International Symposium on Niobium Microalloyed Sheet Steel for Automotive Application
Edited by S. Hashimoto, S. Jansto, H. Mohrbacher, and F. Siciliano
TMS (The Minerals, Metals & Materials Society), 2006

MICROALLOYED STEELS PRODUCED BY USIMINAS FOR THE AUTOMOTIVE INDUSTRY

João F. B. Pereira, Luiz C. O. de Meyer, Túlio M. F. de Melo

Usiminas
Av. Pedro Linhares Gomes 5.431, CEP 35.160-900; Ipatinga, MG, Brazil.

Keywords: Microalloyed steels, Usiminas, Automotive industry

Abstract

Microalloyed steels, including conventional and advanced high strength steels and those extra low carbon steels which offer different combinations of strength and ductility, are currently products highly used by the automotive industry. The use of microalloying elements such as Nb, Ti, V and B allows the production of steels with several combinations of mechanical and technological properties, which can be applied to different body in white parts including closures. Aware of the market movement and as a big supplier of flat steels to the Brazilian automotive sector, Usiminas has for many years included microalloyed steels among its products. This paper describes some of the main microalloyed steels produced by Usiminas and supplied as hot rolled or as cold rolled to the automotive industry, their historical evolution in the company and the market. It also discusses the main mechanical and microstructural features of these steels as well as their typical applications in modern auto construction.

Introduction

At the end of 20th century, vehicle producers recognized that survival in this competitive market was centered upon the design of safe, low emission, esthetically acceptable and competitive cost vehicles.

This viewpoint, strongly based on the concepts introduced by the ULSAB program [1], highlight the importance of steel as the main material in the vehicle mass production, taking into account the mechanical properties, recyclability and low cost of steels compared to the most important plastic and aluminum alternative materials.

Among the different types and grades used in the ULSAB program and presently available to the automotive industry, microalloyed steels are quite important materials for the vehicle construction since they offer multiples options and alternatives to project engineers and designers. In this paper, microalloyed steels include (i) conventional high strength steels, where the addition of elements such as Nb, Ti, V or a combination of them, is the main responsible for the strengthening, (ii) advanced high strength steels, such as Dual Phase, TRIP, Complex Phase, and others, where the microalloying additions complement the strengthening obtained by other mechanisms and (iii) microalloyed extra low carbon steels which offer different combinations of high strength and ductility.

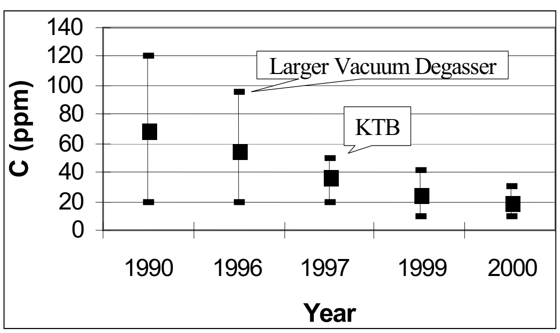
Usiminas, the main Brazilian domestic steel supplier, an important player at the international automotive market and also an ULSAB program member, starts the new century with a renewed plant, as a result of heavy investments in capacity and quality increases being capable of meeting the markets requirements with a wide range of products including microalloyed steels.

Brief Historical Review

High strength conventional microalloyed steels for the automotive market started to be produced by Usiminas in the beginning of the 1980's whereas extra low carbon microalloyed steels had their production started in the early 1990's with both having batch annealing as production route.

The first development experience of high strength conventional microalloyed steel was done in 1982 and had a domestic carmaker partner. The steel product, 450 ~ 500 MPa grade with niobium added, was applied to different parts of a vehicle body, including closures. Thickness down to 0.6 mm was tested. Despite initial poor results obtained in panels, which required superior formability, the domestic automotive industry began the first step toward what would be the essence of many studies carried out in the next decade, i.e., the use of high strength steels to reduce weight in vehicles.

