# NIOBIUM BEARING STEELS IN THE AUTOMOTIVE INDUSTRY

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**Abstract**

This paper reviews the applications of niobium bearing steels for the automotive and heavy transport industries and assess the challenges that face the steelmaker particularly with respect to the on going use of niobium in the future when there is little doubt that a larger volume of even higher strength steels will be required. Consideration is given to the application of niobium bearing ultra-low carbon, interstitial-free (ULC IF) steels, and niobium as an addition in micro-alloyed and advanced high strength steels. The future challenge facing the steel/auto partnership is reviewed relating to the introduction of advanced steel products, especially modern high-strength steels with improved properties such as the new multiphase steels, which will gain more and more importance in the future. In the case of these new steels, the role of microalloying elements such as niobium is discussed, from which it is considered to play an important role in future steel developments.

## Introduction

For more than a decade the international steel industry has worked in close partnership with leading automotive design and material experts to respond to the challenges posed by the pace of change within the automotive market. The competitive pressures to offer attractive guarantees against corrosion not only had a major impact on strip steel manufacturing but focussed even more attention on surface quality and other styling related issues, some of which had an important influence upon the forming and fabrication processes traditionally used by the automakers.

The demands for consistently high quality, continuously coated, deep drawable steels set the trend for product development initiatives throughout the early 1990's. Competitive pressures also focussed attention on light-weighting initiatives promoted initially by the aluminium producers. This in turn led to the formation of steel industry consortia and collaborative projects aimed at establishing cost-effective light-weighting autobody structures, the first and most popular being the Ultra Light Steel Auto Body (ULSAB) project. This project helped convince materials specialists and production managers in the automotive sector that lightweighting and performance targets could be achieved using higher strength steels in combination with innovative design and modern manufacturing processes.

These drivers to upgrade quality and performance, and to manage costs continue today with even greater emphasis now being placed upon passenger safety, dynamic performance, control of emissions and other environmental concerns. These new challenges to steelmakers are being addressed in the latest Consortium project – ULSAB/Advanced Vehicle Concepts (AVC).

Previous papers presented at this International Symposium have considered in depth the processing and metallurgy of niobium bearing steels that have been and continue to be used to meet these severe challenges. The aim of this paper is to review the applications of these products and assess the challenges that face the steelmaker particularly with respect to the on going use of niobium in the future when there is little doubt that a larger volume of even higher strength steels will be required.

The following sections of this paper consider the application of niobium bearing ultra-low carbon, interstial-free (ULC IF) steels, niobium as an addition in micro alloyed and advanced high strength steels and reviews the future challenge facing the steel/auto partnership.

## Development and Application of ULC Steels

The rapid growth in the development and application of ULC steels for autobody construction is one of the best examples of supplier response to a rapidly changing market requirement. The inherently variable quality of aluminium-killed, batch-annealed steels challenged the ability of steelmakers to respond to the need for zinc or zinc alloy coated steels that met customers requirements with respect to corrosion resistance coupled with the necessary surface finish and formability. Electro-galvanised strip steels were specified for many surface critical applications but high processing costs were a problem and the soft zinc or zinc/nickel coating could be the cause of concern during fabrication or use.

The market demanded a range of continuously processed hot dip zinc coated steels that offered an attractive combination of excellent formability, first class surface finish and trouble free weldability, coupled with the corrosion protection needed to promote the end product in the showroom. Major strip steel suppliers to the automotive sector responded by massive investment in steelmaking, processing and continuous coating facilities, focussing upon a commitment to supply a range of highly formable ULC steels.

The successful development and widespread use of ULC steels however, has been possible only as a consequence of the in-depth understanding of the steelmaking and strip processing methods to allow the cost-effective manufacture of the range of products presently available to and used in autobody construction.

Taking the metallurgical basics, which have been covered in earlier presentations, for granted, the detail most relevant to the present audience relates to the understanding of the roles of titanium and niobium to stabilise nitrogen and carbon in ULC steels. Of particular interest is the established preference to use a dual stabilised composition when manufacturing galvannealed, bake hardenable or higher strength ULC steels.

Most major producers of ULC IF steels offer a range of highly formable titanium and titanium/niobium stabilised products and additionally higher strength grades which usually feature the addition of manganese, phosphorus, silicon or boron as solid solution strengthening elements to provide strip with 0.2% proof stress levels of up to or even higher than 300MPa (1). The influence of strengthening elements on mechanical properties has been reviewed by Engl and Gerber (2) and their summary is reproduced in Table I. An increasing number of manufacturers are also supplying titanium/niobium ULC bake-hardening grades normally with proof strengths up to 260MPa.

Table I Results of regression calculations illustrating influence of key elements on solid solution strengthening of IF steels (Engl & Gerber (2))

| Element | Unit | Yield Strength (MPa) | Tensile Strength (MPa) | Uniform Elongation (%) | Total Elongation (%) |
|---|---|---|---|---|---|
| C | 0.001wt% | 2.3 | 1.9 | -0.25 | -0.26 |
| Si | 0.1wt% | 9.7 | 13.3 | -0.52 | -0.85 |
| Mn | 0.1wt% | 2.7 | 3.4 | -0.28 | -0.34 |
| P | 0.01wt% | 3.5 | 7.1 | -0.38 | -1.2 |
| B | 0.001wt% | 8.0 | 4.2 | -4.42 | - |

One of the clearest demonstrations of the benefits of titanium/niobium stabilised IF steels was reported by Carless *et al*. (3) who had investigated the influence of cold-rolled surface texture of both titanium and titanium/niobium ULC strip on the development of the FeZn phases during the continuous galvannealing process. Surface texture was found to have little or no influence but they did show that substrate chemistry controlled the initial reactivity in the galvanising bath and had a significant influence on the consequent development of the FeZn phases during the galvannealing cycle. Using a Rhesca Hot-Dip Simulator they observed that in the titanium steels initial phase growth in the pot was dominated by the formation of outbursts with the bulk of the structure being the ($\delta$) phase. In contrast the titanium/niobium strip was found to be less susceptible to outburst behaviour and produced a thin continuous layer of ($\varsigma$ and $\delta$) crystallites. This was also linked with a slightly faster alloying reaction in the titanium strip as illustrated in Figure 1. This in turn would tend to produce a thicker ($\Gamma$) phase.

