HISTORY OF NIOBIUM AS A MICROALLOYING ELEMENT

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Abstract

This paper serves as an introduction to the session 'Application of Niobium as a Microalloying Element' at the International Conference Niobium 2001. It serves to outline the historical developments of niobium as a microalloying element through to the present day. Attention is given to the economic advantages of employing niobium as a microalloy and the various milestones of its development from plate steels through to advanced steels for the modern automobile. In addition, the equipment developments made within the steel industry are highlighted along with the invaluable contributions made by the various research groups and individuals within the metallurgical community.

Introduction

Niobium is beyond any doubt the most important microalloying element (MAE) for steel. Several million tonnes of niobium-alloyed steel are produced annually and used in the most important sectors of our technical world. Before we bring the historical development of niobium as a MAE up to date, two questions must first be answered:

- what is a MAE?
- how did niobium become an attractive MAE?

We can define steel as iron that has been given special properties by the alloying of specific elements. In addition to its chemical composition, the processing of steel by forming and heat treatment play a major role. The classical alloying elements influence the properties of steel by changing the structure of the iron. The desired effects such as increased strength, better toughness or resistance to corrosion appear when the alloying content is of the order of 0.5 to 20%. Examples are metals such as manganese, chromium and nickel.

The MAEs basically have a different role (Figure 1). They do not change the iron structure but instead have a strong interaction with the accompanying elements carbon and nitrogen. The high affinity of the MAEs for these elements causes the precipitation of secondary phases in the matrix. In the dissolved state, but primarily as precipitates, the MAEs can exert a strong effect on the microstructure and thus on important properties of the steel such as strength and toughness. Since even a very low concentration of 10^{-3} to 10^{-1}% is enough to drastically change the mechanical properties of the steel, the term <u>micro</u>alloying element is justified. It was used for the first time in 1963 by the Swede Norén before the US Ship Structure Committee and soon adopted internationally. The term 'microalloying element' contrasts with the macro-effects achieved by the MAE.

- Very low content of 10^{-3} ... 10^{-1} %
- Interaction with carbon, nitrogen, and sulphur
- Precipitation of secondary phases in the matrix
- Strong effect on structure and properties
- Control of dissolution and precipitation reactions through processing and heat treatment

Figure 1: Characteristics of MAEs.

Since the MAEs are candidates for use in CMn or low alloy low carbon steels, for which production costs are always an especially sensitive factor, they need to meet a further important requirement – their price should not exceed the alloying costs that are deemed acceptable for ordinary low carbon tonnage steels. It is also an advantage if future cost levels and fluctuations are easily predictable.

Having defined the characteristics of a MAE, there is now a need to address the question why niobium can qualify as a MAE. The answer can be found in:

- The natural properties of the metal
- The economic prerequisites for niobium as a MAE.

Natural Characteristics of Niobium Related to Its Role as a MAE

Niobium is to be found in the middle of the periodic table of elements and is surrounded by many metals that we know as proven alloying elements (Figure 2). It is characterised by, and is distinguished from other elements by an unusual and unique profile of properties that have special effects in steel, namely in an iron matrix with accompanying elements such as carbon, nitrogen and oxygen. Niobium has a high but not too high affinity for carbon and nitrogen and can form cubic compounds of type NbX. It is sufficiently soluble in gamma-iron (austenite) to be capable of being precipitated again in a targeted way. The potential for precipitation in austenite and ferrite is especially important as a means of influencing the microstructure. The addition of niobium as an alloying element in the steelworks is especially favoured by its relatively low affinity for oxygen. The diffusion and precipitation processes in a niobium alloyed steel are substantially determined by the relatively large atomic radius of niobium in comparison with iron. Thus, the importance of the metal niobium as an alloying element in steel is due both to its effect in solution and also primarily, to its tendency to combine with carbon and nitrogen.

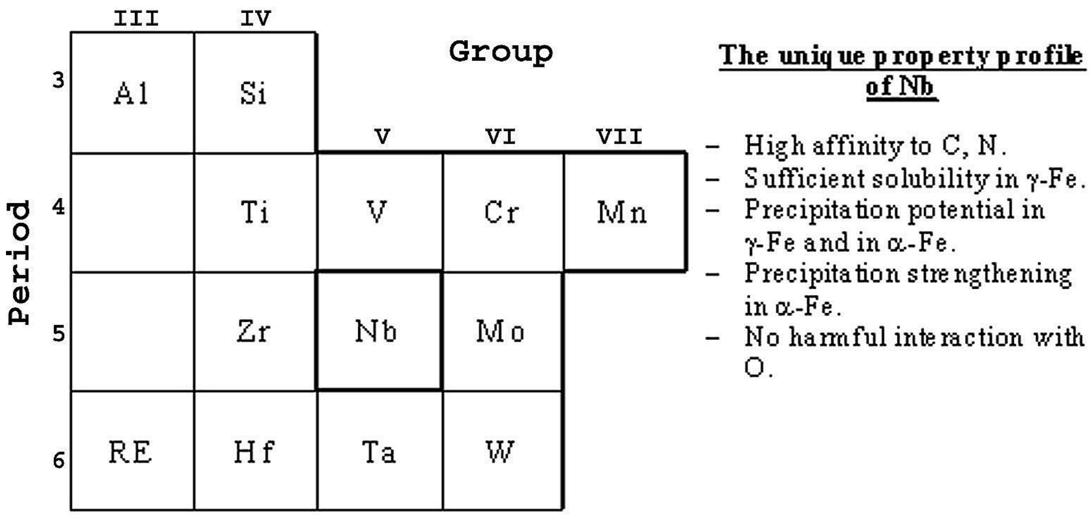

Figure 2: Niobium in the periodic table.

Thus the properties profile of niobium as an alloying element shows that it is more predestined to be a MAE than other potential candidates. This can be shown both by the variety and the intensity of its effects on the microstructure of steels. The following major effects can be emphasized:

- Grain refining;
- Retardation of recrystallisation;
- Precipitation hardening;
- Scavenging of the iron matrix (in IF steel).

Niobium can be regarded as the most effective of the MAEs. The specific effect of niobium is so enormous that the desired improvements in properties can be achieved even with extremely low concentrations of 1 niobium atom in 10,000 iron atoms. Effects of this type are thus comparable with those medications for the control and influencing of physiological processes in medicine. Here the term “microalloying” is actually justified.

Economic Case for Niobium as a MAE

Charles Hatchett discovered niobium in 1801. Although relatively rare it occurs in the earth's crust about as frequently as copper, tin or molybdenum. Compared to these metals, it occurs less often in a form that can be extracted commercially. Initially, it was used as an alloying element only in special steels, mainly for stabilisation in high alloy Cr-Ni steels. Up to the end of the 1950s it remained in the strategic reserves of the USA and had a high priority as a strategic alloying metal. The availability of niobium was restricted and its price was high. For that reason the 1939 patents of Becket and Frank in the USA, which described an increase in yield strength in plate made of carbon steel, did not lead to any commercial use.