The application of extra low carbon microalloyed steels in the domestic market initiated in a very tenuous way in the beginning of the 1990's using Ti as microalloying element. The natural instability of a new process and the resulting inhomogeneity of mechanical properties, Figure 1, presented challenges in meeting the directives issued by the automotive industry concerning new materials. The batch anneal process did not resolve the inhomogoneity problem. So, the introduction of continuous lines (CAPL - Continuous Annealing and Processing Line and CGL – Continuous Galvanizing Line) at the end of that decade addressed these inconsistencies in mechanical properties. Since then, carbon content and yield strength have been kept under control and in 2005 average values are 18 ppm $\pm$ 5 and 153 MPa $\pm$ 9, respectively.



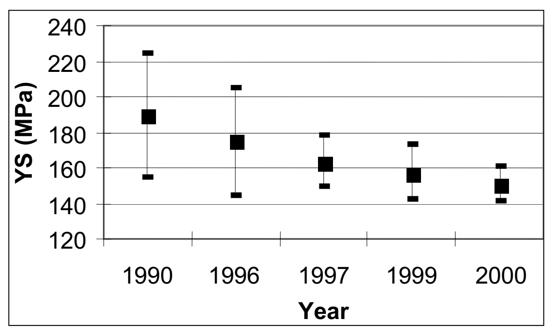


Figure 1. Average carbon content and yield strength of IF steels through the years at Usiminas [2].

These new production lines allowed Usiminas to match up with the main steelmakers of the world, enabling the company to meet most of the market demands, consolidating itself as the main domestic steel supplier to the automotive industry and as an important player of the international market.

Since the early 1980's Usiminas has developed and successfully applied hot rolled microalloyed sheet steels with tensile strengths in the range of about 400 MPa up to 600 MPa. Besides the conventional microalloyed steels for structural parts, such as cross members and rails for trucks and cars, the most significant developments involved steels for wheel discs and rims.

Nowadays, microalloyed steels, hot or cold rolled, covering the yield stress range from 140 to 550 MPa are normally produced using different alloy design concepts.

Hot Rolled Microalloyed Steels

Usiminas started in the mid 1980's the production of hot rolled microalloyed steels for application on structural parts of vehicles, especially trucks. Since then, the volume of such steels produced and supplied to the automotive sector has continuously increased, as illustrated in Figure 2, where the amount of hot rolled microalloyed steel sales to this sector is plotted for the last five years.

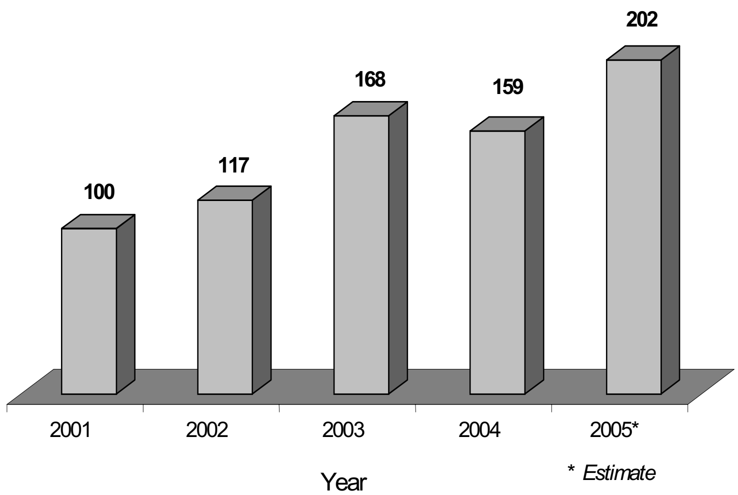


Figure 2. Evolution of sales to the automotive sector of hot rolled microalloyed steels produced by Usiminas taking the year 2001 as an initial reference.

