

T I C

TANTALUM-NIOBIUM INTERNATIONAL STUDY CENTER

VIENNA, OCTOBER 1993

From October 4th to 6th 1993 the T.I.C. will meet in Vienna, where it will hold its Thirty-fourth General Assembly on October 5th. The Assembly, technical sessions and social functions will take place at the Parkhotel Schönbrunn, where rooms have been booked for delegates to stay.

The registration desk will be open on Monday October 4th, and participants and those accompanying them will be welcomed at a reception on that evening. The General Assembly will be the first event on Tuesday morning, and the rest of the day will be occupied by a wide-ranging technical session. Niobium will be a focus of the programme, alongside tantalum in a variety of applications, but especially in its particular use in superconducting materials. Papers are expected from Cabot Performance Materials, H.C. Starck, Vishay Sprague and other major firms in the tantalum field. Presentations on features of the tantalum and niobium industry in Russia and Kazakhstan will also be offered. A gala dinner will be served in the evening.

On Wednesday October 6th, a plant tour of Treibacher Chemische Werke is planned, with the delegates travelling by bus to Treibach in the morning and returning to Vienna in the late afternoon at the close of the meeting.

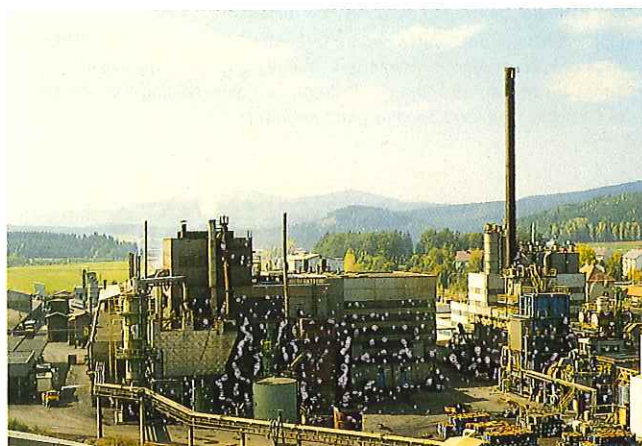
A sightseeing programme will be arranged for those accompanying delegates to Vienna.

Pre-registration by early September is essential for those wishing to attend the conference: invitations will be sent to the nominated delegates of member companies, others interested should contact the Secretary General, T.I.C., 40 rue Washington, 1050 Brussels, Belgium, telephone (02) 649.51.58, fax (02) 646.05.25.

TREIBACHER CHEMISCHE WERKE

Treibacher Chemische Werke AG was founded almost 100 years ago at Treibach, Austria, by Carl Auer von Welsbach, a great Austrian inventor.

Today Treibacher is one of the major producers of ferro-alloys, the worldwide leading manufacturer of fused aluminium



oxides and lighter flints, and a specialist in rare earth products and hardmetal powders. In addition Treibacher produces sodium perborates for detergent powders.

Treibacher is an international producer with production facilities not only in Austria but also in Italy, the United States and Canada, employing in all about 1500 people.

In the field of tantalum and niobium carbides, Treibacher has achieved a significant worldwide market share and is well known as a top quality producer and as a reliable partner for the customer.



TCW Headquarters

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TANTALUM

PRIMARY PRODUCTION

(quoted in lb Ta ₂ O ₅ contained)	1st quarter 1993
Tin slag (2 % Ta ₂ O ₅ and over)	83 289
Tantalite (all grades), other	85 352
Total	168 641

Note : 14 companies were asked to report, 13 replied.
The companies which reported included the following, whose reports are essential before the data may be released :
Datuk Keramat Smelting, Gwalia/Greenbushes, Malaysia Smelting, Mamoré Mineração e Metalurgia, Metallurg group, Pan West Tantalum (Wodgina Mine production), Tantalum Mining Corporation of Canada, Thailand Smelting and Refining

QUARTERLY PRODUCTION ESTIMATES

(quoted in lb Ta ₂ O ₅ contained)			
LMB quotation :	US \$ 30	US \$ 40	US \$ 50
2nd quarter 1993	290 500	403 500	413 500
3rd quarter 1993	290 500	403 500	463 500
4th quarter 1993	290 500	403 500	463 500
1st quarter 1994	290 500	403 500	463 500
2nd quarter 1994	290 500	403 500	463 500

Note : The quarterly production estimates are based on information available, and do not necessarily reflect total world production.

PROCESSORS' RECEIPTS

(quoted in lb Ta contained)	1st quarter 1993
Primary raw materials (e.g. tantalite, columbite, struverite, tin slag, synthetic concentrates)	294 844
Secondary materials (e.g. Ta ₂ O ₅ , K ₂ TaF ₇ , scrap)	147 937
Total	442 781

Note : 18 companies were asked to report, 18 replied.

PROCESSORS' SHIPMENTS

(quoted in lb Ta contained)	1st quarter 1993
Product category	
Ta ₂ O ₅ , K ₂ TaF ₇ , carbides	156 347
Powder/anodes	264 768
Mill products	93 457
Alloy additive, ingot, unworked metal, scrap, other	50 741
Total	565 313

equivalent to 763 173 lb Ta₂O₅.

Notes :

In accordance with the rules of confidentiality, categories have been combined as shown.

Response : January 17/18, February 17/18, March 18/18.