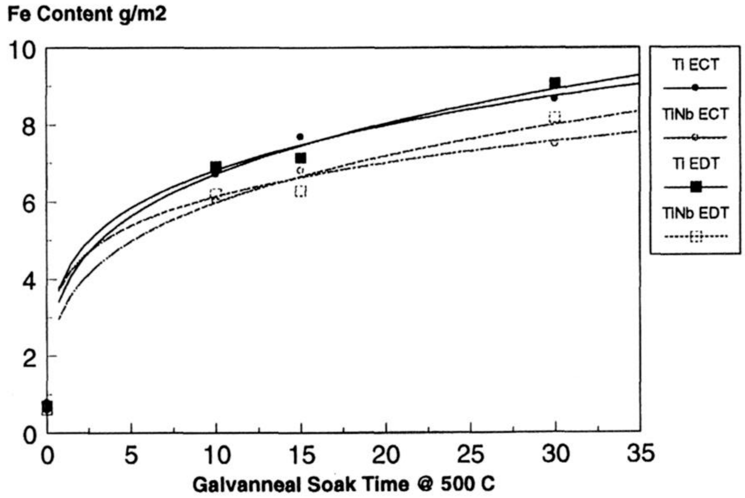


Figure 1: Influence of soak time on alloying kinetics of titanium and titanium/niobium ULC IF steels (Carless *et al.*).

After completion of the galvannealing treatment both steels showed a much increased level of surface roughness with the titanium/niobium strip being significantly rougher than the titanium only product. The authors relate this to an increase in crater density in the titanium/niobium strip, which is, in turn, a consequence of crystallographic differences and the dominance of the preferred {111} orientation. Furthermore the adhesion of the coating to the substrate as measured by the lap shear test confirmed that the titanium/niobium product had consistently higher interfacial shear strength as illustrated in Figure 2.

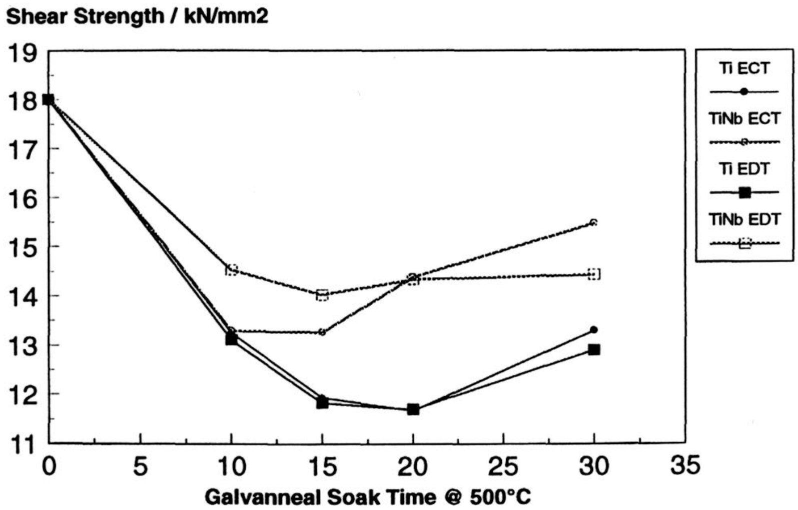


Figure 2: The effect of soak time on interfacial strength (Carless *et al.*).

The titanium/niobium variant also exhibited a higher proportion of FeZn phase remaining attached to the surface after testing. The authors suggest this could be explained by a reduction in the brittle (L) phase at the interface or be related to crystallographic texture as previously mentioned. Either way the end result is an impressive reduction in the susceptibility to powdering of the coating of the titanium/niobium steel as summarised in Figure 3.

It is very much as a consequence of work of this nature that the steel industry has been able to produce such a range of highly formable ULC steels to meet the very demanding quality requirements for outer body panels. In these circumstances yield or tensile strength is of relatively little importance although the desire to keep mass to a minimum encourages the consideration of the use of thinner gauge higher strength steels where the challenge is always to balance gauge reduction with adequate resistance to oil canning and denting. This trend has focussed attention on the more recent development of the current range of bake hardenable ULC steels.