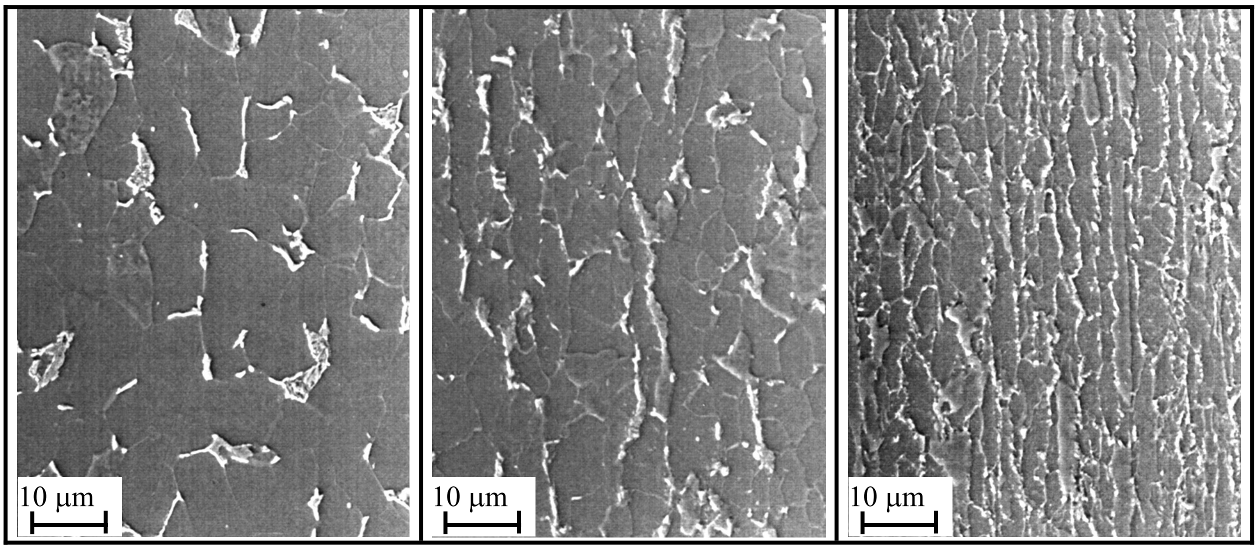
Nowadays, the company is capable of supplying hot rolled microalloyed steels in the form of strips or plates, with gauges between 2 mm and 12.7 mm and from 6 mm to 50 mm, respectively. The minimum yield strength of strip products ranges from 280 MPa to 600 MPa, and from 340 MPa up to 950 MPa in the case of plates. These steels have been widely used for wheels, rails, cross members, axles, suspension and structural parts of cars and trucks.

A special group among these products comprises the steels for automotive wheels, where the full hardening potential of the microalloying elements is used [3,5]. Presently two grades of microalloyed steels are produced and supplied by Usiminas for the fabrication of wheels, USIRW450 and USIRW550, as shown in Table I together with the highest strength unalloyed C-Mn steel for this application, USIRW340, given here as a reference [6,8]. Both microalloyed steels have low sulfur content and are Ca-treated for inclusions shape control, using Nb for grain refinement and precipitation hardening via controlled rolling. USIWR450 has a microstructure composed by ferrite and pearlite, as illustrated in Figure 3, whereas in the USIRW550 pearlite is replaced by bainite as a result of the lower coiling temperature used after hot rolling.

Table I. Hot rolled microalloyed steels produced by Usiminas for car wheels: typical chemical composition and mechanical properties.

Grade	Chemistry (mass %)		Typical mechanical properties		
	Ceq	Nb	YS (MPa)	TS (MPa)	EL(%) GL = 50mm
USIRW340	0.16	-	300	420	37
USIRW450	0.19	0.023	400	500	32
USIRW550	0.31	0.033	515	595	26

Ceq = C + Mn/6 + Si/4



(a) USIRW340 (b) USIRW450 (c) USIRW550

Figure 3. Typical microstructure of hot rolled high strength steels produced by Usiminas for the fabrication of car wheels.

