 4360-50D (4)	0.14	1.23	0.016	0.003 *	0.27	0.042	-	-	0.035	-	-	443	557	28	67(4) AT-10ºC	-	-
COS-AR-55 (5)	0.16	1.40	0.020	0.012	0.40	0.040	-	-	-	0.054	-	420	580	25	35 AT 0ºC	-	-

NOTES: 01 - Data for Cosipa products

02 - t= 10.31 mm; w= 3,200 mm; HIC Resistant Steel

03 - t= 14.27 mm; w= 3,802 mm

04 - t= 37.50 mm; CVN Data after ageing at 100ºC - 1 hour and strained 3%

05 - t= 20 mm

06 - All properties are transverse to the rolling direction, apart from toughness of COS-AR Steel

* - Sulfide Shape Control

several countries including the USA and USSR.

STRUCTURAL STEELS

Under the heading of structural steels consideration is given to product areas of plates for offshore and naval construction, structural steels for general use and heat treated plates.

Offshore oil exploration has been in progress in Brazil for several years. However, it was confined to regions of shallow water where platform materials did not require plates with superior characteristics of toughness and through-thickness ductility. The situation changed in the early eighties when oil production started at Campos basin (East of Brazil). In this region oil is obtained from platforms located in places where water depth reaches 170 m. (37).

Although Brazil is a tropical country, oil exploration under the deep water conditions of Campos basin requires offshore platform characteristics, to alarge extent, similar to those of the North Sea (38). Among 20 offshore platforms which have been constructed, or are under construction in Brazil, 5 have structural components weighing over 20,000 t (37).

At about the same time the first platforms to Campos basin were under construction, Usiminas, with the start up of a RH degassing unit in 1980, completed its installations to fully satisfy the market for steel plates. The evolution of steel development for offshore platforms by Usiminas is shown in table VI (39). It can be seen that production of higher grade plates requiring through-thickness properties started in 1982. Low sulfur content plus sulfide shape control, degassing and normalising are part of the normal processing routes at Usiminas in the production of niobium mocroalloyed steel to BS 4360 - 50 D used in the fabrication of nodes. For other structural components of the platform either normalised or controlled rolled plates are supplied. At Cosipa development of steel BS 4360 50 D was concluded in 1981 and the plates, with sulfide shape control, are produced by controlled rolling. Typical chemical composition and mechanical properties are shown in table V.

TABLE VI - OFFSHORE PLATFORM STEELS DEVELOPED BY USIMINAS

YEAR	STEEL	APPLICATION
1977/78	DIN RRST - 52 - 3N (with extra requirement)	Modules and Jackets (not including nodes)
1979/81	SAR - 50 - BN RRST - 42 - 3N	Modules Various
1982	BS 4360 - 50 DN DIN - RRST - 44 - 3N	Jackets (including nodes) and modules Modules, structures, etc.

In the area of hull plate for ship building, grades AH/DH 32 and 36 were initially developed by Usiminas in 1972, as previously mentioned. More recently,in 1984, Usiminas concluded development of steels EH 32 and 36 (26). At Cosipa, hull plate steels, grades DH 32 and 36, were developed in 1979. Those steels are low sulfur (0.015% max) Nb microalloyed products processed by controlled rolling. In the above product area a significant timing difference is observed between Usiminas and Cosipa. That is explained by the fact that Cosipa, in addition to being a younger company, had its plate mill start up in 1978 (40).

In the period 1975 - 1984 other HSLA microalloyed steels for general structural use were developed by the three flat product integrated steel companies in Brazil. These include the COS-AR steel developed by Cosipa in 1980, a V microalloyed product with minimun yieldstrength of 355 MPa (Table V) and COS-AR-COR (weathering steel, Nb microalloyed).

In the product area of quenched and tempered plates microalloyed steel developments were initiated by Usiminas in 1981, after installation of its roller quench heat treating unit (41). Steels to standards ASTM A 517, A 514, A 678 and A 387 were already developed by 1982 (42). More recently, production of plates with tensile strength above 1,000 MPa has been started (41).

HOT AND COLD ROLLED FORMABLE HSLA STEELS TO THE AUTOMOBILE INDUSTRY

As previously discussed, production of microalloyed formable steels for use in longitudinal girders for the bus and truck industry started in the early seventies. At that time, steel sulfur content was relatively high and sulfide shape control by calcium or rare earths was not practiced on a commercial scale. The first HSLA steel with superior formability characteristics was developed by Usiminas and its production was started in 1972. Since it was a titanium strengthened grade, sulfide shape control was automatically achieved. This steel is still produced by Usiminas and has a minimum yield strength of 375 MPa.