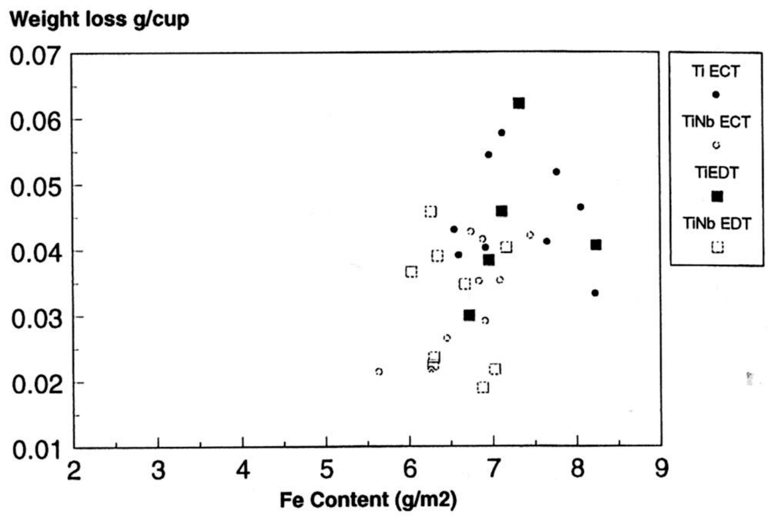


Figure 3: Powdering performance of titanium and titanium/niobium ULC strip (Carless *et al.*).

Over the past three years the attention of the steelmaker has turned more to the future as the ULSAB Advanced Vehicle Concepts (AVC) Project attempts to anticipate and respond to the demands that will face the Automotive Design Engineer in the decade that starts in 2004. The AVC programme embraces a range of critical issues that have to be resolved so that the personal freedoms we enjoy today can be preserved for the future in a manner that addresses the concerns of society. Consequently the AVC programme will deliver steel based concepts for the car of the future that will:

- meet or surpass future safety requirements
- retain the current level of affordability
- be fuel efficient and meet proposed $CO_2$ pollution control levels
- retain the environmentally friendly image of steel.

The final results of the AVC programme will be published early in 2002 but information that has already been released has emphasised the importance of design innovation and structural efficiency (4-9). So far as this paper is concerned the two most important factors are the use of computer aided design and performance simulation and the inevitable increase in the use of higher strength steels that is being proposed. Whilst the latter subject will be addressed in the following part of this paper, the relevance of the former point may require some elaboration here.

The beneficial influence of a higher rate of strain causing an increase in the strength of steels is well appreciated. An analysis of what real benefit would accrue from the use of dynamic properties was performed by computer simulation using the original body structure from the first ULSAB project. Simply using the appropriate dynamic properties in computer analysis it was demonstrated that this steel intensive structure was more crash resistant than convention suggested (10). Clearly a design that is optimised to take full advantage of the strain rate hardening behaviour of steels will provide the steel/auto partnership with a highly valued opportunity in the coming years. The results of the AVC project will provide a good example of what can be achieved.

For the moment it is interesting to note one or two key factors that relate to the future choice of steel grade for a crash sensitive component of a vehicle. Marsh *et al*. (11) clearly demonstrated the potential for the use of ULC IF steels and has shown that the low strength and high work hardening capacity of these products is conducive to the promotion of stable folding modes of structural collapse that absorb large amounts of energy in a crash situation. The extent of strain rate induced strengthening is not so significant when the notional static strength level is increased.

It thus appears that the research and development into steels for autobody construction has not yet provided all the answers and needs to consider some new questions! The high work hardening characteristics of the advanced dual phase high strength steels that feature so prominently in the ULSAB AVC Project (9) could be very advantageous. Even so it may be that the performance of titanium/niobium ULC steels may be hard to match!

## Development and Application of Microalloyed and Advanced High Strength Nb-bearing Steels

Hot-Rolled Microalloyed Steels

Figure 4 shows the development of hot-rolled and cold-rolled steels during recent years (12). Microalloyed steels were developed more than 20 years ago (13). By using the micro-alloying elements niobium, vanadium and titanium in combination with control of temperature during hot rolling, it was possible to obtain high strength steels with properties significantly superior to those of structural steels known previously. Chiefly the mechanisms of grain refinement and precipitation hardening were used to increase the strength of these steels. The carbon content usually remained less than 0.12% so that the carbon equivalent, which is important for the weldability, can be kept low even with yield strengths greater than 355MPa. In combination with thermomechanical rolling, this made it possible to obtain hot-rolled steels with minimum yield strengths of up to 700MPa. Steels in the normalised condition also benefit from the afore-mentioned microalloying elements. They are available today with minimum yield strengths of up to 420MPa.

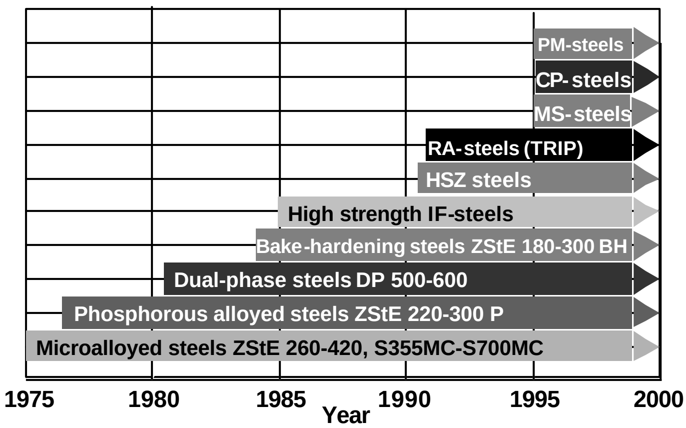


Figure 4: Steel development over time.PM - partially martensitic; CP - complex phase; MS - martensitic;RA - residual austenite; TRIP - transformation-induced plasticity;IF - interstitial-free.