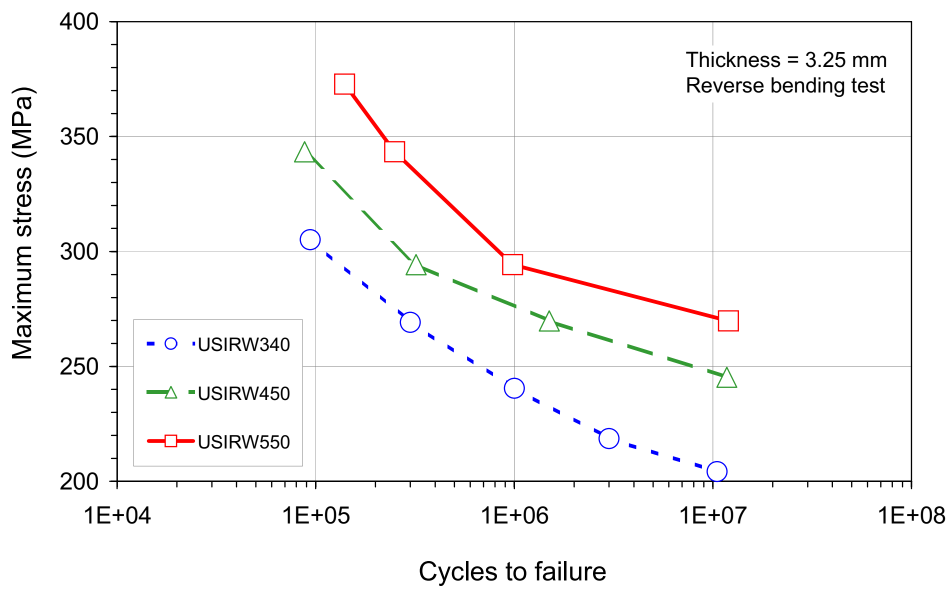


Figure 4. Fatigue behavior of hot rolled high strength steels produced by Usiminas for the fabrication of car wheels.

These grades were developed between the mid 1980's and the early 1990's, following the demand for higher strength steels in order to reduce the weight of the wheels. The use of RW550 instead of RW450 or RW340 in the discs of different wheels of domestic cars, for instance, has allowed thickness reductions of 5% to 8.5% and 10% to 12%, respectively, with significant weight savings of the whole vehicle as a consequence [6]. Another advantage of the introduction of these high strength steels is that this thickness reduction does not result in a decrease in safety. This advantage is because higher strength steels also exhibit higher fatigue resistance, as shown in Figure 4 for laboratory stress controlled tests and confirmed by fatigue tests in wheels [6,8-10].

Further weight decreases shall be feasible with the use of a 780 MPa tensile strength grade steel presently under development at Usiminas for application in discs and rims. This steel has a microstructure formed by a fine-grained ferrite matrix with martensite islands and a dispersion of microalloying precipitates. According to partial results, this microstructure results in an excellent combination of high strength with good ductility and hole flangeability besides the good weldability and high fatigue strength.

Cold Rolled Microalloyed Steels

Conventional Microalloyed High Strength Steels.

After the start up of the continuous annealing lines (CAPL and CGL), Usiminas expanded its portfolio of products increasing the availability of conventional Nb and/or Ti microalloyed steels. Table II presents the group of microalloyed conventional high strength steels produced by Usiminas distributed by strength levels. The main microalloying elements used, typical mechanical properties and some usual applications are also presented.

Table II. Conventional microalloyed high strength steels, typical mechanical properties and some applications.

Grade	Chemistry (mass %)			Typical mechanical properties						Coating	Some apllications
	Ceq	Nb	Ti	YS (MPa)	TS (MPa)	EL(%) GL=80 mm	r(bar)	n	BH (MPa)		
ZStE220i	0.07	-	0.015	240	340	39	1.12	0.19	-	CR/EG	Door outer
ZStE260i				280	380	35	1.10	0.17	-	CR/EG	Bonnet outer
ZStE260	0.09	0.015	-	295	400	34	1.10	0.17	50	CR/EG	Rail parts
				300	390	34	-	-	-	GI/GA	
ZStE300	0.13	0.023	-	330	440	28	1.15	0.15	48	CR/EG	Reinforcements parts, bumper inner, B pillar reinforcement, rail parts
				325	415	32	-	-	46	GI/GA	
ZStE340	0.18	0.033	-	400	500	27	1.02	0.14	46	CR/EG	Bumper inner reinforcement
	0.23	0.030	-	385	485	28	-	-	-	GI/GA	
ZStE380	0.29	0.033	-	420	540	26	-	-	-	CR/EG	Floor pannel reinforcement
	0.28	0.030	-	440	540	25	-	-	-	GI/GA	
ZStE420	0.29	0.033	-	460	580	22	-	-	-	CR/EG	Reinforcement wind shield cross member
	0.28	0.030	-	460	565	22	-	-	-	GI/GA	
ZStE480(1)	0.36	0.033	-	540	620	19	-	-	-	CR/EG	Floor rail where seats are fixed
ZStE550	0.38	0.040	-	630	720	16	-	-	-	CR/EG	

