Mines Branch Information Circular IC 188

A REVIEW OF DMIC MEMORANDUM 215, "TITANIUM, 1966" (SEPTEMBER 1, 1966)

H. V. Kinsey*

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ABSTRACT

The publication under review, "Titanium, 1966" (issued on September 1, 1966, as Memorandum 215 by the Defense Metals Information Center, Battelle Memorial Institute, Columbus 1, Ohio), is a collection of fourteen lectures that were presented at a Titanium Symposium held at Hawthorne, Calif., on March 28-29, 1966, under the sponsorship of the Norair Division of the Northrop Corporation.

The primary objective of the symposium was to provide technical personnel of diversified disciplines with a working knowledge of titanium technology. The papers were designed to be of value to a non-metallurgical technical audience as well as to those familiar with titanium technology. The secondary objective was to emphasize the need for the utilization of all required support technologies, such as materials, manufacturing, quality control, and so forth, early in the conceptional design state rather than piecemeal after the design has been formalized.

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Direction des mines

Circulaire d'information IC 188

RECENSION DU MÉMOIRE 215 DU DMIC, "TITANIUM, 1966"
(1er SEPTEMBRE 1966)

par

H.V. Kinsey*

RÉSUMÉ

La publication à l'étude, "Titanium, 1966" (publiée le 1er septembre 1966, à titre de Mémoire 215 par le Defense Metals Information Center, Battelle Memorial Institute, Columbus 1, Ohio), réunit quatorze conférences qui ont été données à un symposium sur le titane, tenu à Hawthorne (Calif.) les 28 et 29 mars 1966, sous les auspices de la division Norair de la Northrop Corporation.

Le premier objectif de ce symposium a été de donner au personnel technique de différentes disciplines une connaissance pratique de la technologie du titane. Les exposés ont été publiés à l'intention des techniciens des disciplines non métalliques, tout autant que de ceux qui connaissent la technologie du titane. Le second objectif consiste à souligner le besoin d'utiliser toutes les techniques auxiliaires requises (techniques de matériaux, de la fabrication, du contrôle de la qualité, etc.) dès le début de la conception et du dessin des plans, plutôt que d'y recourir au fur et à mesure après que les plans sont définitifs.

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The papers presented in the publication under review are listed in the table of contents.

REVIEWS OF PAPERS

1. "Titanium, Yesterday, Today and Tomorrow" - J. G. Louvier

In this introductory paper the author presents a brief history of the growth of the titanium metal industry, a review of typical applications, a general discussion of the physical and mechanical properties of titanium alloys as compared with aluminum alloys and steel, a brief discussion of the predominant commercial titanium alloys, and an indication of the current trends in titanium alloys, their production techniques and future applications.

2. "Basic Titanium Metallurgy" - Dr. E. L. Harmon

This paper is a very general discussion of the principles of the physical metallurgy of alloys, with specific reference to the application of these principles to titanium alloys. Written in very general terms, it is intended to enable the non-metallurgical technical reader to obtain some understanding of the whys of titanium alloys.

3. "Titanium Process Metallurgy" - W. H. Heil

Mr. Heil begins his paper by dealing very briefly with the production of titanium sponge by the Kroll process, and the production of titanium alloy ingot by the consumable electrode vacuum-arc melting process. He then goes on to describe, in more detail, the mill processing by which the ingots are converted to sheet, plate, and forging stock. According to the author of this paper, a typical mill installation would consist of a continuous vacuum annealing furnace and a Sendzimir rolling mill. Installations of this type are now producing cold rolled sheet product up to 48 in. wide with a 1/2 AISI gauge tolerance. Excellent flatness is obtained for thicknesses down to 0.01 in. A general description of the hot forging and hot rolling operations is given. Billets are finish forged to a size 1/4 to 1/2 in. oversize to allow surface contamination and forging defects to be subsequently removed by lathe turning on rounds or over-all surface grinding on squares, octagons, rectangles, etc. Bar product is subsequently hot rolled from the forged billet and the outside contaminated skin is ground or acid-pickled off. The paper goes on to deal briefly with the hot rolling of sheet and plate and with the problems involved in the removal of the contaminated surface resulting from these hot rolling operations. The problems of producing solution-treated or solution-treated-and-aged titanium alloy sheet are also mentioned. The heat treatment of titanium alloy sheet introduces the problem of maintaining good flatness.