Two crucial factors in the 1950s brought about the preconditions for a breakthrough of niobium as an attractive alloying element for use in unalloyed ordinary low carbon steels:

- The strategic reserves of niobium were released in the USA
- In addition to large deposits in Canada, an exceptionally rich source of niobium ore was found in 1954 at Araxá in Brazil (the origin of Companhia Brasileira de Metalurgia e Mineração – CBMM)

The time after World War II was characterised by a rapid rebuilding of industry. Steels were required in the main sectors of energy, transport and structural applications for civil engineering that displayed:

- High strength;
- High toughness;
- Good formability;
- Good weldability.

In this situation, niobium now appeared as a potential alloying element in the field of steel metallurgy. The price had dropped to almost a quarter of the original, with the result that a "microalloying addition" need not cost more than US$1 per tonne of steel. This was a good precondition and provided a challenge for metallurgists to uncover the secrets of niobium as a MAE.

The niobium deposits in Brazil, which had in fact been discovered as a by-product when searching for uranium reserves, turned out to be exceptionally rich and could be won by opencast mining. The owner, CBMM, had a pioneering spirit and committed itself to opening up and developing the metallurgical plants necessary for niobium extraction. The reserves and the infrastructure developed by CBMM provided the necessary foundations to ensure a worldwide supply of niobium. From 1965 niobium was made available as a ferro-alloy for the steel industry in almost unrestricted quantities. The niobium reserves of the deposits are enough to cover the demand for niobium for centuries. But it was more important for the flourishing development of niobium as a MAE that CBMM followed a pricing policy that made the use of niobium attractive and predictable. In comparison with other alloying elements or other major commodities, the price of niobium has remained substantially stable (Figure 3).

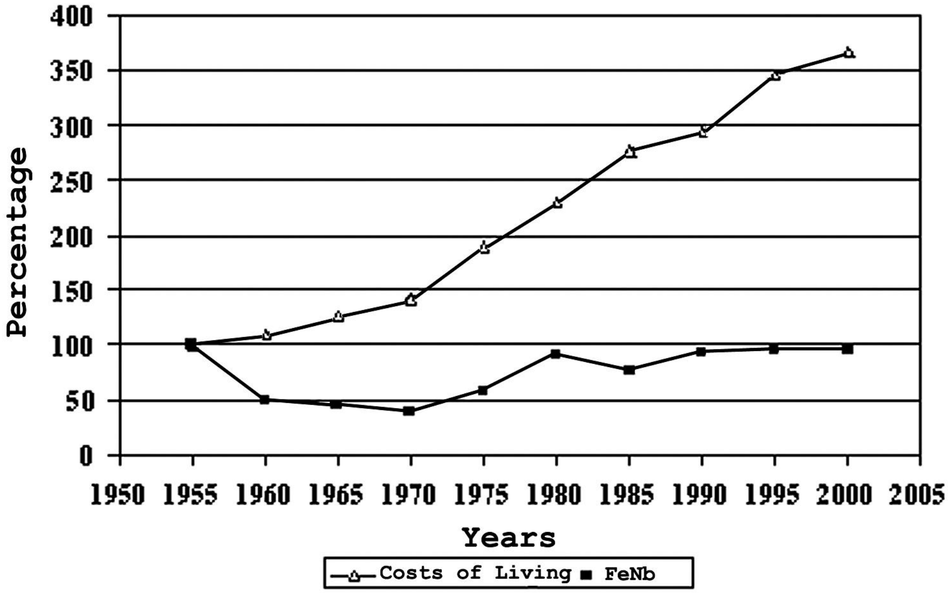

Figure 3: Price of FeNb and costs of living in Europe.

Commitment of Engineers and Researchers in Metallurgical and Industrial Developments

The impressive history of niobium as an MAE had a third major basis. In addition to the favourable properties endowed by nature on niobium and the advantageous economic circumstances which we have just described, there are also the people who committed their technical knowledge, creativity and persistence to its study as a MAE. This large family includes engineers and researchers in the production plants and company facilities as well as in research institutes and universities. Their roles and successes can only be touched on and acknowledged in passing. When names or institutions are listed, there is no attempt to be exhaustive or to place them in any ranking.

Operational tests of niobium additions began in the USA in the late 1950s at a time when, for cost reasons, constructional steel was generally made of semi-killed steel. In 1957 Bill Wilson was the first to test the use of niobium at a commercial level and produced plate at the Homestead plant of US Steel that indeed had a higher yield point but did not display acceptable toughness due to weak grain refining. On the other hand, the first operational tests at the Great Lakes Steel Works of National Steel, where niobium-alloyed steel was rolled to wide hot strip, were a complete success. The low final rolling temperature and more rapid cooling compared to thick plate were crucial in this case. A report was made of this in 1958 (1). A new series of steels, called GLX-W, was created which was suitable for pipeline construction (Figure 4).

COLUMBIUM-TREATED STEELS
low-cost, high strength

Efforts to produce high-strength, mild-carbon steels have led to the investigation of additives required for the formation of fine grain structure. Vanadium has been used for several years. Now columbium-treated steels have hit the market as a new low-cost answer.

by F. Weston Starratt

Figure 4: An early publication on niobium-alloyed steels.

MacDonnell of Great Lakes Steel justifiably reported:

"The new steels are regarded as an important metallurgical advance, because they make available superior qualities of strength, toughness and weldability."

This statement aroused great interest in steelmakers worldwide. Tests were carried out with niobium in Europe as well. In the UK in 1959, Colvilles Ltd. reported on the results of tests with low niobium contents of up to 0.015% in plate steels. Bill Morrison, who wrote his Master's thesis at Sheffield University on niobium in steel in 1960, was heavily involved in those tests (2). In this early phase it was also necessary to optimise the alloying technology used with regard to the ferro-niobium addition in the steel plant.

In addition to flat products, long products were also included when it came to improving the mechanical properties through the use of niobium. In 1959 Dorman Long in the UK produced the first girders made of niobium-alloyed steel with a tensile strength of 470MPa.

It was shown very soon that a targeted and optimum utilisation of the new MAE required a corresponding knowledge of the physical-metallurgical basis for its effects. In 1961, for example, Mareta and Joseph (3) had to concede after operational tests with semi-killed steel:

"The mechanism by which columbium refines the grain is not known."

