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TANTALUM-NIOBIUM INTERNATIONAL STUDY CENTER

PRESIDENT'S LETTER

Dear Friends,

There are numerous signs that the tantalum and niobium businesses will continue to improve in 1996. Demand is growing and the performance of the companies in our industry is improving. The growth we are experiencing is a combination of improved economic conditions around the world and a continuation of the advances in technology and development of new applications.

It is nearly impossible to gauge the impact that the efforts of our Technical Advisor, George Korinek, have had on overall tantalum demand. His efforts to spread the word about tantalum through the "Promotion Fund" that was set up nearly a year and a half ago have been significant. It is possible to say that a lot more people have been exposed to the unique properties of our materials because of his efforts to organize and conduct conferences and present papers. The latest of these was a very successful 3 day annual TMS meeting in Anaheim in February that contained a symposium on tantalum. There were 45 papers presented on tantalum in six sessions and nearly 3,000 people attended the conference.

It has been decided that the concept of the separate promotion fund supported by a few companies in our association will be terminated at the end of February 1996. These efforts will continue as part of the general budget of the association with specific activities and expenses approved by the Executive Committee.

I would like to thank George for his efforts to get this promotion program off the ground and look forward to a continuation of his efforts to promote the use of our materials. Plans for the coming year will be discussed at the upcoming bi-annual meeting of the Executive Committee.

APRIL MEETING

The Executive Committee meeting will be held on the morning of April 23rd 1996 in Brussels. All members are invited to a luncheon to be held that day, followed by a meeting open to all members. I hope all of you will be able to attend, but if you are unable to do so, please forward any suggestions, thoughts, or ideas for discussion to the Secretary General.

Plans for the General Assembly this year, October 20th to 22nd, continue and the principal technical topics for this meeting are expected to be tantalum capacitors and niobium superconductor materials. We will discuss the plans and agenda for the General Assembly at our meeting in April.

Yours sincerely,
R.S. Barron, President

SUMMARY

President's letter	1
The Niobium Industry - A commentary	1
Tantalum - An overview	5

THE NIOBIUM INDUSTRY A Commentary

This paper was presented by Dr Harry Stuart, Reference Metals Company, Inc., at the International Symposium on Tantalum and Niobium, on September 25th, 1995

INTRODUCTION

As a representative of the world's foremost producer of niobium, I am periodically asked to make a presentation on the subject of niobium. This I have done with great pleasure on many occasions in very pleasant locations such as Goslar.

However, it is becoming increasingly difficult to find something different and/or interesting to say about niobium, because although being involved with this metal has been fascinating in many ways, it is a business that changes only slowly from year to year.

There have been few truly revolutionary changes in the supply/demand picture of niobium since the discovery of the Araxá carbonatite way back in the 50's, and the development of niobium microalloying technology in the 60's.

The switch away from cobalt-base to niobium containing nickel-base superalloys in the 70's should be viewed as only a minor revolution. The development of niobium-using superconducting MRI magnets in the 80's was important but not revolutionary, at least not yet.

On the contrary, most changes in the niobium industry are evolutionary and so for this reason, and also to avoid boring today's audience many of whom know at least as much as I do about niobium, I decided that although I would give some attention to recent trends in the niobium supply/demand picture, I would concentrate my talk on another issue of relevance to our industry. I have decided to talk a little about specifications, a subject of profound importance to us all but one which is almost always ignored in meetings such as this.

Although all niobium raw materials and finished products must be produced and purchased according to some specification, especially in an environment that is increasingly being influenced by the dictates of ISO 9000, I am of the opinion that many of the specifications being used in our industry are not only anachronistic to the point of being absurd, but in some cases scarce capital is being wasted in building facilities to purify materials needlessly. Also, crucial materials resources are being squandered in meeting often irrelevant specification requirements. In some cases companies may even risk polluting their environment in the quest for unnecessary product purity. Needless to say, we should do our utmost to change and to persuade others to review their needs more critically.

Exploitable tantalum reserves (tantalite) always reveal a significant (several percent) niobium (columbium) mineralization present in the deposit. In some cases the mineral is more accurately referred to as "columbite". The opposite is true to a much lesser extent for commercially viable niobium deposits. Extractable tantalum has never been found associated with a niobium reserve although all niobium minerals are found with some tantalum association. CBMM's pyrochlore (pandaite) in Araxá shows the presence of tantalum at the 2000-3000 ppm level.

The cost of extracting low level tantalum from pyrochlore is prohibitive and, as a consequence, virtually all niobium products contain some tantalum. In some cases CBMM customers, even tantalum producers, consider this low level tantalum in niobium (2000 ppm) to be an impurity because in turn their customers' specifications severely restrict the allowable tantalum content in the products that they are purchasing. In virtually all of these instances, the presence of tantalum has never been shown to be of any deleterious consequence. In fact in some cases tantalum is beneficial to the performance of the niobium alloy. The specification limits tantalum only for "historical reasons" and through the reluctance of people to make a change (make a decision). But more of this later.

On the other hand, companies whose principal business is the extraction and sale of tantalum from tantalite minerals have unavoidably extracted niobium from their tantalum raw materials and by default have found themselves in the niobium business. There was even a time in the 50's and 60's when this niobium was considered to be a waste by-product having little or no value. Some ferroniobium for stainless steel manufacture was made from this material but this was the time before microalloying technology had been developed in the basic steel industry and the demand for ferroniobium was very low. In some cases, I am told, niobium compounds were even stockpiled.

The niobium producers are still significantly impacted by this history in the case of many niobium alloy specifications. Clearly, in the past when ferroniobium was made from by-product niobium compounds it was very low in elements considered to be impurities compared to that made from pyrochlore concentrate. This has created an expensive problem for today's niobium industry.