For both receipts and shipments by processors, reports by the following companies are essential before the data may be released :

Cabot Performance Materials, W.C. Heraeus, Kennametal, Metallurg group, Mitsui Mining and Smelting, H.C. Starck Inc. (NRC), Showa Cabot Supermetals, H.C. Starck, Thai Tantalum, Treibacher Chemische Werke, Vacuum Metallurgical Company, H.C. Starck - V Tech

NIOBIUM

PRIMARY PRODUCTION

(quoted in lb Nb ₂ O ₅ contained)	1st quarter 1993
Concentrates : columbite, pyrochlore	7 304 206
Occurring with tantalum : tin slag (over 2 % Ta ₂ O ₅), tantalite, other	62 468
Total	7 366 674

Note :

15 companies were asked to report, 14 replied. The companies which reported included the following, whose reports are essential before the data may be released :

Cambior, Mineração Catalao de Goiás, Niobium Products Co. (CBMM)

PROCESSORS' SHIPMENTS

(quoted in lb Nb contained)	1st quarter 1993
Compounds and alloy additive : chemical and unwrought forms (e.g. NbCl ₅ , Nb ₂ O ₅ , NiNb, FeNb [excluding HSLA grades])	631 738
Wrought niobium and its alloys in the form of mill products, powder, ingot and scrap	
(i) Pure niobium	33 448
(ii) Niobium alloys (such as NbZr, NbTi and NbCu)	49 908
HSLA grade FeNb	7 862 708
Total	8 577 802

Note :

19 companies were asked to report, 19 replied. Reports by the following companies are essential before the data may be released :
Cabot Performance Materials, W.C. Heraeus, Kennametal, Metallurg group, Mitsui Mining and Smelting, Niobium Products Co. (CBMM), H.C. Starck Inc. (NRC), H.C. Starck, Teledyne Wah Chang Albany, Thai Tantalum, Treibacher Chemische Werke, Vacuum Metallurgical Company

CAPACITOR STATISTICS

CONSUMPTION BY AREA

(figures in millions of units)				
	Average per quarter			
	1988	1989	1990	1991
North America	340	302	337	356
Europe	220	206	232	230
Japan	635	681	808	965
Rest of world	207	304	361	492
World	1402	1493	1738	2043

			1992		
Quarter :	1st	2nd	3rd	4th	Total
North America	392	403	448	457	1700
Europe	245	259	216	220	940
Japan	847	769	735	741	3092
Rest of World	541	637	592	602	2372
World	2025	2068	1991	2020	8104

Source : Members' estimates

PRESIDENT'S LETTER

This issue of the Bulletin follows by a few weeks the informal Spring meeting of the T.I.C. in Brussels. Without reporting the course of the entire meeting, I would like to address briefly several important themes which formed the bulk of the discussions. They are, I believe, inter-related.

Firstly, commercial information regarding the tantalum/niobium business in various geographic areas of the world seems to be much in demand. In this regard, the well researched and documented information from Japan which Mr Takekuro has made a regular feature of our meetings is of particular interest.

Similar inputs from Europe and North America are solicited. The T.I.C. membership now includes representatives from the Commonwealth of Independent States and China which in time may bring information about tantalum and niobium activity in these regions.

Following the interest in commercial prospects for the tantalum and niobium businesses comes the recurring admonition that the T.I.C. must do more to encourage the application and usage of these materials. The traditional markets, particularly for tantalum, continue to show little or no growth in their requirements for material. Obviously, new markets must be found and developed if the raw material side of the industry is to enjoy growth. Market development implies a strong technical content in the activities of the T.I.C.

At the moment, the services of the secretariat and our technical advisor are available to people requiring information concerning the use of our materials. If these efforts are not sufficient, can more be gained from advertising, participation in metals shows, or sponsorship of prizes for research or papers in the field of tantalum and niobium?

The second issue inevitably leads to my final point, the matter of matching the objectives of T.I.C. to the size of its membership and financial strength. Conditions within our industry have resulted in a stable to slightly declining membership. This, in combination with a flat cost of membership, has caused the preparation of each year's operating budget to be an exercise in rigorous cost control and hope. Simple economics dictate that if T.I.C. as an organization aspires to do more it must improve its financial circumstances either via an expanded membership or higher membership fees.

I recognize that the answer is not especially easy but look forward to hearing from as many of you as possible on these matters.

Sincerely,
Peter W. Maden

INFORMAL MEETING

On April 27th 1993 an informal meeting was held in Brussels, giving the President, Mr Peter Maden of Vishay Sprague, the opportunity to report on the meeting of the Executive Committee on the previous day.

Progress was made with the arrangements for the meeting in Vienna, and the Committee discussed proposals for a meeting in Japan in 1994, one in Goslar in 1995, and initial plans for a further international symposium. The financial situation of the association was considered, and the Committee decided on a small increase in the annual fee for 1993-94, the dues having been unchanged for four years. The T.I.C. would take part in the exhibition at the Powder Metallurgy World Congress in June 1994. Among other administrative matters on which the



Committee reflected were the institution of a structure with several levels of membership, and expansion of the representation of the Committee. Dr Korinek had agreed to succeed Mr Tolley as adviser on technical matters, with effect from October 1993, announced the President.

The T.I.C. will produce a tie for those involved in the tantalum and niobium industry: if you would like to order a tie or ties, please contact the Secretary General as soon as possible so that a suitable number can be ordered.

In the second part of the informal meeting, Mr Yoichiro Takekuro, Vacuum Metallurgical Company, presented a summary of the report he had prepared on "Tantalum market movement in Japan, April 1993".

THE NIOBIUM MARKET AND THE EFFECT OF RECENT INNOVATIONS IN TECHNOLOGY

written by Dr Harry Stuart and Dr Geoff Tither,
Niobium Products Co. Inc.

SUMMARY

During the last thirty years, niobium has steadily emerged as an important specialty metal. In particular, steel consuming industries have greatly benefited from the materials savings which result from using niobium microalloyed high-strength low-alloy steels. Listed among applications for these niobium HSLA steels are high pressure oil and gas pipelines, automobiles, trucks, ships, offshore drilling platforms, railroad lines, seamless tubing for oil wells, concrete reinforcing bars, etc. Other significant consumers of niobium include aircraft engines, superconducting magnets and various nuclear/chemical plant.

Niobium, unlike molybdenum, nickel, tungsten, manganese, silicon, etc., is not a commodity. It is not traded on the open market to any significant degree but is sold in an orderly manner through well defined channels representing the various producers. Compared to the above metals, the annual consumption of niobium is small and thus niobium should be considered to be a specialty metal.