Thus, in parallel with the developments in the steel works and rolling mills, and stimulated by the economical and technical successes, detailed investigations were begun in various laboratories and research institutes concerning the behaviour and the mode of action of niobium in steel. Metallurgists and researchers in Europe worked especially hard making great strides in this area. A number of working groups from the early years who made a substantial contribution to the fundamental knowledge about niobium as a MAE can be listed here:

- Sheffield University - *Woodhead, Morrison, Gray;*
- Colvilles Ltd - *Morrison, Mackenzie;*
- BISRA - *Duckworth, Irani;*
- Swinden Laboratories - *Irvine, Gladman, Pickering;*
- US Steel - *Leslie, Repas;*
- CNRM - *Greday;*
- IRSID - *Mandry, Grumbach, Le Bon;*
- CSM - *Brozzo, Parrini;*
- Oxelösund - *Kazinczy, Norén;*
- Thyssen Stahl - *Meyer, Heisterkamp;*
- Hoesch - *Kaup, Täffner;*
- Hoogovens - *Hoogendoorn;*
- Japan - *Narita, Gondoh, Kozasu, Tanaka, Takechi.*

Many of the names are still relevant in today's niobium scene.

Beginning in the 1960s, there was impressive progress in the physical metallurgy and in the overall understanding of the mechanisms related to the microalloying of steel. An especially important foundation stone was the findings of Hall and Petch, which quantitatively described how an increase of the yield strength depends on grain refinement and other strengthening mechanisms including precipitation hardening (Figure 5).

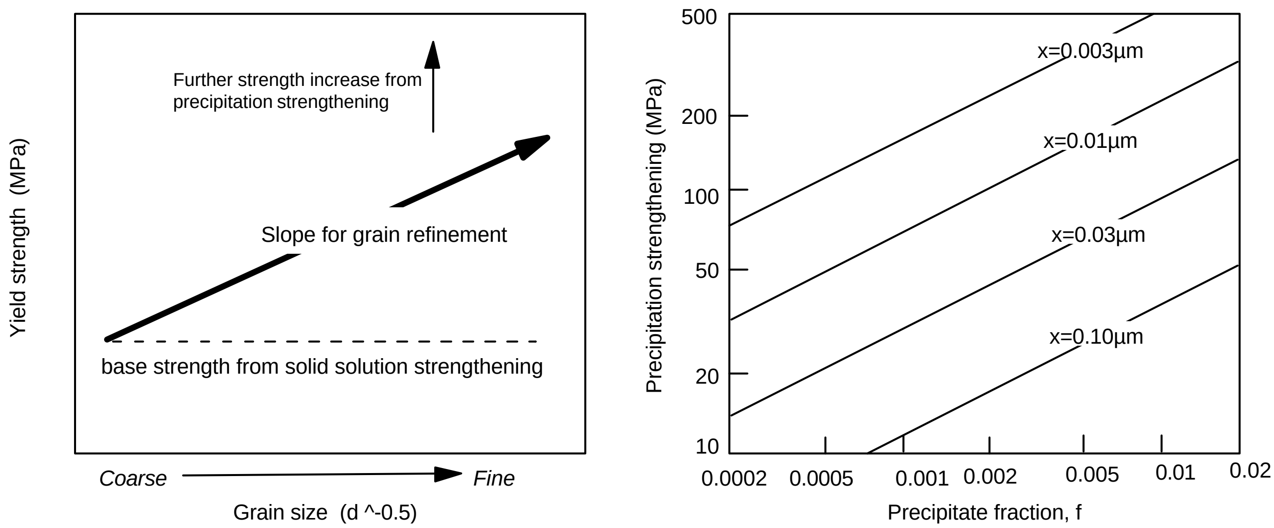

Figure 5: Hall-Petch analysis of yield strength increase by grain refinement and precipitation strengthening. (Note the precipitation strengthening is based on the Ashby-Orowan model on the dependence of precipitate strengthening on precipitate size (x).)

A marked feature of the history of microalloying is the intensive cooperation that existed at an international level. Since the family of engineers and researchers remained relatively small and the common interest in scientific and technical progress brought everyone together, this produced a welcome and productive culture of knowledge and experience exchange, and which was strongly promoted by the many and varied personal contacts made. Even the various competitive interests among the companies involved scarcely affected this cooperation. Thus the history of niobium as a MAE is reflected in the large number of international conferences, symposiums and colloquiums. A selection of these important events is given in Figure 6.

- **1963,** London - Metallurgical developments in carbon steels
- **1970**, Nürnberg - Low alloy high strength steels.
- **1972**, Cleveland - Processing and properties of low-carbon steels.
- **1975**, Washington D. C – Microalloying 75.
- **1981**, Pittsburgh - Thermomechanical processing of microalloyed austenite.
- **1981**, San Francisco - Niobium.
- **1985**, Beijing - HSLA Steels-metallurgy and applications.
- **1990**, Düsseldorf - IF Steels.
- **1994**, Tokyo - IF Steel design.
- **1995**, Pittsburgh - Microalloying 95.
- **1996**, Stockholm - Thermo-mechanical processing (TMP)^2.
- **1997**, Wollongong - Thermec ’97.
- **1998**, Aachen - Modern LC and ULC sheet steels for cold forming.
- **1998**, San Sebastian - Microalloying in steels: New trends for the 21st century.
- **2000**, Pittsburgh - IF Steel 2000.

Figure 6: Some important events on microalloying.

The first conference at which niobium-alloyed steels were reported on and discussed was in London in 1963. The conference that was organized by the alloying metals industry in Nürnberg in 1970 offered a platform for the various MAEs to be compared and contrasted. The trend towards steels with greatly reduced carbon contents was underlined at the event in Cleveland in 1972. Microalloying '75 represented an important milestone in this series of conferences. The state of the art in microalloying was discussed at a high level and in great detail. The impressive thing even then was the proportion of contributions that dealt with niobium as a MAE. Here too the various possibilities of combining niobium with other MAEs to bundle together the specific effects of the elements were discussed.

A special highlight in the history of niobium as an alloying agent was of course the symposium "Niobium" in San Francisco in 1981, the predecessor of this present conference. Organized and technically supported by CBMM, this international conference provided an occasion to illustrate in detail all the aspects from mining up to specific applications. Niobium was given special prominence here as a MAE. The published proceedings provide a particularly important textbook for scientists and metallurgists.

Up until the 1980s, microalloying was primarily synonymous with the term High Strength Low Alloy (HSLA) steels, as at the conferences in 1983 in Philadelphia and in Beijing in 1985. The technical developments of the 1990s showed a new focus of application for MAEs i.e. cold rolled sheet, especially that made of IF steel. In 1990 NPC organized an international symposium in Düsseldorf at which a wide discussion of the physical metallurgy, the advantages and application potential of niobium- and/or titanium-alloyed IF steels took place.

Once again, all the aspects of and products involving microalloying were summarised at the major conferences in Pittsburgh in 1995, in Stockholm in 1996, and in Wollongong in 1997. Advances in the production, thermo-mechanical treatment and – as a new emphasis of work – in the modelling of the processes and product properties were presented in detail. The events were given special prominence by the open and fruitful dialogue between the researchers and the engineers involved in everyday work.