NIOBium SUPPLY AND DEMAND

The **supply** picture of niobium has not changed to any significant degree since we all met in Orlando in 1988. Brazil still supplies the vast preponderance of the world's raw materials with CBMM being by far the biggest supplier.

Since our last international symposium, however, CBMM has established its place as a bona fide niobium company rather than just a mining company. CBMM is now participating in the supply of niobium-based alloys as well as high purity masteralloys - ferroniobium and nickelniobium. Beginning in 1994 CBMM also began manufacturing its standard grade ferroniobium using an electric arc process. This was the result of CBMM's commitment to minimizing the impact of cost escalations and to eliminating pollution from its operations.

Catalao de Goiás in Brazil and the Niobec mine in Quebec continue to be secondary sources for niobium in the form of standard grade ferroniobium. Starting in the fall of 1994 the Niobec mine facilities now include an aluminothermic process to manufacture ferroniobium on-site, eliminating the need to use converters. Their product has been well received by the end-users.

In the last three years or so, the international market has seen niobium materials exported from the former Soviet Union. These

products include standard grade ferroniobium, niobium oxide, niobium metal and niobium alloys. The prices of these materials were uniformly low but quality was not always pleasing to the purchasers. More of these materials seem to have been targeted at European users than US consumers. The supply of these materials, some of which appeared to have originated from former government stockpiles, seems to be slowing perceptibly.

From time to time the niobium industry hears of new deposits that promise to revolutionize the supply picture and we are sure that additional supplies will be developed at some juncture. However, it is difficult to conceive of operating mines in the depths of equatorial Africa or the far-flung Siberian tundra. The realities of the economics of niobium production would not seem to favor such locales.

Recent **demand** for niobium has shown a mild departure from the trend of the 80's and early 90's. We could argue that we are beginning to see a positive departure from the apparent stagnant demand of the 80's. This is illustrated in Figure 1.

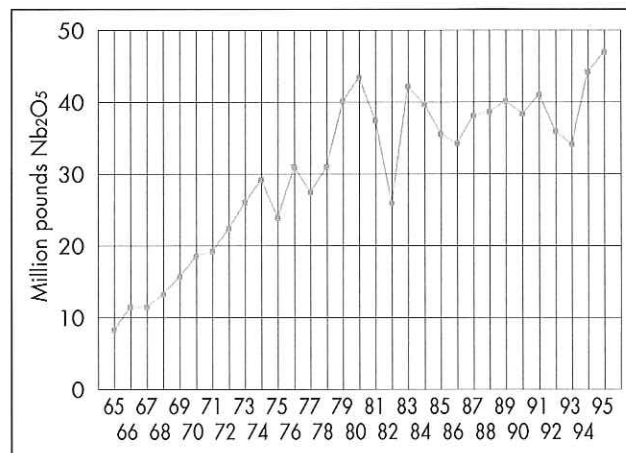


Figure 1 : World niobium consumption, 1965-1995

Although there do seem to be some grounds for optimism that the promise of the 70's is beginning to be fulfilled, we must remain **extremely cautious**. It is clear that although it is tempting to claim that the consumption curve between 1965 and 1995 shows a nice linear increase at the rate of a few percent per year or at least a parabolic relationship, if we examine only the data between 1980 and 1993, the more relevant group of data, we can equally well claim that the rate of increase was negative because in reality that is what happened on a statistical basis.

We have in the recent past used the data in Figure 1 (1965-1993) to reach the conclusion that the niobium industry is mature because of the shape of the curve. Our hypothesis assumed that

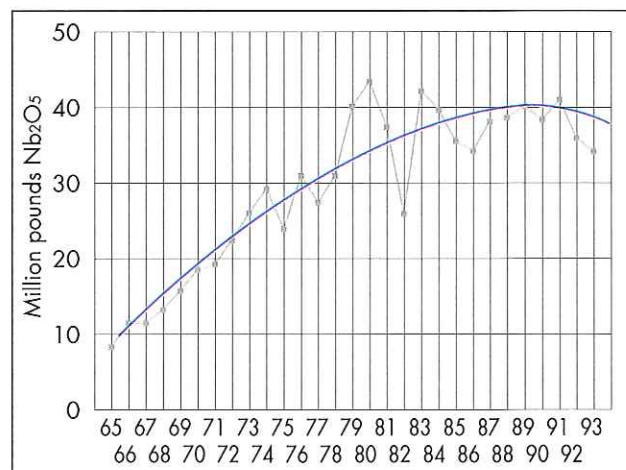


Figure 2 : World niobium consumption, 1965-1993, showing trend curve

since the bulk of niobium is used in microalloyed steels, and since this technology had been largely assimilated by the world's steel industry we had a sound basis for our maturity hypothesis illustrated in Figure 2. We may well have been correct then and may still be correct, because even a mature industry may show positive consumption excursions due to increased economic activity and that has certainly been the case for most regions of the world in the last three years except for the very recent past in Japan.

We still believe we are involved in a mature industry, but it is remarkable that niobium is merely mature when we consider the situation of our principal customer, the steel industry. Figure 3 shows the close similarity between the production of steel and

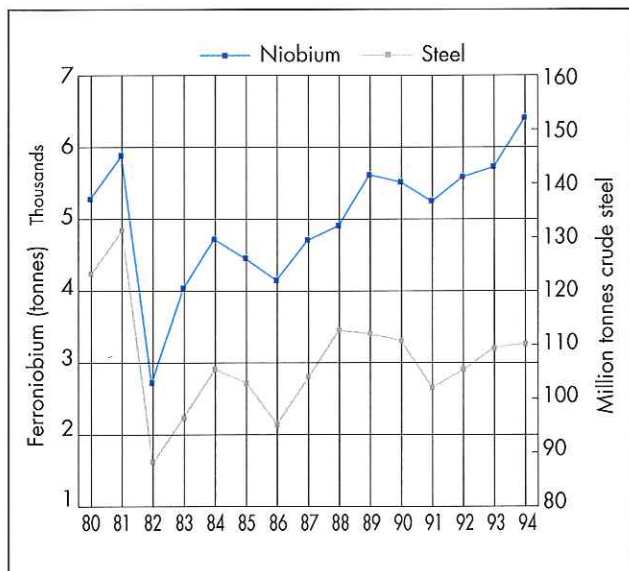


Figure 3 : Niobium sales vs. crude steel production, North America

niobium consumption in North America. This relationship is confirmed more convincingly in Figure 4 which shows a correlation of the two independent variables in Figure 3. There is a good linear correlation between steel production and niobium consumption.