These too are usually produced today by rolling with controlled temperature, so that additional heat treatment is no longer necessary. Significantly better surface qualities are possible by avoiding heat treatment. Subsequent normalising annealing or hot working does not significantly modify the mechanical properties of these steels, whereas such heat treatment is not possible with thermomechanically rolled steels because it would result in a significant loss of strength. Soon afterwards the concept of microalloyed steels started to be used also for producing cold-rolled steels. The recrystallising annealing process leads to the loss of a large part of the hardening potential, therefore the achieved yield strengths of 420 and 460MPa are somewhat lower than those of hot-rolled steels. In the course of the following years, steel development was primarily concerned with improving the combination of strength and formability, whereby the recently developed multi-phase steels, which will be considered later in more detail, play a special role. Niobium can be used to advantage for these steels too. In the course of time microalloyed steels have become established as important materials in the automotive industry, and their advantageous properties are now proven in numerous applications (Figure 5).

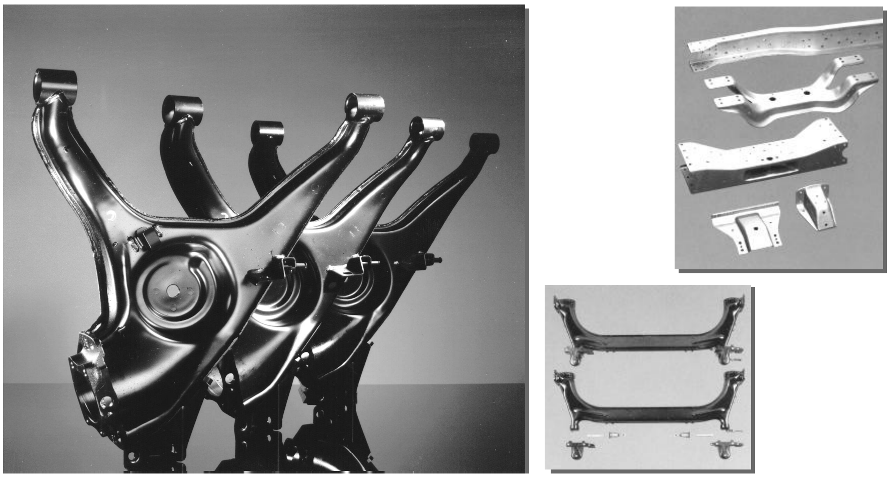

Figure 5: Application examples for hot-rolled microalloyed steels.

Although the concept has been known for more than 25 years, further development of the production conditions and chemical composition of these steels has continued. Primary attention was thereby given to reducing the scatter band of the mechanical properties in order to relax the processing conditions. For example, the scatter band of the mechanical properties of a QStE500TM steel can be halved by changing the alloying concept from niobium/titanium to niobium/vanadium. This is attributed to the fact that vanadium is considerably less sensitive to fluctuations in the rolling temperature, compared with titanium (14-15) (Figure 6).

Niobium delays recrystallisation, thus permitting thermomechanical rolling with the resulting fine-grained microstructure of thermomechanically rolled steels. However, niobium also delays grain growth during austenitising. This positive effect can also be used for heat-treated steels to improve their mechanical properties.

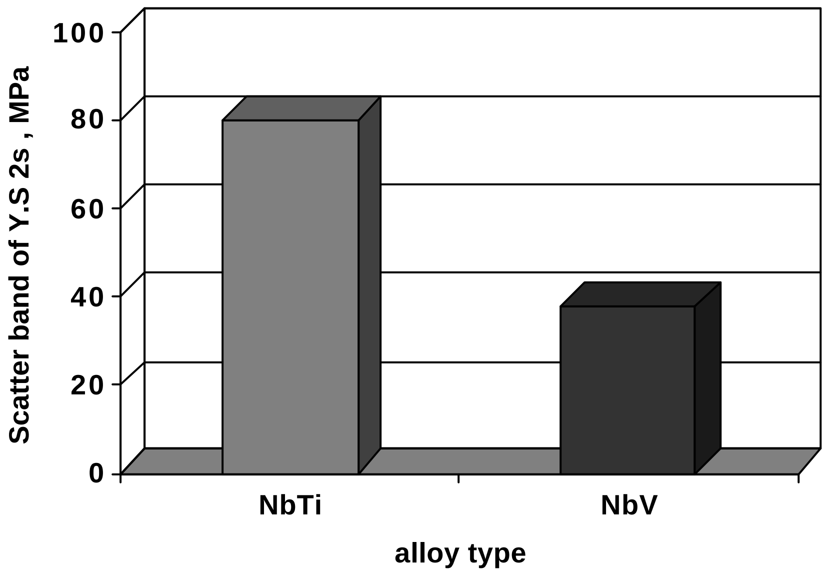


Figure 6: Reduction in the scatter band of Y.S. in the case of StE500TM.

## Quenched and Tempered Fine-grained Structural Steels

Fine-grained structural steels have a wide range of applications in modern utility vehicle and mobile crane construction by virtue of their excellent forming properties. The utility vehicles used in the various fields of materials handling technology and transportation, such as trucks, tank vehicles, mobile cranes and trough dumping trucks must fulfil specific requirements for their respective tasks. Fine-grained structural steels are frequently used in particularly important places such as the side members and cross beams for trucks, rear axle casings, frames, supports and struts, structural pipes, tank vessels and for components of mobile cranes, such as underframes, live rings and telescopic jibs. By exploiting the specific steel advantage of high strength combined with excellent processability makes possible to have constructions which have high load capacity combined with a favourable ratio of useful load to dead weight. The highest strength and toughness parameter demands, in particular for large plate thicknesses, are fulfilled by quenched and tempered fine-grained structural steels. Today steels with 690 to 960MPa, recently also with 1100MPa minimum yield strength, are of the greatest importance. The high strength of these steels permits material and production costs savings by reducing wall thickness. The reduced dead weight of the structure can reduce the operating costs of transport vehicles. In many cases particular constructions are only possible by utilising high strength steels. Figure 7 shows a typical application.