1. INTRODUCTION

In 1982 Stuart concluded that world niobium consumption would be approximately 55 million pounds of Nb_2O_5 equivalent by 1990. This opinion was based on the data shown in Figure 1. In reality the graph shows that the total

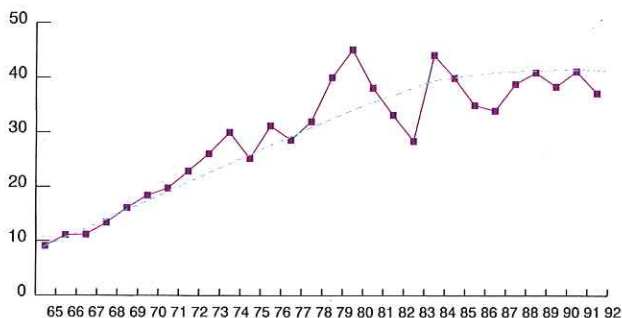


Figure 1 :
World niobium shipments (million lbs Nb₂O₅)

niobium shipments in 1990 turned out to be more than 25 % less than this prediction.

It is clear from this discrepancy that the self-evident high growth rate experienced in the 1970's was replaced by little or no growth in the 1980's. Furthermore, we have, in the niobium business, experienced large fluctuations in demand from year to year. This paper will be concerned with a discussion of this market behavior of the 1980's and 1990's and will present some observations concerning current trends in technology which may help niobium to at least "hold its ground".

Historical Perspective

Niobium was discovered in 1801 by the English chemist, Charles Hatchett. He named it columbium in honor of the new world since the mineral sample he was working with came from New England in the United States. However, Hatchett did not isolate the element. This was left to Heinrich Rose, a German, who separated an impure Nb₂O₅ from tantalite in 1844. Rose, thinking that he had found a new element, re-named it niobium.

Applications for niobium began around 1925 when it was added to tool steel as a partial substitute for tungsten and later in 1933 when it was first used to stabilize interstitials in austenitic stainless steel. This latter use became the major application of niobium for the next thirty years. Niobium was added to superalloys for use in gas turbines in the 1940's. "Niobium" was adopted by the International Union of Chemists in 1948 although the original name, columbium, is still widely used by metallurgists especially in the United States, Canada and Mexico.

Interest in using niobium in plain carbon steels can be traced back 40 years to the pioneering investigations of Becket and Franks at Union Carbide in the United States. They showed that small amounts of niobium added to fully killed carbon steel increased yield strength (and also tensile strength but to a lesser degree). Becket and Franks demonstrated that niobium strengthening reduced reliance on conventional hardeners such as carbon and manganese, thereby improving weldability.

A major development in the niobium supply picture occurred in 1958 with the discovery of the Araxá deposit in the State of Minas Gerais in Brazil. This unique carbonatite formation was found to be extremely extensive and very rich (2.5 % Nb₂O₅) and was in a geographic location having the infrastructure to allow rapid development. Thus, with the existence of such a major developable niobium deposit, and a growing awareness of the metallurgical benefits from the use of niobium in steel, the stage was set in 1960 for the growth of niobium use on a world-wide basis.

2. CONSUMPTION OF NIOBIUM

The world consumption pattern for niobium can be seen from Figure 1 which shows total shipments of all niobium products from the world's producers over the period 1965-1992. Of course, shipments and consumption are not equivalent due to fluctuations inventory. However, over the twenty year time period involved, inventory changes will not have a major impact, and Figure 1 can be used to illustrate niobium consumption. Between 1965 and 1980 a steady increase can be seen. After 1980 we experienced quite drastic fluctuations, the lowest being 1983 when shipments were lower than those of 1974. A recovery in 1984 could not be sustained and subsequent shipments have shown a decline. Overall, the annual consumption growth rate since 1980 has been less than 0.5 %.

In fact, since 1984 a case should be made for a decline in consumption of almost 1 % annually.

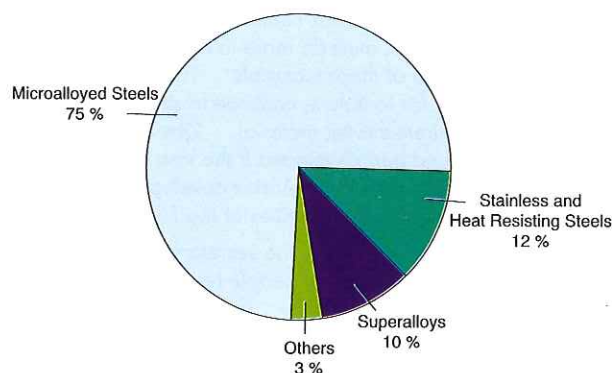


Figure 2 :
Consumption of niobium per application

What factors have influenced this consumption pattern over the years? As previously referred to, niobium is very much a steelmaking raw material, although there are other applications for niobium, including stainless steels, heat resisting alloys, and superalloys, with minor uses in the chemical and nuclear industries (Figure 2). However, the predominant use for niobium is in structural steels where it is used to strengthen and toughen these materials. It might be expected, therefore, that the fortunes of the world's steel industry would strongly influence the demand for niobium. Figure 3 shows the relationship between world crude steel production and niobium consumption and confirms a relatively close correlation, even though less than 10 % of steel produced in the world benefits from the advantages of the niobium treatment. Clearly, with this present scenario, the future for niobium is very dependent on the production of steel in the world.