Due to the characteristics of the consuming market for HSLA formable grades in the hot rolled condition the highest strength level produced is still the 375 MPa minimum yield strength product. Cosipa developed this steel and began production in 1979. Instead of titanium, the microalloying element most used is niobium. The typical chemical composition in table VII shows an aluminum-killed steel with low sulfur content which guarantees the transverse bending standard requirement of 180º. Since 1979 Cosipa has also been producing the Ti microalloyed grade, but to a minor extent. More recently, CSN developed its grade to meet the above requirement and the route followed was Nb microalloyed silicon - aluminum killed steel plus sulfide shape control through the addition of rare-earth metals.

HSLA cold-rolled steels belong to the youngest family of microalloyed steels developed in Brazil. Only in recent years has the Brazilian automobile industry shown significant interest in that product area. Usiminas and Cosipa have developed two grades of high strength steel with minimum yield strength requirements of 270 MPa and 343 MPa. The lower strength grade is a plain carbon rephosphorized steel and the higher grade is niobium microalloyed with the typical chemical composition shown in table VII . In the development program conducted by Usiminas, titanium and niobium microalloying were investigated (43). Ti steel, as compared to its equivalent Nb microalloyed product, gave inferior ductility properties. CSN is in the final development stage of the 343 MPa grade. It should be mentioned that a significant acceleration in the development of HSLA cold rolled products at CSN will occur in the near future after start up of its continuous annealing line for sheets.

TABLE VII - HSLA FORMABLE STEELS

STEEL	CHEMICAL COMPOSITION WT %						
	C	Mn	P	S	Si	Al	Nb
375 MPa H-Rolled (1)	0.07	0.60	0.008	0.007	-	0.052	0.028
343 MPa C-Rolled (1)	0.06	0.50	0.015	0.011	-	0.05	0.04

NOTE: 1 - TYPICAL DATA FOR COSIPA PRODUCTS.

LONG PRODUCTS

In the long products area, as is the case for plates and hot rolled sheets, microalloyed steels are widely used in the production of structural sections. Developments of HSLA microalloyed sections occurred parallel to those of flat products and used the same grades of steels for general structural purposes.

Production of Niobium microalloyed rail steel has continued and the product is basically the same as in the early seventies, apart from quality improvement through secondary refining and uphill teeming practice.

During recent years the development of forgings produced from microalloyed bars has gained increasing importance worthwide due to the energy savings made possible by the elimination of heat treatment of the final component. About 1975 Krupp Metalurgica Campo Limpo, with collaboration from Volkswagen do Brazil, concluded the development of microalloyed crankshafts for Volkswagen vehicles produced in Brazil. By applying controlled forging practices in a niobium microalloyed medium carbon steel the traditional quenching and temper heat treatment was eliminated. In addition, the new product exhibits better machinability. Since 1976 as-forged microalloyed crankshafts have been produced on a commercial scale (44). Several million parts have been produced to date for the local market and for export.

Seamless tubes for oil country tubular goods (OCTG) constitute another product area where continuous development utilizing microalloyed steels have occurred. Mannesmann, the principal producer of seamless products in Brazil, concluded development of niobium mocroalloyed steels for API grades X52 and X60 in 1980 (45). In subsequent years grades up to X70 and other special microalloyed products were developed and put into commercial production (46).

CLOSURE

The development of microalloyed steels in Brazil traces back to 1964. In the late sixties and early seventies various HSLA microalloyed steels were under normal commercial production in the major Brazilian integrated steel plants. Product quality was improved and new steels to meet strict property requirements were developed in the late seventies and early eighties following modernization and expansion of the Brazilian steel industry.

The acquisition of foreign product technology in the early stages of microalloyed steel production has helped Brazilian metallurgists to assimilate the basis of microalloying discipline and to proceed in the development of new steels.

Today, high quality HSLA microalloyed steels are fully integrated in the Brazilian steel product mix.

REFERENCES

1. A.O. Pereira, & M.L.E. Caron, Manual de Siderurgia. São Paulo , Assetec: Assessoria Técnica Industrial, p. 464 - 1967.

2. B.M. Batista, 40 anos da CSN e sua atuação no desenvolvimento nacional. Volta Redonda, Companhia Siderúrgica Nacional Publ., 1981.

3. M.L. Leão, A expansão da Siderurgia Brasileira. Metalurgia ABM, 28 (176) (1972) p. 479-83

4. P.O. Assman, B.M. Baptista, J.G.P. Evangelista. A siderurgia brasileira de planos da década de 80.P.1-38 In: Congresso Brasileiro de Siderurgia, 9. Rio de Janeiro, Instituto Brasileiro de Siderurgia, May 1979.