The chemical composition, shaping and heat treatment of quenched and tempered steels are adjusted such that the minimum yield strengths can be guaranteed. The final microstructure of these steels consists of martensite and fine-grained bainite. With increasing plate thickness it is necessary to use alloying elements such as manganese, molybdenum, nickel, vanadium and boron in order to obtain a suitable microstructure giving the required material properties in the plate core too. Such a microstructure, which has an extremely fine-grained substructure with finely dispersed precipitated carbides, possesses a good combination of strength, toughness and deformation capacity.

800t max. lifting capacity
134m max. lifting height
104m max. radius
96t total weight (without telescopic boom)

Figure 7: XABO 960 / mobile crane LTM 1800 of the company Liebherr.

The alloying element boron in the dissolved state has a key role with regard to achieving good full quenchability and temperability. However, no increase in hardenability can be expected if the boron present in the steel is chemically bound in the form of boron nitrides and boron carbides. The favourable effect of small quantities of boron on the hardenability of quenched and tempered steels makes possible partial replacement of expensive alloying elements such as Mo, Cr and Ni. To achieve the full benefit of the hardenability increase associated with the presence of boron, nitrogen is usually almost completely and stably bound by titanium, so that boron is present practically only in the dissolved form (Figure 8). However experience has shown that the toughness properties are negatively affected by the precipitation of titanium nitride. This can be avoided by using niobium instead of titanium, since effective protection of boron against nitride formation can also be achieved with niobium.

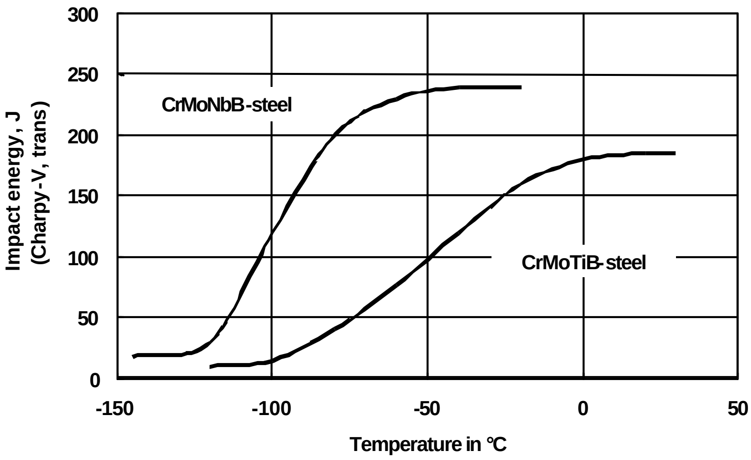


Figure 8: Toughness properties of a quenched and tempered StE690.

## Wear-resistant Fine-grained Structural Steels

Plates of wear-resistant special structural steels having minimum hardness up to 600 HB are widely used for structures subjected to wear in utility vehicles construction such as truck troughbutts, or for components of mining and excavating machines. In these steels niobium is often used as an additional alloying element in order to obtain plates which combine high wear resistance combined with good toughness and perfect processing behaviour. Figure 9 shows typical applications for wear-resistant steels.

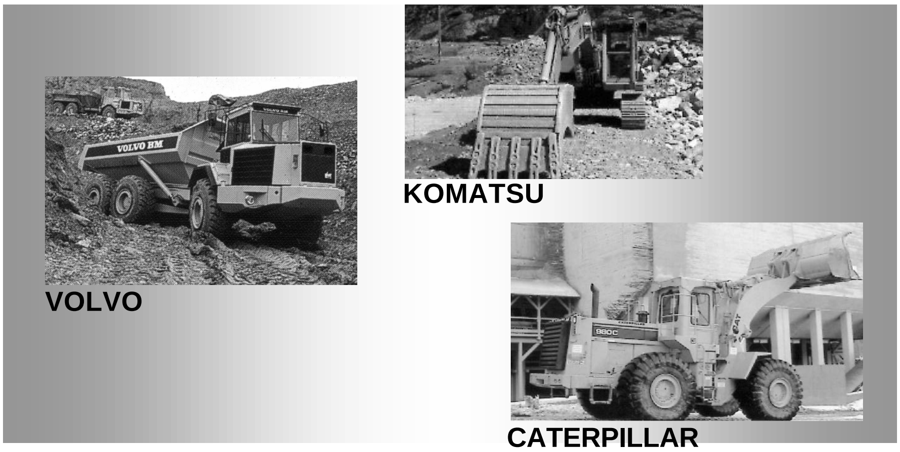


Figure 9: Application examples of wear resisting XAR-steels.

## Cold-rolled Microalloyed Steels

As already mentioned, microalloyed cold-rolled steels for mass production were still at a very early stage of development in the eighties. Whereas hot-rolled steels were utilised in numerous applications at that time, the equivalent cold-rolled steels were utilised only to a very limited extent. Therefore an extensive research project was carried out together with Porsche from 1979 to 1982 in order to determine the potential for microalloyed steels in light automotive construction (16). Cold-rolled steels in the yield point range from 275 to 420MPa and hot-rolled steels in the range from 355 to 520MPa were taken into consideration. Surface coated sheets were partly included in the investigations (Table II).

The example of the Porsche model 928 showed that a weight reduction of up to 20% could be achieved through the use of these high strength steels without loss of static strength. Further 17% of the weight, compared with mild steels, could also be saved if dynamic stress factors are included, such as encountered in a crash (Figure 10). The investigations also showed that microalloyed steels could be assembled using conventional welding procedures.