The niobium consumption pattern shown in Figure 1 refers, of course, to total niobium. Figure 4 shows consumption data

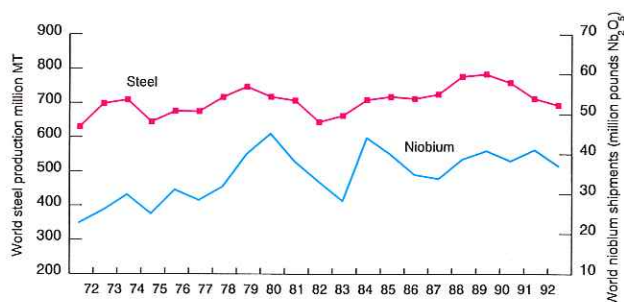


Figure 3 :
World steel production vs niobium shipments

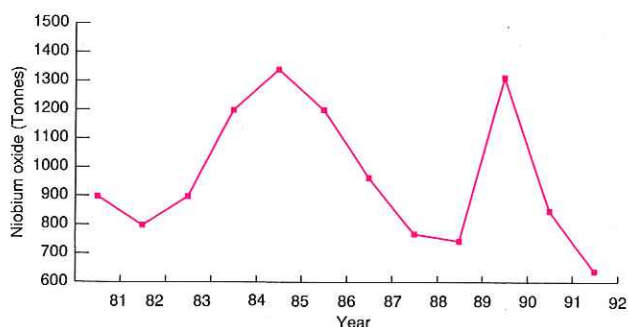


Figure 4 :

World niobium oxide consumption (excluding PRC and former communist block)

separately for niobium oxide (99 % pure). Niobium oxide is the niobium source material for superalloys and niobium-based alloys in general. No growth in consumption can be seen. The consumption of niobium oxide in 1992 was much less than that of the previous few years since we were experiencing the negative effects of defense cut-backs in the USA.

Where does this foregoing consideration of market data leave the companies involved in the basic end of the niobium business? It is certainly not the intention to try and forecast the future in any quantitative way bearing in mind the quite large fluctuations of the 1980's. However, it is clear that a realistic case appears to be one where the consumption of niobium remains stagnant. Even so, there are some technology trends worthy of mention which could positively influence the rate at which the niobium business is maturing.

3. RECENT MARKET DEVELOPMENTS

As already discussed, the volume market for niobium usage is steel. Several recent developments are currently having, or will have, an impact on total worldwide consumption of niobium.

3.1. Interstitial-Free Steels

Although developed in the United States some twenty years ago, interstitial-free (IF) steels have only recently been widely commercialized, initially in Japan and subsequently in the United States and Europe. Two major forces have promoted their development :

- 1) the desire for steels, especially in the automotive industry, which possess excellent stretch formability and deep drawability while achieving relatively high strength, and
- 2) the development of vacuum degassing during steelmaking which allowed steels to be produced containing residual carbon and nitrogen levels of less than 20-30 ppm.

It has long been recognized that removal of carbon and nitrogen from solid solution in ferrite contributes markedly to improving formability in cold-rolled and annealed strip. In conjunction with vacuum degassing, small additions of Nb (0.04 %), Ti (0.065 %) or Nb + Ti (0.015 % + 0.025 %) are used to render these steels "interstitial-free" by "tying-up" the remaining nitrogen and carbon as precipitates.

Most IF steels are produced using continuous annealing technology (CAL) which in some cases is applied in-line with the cold-rolling mill. Zinc coating is almost universally applied to IF steels.

Dual stabilization (Nb + Ti) is of particular importance in the production of hot-dip galvanized sheet. Ti-only steels are prone to "powdering" (poor coating quality and variability of

zinc coating adherence) and the addition of niobium eliminates this problem. Also, Ti-only steels are prone to surface defects ("slivers") which for many applications would require a surface grinding operation to produce an acceptable product.

Apart from "gettering" of interstitials which gives better formability and drawability, a further effect of niobium is related to the formation of a finer grain size prior to cold rolling and annealing which improves planar anisotropy thereby providing greater uniformity of mechanical properties.

Production of Nb-only IF steels is somewhat more expensive than Ti-only steels but uniformity of properties coupled with better surface quality and adherence of zinc coatings make the Nb-only steels a viable commercial proposition.

Nonetheless, producers tend to favor the use of a combined addition of Nb + Ti because of cost advantages, ease of production, properties and galvanizing performance.

The excellent formability of ultra-low (less than 0.004 %) carbon IF steels is being exploited in the automobile industry, primarily for roof panels, door side panels, oil pans and other similar parts. Consequently, IF steels represent an important product in meeting the challenge of other metals and plastics in the automobile industry.

Japan has led the commercialization of IF steels and the increase in production of cold rolled and zinc coated sheet steels relative to 1985 tonnage is presented in Table I [1].

Year/Ave	Hot rolled strip	Cold rolled strip	Cold rolled	Zn coated	Tin plated
1988	108.9	116.9	115.5	130.4	113.1
1989	110.2	117.3	116.1	142.5	111.9
1990	108.0	114.2	117.1	150.0	109.5
1991	108.9	118.7	120.7	157.0	116.3

* The production in 1985 is set as 100.

Table I

Sheet steel production in Japan, 1988-1991 - relative to 1985 production

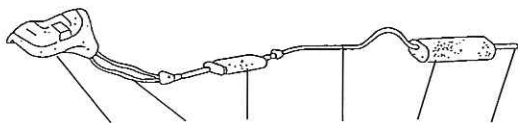
While exact figures for niobium consumption of IF steels in Japan are not available it is estimated that the Nippon Steel Corporation alone currently produces over 2.3 million tonnes of IF steel per year of which 1.0 million tonnes are Nb + Ti dual-stabilized steel. This could consume some 135 000 kg of niobium. Other major Japanese steelmakers are also heavily involved in the production of IF steels and total annual tonnage is estimated at close to 8.0 million tonnes per year with Nb + Ti steel production being about 3.0 million tonnes. The latter would consume approximately 360 000 kg of Nb-contained (550 tonnes of FeNb).

Production figures for Europe and the United States are not readily available although in both geographical areas several million tonnes per annum of IF steels are currently being produced. However, in terms of niobium consumption it has to be realized that IF steels are being substituted for existing Nb containing steels in many cases, and the IF grade contains half as much niobium.

3.2. Stainless Steels

The automotive industry is also rapidly becoming an established consumer of both dual-stabilized (Nb + Ti) ferritic stainless steels (409) and Nb + Cu, 430-type stainless steels. Japan is the prime producer of the latter type of steel while the market for the former steel is developing in North America.