(1) Not specified in SEW. Customer requirements.
Ceq = C + Mn/6 + Si/4
CR/EG = cold rolled/electrogalvanized; GI/GA = hot dip galvanized or galvannealed.

Notwithstanding the great availability of strength grades, the automotive market has concentrated its demand basically on the ZStE340 steel grade, which corresponds to around 60% of all conventional cold rolled microalloyed steels, electrogalvanized or hot dip galvanized, produced by Usiminas. The remaining production is approximately equally distributed among the other grades. Figure 5 presents the evolution of conventional microalloyed high strength steels production at Usiminas to supply part of the domestic automotive demand.

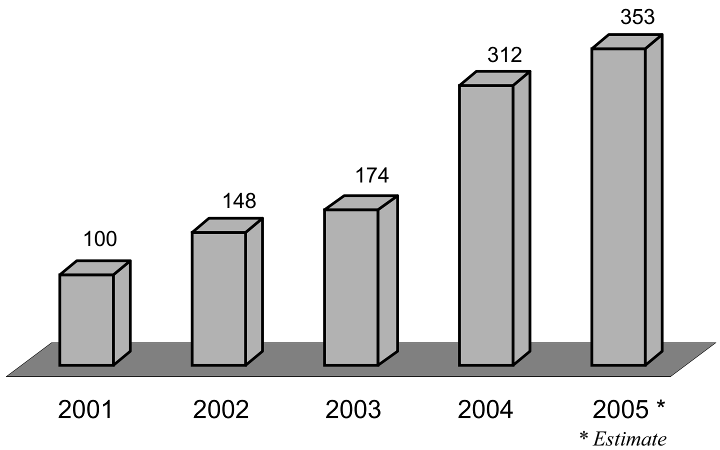


Figure 5. Production evolution of Usiminas concerning microalloyed high strength conventional steels. The year 2001 is taken as initial reference.

Development of 700 MPa Conventional Microalloyed Steel Grade.

Notwithstanding the high strength classes of conventional microalloyed steels, as shown in the Table II, cover a great strength range, the market has demonstrated interest for superior grades, specifically the 700 MPa, to be applied in floor rail parts where the seats are fixed.

Ongoing experiments for the development of this steel grade have demonstrated the impossibility of attaining such required strength level through the conventional strengthening mechanisms provided by microalloying elements (second phase precipitation and grain refinement), asking for the necessity of an additional mechanism, the partial recrystallization, to meet customer requirements, Figure 6.

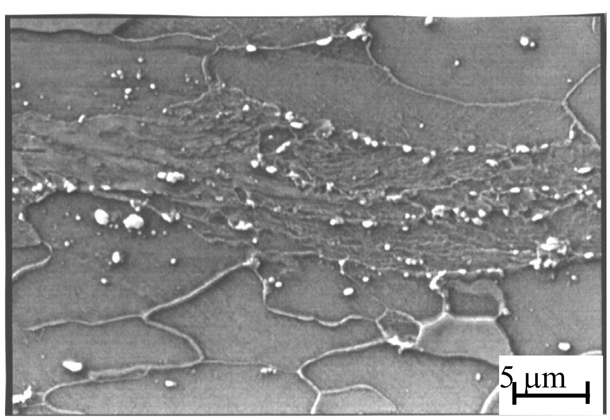


Figure 6. Microstructure of microalloyed 700 MPa steel grade showing non-recrystallized regions (Nital 4%).