5. Anuário Estatístico da Indústria Siderúrgica Brasileira. Rio de Janeiro, Instituto Brasileiro de Siderurgia, 1975.

6. Ibid., 1983.

7. Ibid., 1984.

8. Ibid., 1986.

9. P.D. Villares, Perspectivas da Siderurgia Brasileira. Instituto Brasileiro de Siderurgia Publ., Rio de Janeiro, Aug. 1984.

10. R.D. Azevedo, P.J.P.Bordignon, A.M.P. Garcia Do Ó. Emprego das terras raras em aços. Metalurgia ABM, 31 (206) (1975) P.35 - 41.

11. C.R.Galvão,J.L.Crudis,J.C.G.Parish, Equipamento para injeção profunda de pós reativos em panela de aço - desenvolvimento IPT/Cosipa. P.1-20 In:ABM XXXVIII Annual Congress, Associação Brasileira de Metais, São Paulo,- SP, 1983

12. M.C. França, Estudo sobre o emprego de Ti e Nb na produção de aço em forno elétrico básico, Companhia Siderúrgica Nacional - Departamento de Pesquisas, Feb. 1965 (Internal Report)

13. Aços Cor-Ten. Companhia Siderúrgica Nacional, Feb. 1967. (leaflet).

14. Aços de Alta Resistência. Companhia Siderúrgica Nacional, 1968 (leaflet).

15. M.C. França, Aço ao Colúmbio. Companhia Siderúrgica Nacional(1968). (internal report).

16. M.Viana, Produção e utilização de chapas grossas.Metalurgia ABM, 25 (137) (1969) P.282-4

17. E.C. Nunes, C.O.S. Cortes, Soldabilidade dos aços SAR-50 e 55. Metalurgia ABM, 31 (207) (1975) P.91-100.

18. P.J.P. Bordignon, Aços ao Cb de alta resistência e baixa liga com boas características de conformação e sua produção. Companhia Siderúrgica Nacional - Linha de Pesquisas , March 1973 .(Internal Report nº 26/73).

19. C.A. Nolasco, E.Q. Oliveira, P.J.P. Bordignon, Trilhos de elevada resistência mecânica e ao desgaste para ferrovias. Metalurgia ABM, 33 (234) (1977) P. 257-63.

20. P.J.P. Bordignon, E.Q. Oliveira, F.H.A. Silva, The development of a high strength and wear resistance-Niobras 200-Rail Steel for Intense and Heavy Traffic Railways. Paper X6 In:

Heavy Haul Railways Conference.Proceedings..., Institution of Engineers, Perth, W. Australia, 1978.

21. H. Kageyama, K.Sugino, H.Masumoto, Determination of alloying elements for the improvement of rail weldability (Development of high strength weldable rail steels - II). Transactions of the Iron and Steel Institute of Japan, 22(5) (1982) P.B 148.

22. J.B.S.Ramos, P.J.P.Bordignon, D.I. Souza Jr, Aço, alternativa mais econômica. Companhia Siderúrgica Nacional - Linha de Pesquisas, Nov. 1973.(Internal Report)

23. C.A.Nolasco, P.J.P.Bordignon, E.Q.Oliveira,Niocor: aço ARBL ao nióbio com elevada resistência à corrosão. Metalurgia ABM, 32 (229) (1976) P. 817-24.

24. P.J.P.Bordignon, R.M. Brito, Fabricação processamento e características mecânicas e metalúrgicas do primeiro aço patinável totalmente brasileiro - Niocor 2. Companhia Siderúrgica Nacional - Sup. Geral de Pesquisas e Desenvolvimento, Jan. 1979 (internal report nº 006/79).

25. P.J.P. Bordignon, R.M.Brito, S.Azambuja, W.R. Rosas, Caracterização e aplicação de um aço ARBL patinável - Niocor, desenvolvido na CSN. Metalurgia ABM, 36(275) (1980) p. 685-9.

26. Personal Communication, I.S.Ferreira, Usiminas, 1985.

27. Personal Communication, A.Oliveira Neto, Companhia Siderúrgica de Mogi das Cruzes, 1985.

28. S.L. Andrade, J.I.Oliveira, I. Hanan, Desenvolvimentos recentes de chapas grossas na Usiminas. P.111-26 In: Seminário de Laminação de Planos e Não Planos. Proceedings..., Associação Brasileira de Metais/COPLAM, Ipatinga, MG,1982.