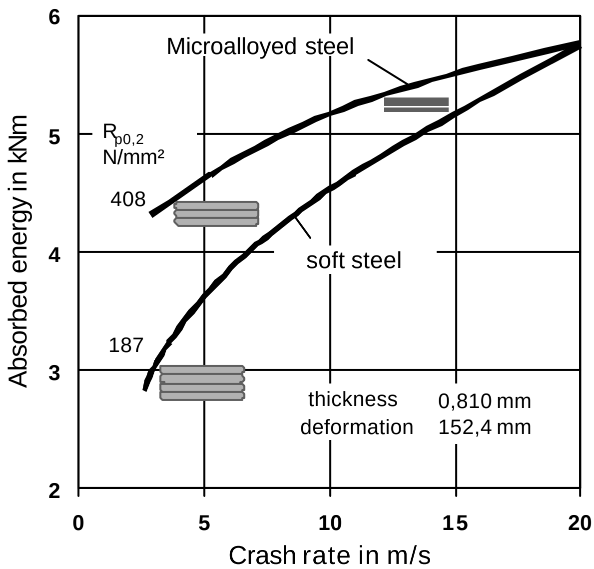


Figure 10: Crash – behaviour of microalloyed-steels in comparison to a mild steel.

Table II Steels used in VDEh – Porsche programme

| Sheet Thickness (mm) | Steel Type – Yield Strength in MPa | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | St14 | P275 | FeE275 …. 420-HF | | | FeE355 …. 560TM | | |
| | Cold-rolled Strip | | | | | Hot-rolled Strip | | |
| | < 210 | 275 | 275 | 355 | 420 | 355 | 420 | 560 |
| 4.00 | | | | | | ● | | |
| 3.40 | | | | | | | ● | |
| 2.50 | | | | | | ● | | ● |
| 2.00 | | ● | ● | | | | | |
| 1.75 | | ● | ● | ○ | ○ | | | |
| 1.50 | | ● | ● | ● | | | | |
| 1.25 | | ● | ● | ● | | | | |
| 1.00 | | ● | ○ | ● | ● | | | |
| 0.88 | | ● | ○ | ● | | | | |
| 0.80 | | ○ | ○ | | | | | |
| 0.75 | | ● | | | | | | |
| 0.70 | ○ | ● | ○ | | ○ | | | |
| 0.65 | | ● | ● | | | | | |
| 0.60 | ○ | ● | ○ | | | | | |

● Without coating ○ With and without coating EG, HDG, GA

| Steel type | %C ($10^{-3}$) | %Mn ($10^{-2}$) | %Si ($10^{-2}$) | % other ($10^{-2}$) |
|---|---|---|---|---|
| St14 | 39 – 56 | 21 – 24 | 2 – 3 | |
| P275 | 48 – 86 | 40 – 51 | 2 – 8 | Phosphorus = 7 – 9 |
| FeE275HF | 10 – 61 | 26 – 69 | 2 – 27 | Nb = 2 – 4; Zr = 0 - 11 |
| FeE355HF | 58 – 70 | 68 – 74 | 2 – 3 | Nb = 6 – 7 |
| Fe420HF | 68 - 76 | 80 - 92 | 35 - 39 | Nb = 6 – 8; Ti = 12 - 14 |

The Mercedes models W201[1982] and W124[1984] are an example of the utilisation of niobium microalloyed steels in serial production (17). Figure 11 shows the consistent utilisation of ZStE340 for structural components of the passenger cabin and the crash structure in the model W124 where in the latter it comprises 17% of the body structure.

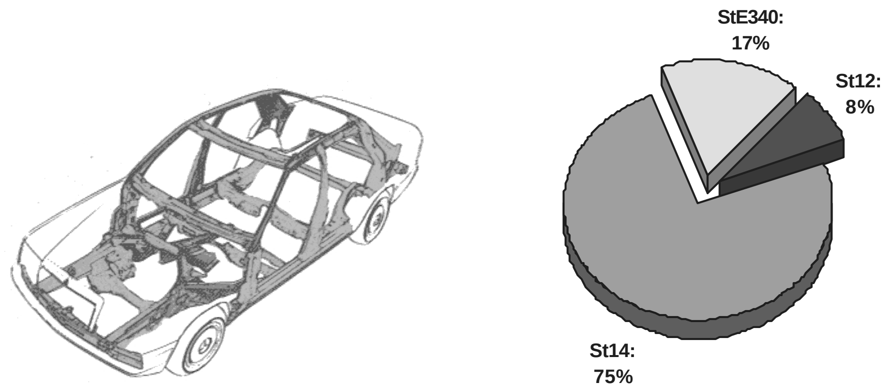


Figure 11: Use of microalloyed-steels in the Mercedes model W124.