Table III presents the chemistry and mechanical properties obtained in preliminary studies for the development of 700 MPa steel grades.

Table III. Preliminary results of microalloyed 700 MPa steel grade.

Ceq	Nb	Ti	YS (MPa)	TS (MPa)	El (%) GL=80 mm
0.25	< 0.05	< 0.1	747	794	13

Ceq = C + Mn/6 + Si/4

Microalloyed Advanced High Strength Steels

Microalloyed advanced high strength steels are those materials whose strengthening is basically determined by non-diffusional austenite transformation. Although, in certain specific cases where ultra high strengths are involved, the strengthening provided by phase transformation is not enough to provide the strength level required and an additional mechanism becomes necessary. This can be done by microalloying elements, which provide ferrite strengthening and grain refinement. The main Usiminas steel products developed making use of these steel concepts designs are shown on Table IV including some applications.

Table IV. Microalloyed advanced high strength steels.

Grade	Chemistry (mass %)			Typical mechanical properties					Some apllications
	Ceq	Nb	Ti	YS (MPa)	TS (MPa)	AL (%) GL=80mm	n	BH (MPa)	
DP60K	0.34	0.018	-	380	660	25	0.15	60	Side rail parts
DP100K	0.6	-	0.03	580	1050	15	0.145	50	Door guard bar, tunnel reinforcement, rail reinforcement parts

Ceq = C+Mn/6 + Si/4

These new products have just started to be used by the automotive industry as demonstrates in Figure 7 where the evolution of Usiminas production is presented.

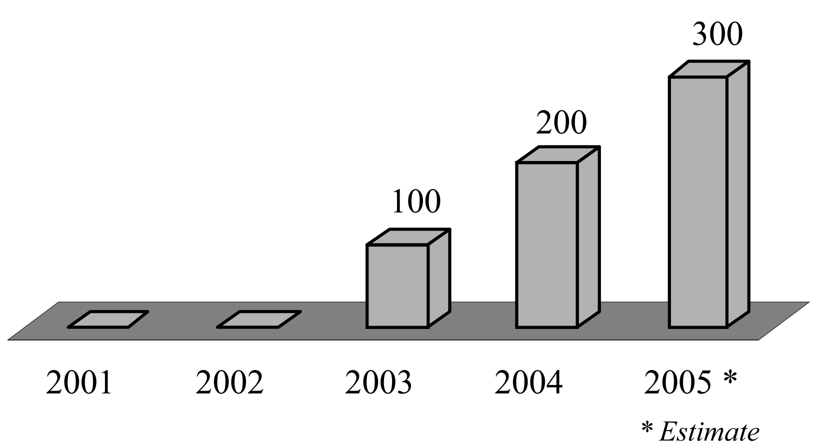


Figure 7. Production evolution of domestic market concerning microalloyed advanced high strength steels supplied by Usiminas. The year 2003 is taken as initial reference.

Microalloyed Extra Low Carbon Steels

This series is dedicated to microalloyed extra low carbon steels, including interstitial free steels IF, specified for difficult forming operations, extra low carbon steels, which combine high strength and ductility and the bake hardenable steels. Table V presents the steels included in this series distributed by strength level. The alloy design concepts involved, typical mechanical properties and some applications are presented as well.

Table V. Microalloyed extra low carbon steels.

Grade	Chemistry (mass %)			Typical mechanical properties						Coating	Some apllications
	C (ppm)	Nb	Ti	YS (MPa)	TS (MPa)	EL(%) GL=80 mm	r(bar)	n	BH (MPa)		
EDDQ/DC06	18	-	0.06	155	300	47	2.1	0.24	-	CR/EG	Rear quarter inner and outer, floor, wheelhouse, door inner, bonnet inner, deck lid inner
	16	0.15	0.20	157	300	44	1.8	0.23	-	GI/GA	
ZStE180BH	20	0.01	-	210	330	43	1.8	0.22	47	CR/EG	Bonnet, door outer, deck lid outer, roof, fender
	20	0.01	-	210	335	41	1.7	0.22	46	GI/GA	
ZStE220BH	20	0.01	-	230	345	39	1.7	0.22	48	CR/EG	Rail parts, rail reinforcements, wheelhouse, A pillar reinforcement
	20	0.01	-	235	345	40	1.6	0.21	48	GI/GA	
ZStE220P	25	-	0,025	255	390	37	1.8	0.20	-	CR/EG	Pick up floor of luggage compartment
	21	-	0,025	250	390	37	1.7	0.22	-	GI/GA	