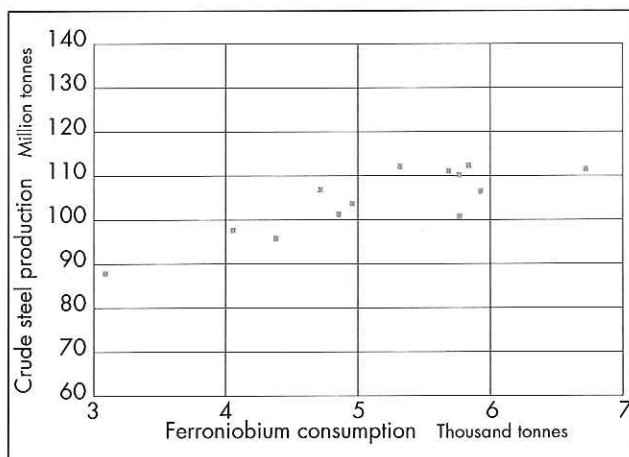


Figure 4 : Correlation of steel production and niobium consumption in North America, 1982-1994

When we examine the state of the steel industry in macro-economic terms, and relate its growth to the growth of the world economy (Figure 5) we see that the steel industry is advanced post-maturity. On the other hand, niobium has declined only slightly compared to the world economy in the recent past. The reason for this is a consequence of the fact that with the passage of time, each tonne of steel produced in the world contains, on average, more niobium. This is illustrated in Figure 6 for North America, but the trend is the same throughout the world.

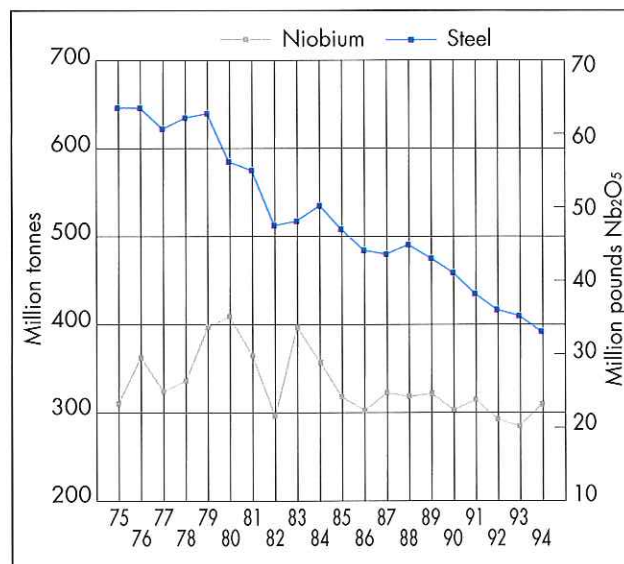


Figure 5 : Consumption intensity, steel and niobium

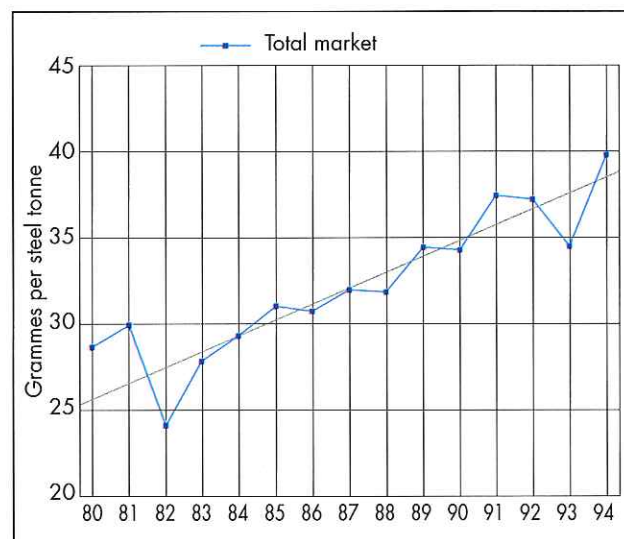


Figure 6 : Niobium consumption in North America (grammes Nb per steel tonne)

The data shown in Figure 1 refer to the entire niobium market and it is clear that the vast preponderance of niobium is used in HSLA steel and not surprisingly there is a close relationship between steel production and niobium consumption as is shown in Figure 4. Nonetheless, it is worth examining some of the individual components of this total curve.

Figure 7 shows the change in the consumption of niobium oxide. The data are shown in terms of percentage change compared to the starting year of 1980 when CBMM began producing technical grade niobium pentoxide.

It is clear from this graph that oxide demand is quite cyclical. This is a consequence of the fact that oxide is a raw material which has been used extensively in the manufacture of super-alloys for aircraft engines. Strong consumption growth, albeit cyclical, in the 80's gave way to rapid decline following the end of the cold war and demilitarization, especially in the United States. The last two years, however, have seen a pleasing recovery and 1995 will be the second strongest year for oxide since the peak in 1990. This recovery has been the result of an increased application of niobium bearing nickel-base alloys in applications which require corrosion resistance more than high temperature resistance. These uses are referred to as "environmental applications".