An overview of the utilisation of higher strength steels in Europe in 1994 is summarised in Table III which was compiled from a market study. The contribution to the body structure ranges from 1 to 20 % depending on the manufacturer. Microalloyed steels are still used chiefly in structural components. One Japanese model at this time already had 46% of high strength steels

Table III Use of high strength steels in Europe 1994

| high strength steels in % of total sheets | | outer parts BH | outer parts M | outer parts R | structural parts BH | structural parts M | structural parts R |
|---|---|---|---|---|---|---|---|
| 1 | A | P | | | | ● | |
| 8 | B | ● P | | | | ● | |
| 9 | C | ●● LP | | | ● P | ● | ● |
| 3 | D | | ● | ● | | ● | |
| 17 | E | P | | L ●● | | ●●● | |
| 1 | F | P | | | | ● L | ● P |
| 6 | G | P | | | P ● L | | P ● L |
| 20 | H | P | | | | ●●● L | |
| 17 | J | | | | | ●● | ●● |
| 5 | K | P ● L | | | | ● P | ● P |
| | | | | | | | |
| 30 | M* | ●●● L | | | | | |
| 46 | N** | | | ●●● | | | |
| | O | P | | | | | ●●● |
| | P | P | | | | | |

BH = bake-hardening-steels
M = micro-alloyed steels
R = phosphorus-alloyed steels
L = serial production
P = trial production

● low amount
●● mean amount
●●● high amount

## Ultra Light Steel Auto-Body (ULSAB)

In 1994 an international consortium of 35 steel manufacturers commissioned Porsche Engineering Services, Inc., with the execution of the project mentioned above. The goal was to assist the automotive industry in the production of light, safe and cost-optimised bodies for weight-optimised vehicles.

On a cost-neutral basis, a weight reduction of 25% with improved structural properties was achieved. The basis for this success was the utilisation of higher strength steels available on the market and the utilisation of advanced production technologies such as tailored blanks, hydroforming, 3D laser welding and sandwich components. Of the 90% higher strength fraction, microalloyed steels constituted about 80%.

In 1999 a similar international consortium also commissioned Porsche Engineering Services to introduce the design and engineering work to develop advanced vehicle concepts that would increase the use of steels which would become commonly available by 2004 and beyond.

## Multi-phase Steels

As shown in Figure 4 steel development has concentrated on devising new high strength steels with good formability and shape retention. This has given rise to a new steel family, namely the so-called multi-phase steels (19-22). Microstructural hardening in particular is exploited here, apart from the known work-hardening mechanisms such as grain refinement, precipitation hardening and solid solution strengthening. By this means it is possible to cover a strength range from 500 to 1200MPa. Significant improvement of the formability compared with conventional steels was achieved in particular for dual-phase steels and residual-austenite phase (RA) (TRIP) steels. The available strength range of hot-rolled steels was dramatically extended by the use of both complex and martensite phase steels (Figure 12).

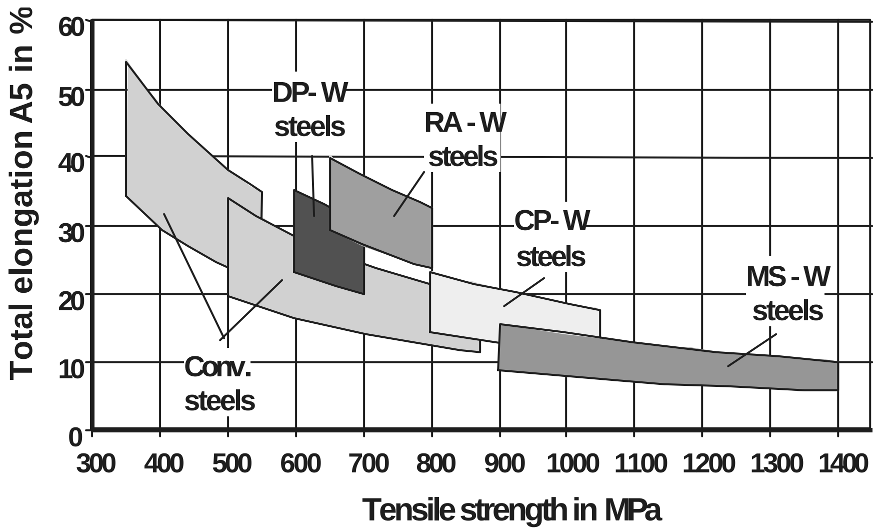


Figure 12: Mechanical properties of hot-rolled steels.

The specific properties of these steels are the result of the tailored combination of hard and soft microstructural components. Dual-phase (DP) steels have a basic ferritic matrix in which up to 15% of martensite is embedded as islands. The martensite fraction is increased up to 60% in the partial martensitic (PM) steels. This achieves significantly greater strength values. The special feature of residual-austenitic (TRIP) steels is a residual austenite content of 8-16% remaining in the microstructure, responsible for the unusually good shaping properties of these steels. The extremely fine-grained bainitic basic structure with embedded islands of ferrite and martensite, as well as precipitation hardening, are responsible for the very high strengths of complex-phase (CP) steels. The greatest strengths of all are obtained with the chiefly martensitic microstructure of the martensite-phase (MS) steels.

An interesting aspect is the very positive effect of niobium in hot-rolled dual-phase and residual-austenite (TRIP) steels. For example, with the same basic composition (CMnCrP), the addition of niobium produces significant grain refinement in DP-steel and therewith gives a strength increase of about 100MPa. In both cases a typical ferritic basic matrix with embedded martensite islands was obtained for the DP-steels.

For the residual-austenite (TRIP) steels also, the microalloying element niobium contributes in many ways towards the improvement in material properties. In principle, these effects can be grouped in two categories. Niobium in solid solution lowers the martensite starting temperature and thus gives a larger production window in the region of the coiling temperature. Furthermore, in dissolved form it suppresses carbide precipitation in the temperature range of bainite formation, with consequent increase in the residual austenite content and its carbon content, so that greater elongation parameters can be achieved. In precipitated form as carbide, nitride or carbonitride, niobium has a grain refining effect increasing the tensile strength. The tensile strength and yield strength are also further increased by precipitation in the ferrite. Furthermore, niobium suppresses undesired pearlite formation in TRIP-steels.