In view of the increasing importance of microalloying for sheet products, the experts from research institutes and industry have come together in recent years at high quality conferences to discuss "IF steel design" (Tokyo 1994), "Modern LC and ULC steels for coldforming" (Aachen 1998) and "IF steel" (Pittsburgh 2000). It showed that the modern microalloyed sheet materials for car making could no longer be ignored in view of their favourable properties profile that could be tailored to a particular application.

The worldwide activities of engineers and researchers regarding the basic features, manufacture, properties and use of niobium-alloyed steels has been reflected in the huge number of publications over the past 40 years. The expert who is interested in this field can have a problem in finding the papers that are relevant to him. The conferences, symposia and seminars are a welcome aid for him to this end.

A special type of appreciation for especially worthy publications about niobium was shown by the establishment by CBMM in 1977 of the Charles Hatchett award. The medal that is made from pure niobium is awarded annually to the authors who have produced the best paper. What is especially impressive is the number of publications that the international jury in question has to evaluate. Up to now, with the aid of computers, several thousand publications dealing with niobium have been recorded. More than three quarters of the 22 awards given so far concern work on niobium as a MAE.

If an important basis for the triumphal progress of niobium as an MAE is the commitment shown by many colleagues in their professional sphere, then last but not least, it is necessary to emphasize the role played by CBMM and its European and North American organization, Niobium Products Company and Reference Metals Company. They have made a decisive contribution to the success of niobium in various ways. They have ensured that there was constant, lively and open communication between colleagues by providing a platform through conferences, seminars or small discussion groups. Researchers, steelmakers and users, authorities and institutions were brought together. The colleagues of CBMM, NPC and RMC have thus ensured an effective and up to date dissemination of the available knowledge about niobium-alloyed steels. In addition, they have also set up and supported interesting, mainly international research and development projects, through financial support and active coordination. The meetings held under the auspices of our colleagues from CBMM, NPC and RMC have also always profited from the open and cooperative atmosphere, which also had an indirect effect on the use of niobium as a MAE. But for me, what is important – and I think that many of you would agree too – is the personal contact with my "niobium friends". That too is a positive aspect of niobium as a MAE.

Milestones in The History of Niobium as a MAE
Physical Metallurgy, Products and Applications

The development of microalloyed steels was marked throughout the 1960s by the introduction of *controlled rolling*. This rolling technology, which came into consideration for conventional plate mills and for hot strip mills, involves a matching of the deformation and temperature control in the rolling mill. The aim of this is to produce the finest possible grain size in the microstructure giving an increased yield strength and improved toughness in the final product. The measures required to achieve this are, above all, a reduction in the reheating temperature and the finishing temperature. Hot strip mills turned out to be especially suitable but older plate rolling mills were often at their technical limits.

In the first instance, steels for pipelines profited from the positive effects of this changed microstructure. A special advantage of controlled rolling was that the increase in strength through the use of microalloying elements such as niobium or vanadium made it possible to reduce the carbon content of the steel and thus weldability was greatly improved. Niobium-alloyed controlled-rolled steels now had a dramatic effect in opening up the market for high-strength, tough, weldable, large-diameter pipelines for the transport of oil or gas. Given an optimum steel composition and improved rolling techniques, it was possible to increase the yield strength of pipeline steels from around 300 to over 700MPa within a relatively short time (Figure 7) (4).

The good weldability and toughness of the steels made it possible to use them in Arctic areas such as in Alaska, Canada and Russia. As a result of the new steels, the laying of pipelines was possible even under the most difficult conditions. The development of the gas pipeline network in Siberia was especially impressive. Within 30 years around 150,000km of large diameter pipeline made of niobium-alloyed steel had been laid. These successes are due more than anything else to the commitment displayed by CBMM and Niobium Products Company (NPC). Further progress of steel grades and the production of large diameter pipes was stimulated by the more difficult conditions involved in the transport of gas. Here we should mention the increased pressure, the increased wall thickness, transport of sour media and, above all, the exploitation of oil and gas fields under the seabed. The market for large diameter pipelines has grown worldwide in the meantime to a requirement of around 30 million tonnes a year. In this case each tonne of steel is niobium-alloyed.

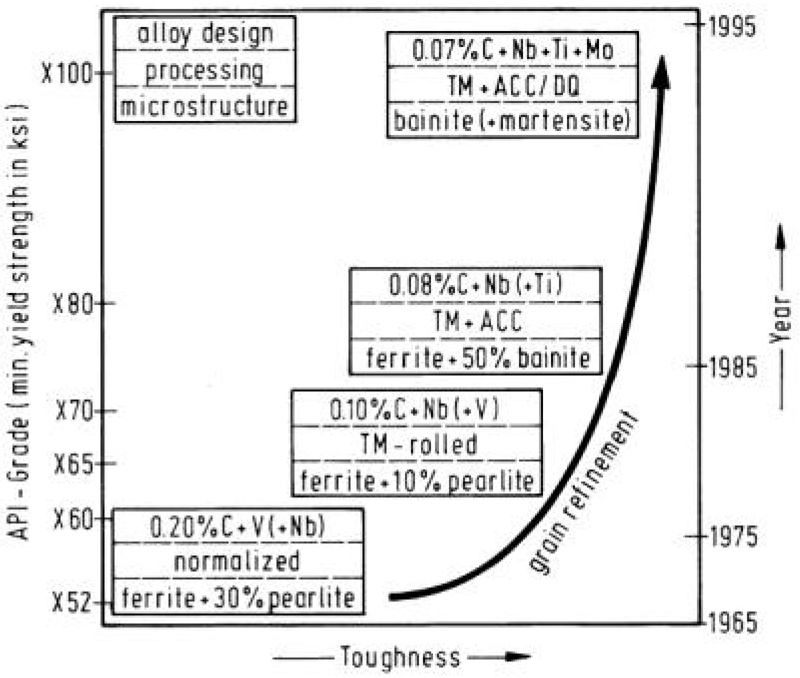

Figure 7: Development of high strength line-pipe steel.

A huge demand for platforms arose as a result of the exploitation of offshore reserves of oil and gas, the steels for which have to meet a number of special requirements such as extremely high mechanical stresses, difficult climatic conditions and the huge scale of the constructions. Here too the new microalloyed steels proved their worth.

The 1970s were characterised by the implementation of the knowledge gained from physical metallurgy into operational practice. This led to further development and refinement of the processing in hot strip mills. From the somewhat imprecise term "*controlled rolling*" came "*thermo-mechanical rolling*", which was also reflected in the standards and design codes. The hot strip mills profited in a special way from this development. In this case the influence of microalloying, and of niobium in particular, had to be taken into consideration with regard to the three basic mechanisms occurring during thermo-mechanical treatment, namely:

- The recrystallization;
- The precipitation of carbides or carbonitrides;
- The austenite to ferrite transformation.

Figure 8 (5) shows, in a classic illustration, how strongly the recrystallisation of the austenite is delayed by niobium and thus the temperature is increased for the start of recrystallisation in the rolling mill.