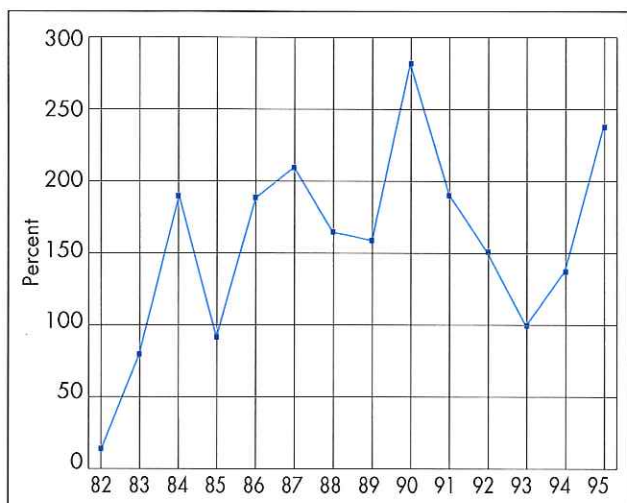


Figure 7 : Demand for niobium oxide, as percentage of demand in 1980

Figure 8 shows a similar "percentage change" plot for niobium metal and niobium based alloys. The consumption of these products has shown cyclicity similar to that for niobium oxide. Although there is obviously a relationship between these two materials, we believe that the recent high for consumption of niobium-based alloys in 1991 was a consequence of materials that were being purchased in connection with the construction of the ill-fated SSC particle accelerator. When this project was cancelled by the US government, a rapid decrease in activity resulted. However, we are seeing a return to a "normal" level of business which is strongly influenced by the manufacture of Nb47%Ti for superconducting MRI magnets for medical diagnostic purposes. There is also a secondary but strong Nb1%Zr component in this niobium based alloys consumption picture.

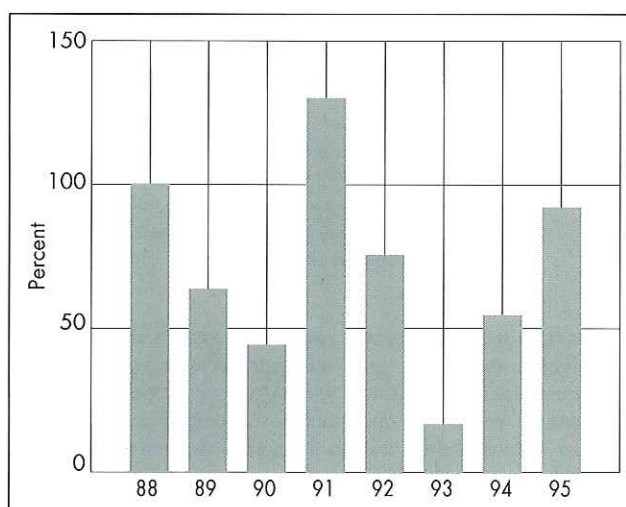


Figure 8 : Demand for niobium-based alloys as percentage of demand in 1988

SPECIFICATIONS

Ferroniobium specifications

Niobium first began to be exploited industrially as an alloying addition to high temperature steel principally for aircraft jet engines. Its role was to stabilize interstitial carbon and nitrogen and contribute to creep resistance. The niobium raw materials available at that time, more than fifty years ago, were derived principally from columbite minerals. Later, synthetic concentrate made from Malaysian tin slag also became available. These raw materials were very pure compared to the principal niobium raw

material used today - pyrochlore. As I have already indicated, at that time niobium oxide was unavoidably produced as a by-product of tantalum operations while demand for niobium was modest. Consequently, its market price was low and allowed the production of standard grade ferroniobium from this very pure raw material source. Naturally the impurities in the ferroniobium produced were quite low, especially lead and phosphorus. Furthermore, because the chemical extraction processes being used aimed for maximum tantalum yield, the niobium by-product was naturally very low in tantalum. Both these essentially fortuitous situations were very consequential for the niobium business and still are today.

When specification writers such as the ASTM in the USA decided to create a specification for ferroniobium, it was natural for them to decide on a composition that reflected the materials customarily available from the manufacturers of the day. Clearly, they had no incentive to allow impurity levels to be any higher than those in the ferroniobium materials then available commercially. Furthermore, since the principal use for ferroniobium was in austenitic stainless steel, they applied the severest restrictions to lead, sulphur and phosphorus, those elements that were believed to harm the processability of this class of steel.

Production of pyrochlore ore concentrates from the Araxá carbonatite began in the 1960's. Initially this concentrate was exported from Brazil for conversion to ferroniobium in the consuming industrialized countries. The principal converters at that time naturally demanded a concentrate with sufficient purity to allow them to produce a ferroniobium that would meet ASTM specifications. However, the Araxá concentrate was too impure to allow the production of a ferroniobium equivalent to that produced from columbite-origin raw materials and out of necessity CBMM was obliged to introduce an expensive concentrate leaching step into its processing regime.

Almost coincident with the development of the Araxá niobium deposit in the late 1950's, a new application for niobium was found in the newly developing HSLA steels. These steels utilized a niobium content which was more than an order of magnitude lower than that of stainless steel and they also had a very much greater tolerance for impurities such as lead, sulphur and phosphorus. In a very short period of time HSLA steels became the dominant consumers of niobium and by the end of the decade of the 70's more than 80 percent of standard grade ferroniobium was being used in these steel products. At the same time, changes in the technology of stainless steel production (the AOD process) had rendered niobium containing austenitic stainless grades of minor importance.

Despite this new reality, however, purchasers of ferroniobium had no incentive to reflect the change in their ferroniobium purchase specifications and ferroniobium continued to be ordered according to the prevailing specifications that bore no relationship to its use in HSLA steels. CBMM's distributors and converters similarly had no incentive to "rock the boat". Likewise their customers in the basic steel industry. Accordingly, CBMM installed an expensive leaching process to purify its concentrate and allow the manufacture of ferroniobium to meet the now largely irrelevant specifications.