The use of stainless steel in automobile production in Japan has grown by 15 % per year since 1986. The major area of growth for Nb-containing steels has been in exhaust systems. A typical system is shown in Figure 5 which shows past, present and future materials for the various parts. Currently, some 45 % of a car's exhaust system is made from stainless steel compared to less than 20 % five years ago.



Parts	Manifold	Front Pipe	Catalytic converter	Mid pipe	Muffler	Tail pipe
Past	Cast iron	Zn coated steel	-	Zn coated steel	Zn coated steel	Zn coated steel
Present	Cast iron or Stainless 409, 430M	Stainless steel, 409	Stainless steel, 409, 304	Al coated steel	Al coated steel	Al coated steel
Future	Cast iron or 409, 430M	Al coated 409, 430	409, 304 430M	Al coated 409	Al coated 409 or 430M	Al coated 409

Figure 5 :

Schematic illustration of a typical exhaust system and the evolution of materials used for various components.

Presently, the typical auto applications for the Nb-Cu grade and the Nb-Ti grade include exhaust manifolds, front pipes and catalytic converter systems. Expanding applications for both types of Nb-containing steels involve intermediate pipes, mufflers and tail pipes. In addition, the Nb-Cu steel is used for automobile trim in Japan.

The increasing use of stainless steel in automotive design is being dictated by the advent of more stringent service conditions and the introduction of extended warranties, for example, an increased warranty period for mufflers in Japanese cars from 1 year (20 000 km) to 3 years (60 000 km). The latter is likely to be further increased in the near future.

The new ferritic stainless steels contain niobium and either copper or titanium to ensure good thermal fatigue properties [2] and oxidation resistance [3] at the manifold and within the catalytic converter, and good corrosion resistance to condensed exhaust gases in the muffler and rear end components. Niobium is also beneficial in reducing corrosion in salt (NaCl) solution and H_2SO_4 .

In Japan, it is estimated that 2000 tonnes of Nb + Cu ferritic stainless steel (0.6 % Nb) per month is consumed for trim material and in the exhaust system. This translates into a consumption figure of 218 tonnes of FeNb per year. Recent forecasts indicate that these figures could reach 2400 tonnes of Nb + Cu steel in 1992, consuming over 260 tonnes of FeNb.

The prospect for increased usage of Nb + Cu stainless steel is promising and further displacement of Al-coated steels in the exhaust system and austenitic cast iron for manifolds should raise the monthly tonnage to 4000 tonnes of steel within the next two years. Consequently, consumption of FeNb would increase to around 340 tonnes per year.

In the United States, where the Nb + Ti ferritic stainless steel is being introduced into the exhaust system market, the potential for growth is considered to be significant. All of the "Big Three" automobile producers plan to introduce stainless steel into more of their 1993/4 models, resulting in about a 6 % increase in usage in 1993 to around 20 kg of stainless per car. This increase in stainless steel usage, together with a greater share going to Nb + Ti steel (relative to 409 Ti) indicates an increase in niobium consumption in stainless steels over the next few years.

For example, beginning with 1993 models, Chrysler's plans to re-introduce stainless steel into its exhaust systems will

consume about 10 000 tonnes of steel per year. General Motors Corp. plans to increase production of its Northstar V-8 engines to over 200 000 units per year. The exhaust manifold assemblies, which weigh more than 9 kg, will be made from ferritic stainless steel. Ford Motor Co. will employ all-stainless steel exhaust systems on many of its 1993 models including its larger models.

Predictions are that more than 11.5 million vehicles will be produced in the new model year and the market for stainless steel will amount to 230 000 tonnes. The Nb-containing ferritic steels seem destined to win a notable share of this market and should make further significant in-roads throughout the next few years.

The implementation of these higher quality stainless steels in Europe has, so far, been very small but the adoption of strict emission standards similar to those in the United States means that every vehicle will need a catalytic converter. This, in itself, is an annual market for 90 000 tonnes of steel. In addition, exhaust systems will also have to meet the extended warranties being introduced by the rest of the world. Hence, the growth prospects for Nb-alloyed ferritic stainless steels in Europe appear promising.

3.3. High Temperature Processing

Controlled rolling, coupled with microalloying, revolutionized the production of high strength structural and linepipe steels during the 1960's. The success of controlled rolling in producing steel with improved properties relies on rolling schedules being designed so that sufficient deformation is introduced below the recrystallization temperature in order to produce a fine grain size. Finish rolling temperatures of 700-740 °C are usual.

Although many of the large integrated steel plants have relatively modern, powerful rolling mills which allow heavy controlled rolling, there are many plants worldwide that are not capable of taking advantage of this processing route. This has encouraged the development of the "High Temperature Processing" concept (HTP) whereby the correct steel design permits more relaxed rolling conditions.

Because of its strong influence on retarding recrystallization, compared to other microalloying elements, niobium is an ideal addition for HTP design [4].

Although commercialization of the 0.10 % Nb, HTP steel is not yet widespread, hundreds of thousands of tonnes have already been produced in North America. The steel chemistry has been found to be particularly amenable to hot-strip mill processing, either on a tandem mill or a Steckel mill.

In addition to the benefit of the HTP steel design for underpowered mills, all rolling mills would benefit economically, and a faster production rate would be assured, if steels are controlled rolled to higher temperatures while still maintaining similar high strength/good toughness combinations to those produced by finish rolling at lower temperature.

3.4. Microalloyed Forgings and Wire

Microalloying allows some forged components to be produced in the as-forged condition thereby eliminating the need for costly reheat, quench and temper treatments. Although microalloyed forging steels have been available for many years, especially in Europe, a recent innovation developed in the USA is finding increasing interest.