Behind this effect is the delay of recrystallisation through the spontaneous, deformation-induced precipitation of extremely fine niobium carbides or carbonitrides, which is greatly accelerated by the deformation of the austenite (Figure 9) (6).

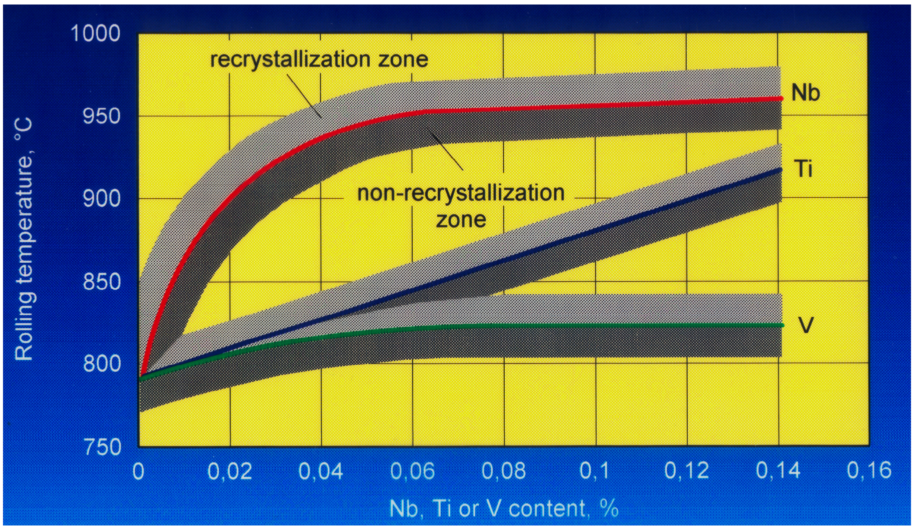

Figure 8: Effect of Nb, Ti, and V on the critical temperature for austenite recrystallisation (0.15% C).

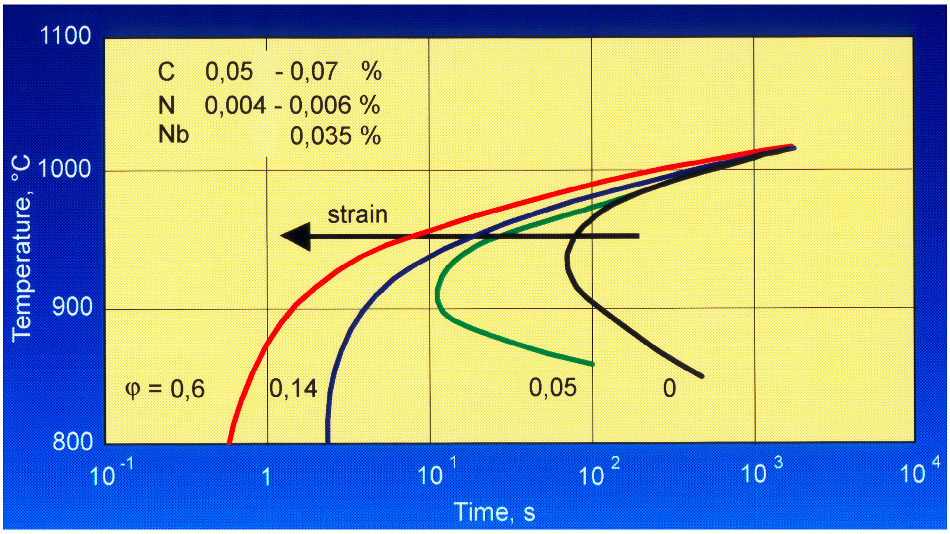

Figure 9: Effect of strain on time for precipitation.

The transformation of a matrix of non-recrystallised austenite takes place at a markedly higher temperature or after a shorter time. After the ferrite is formed, it is necessary to take into consideration the potential for NbC precipitation hardening. All these mechanisms, which interact with each other, require a delicate optimisation of the process steps of heating – preliminary rolling – final rolling – cooling down. The complexity of the situation is indicated in Figure 10 (7).

The most wide-ranging exploitation of niobium and its use in combination with other microalloying elements or classical alloying elements makes possible an optimum utilisation of the grain refining, transformation hardening and precipitation strengthening to allow the production of hot strip with a yield strength of more than 800MPa at a thickness of 12mm. In the case of hot strip steels, in addition to their use in large diameter piping, they have also been used to an increasing extent in car making, especially for trucks and commercial vehicles. The market generally profited from the favourable properties of high strength, good cold formability and good weldability of the microalloyed steels.

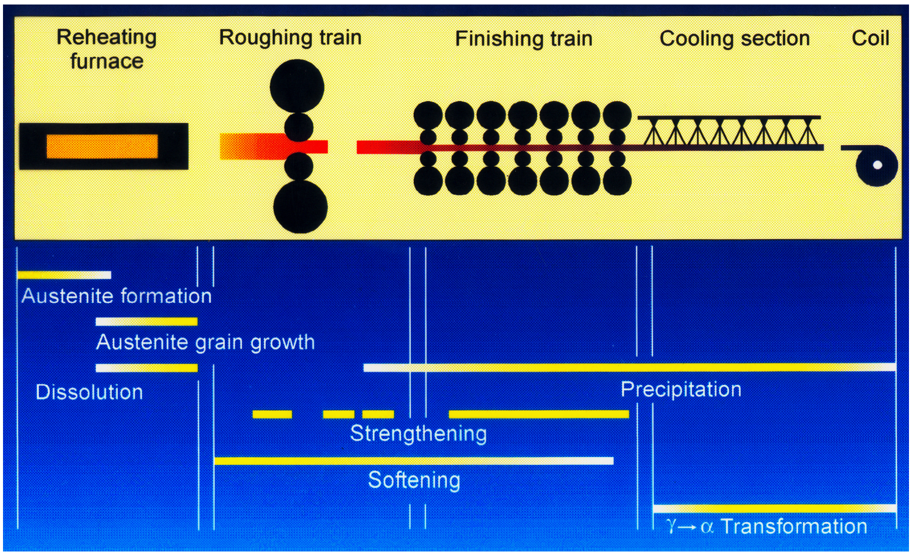

Figure 10: Processing steps and physical metallurgy in a hot strip mill.

These technological developments and the opening of bigger market shares for microalloyed steels also applied to plate production. In addition to the use of classical thermo-mechanical rolling, the introduction of "*normalising rolling*", which corresponds to "*recrystallisation controlled rolling*" in North America, turned out to be very useful. Since the technical requirements for this technology were less stringent than those for thermo-mechanical rolling, it was possible to make use of it also in weaker plate mills. Using such a technique no further heat treatment was required for applications for which the standards still required "normalised steels", with all the advantages of reductions in costs, simpler logistics and ultimately, a better surface for the plate.