29. R.S. Fontes, L.O.Pereira, Qualidade do material produzido no lingotamento contínuo da Usiminas. Metalurgia ABM, 33(238), (1977) P. 573-7.

30. R.S. Fontes, W.C. Damião, L.O.Pereira, M.R. Horta Filho, Principais tipos de defeitos em placas de lingotamento contínuo. Metalurgia ABM, 34(251) (1978) P. 721-8.

31. R.S. Fontes, E.J.M. Taiss, T.Miyashita, Chapas grossas de alta resistência originadas do lingotamento contínuo. Metalurgia ABM, 35(259) (1979) P. 429-33.

32. R.S. Fontes, T. Myashita, V. Guidoni, N.C. Braga, A.D. Cardoso, F.W. Puntigan, A. Mangualde, L.C. Castro, Chapas grossas para tubos com especificações extras. Metalúrgia ABM, 36(273) (1980) P. 517-21.

33. O.E. Alarcon, Desenvolvimento da tecnologia de fabricação dos aços de baixa liga e alta resistência (aços BLAR) com nióbio. Siderurgia Latinoamericana, (226) (1979) P.61-73.

34. Personal Communication, S.L. Andrade, Usiminas, 1986.

35. R.M.Brito, M.W.Scal, R.L.S. Germano, F.D. Caetano, O.A. Souza, M.C. Candido, Aplicação de conceitos de tratamentos termomecânicos no desenvolvimento de aços para atendimento à norma API. P-295-311 In: XXXIX ABM Annual Congress. Proceedings..., Associação Brasileira de Metais, Belo Horizonte, MG, 1984.

36. F.J.F.Miranda, R.C. Ratnapuli, T. Miyashita, Avaliação da susceptibilidade de aços API da Usiminas à trincas induzidas por hidrogênio em meios contendo H_2S e água. P. 279-312 In: ABM XXXIX Annual Congress. Proceedings..., Associação Brasileira de Metais, Belo Horizonte, MG, 1984.

37. J.P.Silveira, Tecnologia metalúrgica nas plataformas marítimas. Metalurgia ABM, 38(293) (1982) P. 187-9.

38. M.C.B.Marcon.Materiais e processos na construção de plataformas marítimas. Metalurgia ABM, 38(293) (1982) P. 190-4

39. S.L.Andrade, I.Hanan, Fabricação de chapas grossas para aplicações especiais. P. 159-70, In: I Encontro de Tecnologia e Utilização dos Aços Nacionais, 1. Proceedings..., COPPE/UFRJ, Rio de Janeiro , RJ, 1982.

40. J.M.Bonfim , S.A. Machado, M.R. Vasques, Chapas grossas de aço microligado ao nióbio de alta resistência para a indústria naval, P. 138-58 In: I Encontro de Tecnologia e Utilização dos Aços Nacionais, 1.Proceedings, COPPE/UFRJ, Rio de Janeiro, R.J., 1982.

41. J.T.Nakashima, A.V.Faria, J.E.A.Pereira, Desenvolvimento industrial de chapas grossas temperadas e revenidas com 1000 N/mm^2 de resistência. Metalurgia ABM, 41(327) (1985) P. 71-6.

42. R.C.Ratnapuli, A. Assaoka, A.V. Faria; O desenvolvimento de aços temperados e revenidos na Usiminas.P.183-95 In: I Encontro de Tecnologia e Utilização dos Aços Nacionais, Proceedings..., Associação Brasileira de Metais, Rio de Janeiro, RJ, 1982.

43. L.N.T. Klein, H. Barcelos, V. Oliveira Jr. Desenvolvimento de aços de média e alta resistência, baixa liga laminados a frio na Usiminas. P.331-46 In: ABM annual Congress, XXXIX Proceedings..., Associação Brasileira de Metais, Belo Horizonte, MG, 1984.

44. W. Albiero, Forjamento de árvores de manive

las com adição de nióbio. Metalurgia ABM, 37 (281) (1982) P. 192-4

45. C.Motter, L.O.G. Moreira, J.O.G. Silva, A.L. Hanum; Algumas características mecânicas de 2 aços microligados após tratamento térmico. P. 127-47 In: Seminário de Ensaios de Materiais e Controle de Qualidade. Proceedings..., Associação Brasileira de Metais/COEMA, São Paulo, S.P., 1980.

46. Personal Communication, L.O.G. Moreira, Mannesmann, 1985.

NOTE

This paper is based on "Experience in the Metallurgical Design and Production of HSLA Steels in a Developing Country - Brasil", by P.J.P. Bordignon; J.R.P. Schiesari and E. Q. de Oliveira, presented at HSLA 85 Conference , Beijing, 1985.