Until recently, all commercial MA forging steels exhibited ferrite-pearlite microstructures which limit the attainable yield strength and toughness and has prevented their ready acceptance by the North American auto industry. The newly developed multi-phase steel is a low carbon (0.10 %), Mn-0.4 %

Mo-0.05 % Nb steel which has been designed to be hot deformed under recrystallization controlled forging (RCF) conditions and to be directly quenched to room temperature after forging.

Direct quenching almost doubles the yield strength compared with conventional air-cooled bar while still maintaining good toughness.

Several large-scale production trials have been undertaken where components fabricated have included connecting rods, idler arm brackets and lower control arms [5]. The latter are usually manufactured from 1541 and reheated, quenched and tempered after forging in order to achieve the required high strength, high toughness and good fatigue resistance.

The strength and toughness properties of the Mn-Mo-Nb steel (designated BHS-I) were similar to the conventionally treated 1541 steel. However, there was a significant difference between the fatigue behavior of the two steel components with the Nb-multi-phase lower control arm exhibiting a fatigue life of over 200 000 kilocycles, more than 2.5 times better than the conventional steel. In fact, under the standard test conditions the direct oil quenched arms did not fail. In the connecting rod trials the strength of the Mn-Mo-Nb steel was over 30 % greater than conventional 1045 or V-alloyed steel rods.

Apart from the superior performance of the multi-phase steel the major cost savings due to the elimination of the various heat treatment processes and the need for straightening pinpoint this steel as the basis of the next generation of microalloyed steels for the automotive industry. Potential components apart from the above include crankshafts, steering knuckles and various suspension parts.

The Mn-Mo-Nb multi-phase steel also lends itself to cold forging and cold drawing operations whereby significant increases in strength can be obtained after small amounts of deformation [6].

With a die angle of 8 % yield strength is almost doubled after only 10 % reduction with little loss in ductility. This high rate of work hardening is typical of multi-phase microstructures making the steel ideal for the manufacture of bolts, nuts, tie rods, studs and other fasteners.

Conventional steels currently used for high strength, cold drawing-heading applications are typically medium carbon steels (AISI 1045) sometimes containing alloying elements such as chromium and molybdenum (AISI 4135, 4140, 5140). In order to cold form these steels the wire rod has to undergo spheroidize annealing to facilitate wire drawing and cold heading, and subsequently be reheated, quenched and tempered in order to achieve the desired combination of mechanical properties. It is the *elimination of all the costly and time consuming heat treatments* which is by far the major advantage of switching to microalloyed steels for cold heading and drawing applications.

Commercial trials using the Mn-Mo-Nb steel have been completed and include the production of axle shafts, steering center links, tie rods ends and Grade 5 and 8 bolts [7]. The properties of the bolts made from Mn-Mo-Nb steel were more or less identical to those made from AISI 1335 even though a spheroidize anneal and a subsequent quench and temper treatment were omitted from the processing schedule of the microalloyed steel. In addition, every bolt made from the microalloyed steel passed the required 10 degree wedge test, and, unlike the 1335 bolts, exhibited no delayed failure under static loading which results from hydrogen pick-up that accompanies the final plating process.

The mechanical properties of steering center link components produced from conventional 1541 and BHS-I are given in Table II [6]. The superior properties of the cold forged, non-heat treated multiphase steel part are obvious.

STEEL	YS N/mm ²	UTS N/mm ²	El. (%)	RA (%)	CVN (ft.lbs.)	
					RT	0 °F
1541	689	758	14	55	16	7
* BHS-I	744	840	15	57	70	32

* Mn-Mo-Nb multi-phase steel.

Table II
Mechanical properties of center link components [6]

While the implementation of the multi-phase steel technology is in its infancy the huge cost savings available by the elimination of such a heat treatment as spheroidize annealing offer tremendous appeal to producers and it is envisaged that once these data receive wider publicity increased production could be triggered.

3.5. Advanced materials

3.5.1. Superalloys

Although it is over 10 years since Inconel 718 was developed initially for turbine disks in aircraft engines, this alloy, typically containing 5.0 to 5.5 % Nb, still dominates superalloy production. A typical chemical composition is given in Table III.

Ni	Fe	Cr	Nb	Mo	Ti	Al	Cr
51.5	19.9	18.2	5.1	2.9	1.15	0.57	0.035

AREAS OF APPLICATION

JET ENGINES disks, bolts, fasteners,
AEROSPACE ** shafts, high temperature
NUCLEAR tooling, and other

CRYOGENIC

PETROCHEMICAL

* High strength and good low-cycle fatigue properties.
Good castability, workability and weldability.

** Alloy 718 comprises 51 % of the total weight of the Space Shuttle Main Engine (> 1500 individual parts)

Table III
Alloy 718 *
Chemical composition (wt %)

Alloy 718 accounts for about 35 to 45 % of total nickel-base wrought alloy production and around 25 % of castings production. The alloy possesses high strength and good low-cycle fatigue properties which are particularly necessary for jet engine disks. It also exhibits good castability, workability and weldability. Alloy 718 is also used extensively in the aerospace, nuclear, cryogenic and petrochemical industries. These increasing "other" market applications will mitigate the effect of the current recession in the aircraft industry on the consumption of niobium in Alloy 718 production.

With the increase in operating temperature of modern jet engines conventional Alloy 718 has reached its maximum capability. There is, therefore, a need to develop a higher strength alloy to operate within the current 650 °C limit or develop an alloy of equal or greater strength for operation at even higher temperatures.

Recent work [8] has shown that by reducing the Fe content of Alloy 718 to 14 % from about 17-19 % and adding 2.3 % W, the stress rupture life, at 650 °C under a stress of 686 MPa, increased almost threefold compared to conventional Alloy 718. Also, the 100 hr rupture life of the modified alloy was some 14 to 22 °C higher.

This alloy development, combined with thermomechanical processing which provides for microstructural refinement and uniformity of microstructure, could extend the usefulness and commercial life of Alloy 718. However, the increasingly stringent demands of operation have prompted development of various intermetallics containing high niobium levels and which are described later.