Although Usiminas is capable of supplying a vast range of IF steels the automotive industry has placed emphasis on three grades: steels with yield strength of 150 MPa for applications which demand superior formability, steels with yield strength of 220 MPa for higher resistance, and bake hardenable steels with yield strength of 180 MPa.

Figure 8 illustrates the production of microalloyed extra low carbon steels by Usiminas along the last six years and the preference by domestic automotive industry for the different alloy designs.

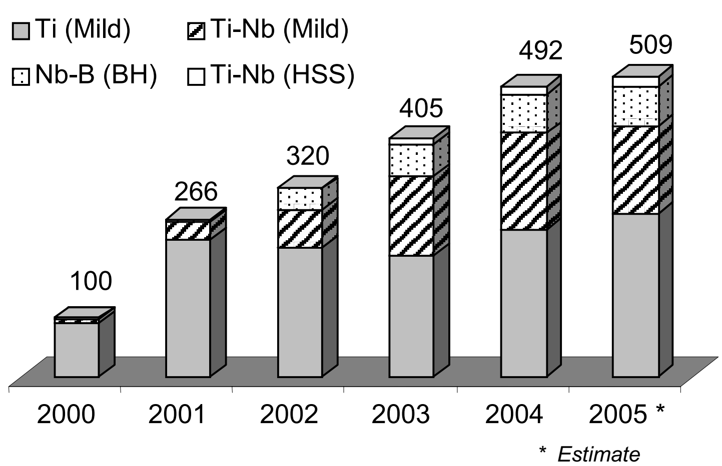


Figure 8. Production evolution and preferred alloy concepts of domestic market concerning microalloying extra low carbon steels supplied by Usiminas taken the year 2000 as initial reference.

Microalloyed Isotropic Bake Hardenable Steels.

Although the demand for a determined material quite always follows the carmakers specifications, in certain circumstances the search for cost reduction determines the necessity of looking for alternative lower cost materials, which are able to substitute the old material with no compromise of vehicle integrity.

Work done to compare the performance of bake hardenable and isotropic steels of similar mechanical resistance, in the production of a cover panel, showed a behavior very close to that schematically illustrated on Figure 9.

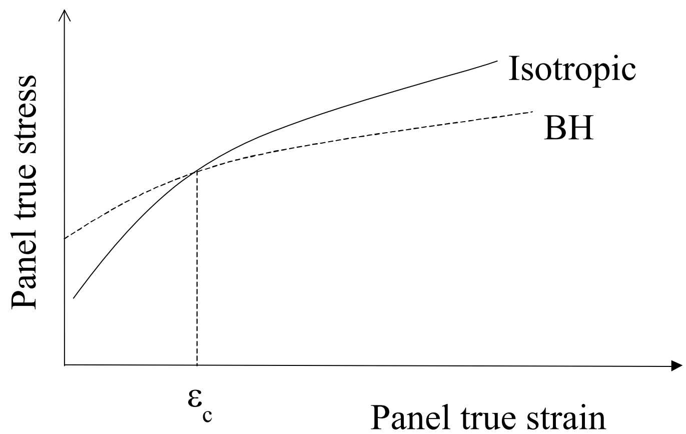


Figure 9. Isotropic and bake hardenable steels behavior as a function of panel true stress and strain. Stress values of bake hardenable steel include BH values [11].