The introduction of ACC, "*accelerated cooling*", was a major step forward for modern plate rolling mills. Based on the well-proven use of intensive cooling in hot strip mills, it was now possible to aim at further improvements in the properties of microalloyed steels, namely, higher strength, better toughness, better weldability, lower alloying costs. These favourable properties were obtained in the first instance by the effect of grain refining and extensive transformation in the bainite phase (Figure 11) (8). However, the accelerated cooling process required additional investment costs and precise process control in the plate mill.

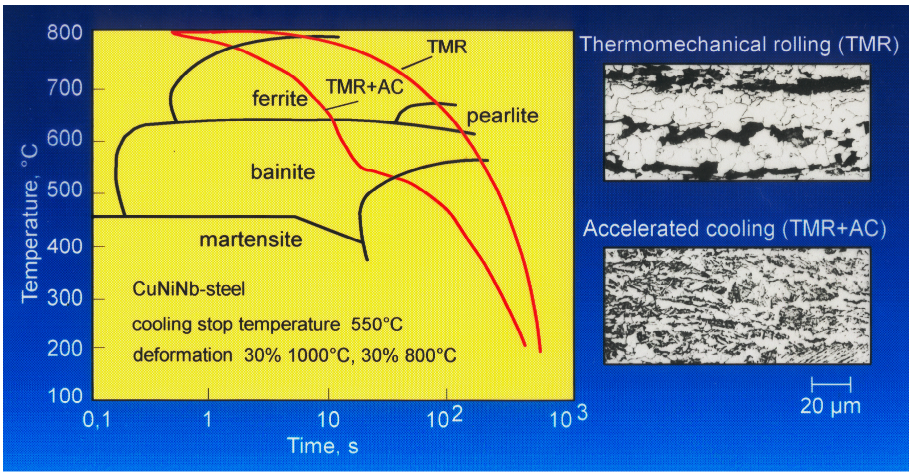

Figure 11: Influence of cooling rate on microstructure.

Technical developments in the steel industry and the demand for high quality steels for the construction of large-diameter pipelines and in the automotive industry led to an above-average growth of 8% to 10% per year for niobium alloyed steels throughout the 1970s. At the end of the 1970s the proportion of niobium used in steels for large pipes was still around 60%. Further possible applications were found in the 1980s. The expansion of thermo-mechanical rolling to plate of greater thicknesses of up to 50mm and the use of niobium-alloyed steels for *long products* also made a significant contribution to the use of niobium. There was a special challenge in the rolling of I-beams, since the flange and the web are of different thicknesses. This had to be taken into consideration during the rolling and cooling down of the beams. Although the strengthening mechanisms of niobium-alloyed steels lead to a relatively high ratio of yield to tensile strength, these high strength beams show good resistance to brittle fracture and have an adequate ductility reserve.

In addition to their classical areas of application in energy technology and car making, in the 1980s niobium alloyed steels increasingly came into use in other market sectors such as engineering construction, container and vessel construction, and shipbuilding. An area of application that places especially high demands on the steel, that of offshore platforms has already been listed. In the case of large steel bridges, spectacular constructions in recent years are the Erasmus Bridge in Rotterdam and the Öresund Bridge connecting Denmark and Sweden. A total of 82,000tonnes of niobium alloyed steel with a minimum yield point of 460MPa and thicknesses of up to 80mm was used for this latter bridge with its total length of 8km. Another example of modern construction is the Commerzbank building in Frankfurt, in which long and flat products made of niobium-alloyed steel were likewise used. The considerable potential for savings in materials offered by the use of microalloyed high-strength steels can be shown by the following calculation. The Eiffel tower in Paris required 7,000tonnes of steel more than a century ago. If a comparable construction was built today using niobium-alloyed steel, only 2,000tonnes would be required (9).

Cold rolled sheet is a steel product that has been of greatly increasing importance for niobium for around 20 years. Two directions for growth revealed themselves as far back as the 1970s. On the one hand, there was an increasing demand for higher strength sheet. On the other hand, the sheet should also have better cold-forming properties. The challenge behind these developments came from the automotive industry. The demand to reduce the weight of cars came about as a result of the first energy crisis and rising fuel prices. In addition, the concern of the carmaker to increase the level of safety for passengers also became a matter of increasing priority. A solution to both problems came in the form of high-strength steels. The trend towards more dramatic styling and attempts to make the body out of as few parts as possible made it necessary to produce sheet with better cold-formability.

The steel industry had answers to meet these requirements. As a result of the experience gained in the production of high-strength hot strip, it was also possible to produce high-strength cold rolled sheet. More than 30 years ago a steel was developed as a material with exceptionally good cold-formability and which contained no free carbon and nitrogen atoms – this being an Interstitial Free (IF) steel (10). Niobium came into consideration for both solutions, and also titanium as a further microalloying element with similar properties. The positive points for microalloying for cold rolled sheet were grain refinement and precipitation hardening – although a more gradual and weaker one than in thermo-mechanically rolled hot strip – a reduction of the ageing susceptibility in high-strength sheet and, above all, the advantages associated with the IF state. Thus it was possible to offer two major families of steel for car bodies, the microalloyed high-strength grades of sheet and - as the most important innovation of the last 50 years in steel sheet – IF steels with their extremely good formability (Figure 12). However, initially, there were still a number of obstacles to the introduction of these steels. It was necessary for the designers and the press shops of the automotive industry to gain experience with and insights into the peculiarities of high-strength sheet and, primarily, the restricted cold-forming properties of the material. In general, the relatively broad scatter of mechanical properties hindered trouble-free production. The steelworks required high-efficiency vacuum units to produce the very low carbon IF steels, but in the 1970s they were not part of the standard equipment.

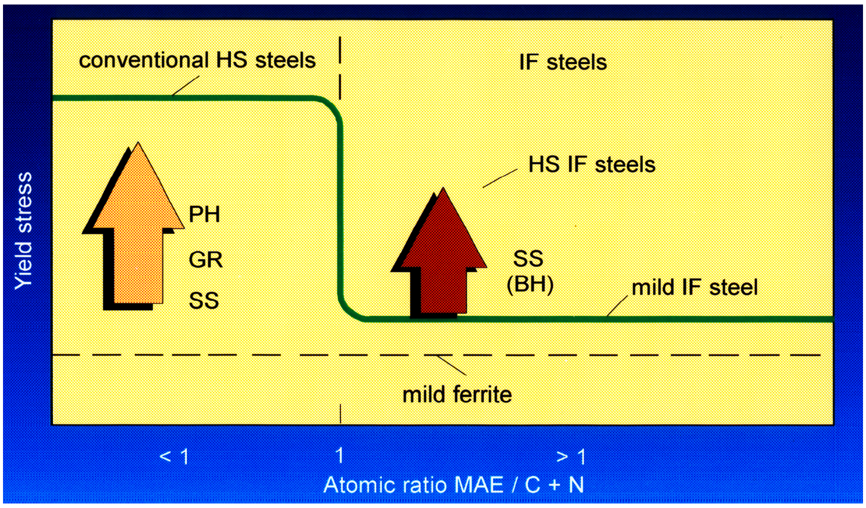

Figure 12: Ranges of mild and high strength cold-rolled sheet steels with regard to the microalloying stoichiometry.(IF - Interstitial Free; HS – High Strength;PH – Precipitation Hardened; GR – Grain Refined; SS – Solid Solution Hardened; BH – Bake Hardened).