3.5.2. Titanium-alloys

A promising market development in the Ti-alloy field is the new Timet Beta-21S (Ti-21Mo-3Nb-3Al-0.2 Si). This alloy has superior oxidation resistance up to 815 °C, compared with Ti-15-3 and commercially pure Ti (C.P.Gr.2), but is not as resistant as the newly developed titanium aluminide materials such as Ti-14 Al-29 Nb ("Alpha-Two") and Ti-33 Al-IV ("Gamma").

Also, Beta-21S exhibits exceptionally high temperature strength characteristics after an appropriate aging treatment. Its creep resistance also is noteworthy when compared to the more predominantly used Ti-6 Al-4 V and the replaced Ti-15-3 alloy.

Because of its exceptional cold rollability and, hence, ease of producing foil, Beta-21S is being considered for high temperature ducting and pressure lines. It has also been chosen as the baseline matrix alloy for metal-matrix composites in the National Aerospace Plane (NASP) airframe program.

Beta-21S (3Nb) possesses high strength, corrosion resistance and three times more resistance to hydrogen absorption than CP titanium. These advantages should encourage its development for sour gas/oil applications. The alloy is in fact being currently evaluated for various industrial applications such as downhole sour oil service equipment where the extreme environment requires maximum corrosion resistance and hydrogen tolerance.

In addition, Beta-21S has better resistance to corrosion by hot hydraulic fluid (hydrogen embrittlement) than does titanium. Beta-21 S is the first Ti-alloy that seems to be immune to attack by hot hydraulic fluid and immediate application is in the housing of jet engines.

3.5.3. Intermetallics

As mentioned earlier, a potential major new market for niobium alloying lies in the development of the intermetallic compounds Ti_3Al Alpha-Two ($\alpha 2$) and $TiAl$ gamma (γ). Their low density and attractive high temperature behavior [they can be used up to 760 °C] both in monolithic and composite forms means that they could replace superalloys in many elevated temperature airframe, engine and missile applications.

The primary Alpha-Two alloys are 2411 (Ti-14Al-20Nb in wt.pct.) and Super Alpha-Two (Ti-14Al-20Nb-3V-2Mo). The high level of niobium is instrumental in improving the ductility of Ti_3Al and hence its fabrication, especially into thin sheet.

General Electric Company [9] have developed Alpha-Two alloys which contain even more niobium, up to 27 % Nb. Two alloys have shown particular promise : Ti-24.5Al-23.5Nb and Ti-22Al-27Nb. Of these, the best combination of high-temperature strength and roomtemperature ductility and fracture toughness is exhibited by the Ti-22Al-27Nb alloy. General Electric are currently working to optimize production methods which will be followed by commercial trials.

3.5.4. Superconductors

Without doubt the greatest impact in the superconductor market throughout the next decade will be the construction of the planned Superconducting Supercollider (SSC). The SSC is the next generation of modern particle accelerator and will be an

instrument of unparalleled power. The collider will measure 54 miles in circumference and will be housed in a tunnel 150 ft beneath the ground. The production of the multifilamentary magnet cables will require over 500 tonnes of niobium during the next several years. Pure niobium will be used to produce Nb 47 Ti alloy for the project. The alloy will then be assembled with copper to produce NbTi multifilamentary cables which will be used to wind the superconducting magnets, Figure 6.

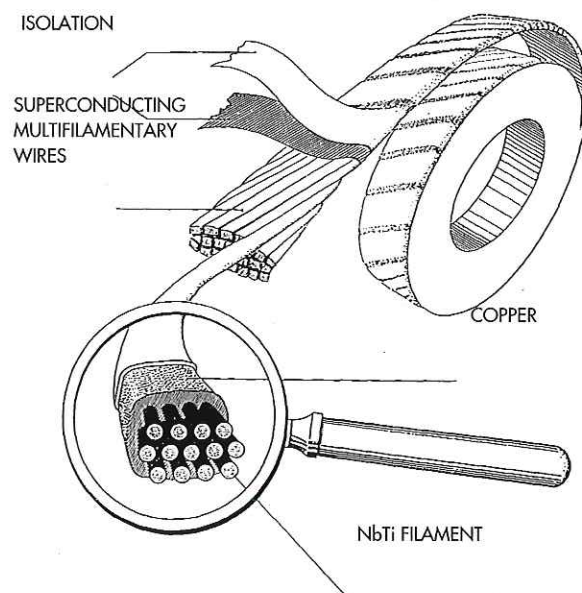


Figure 6 :
Multifilamentary magnet cables of copper-covered NbTi
for the Superconducting Supercollider

The impact that the SSC may have on niobium consumption in the superconductor field over the next six years can be seen from Figure 7, i.e., almost 50 % of the total estimated 1100 tonnes. Superconductors in total are forecast to use some 75 % of the overall pure niobium consumption.

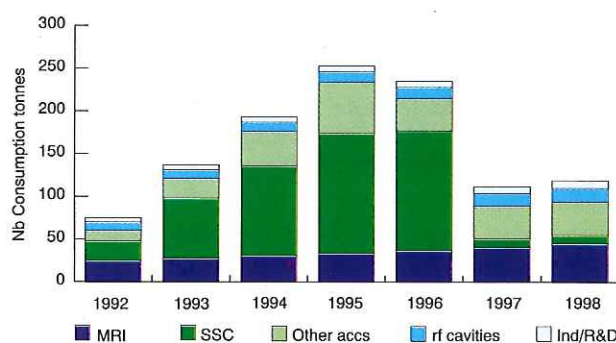


Figure 7 :
Forecast of niobium consumption in superconductors from 1992-1998
(total consumption = 1100 tonnes)

Superconductors, many of which involve niobium, are also being developed for use in computers and their components, ships, magnetically levitated trains and medical diagnostic equipment, as well as other applications. The implementation of several of the above applications will obviously be necessary in order to reduce the shortfall created by the completion of the SSC and to continue growth in Nb consumption above and beyond the current 100 tonnes per year.