Figure 9 shows the existence of a critical strain ε_c, below which panels produced using the bake hardenable steel presents improved mechanical resistance, which is due to the bake hardening effect. For strains higher than ε_c, stiffer panels are obtained using isotropic steel due to its superior cold work hardening. As could be seen, the better performance of a specific steel is dependent on the amount of strain applied. Considering that, in the major automotive panels, the strain is not homogeneous and could vary to a large extent depending on the panel region, a steel was developed that joins bake hardenability and isotropy in the same material. The new product, called IsoBH, presents similar behavior as the isotropic steel concerning work hardening and resistance increases due to strain aging. The chemistry and mechanical properties of the IsoBH steel are presented on Table VI.

Table VI. Chemical composition (mass %) and mechanical properties of the IsoBH steel.

C	Ti/N	YS (MPa)	TS (MPa)	EL(%) GL=80mm	r(bar)	Δr	n	BH (MPa)
0.020	6	241	346	37	1.1	0.02	0.23	36

Final Remarks and Trends

Microalloyed steels constitute an important group of materials available for the automotive industry. They attend applications ranging from those, which involve complex forming operations up to the ones where high resistance is required, including those where a compromise between high resistance and ductility is necessary. This variety of options and flexibility make microalloyed steels indispensable to the present and future vehicle projects.

Usiminas, as the major domestic steel supplier for the Brazilian automotive industry and as an important player of the international market has today a large flexibility concerning microalloyed steels in its product portfolio, being able to meet most of the requirements from this important economical segment.

In the last few years, the results of the ULSAB program and stringent environmental policies have determined an increased consumption of high strength steels, particularly the Advanced High Strength Steels. Following this trend, Usiminas has recently concentrated its research effort in the development of these steels whose microstructures and mechanical properties may also be optimized by the consistent use of microalloying elements.

References

1. Ultra Light Steel Auto Body – (ULSAB) – Final Report, AISI, May (2001).
2. www.ulsab.org.
3. J. F. B. Pereira and L. C. O. Meyer, "Present Situation and Perspectives of IF Steels in Brazil" International Forum for the Properties and Applications of IF Steels, ISIJ, Tokyo, Japan, May, 2003, 47 – 52.
4. M. Mizui, and M. Takahashi, "High Strength Steels for Automotive Wheels", *ISS 33rd MWSP Conference*, St. Louis, USA, October, 1991, 31-38.
5. P. Teracher and G. Marron, "Application of High-Strength Hot Rolled Steels in Wheels", *Proc. of High-Strength Steels for Automotive Symp.*, 1994, 27-36.
6. G. Rigaud, and G. Marron, "Light-weight Automobile Wheels", *La Revue de Métallurgie-CIT*, November, 1997, 1413-1423 (in French).
7. L.C.O. Meyer et al., "Development of Ferrite-Bainite Steels for Automotive Wheel Applications", (Paper presented at the XXXII ABM Rolling Seminar, November, 1995, Curitiba, Brazil) (in portuguese).
8. M.V.G. Souza et al., "Development of Ferrite-Martensite Dual Phase Steel for Application in Wheels", (Paper presented at the XXXIV ABM Rolling Seminar, Processes Rolled and Coated Products, August, 1997, Belo Horizonte, Brazil) (in Portuguese).
9. T.M.F. Melo, A.P. Souza and M.V.G. Souza, "Fatigue Strength of Steels for Automotive Wheels", (Paper presented at the 53rd ABM Annual Congress, September, 1998, Belo Horizonte, Brazil) (in portuguese).
10. S. Hashimoto and M. Sudo, "Development of Nb Added Ferrite-Bainite Steels and their Application to Wheels", *SAE International Congress and Exposition*, 1982, 1011-1020.
11. M. Morita, N. Kurosawa and N. Aoyagi, "TS 540-780 N/mm^2 Grade Hot-Rolled Steel Sheets with Good Formability and High Fatigue Strength, 'RHA 540 DH-RHA 780 DH'", Kawasaki Steel Technical Report, No 34, March, 1996, 32-33.
12. J. F. B. Pereira and R. O. Rocha, "Development of bake hardening isotropic steel", ABM, 42nd Rolling Processes, Rolled and Coated Products Seminar; October, 2005, Santos, Brazil (in Portuguese).