At the present time, about 90 percent of standard grade ferroniobium is consumed in the manufacture of microalloyed steels which are used to build pipelines, bridges, automobiles, etc. These HSLA steels can tolerate high levels of so-called impurities. For instance, some automobile sheet steels contain more than 600 ppm of phosphorus "impurity" (0.06%) as a strengthening agent. Similarly, some HSLA steels can contain much more than 300 ppm of sulphur (0.03%) and resulfurized grades contain double this level to improve machinability without suffering any adverse side effects. All steels contain some lead, which in the case of free-machining long-product grades is more than 800 ppm.

When niobium is added to an HSLA steel, the addition is typically 0.5 kilos of ferroniobium per tonne of liquid steel. Thus, any impurities in the ferroniobium are diluted by a factor of 2000 (1000/0.5) when it dissolves into the steel.

If the ferroniobium contains 0.1 percent each of lead, sulphur or phosphorus, the net addition of each of these impurities to the steel from the ferroniobium is 0.5ppm (0.00005 percent) which is totally insignificant at three orders of magnitude below the pre-existing levels of impurities, and the change would not be detectable by any analytical equipment.

Even if ferroniobium contained 1 percent of an impurity such as phosphorus, when this ferroniobium is added to steel the impurity "pick up" from this source would be five parts per million (0.0005%) which is still totally insignificant for any impurity in steel and not even detectable by normal analytical procedures.

Since stainless steels contain as much as 0.5 percent niobium, there is much less of an impurity dilution when ferroniobium is added to these steels. The impurity pick-up from ferroniobium, therefore, can be as much as 50 ppm of lead. While this is not high enough alone to cause problems in stainless steel manufacture, the producers maintain that when this pick-up is added to the lead accumulated from other sources, a risk of cracking during processing could develop. This position is, none-the-less, still very conservative but probably is defensible.

In addition to its use as a masteralloy in steel manufacturing, ferroniobium is also used in some cases as a niobium source in the production of niobium metal and niobium based alloys. It is also used to make niobium oxide in the manufacture of high purity ferroniobium and nickel niobium masteralloys for the super-alloy melters. There is no industry standard for ferroniobium used for these purposes and the processors simply use steelmaking grade. The cost of removal of other elements is obviously of significance for this application. The cost of disposal of the unwanted fraction of the ferroniobium as chlorides or whatever form the waste products take is also a consideration. Clearly this segment of our industry is interested in ferroniobium having maximum purity and any deterioration in its purity will adversely affect the economics.

Niobium and niobium alloy specifications

Interestingly, the question of maximum contention when we consider niobium metal and niobium based alloy specifications is that of tantalum content. Companies today who purchase niobium to use as a metal or to convert into an alloy or purchase niobium based alloys, are also using specifications which still reflect the fact that niobium was once only a subsidiary by-product of tantalum extraction.

As I have previously described, when niobium metal was first produced from niobium oxide, the oxide was a by-product of the liquid-liquid extraction process used for tantalum extraction. This process very efficiently separates niobium and tantalum, and as a consequence niobium produced from this niobium material contains only a few hundred parts per million of tantalum. As in the case of ferroniobium, when specifications were written for niobium metal, they were based on this material availability and not on any "fitness for purpose" considerations. Subsequent downstream alloys made from this niobium were also similarly specified to have low tantalum contents for the same spurious reason.

Today, we in the niobium industry who produce niobium metal from pyrochlore, which of necessity contains 1000 or 2000 parts per million of tantalum, find ourselves in an unfavorable situation trying to produce "low tantalum" niobium metal for no reason. We can of course produce material with tantalum content well below 1000 ppm, but we do not relish the waste of time, money and resources involved.

A classic case of this nonsense is that of niobium-47%titanium for use in the production of superconducting magnets. From the beginning in the early 80's the producers of this material had to meet a specification that required the tantalum content of the alloy to be less than 1000 ppm only for the historical reasons described above. We in turn as raw material suppliers had to provide ferroniobium with less than 1000 ppm tantalum. This situation continued long after it was well known that tantalum exerts no negative influence on the performance of the superconductor and even today, when tantalum is being added to other superconducting niobium alloys to improve their current carrying capability, we still have a maximum allowable tantalum content in specifications presently being used for superconducting niobium-titanium alloys. We even see encouraging performance data for ternary niobium-tantalum-titanium alloys in superconductivity but still we do not change.

Another example of specifications that are unnecessarily increasing manufacturing costs without conferring any benefit to the final product is that of niobium-1%zirconium alloys for use in high intensity sodium vapor street lights. Again we see a maximum tantalum limit of 1000 ppm specified, which I am sure is simply another consequence of history since there are no data extant that demonstrate any negative effect of tantalum in this alloy at any stage of its manufacture or use.

There are many other examples of baseless specifications in the niobium business but there is no point in continuing to list them. I will simply end my presentation with a plea to everyone to make a resolution to rationalize the way we specify our materials and try and introduce a strong element of "fitness for purpose" into our industry instead of "as you were".

TANTALUM - AN OVERVIEW

Presented by Dr George J. Korinek, Technical Adviser to the Tantalum-Niobium International Study Center, at the International Symposium.

INTRODUCTION

Our last International Symposium on Tantalum and Niobium took place in November 1988 in Orlando, Florida. I would like to survey the development of our industry over the seven years since 1988 and to make some remarks about the future of tantalum. Since we will have several speeches addressing in detail different aspects of the Ta business, I will concentrate on the major trends.