In the 1980s there was an upswing in the use of niobium alloyed steels for car making. The cause lay, on the one hand, in the progress made in steelworks technology and on the other hand, in the new challenges set by the automotive industry with respect to the steel sheet materials to be used. The continuous casting process had been accepted as the standard method in the steelworks. Above all, the necessary investments were made in vacuum units so that the required high tonnages and the desired low final carbon contents could be achieved in IF steels (Figure 13).

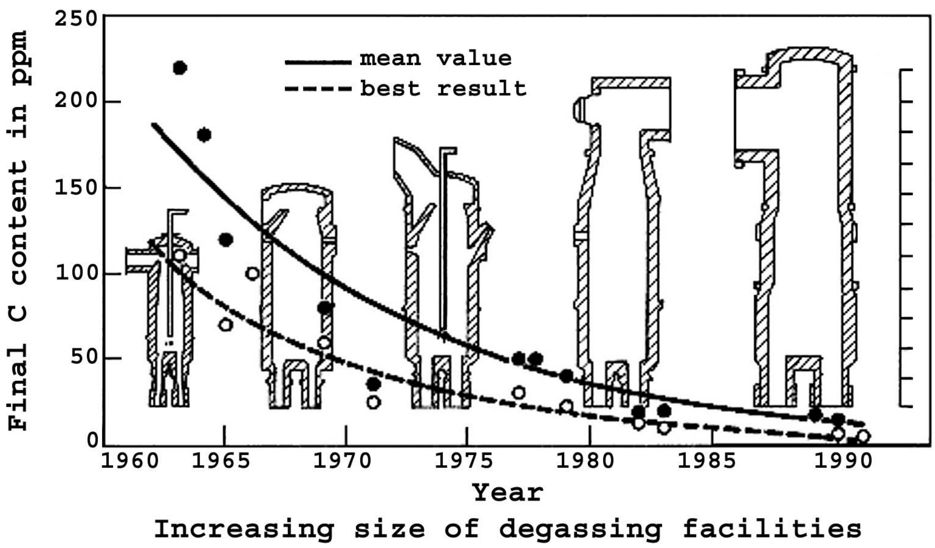

Figure 13: History of RH vacuum degassing metallurgy.

The development and use of the new high-strength grades of steel sheet were greatly stimulated by a competing product, aluminium. The ever tougher requirements in North America, Europe and Japan for corrosion resistance in car bodies led to a drastic increase in the use of surface-treated steel sheet. IF steel was the big favourite as a substrate for hot dip coating with zinc, aluminium or their alloys, since the product had superlative mechanical properties including resistance to ageing in addition to the required resistance to corrosion. The arguments concerning the good mechanical properties of IF steel apply just as much to the production of continuously annealed cold rolled strip, for which IF is likewise the material of choice (11). The trend to the increased application of hot dip coated or continuously annealed cold-rolled sheet is clearly reflected in the growing worldwide capacity of coating and annealing lines (Figure 14).

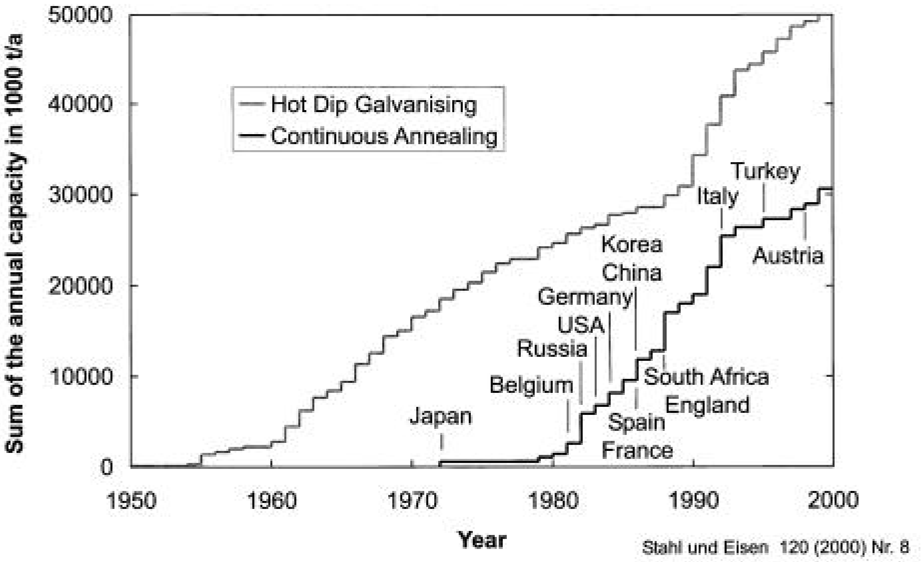

Figure 14: Annual capacity of hot dip galvanising and continuous annealing lines.

Thus the use of niobium has had especially strong incentives from the automotive industry in the past decade. High-strength niobium alloy is used for safety-related parts in the frame of the car, in the door side impact bars and in bumpers. High-strength steels that still need to have good cold formability are used in the body-in-white. Here in particular, especially strong IF steels have proved their worth (see also Figure 12) (11). In the case of IF steels with higher strength, niobium has shown its value in place of titanium, since it can be combined with a higher phosphorus content without adversely affecting its strengthening action.

Today there is a wide spectrum of various steel sheet materials available for car making. They range from extremely mild IF steels, to bake-hardening grades, to extremely high-strength multi-phase steels (Figure 15).

Niobium-alloyed variants are represented in all grades of steel, so niobium will participate in the sustained upsurge for these materials. New incentives for the use of high-strength components in vehicles come from the international Ultra Light Steel Auto Body (ULSAB) study, in which all the leading steelmakers worldwide took part. High-strength steels are well represented and constitute more than 60% of the "Ultra Light Steel Automotive Body" (Figure 16).

- Mild IF steel
- High strength IF steel
- Bake hardening steel
- Microalloyed high strength steel
- Dual phase steel
- Retained austenite steel
- Complex phase steel

Figure 15: Sheet steels for automotive applications – potential use of niobium.