The acid-soluble fraction of the niobium, relative to the total niobium content in the alloy, corresponds to a first approximation to the fraction of niobium in solid solution. If this quotient is large, the fraction of niobium in solid solution is large too, so that the precipitated fraction is correspondingly small. Within the scope of laboratory rolling experiments it was found that the acid-soluble fraction increases with increasing total niobium content in the alloy (Figure 13).

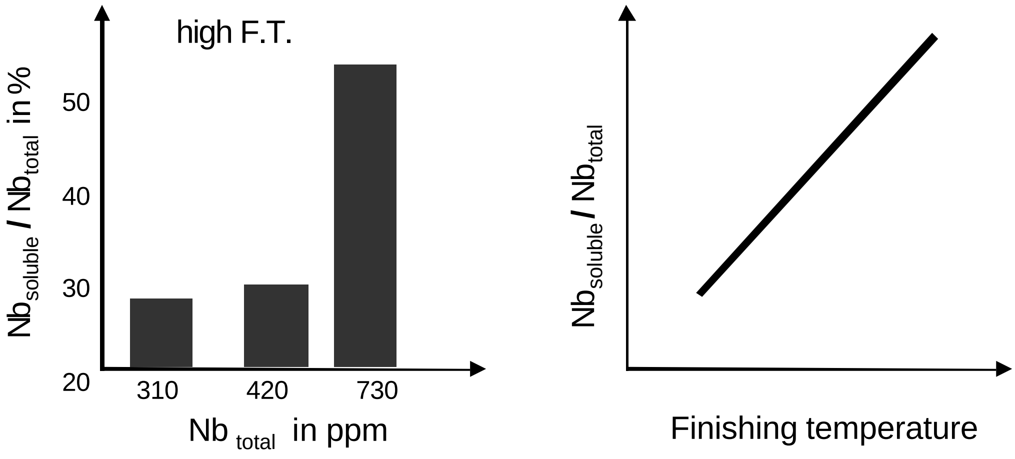


Figure 13: Precipitation behaviour of niobium in hot rolled retained austenite steels.

This phenomenon can be interpreted in the sense that the niobium content above a certain basic fraction remains predominantly in solid solution and is not precipitated. This reinforces the benefits of niobium in solid solution described above. A further parameter for controlling the precipitation fraction of niobium is the finish rolling temperature. The higher the finish rolling temperature, the greater is the acid-soluble (solid solution) fraction. For wheels, hot-rolled DP, Ferrite-Bainite (FB) and MLE steels are already used in 44% of the current wheel steel production at TKS.

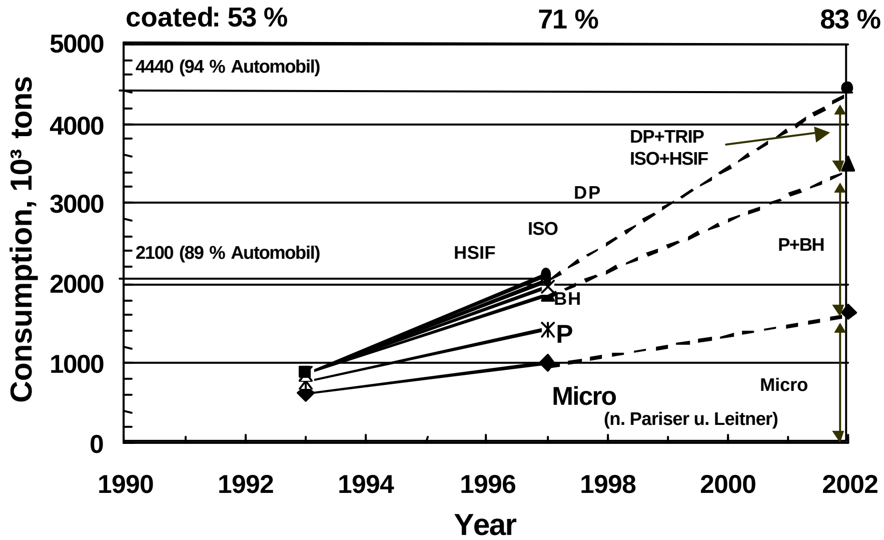


Figure 14: Consumption of high-strength cold-rolled steels in Western Europe.

## Summary and Future Challenges

A market study by Pariser Leitner reveals a clear trend towards further increases in the utilisation of high strength hot-rolled steels. In addition this study forecasts a particularly large increase in the use of cold-rolled high and higher strength steel types (Figure 14) with a simultaneous increase in the fraction of the surface coated version.

Although the proportions of the different grades of steels will vary considerably from company to company or model to model, the future use of a much higher proportion of higher strength steels is beyond reasonable doubt.

A future challenge facing the steel/auto partnership will relate to the introduction of advanced steel products, especially modern high-strength steels with improved properties such as the new multiphase steels which will gain more and more importance in the future. Also in the case of these new steels microalloying elements such as niobium will play an important role in steel development.

Technically sophisticated solutions will not be adopted without a clear analysis of process cost benefits and the use of expensive alloying additions will have to be fully justified through well directed research and development.

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(5) Description of ULSAB-AVC, TTD2 CAE analysis for crashworthiness. *)

(6) Description of ULSAB-AVC, TTD3 Benchmarking and target setting. *)

(7) Description of ULSAB-AVC, TTD4 Styling. *)

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(*) Copies of ULSAB-AVC documentation are available from steel company representations or may be downloaded from the ULSAB-AVC website (www.ulsab-avc.org).