RAW MATERIALS

Our friend, Mr. John Linden, will be telling us about raw materials next, therefore I will make only a few remarks on that subject.

As you all know, Ta is closely associated in nature with niobium and tin. Tantalite is the main primary source of tantalum. Ta is sometimes included in the lattice of cassiterites and cannot be separated by mineral dressing techniques, and during the smelting operation, it reports in slag. Tin slags were an important source of tantalum.

Figure 1 shows the production of tantalum raw materials from 1988 to 1994, according to T.I.C. statistics. Please note that the production figures given are for T.I.C. members. Not included is the production of PRC, the old U.S.S.R., and some small producers (such as Garimpos) in Brazil, South East Asia, and

Africa. The tantalum tin slag production is well covered, since the major tin smelters have been and are members of T.I.C.

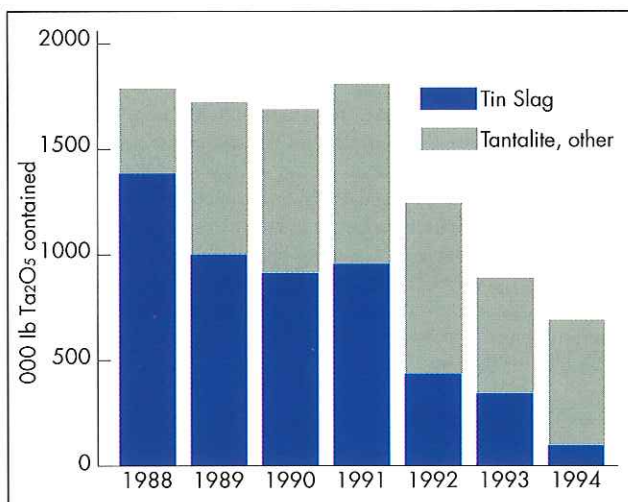


Figure 1: Tantalum primary production (source: T.I.C. statistics (1))

There are two trends which are important :

1. The primary production of member companies over the seven year period decreased by nearly one half.
2. Whereas in the early years production of Ta_2O_5 in tin slags was predominant, this completely changed in the last few years with tantalite production now dominating.

Figure 2 further complicates matters. Figure 2 includes the total production of Figure 1, and also shows the processors' shipments of products in pounds of Ta_2O_5 , and processors' receipts for years data are available. It is obvious that the primary production covered only about half of the products shipped. It also demonstrates that the receipt of raw material by the processors is always larger than the primary production, and in some years by substantial amounts.

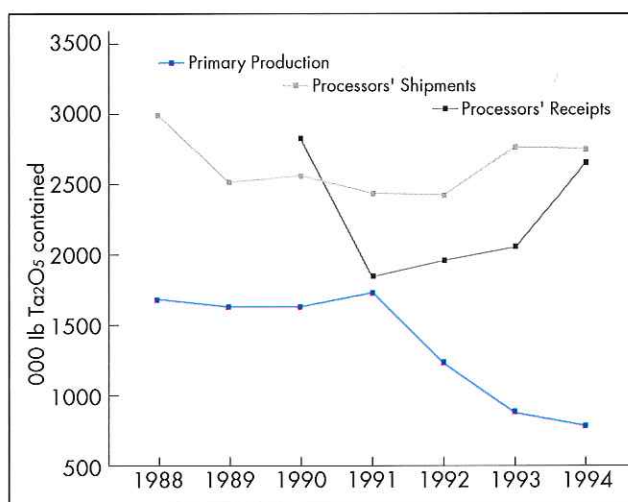


Figure 2: Tantalum primary production and processors' shipments (source: T.I.C. statistics (1))

These points demand some explanation.

Structural changes in the tin industry are responsible for the sharply decreased production of tantalum-containing tin slags. The countries of South East Asia, mainly Malaysia and Thailand, used to be the leading primary producers of tin. That situation changed, and now Brazil, Indonesia, and China are the leading primary producers. Unfortunately, the slags generated from the

concentrates of these countries contain tantalum, if at all, only in concentrations which are not treatable under present conditions. This explains the decrease of total primary production, and of the change in importance between tantalite and tin slags.

Processors' receipts are always larger than primary production for the following three reasons:

1. These receipts also include secondary materials and intermediates.
2. Stockpiled material has been shipped to processors.
3. Material from non-member companies is included in the processors' receipts.

PRODUCTS

I would like to address the development of the product side. Figure 3 shows the total processors' shipments in pounds of tantalum. It is obvious that there is practically no growth in tantalum over the seven years covered. The exceptionally strong year of 1988 somewhat distorts the statistics, but even correcting for this would amount to less than 2% increase per year. To have a more clear view of the situation, we must look at the developments in the major product groups. As is widely known, the major application of tantalum is in electronics in the form of solid electrolytic capacitors. Tantalum powder, wire, and furnace hardware are supplied by processors to the capacitor producers, and the main volume is in the form of powder.

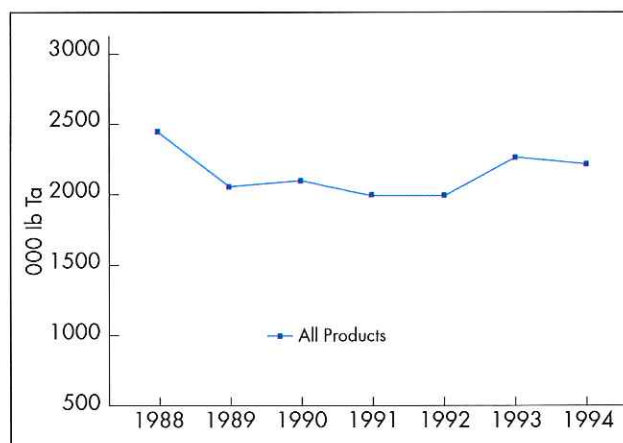


Figure 3: Processors' shipments of all products (source: T.I.C. statistics (1))