4. CONCLUSION

The data presented suggest a maturation of the niobium industry. Niobium shipments have reached a plateau after a rapid growth period throughout the 1970's and early '80's.

Many applications have been developed for niobium primarily in the microalloyed structural steel area, and successful defense of this marketplace against competitive alloying elements has enabled niobium to maintain its position.

Innovations in the steel industry, such as IF steels, ferritic stainless steels and high, Nb, HTP steels, are providing growth potential that could result in some positive movement in the niobium shipment/consumption curve. However, some major tonnage development will be necessary in order to shift the curve into a notable positive mode.

Finally, it should be mentioned that the major growth areas over the past three decades have been linepipe, automotive and aircraft engines. Up to the present time, consumption of niobium in each of these areas has not peaked simultaneously. If this situation were reversed then the niobium consumption plateau would be shifted to a higher level. However, the chances of this happening seem remote.

This paper has been slightly shortened for the Bulletin : a copy of the full version may be obtained on request to the T.I.C.

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NIOBIUM AND TANTALUM OCCURRENCES IN THAILAND

At the T.I.C. meeting in Phuket last November, we were given a talk on the above subject by Mr Sangat Piyasin, who is a geologist and special advisor to Thaisarco (whose tin smelter recovers much of the world's tantalum in its tin slags). Niobium-tantalum ores are commonly associated with tin, and their values are obtained either as by-products of the mineral dressing for tin, or, if they are too closely combined (either by fine grain size, or by being actually "dissolved" in the tin mineral), then in the tin smelting process.

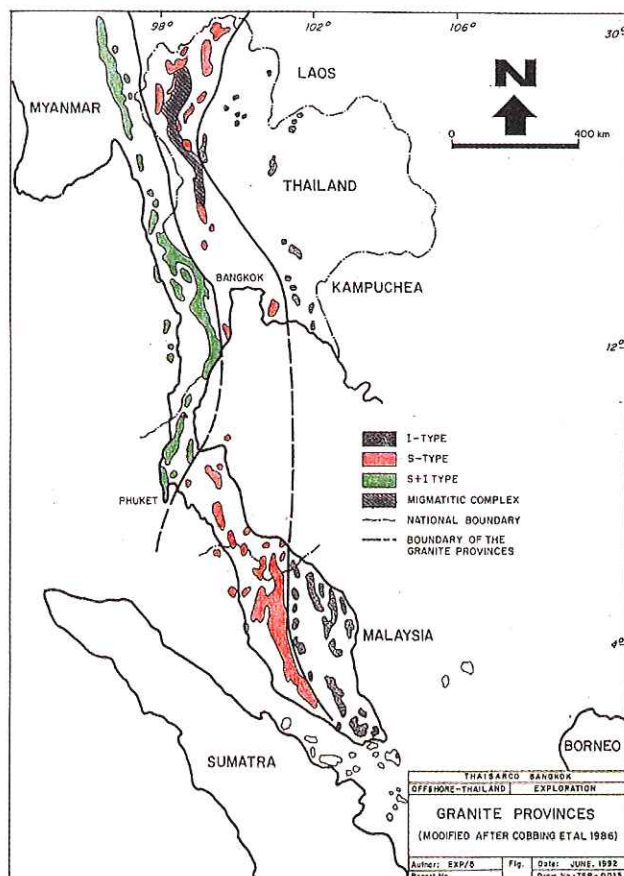
Niobium and tantalum have very similar atomic radii, and so replace each other in a whole range of minerals, and also do so with tin or titanium in their oxides (cassiterite and rutile). Some of the relevant minerals found in Thailand, and their chemical compositions, are given in Table I.

Percent Oxides	TiO ₂	Nb ₂ O ₅	Ta ₂ O ₅	Y ₂ O ₃	SnO ₂
Minerals					
Cassiterite	0.46	0.34	0.37	0.04	94.63
Columbite	0.36	2.28	2.90	0.03	89.1
Cassiterite	4.14	55.2	14.30	0.00	1.07
Yttrocolumbite	1.77	32.8	16.2	12.3	3.18
Tantalocolumbite	3.98	31.1	44.0	0.09	0.89
Niobiumrutile	80.3	7.25	4.34	1.10	0.72
Tantalumrutile	50.0	9.33	28.5	0.01	3.43

(After Warin Samukheethum et al., 1987)

Table I

Chemical compositions of minerals from scanning electron microprobe analyses



There are two types of granite making up the basic rocks of Thailand and they are known as I-type and S-type. The latter which has tin and other associated heavy minerals in pegmatite veins, is believed to have been formed as a result of collision between the Shan-Thai-Malay and the Indochina blocks.

Mapping the outcrops of the two types of granite gives an indication of the potential areas for niobium and tantalum recovery in conjunction with tin deposits : the map shows how the granite provinces tie in well with the tin smelters' experience of tantalum recovery from their tin concentrates : the highest from near Phuket, a moderate amount from Central Thailand down through the west coast of Peninsular Malaysia, and little or none from the east coast (and also, in fact, further southwards to the Indonesian tin deposits in Belitung and Banka).

A MEETING IN ST. PETERSBURG IN MAY 1994

An old friend of the T.I.C., Professor Habashi of Laval University, Quebec, is helping to organise a symposium on Complex Ores Utilization in conjunction with the St. Petersburg Mining Institute, and is now calling for papers. The meeting includes amongst its sponsors Gipro-nickel (the Russian nickel and cobalt producer) and Vami (light metals). Topics to be addressed will be mineral dressing, hydrometallurgy, pyrometallurgy and electrometallurgy of complex ores, simulation and automation of the processes, and waste disposal and environmental impact.

The meeting will be held from May 10th-20th next year : requests for further details, and bookings for hotels etc., should be addressed to the Saint Petersburg Mining Institute, 21 Line, dom 2, Saint Petersburg, Russia 199026. Readers in North America requiring information (or offering papers ?) can contact Professor Habashi in Quebec at telephone (418) 656-7269, fax (418) 656-5343.

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