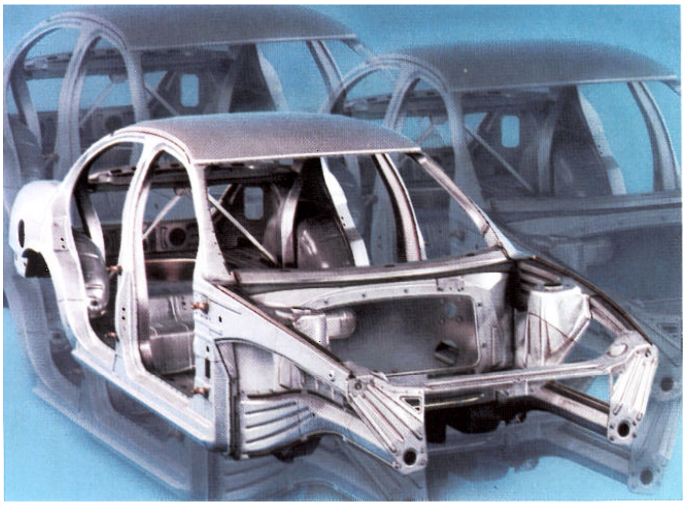

Figure 16: Demonstration body “Ultra Light Steel Auto Body” (ULSAB).

The most recent models from advanced car makers such as BMW also correspond to this trend. Today around 150 kg of Nb-alloyed sheet steel is used in US cars. A further increase in the use of high-strength steels comes today from the rapidly increasing use of Tailored Blanks (12). For components of this type (Figure 17), in which function-oriented high-strength sheet steel is built in, a total quantity of 1 million tonnes has been forecast for Europe in 2002.

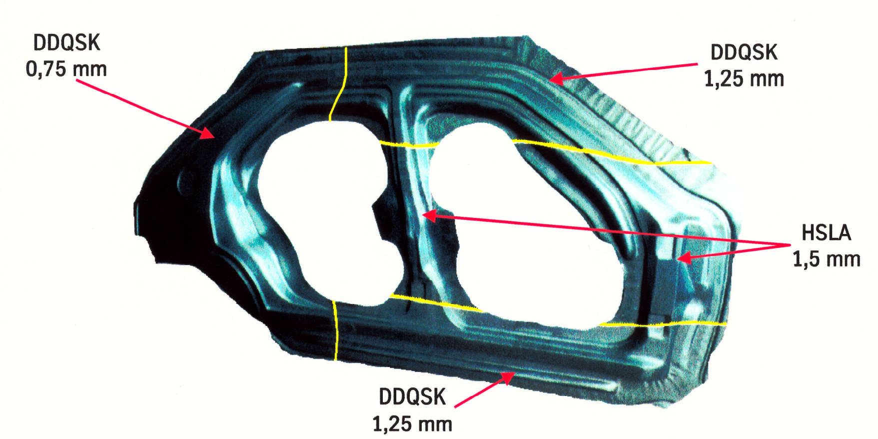

Figure 17: “Tailored Blank” door ring.

It is evident that the history of niobium as a microalloying element was marked by an increasing diversification in the 1990s. Within ten years the proportion of niobium that is used for large pipes dropped from 69% to less than 30% (although the amount of niobium used has stayed almost constant). At the same time, the use of microalloying elements in steels for civil engineering, and above all, for car making, have increased by a similar percentage and the absolute amount of the microalloying element has also increased. It is gratifying to see that the dependence of niobium on the development of specific industrial sectors and their accompanying cyclic behaviour has been reduced. Thus, we can view with optimism the continuous development of the market for niobium.

Future Trends

Although the basis for the production of modern microalloyed steels was laid more than 30 years ago, we can still expect further progress in the production and application of steels using niobium. The possibilities for the use of niobium-alloyed steels will continue to diversify . The highly industrialized countries will set the pace of innovation in this field. When looking at the many possible fields of work in future, a number of them that will benefit from the use of niobium are listed here:

- Thin slab casting;
- Modelling and simulation;
- Ultrafine grain size;
- Optimisation of precipitation and transformation;
- Multi-phase steels;
- Bake-hardening of niobium-alloyed steels;
- New fabrication processes such as hydroforming;
- Adaptation of design codes;
- Products such as forgings and rails.

Nevertheless, there is also great potential for an increased use of niobium in the threshold and developing countries. In these countries the proportion of niobium alloyed steels out of the overall production of steel is still relatively low when compared with the figure of 15-20% microalloyed steels that is usual now for the highly industrialized countries. A particular parameter which has shown itself to be a sensitive indicator of the modernity of a steel industry is the consumption of niobium related to the overall steel production of a national or regional economy. In the industrialised countries of the Western World, this figure is around:

50g niobium per tonne of steel

The higher the production of flat-rolled products such as plate, hot strip and cold rolled sheet within the overall steel products and the more that modern steels such as HSLA and IF steels are produced, the higher is the specific consumption of niobium. The threshold and developing countries will undoubtedly also show a more or less strong increase in this indicator in future. The use of niobium nonetheless is tied to a number of necessary factors and favourable conditions, as we have seen in the course of the long history of niobium as a microalloying element. These factors are:

- Modern steelmaking technologies such as vacuum treatment, alloying technology, casting technology, etc.

- Excellent process control in the rolling mills, annealing units and surface coating lines in recognition of the physical-metallurgical requirements of niobium
- Adapting the composition and processing of the microalloyed steels to the specific requirements of the user of the steel
- Intensive technical support of the steel-processing industry to aid the introduction and acceptance of niobium-alloyed steels

The large community of specialists involved with niobium, like the one assembled for this conference, will certainly contribute to further promotion of the use of niobium by providing the necessary technical knowledge.

Finally, there is also a certain danger to be pointed out with respect to niobium as an MAE. It does have competitors, one of which is titanium. By comparison with niobium, titanium does in fact have a number of disadvantages. It is harder to handle at the steelmaking shop. Its effects on the structure and properties of the steel are more complex and to some extent less beneficial than those of niobium, and some may indeed be unwanted. Thus the entire alloying effect is harder to control. An important bonus is, however, the lower costs. For that reason titanium has established itself as a MAE for many years now both in high-strength microalloyed steels as well as in IF steels. Those of us who are committed to niobium should therefore regard it as a challenge to re-substitute titanium for niobium and to achieve better solutions with niobium.

Two Names – Curiosity and Symbol

Niobium was discovered twice, so to speak. In 1801 it was found in North America in the form of its oxide and was given the name Columbium. In 1844 it was identified as a metal in Europe and was given the name Niobium in view of its closeness to Tantalum. The rare metal existed for several decades, if not almost up to the present day, under these two names. In order to avoid any confusion or mistakes, the name niobium was chosen as the proper and definitive one around 60 years ago. At this point the author would just like to mention something about the symbolic meaning of the two names.

Columbium is named after the discoverer of America and is thus the synonym for the discovery of a New World. We can understand this New World as being the one of microalloying, which has opened up for us a wide vista of new scientific and technical developments and technical and economic improvements.

Niobium is a name from Greek mythology. Niobe, the daughter of Tantalus, was regarded as the goddess of tears. But the tears of Niobe would undoubtedly be tears of joy for steel metallurgists.

You will undoubtedly agree with the author that today, after a history of 40 years as a microalloying element, niobium can be the symbol for progress and success – and also a good omen for the future.

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