Powder

Figure 4 shows shipments of Ta powder and capacitors over the last seven years. This very interesting figure shows that the number of capacitors nearly doubled, whereas the demand in

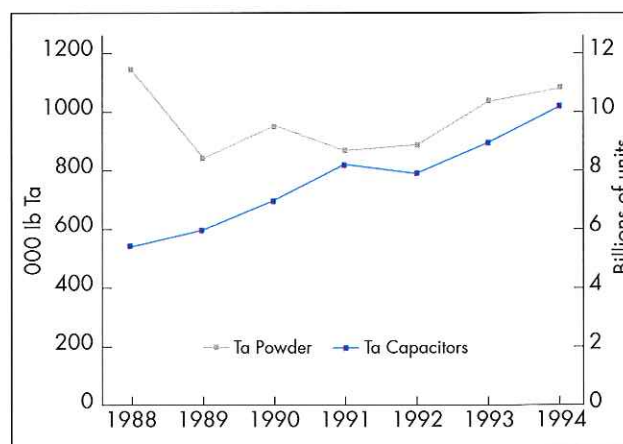


Figure 4: Shipments of Ta powder and Ta capacitors (source: T.I.C. statistics (1))

pounds of Ta powder grew by, at best, less than 10%. There are three main reasons for this:

1. There is a steady increase in the capacitance value of the powders used.
2. The chip capacitors which are very small in size have the highest growth rate of all capacitors.
3. Capacitor producers are progressing on their learning curve and are steadily improving yields and using powders close to their full potential.

I want to elaborate on items 1 and 2. We have today commercially available powders with CV/g values of 40-50K. Developmental samples of even higher CV/g have been prepared. The development of high CV powders required using finer powders, sophisticated agglomeration techniques, and deoxidation. Because the high capacitance powders require lower sintering temperatures and/or shorter sintering times, doping agents are used to preserve the high surface area. In addition to using doping agents, the lowering of sinter temperatures has resulted in decreasing the purification effect during sintering. Because the quality of the anodic oxide layer (dielectric) depends on the purity of the underlying metal, the purity of powders had to be improved.

The total undesirable impurities in Ta powders, such as Fe, Ni, Cr, Na and K, and also carbon, decreased to less than 50 ppm. Considering that molten sodium metal is used as a reducing agent during the reduction of potassium fluotantalate to tantalum metal, and the reduction is conducted in nickel or Inconel equipment, the reduction of impurities is very impressive.

Figure 5 shows the percentage of unit consumption of chips (surface mounted) and leaded capacitors with some projections for the future. The role that the chip capacitors play is quite apparent.

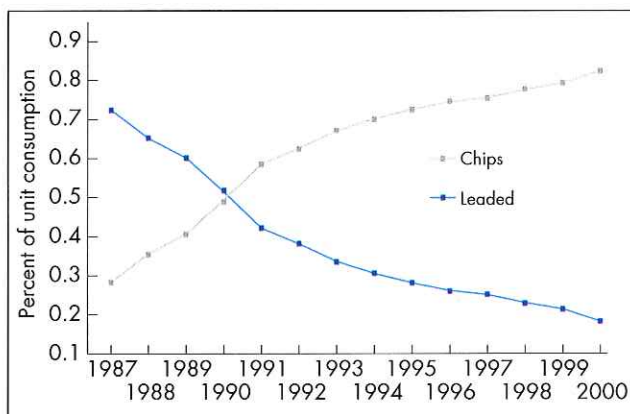


Figure 5: Unit tantalum consumption (world including Japan)

Tantalum carbide

T.I.C. statistics for consumption of tantalum carbide are shown in Figure 6. We should keep in mind that tantalum carbide is only used in the metal cutting tool grades, with the exception of small amounts of about 0.3% which are sometimes added as grain inhibitor.

In the cemented carbide industry, tantalum carbide consumption should increase with a growth of the metal cutting sector. Some developments have occurred which will influence this growth:

1. Introduction of more effective coatings which increase the amount of metal which can be removed per tool bit.
2. Fine tuning of the grades took place, and some grades with high TaC were completely eliminated.

3. Ceramic and silicon nitride type cutting tools achieved good market penetration in Japan.
4. In the entire field of processing of metals there are developments to minimize the amount of metal removed, such as powder metallurgical processing, precision casting, and others, to achieve "near to shape" form and therefore minimize any subsequent machining.

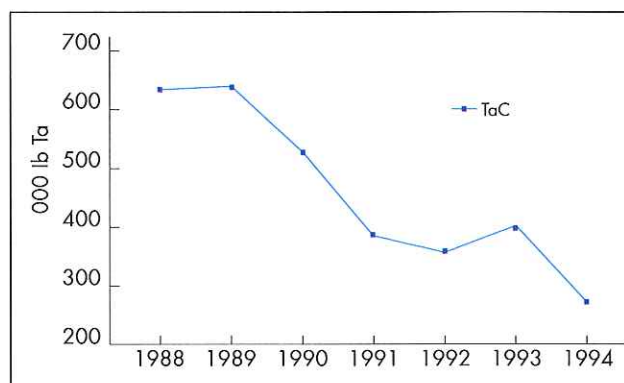


Figure 6: Tantalum carbide demand (source: T.I.C. statistics (1))

Based on the figure for the first five months of 1995, there should be an improvement in 1995, but the trend certainly does not indicate any substantial growth in this sector.

Mill products

Figure 7 shows the consumption trend for mill products over the last seven years. The largest single component of this group of products is tantalum wire capacitor grade, which accounts for nearly half of the total, and because of the strength of the electronic business, this product should continue to grow well. The second largest group in mill products is connected with the chemical industry, mainly sulfuric acid and related production in the form of heat exchangers, bayonet heaters, valves, cladding and others.

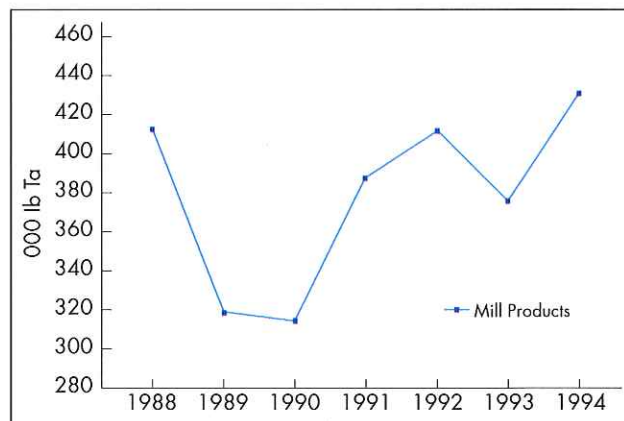


Figure 7: Tantalum mill products shipments (source: T.I.C. statistics (1))

Tantalum has outstanding corrosion resistant properties, as shown in Figure 8. The outstanding corrosion resistance is attri-

Fundamentals of Corrosion Resistance of Tantalum

Tantalum is often compared to glass with regard to corrosion resistance.

Tantalum is resistant to many aggressive chemicals :

Hydrochloric acid	Chromic acid
Sulfuric acid	Phosphoric acid
Nitric acid	
Organic acids - acetic, oxalic, lactic	
Oxidizing metal chlorides	
Others	

Figure 8

buted to the thin, protective, and very stable oxide layer (Ta_2O_5) on the metal's surface, when exposed to atmospheric conditions.

I think that we could increase tantalum participation in the corrosion resistance market, which is the oldest commercial application of tantalum, if we were to sell tantalum on life cycle costing, as outlined in Figure 9.

Life Cycle Costing	
Initial cost	Increase productivity :
Level of product quality	lower downtime
Length of trouble-free operation	lower maintenance time

Figure 9

The remaining applications for tantalum are in the medical industry in the form of screws, clips, and similar items, and in the rare earth industry for melting crucibles and a number of similar applications. Military applications, mainly for high kinetic energy projectiles in the form of sheet, discs, and similar forms are also included in this group. This application is growing more slowly than originally anticipated.

Although there was a marked improvement for 1994 and 1995, the superalloy industry went through difficult times because of the decreased demand from the commercial aviation industry, and decreased demand for military aircraft. One of the new applications of tantalum is its use in the superalloys used in the production of turbine blades for the jet engine industry. The so-called single crystal alloys are shown in Figure 10. The second and third generation alloys contain between 6 and 10% Ta. This sector shows promise for the future.

As far as truly new applications for tantalum are concerned, there are some small volume applications in expensive watches and in the medical field, but they are insignificant in terms of volume.

The first six months of 1995 show an increase of nearly 20% over 1994, and based on the strength of the market, this increase should be realized for all of 1995. All segments contributed, but the driving force for this growth was the strength of the electronic market. We did not have this kind of growth in the past few years. There is an indication that this growth will not be reversed within the next year or two, as was the case in the past because of inventory adjustments, and that growth will continue, although possibly at a lesser rate.

What is the future of tantalum for the rest of the decade?

The present applications are well established and will surely continue. When we meet at our next symposium (in the year 2000?), electronics will still be the single largest application. The trends we discussed will continue; there are no revolutionary new product developments in the pipeline which would find substantial commercial realization in the next five years. Our industry is modest in size, but if large, progressive growth industries such as personal computers, cordless telephones, and automotive electronics, to name just a few, are using products made with tantalum, then we can look with confidence to the future.

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- (3) G. Erickson, *Journal of Metals*, April 1995, p. 36

Single Crystal Alloys Major Alloying Elements									
Alloy	Cr	Co	Mo	W	Ta	Al	Ti	Re	Ni
FIRST GENERATION									
PWA 1480	10.0	5.0		4.0	12.0	5.0	1.5		BAL.
RENE N4	9.0	8.0	2.0	6.0	4.0	3.7	4.2		BAL.
SRR 99	8.0	5.0		10.0	3.0	5.5	2.2		BAL.
RR 2000	10.0	15.0	3.0			5.5	4.0		BAL.
AM1	8.0	6.0	2.0	6.0	9.0	5.2	1.2		BAL.
AM3	8.0	6.0	2.0	5.0	4.0	6.0	2.0		BAL.
CMSX-2	8.0	5.0	0.6	8.0	6.0	5.6	1.0		BAL.
CMSX-6	10.0	5.0	3.0		2.0	4.8	4.7		BAL.
AF 56	12.0	8.0	2.0	4.0	5.0	3.4	4.2		BAL.
SECOND GENERATION									
CMSX-4	6.5	9.0	0.6	6.0	6.5	5.6	1.0	3.0	BAL.
PWA 1484	5.0	10.0	2.0	6.0	9.0	5.6		3.0	BAL.
SC 180	5.0	10.0	2.0	5.0	8.5	5.2	1.0	3.0	BAL.
MC2	8.0	5.0	2.0	8.0	6.0	5.0	1.5		BAL.
RENE N5	7.0	8.0	2.0	5.0	7.0	6.2		3.0	BAL.
THIRD GENERATION									
CMSX-10	1.8-4.0	1.5-9.0	0.25-2.0	3.5-7.5	7.0-10.0	5.0-7.0	0.1-1.2	5.0-7.0	BAL.
RENE N6	4.25-6.0	10.0-15.0	0.5-2.0	5.0-6.5	7.0-9.25	5.0-6.25		5.1-5.6	BAL.

Figure 10 (3)

SYMPOSIUM PROCEEDINGS

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