4. "The Microscopy of Titanium" - Dr. F. A. Crossley and R. E. Herfert

In this paper the authors present, in some detail, a discussion of the microscopy of titanium and its alloys, including the application of both optical microscopy and electron microscopy. The paper is of interest to the physical metallurgist and also to the quality control metallurgist. In addition to a thorough discussion of the metallography of titanium alloys, the author emphasizes the need for careful metallographic preparation. Examples of the result of improper preparation are presented. This paper also contains examples of the application of electron microscopy to the examination of the structures produced in titanium alloys by various heat treatments, and welding.

5. "The Corrosion Resistance of Titanium" - Dr. H. B. Bomberger

The corrosion resistance of titanium, unlike that of most metals, can be defined within rather simple limits. The unalloyed metal appears to be completely resistant to all natural environments, including sea water, body fluids, and fruit and vegetable juices. Wet chlorine, molten sulphur, most organic compounds (including acids and chlorinated compounds) and most oxidizing acids have essentially no effect on the metal. The metal is used extensively in hot salt solutions, including chlorides, hypochlorides, sulphates and sulphides, and for handling wet chlorine gas and nitric acid solutions.

All acidic solutions, which are reducing in nature tend to be corrosive to the metal unless the solutions contain inhibitors. The most powerful oxidizers, including anhydrous RFNA and 90% H_2O_2, attack the metal. Exposure to liquid and gaseous oxygen can result in ignition of the metal under impact. Ionizable fluoride compounds activate the surface and can cause rapid corrosion. Dry chlorine gas is especially harmful. The metal has limited resistance to air at temperatures above about 1200°F, and deposits of chlorides and hydroxides can accelerate the rate of oxidation. Most solutions, except those containing soluble fluorides, can be inhibited by the presence of even small amounts of oxidizing agents and heavy metal ions. Nitric and chromic acids and dissolved iron and nickel, copper and chromium salts are especially effective inhibitors. This is discussed in a little more detail in Dr. Bomberger's paper.

Titanium does not suffer from galvanic corrosion, except in certain powerful chemicals which are highly corrosive to the metal. In fact, contact with the more noble metals has, in all practical cases, a very desirable effect. Titanium can, however, affect the corrosion resistance of other materials with which it may be in contact. It has slightly less tendency than 18/8 stainless steel to promote galvanic corrosion of the following materials: 2S and 24S aluminum, HK31 and AZ31B magnesium, mild steel 410 stainless steel, 17/7 PH stainless steel, and Monel. Commercial alloys behave in a manner similar to that of Monel or titanium. Specific data on the behaviour of galvanic couples with unalloyed titanium in sea water are presented in the paper.

The type of alloying approach used to enhance corrosion resistance is discussed briefly. One method is the addition of a small amount of a noble metal, such as 0.2% Pd, and the other is the addition of substantial amounts of more corrosion-resistant metals, such as 30% of molybdenum.

The sensitivity of certain titanium alloys to sea water embrittlement is discussed in some detail. In general, unalloyed titanium, the Ti-6Al-4V alloys, the Ti-4Al-3Mo-1V alloy and the Ti-7Al-2½Mo alloy are insensitive to sea water embrittlement. The Ti-8Al-1Mo-1V alloy and the Ti-8Mn alloys and the Ti-0.32 O_2 alloy are all sensitive to sea water embrittlement. The Ti-5Al-2½Sn alloy is also sensitive to sea water embrittlement but this sensitivity can be eliminated by the following modification: Ti-5Al-2Sn-1Mo and 1V. The Ti-7Al-2Nb-1Ta alloy is also sensitive to sea water embrittlement but when modified to Ti-6Al-2Nb-1Ta-0.8M0 this sensitivity is eliminated.

The paper briefly discusses some of the theories advanced to explain this sensitivity to sea water embrittlement. It also discusses quite extensively the phenomenon of hot salt corrosion. Titanium and titanium alloys can be damaged by halogenated compounds at temperatures above 500°F. Chloride salts and especially NaCl were found to be the most troublesome agents. Residual salts on the metal were found to pit the surface or even crack certain alloys under high tensile loads.

The phenomena of hot salt corrosion and sea water embrittlement have been observed only in laboratory tests and not in actual service applications. Cracking of titanium parts has been encountered by fabricators, however, in stress-relieving operations when vapours of chlorinated hydrocarbon cleaning fluids were not completely removed from part enclosures. This latter problem has been widely recognized by fabricators, and fabricating operations are set up to avoid it.

Much has been learned about the hot salt corrosion phenomenon, relative susceptibilities, and related variables. However, it is generally agreed that the laboratory tests do not simulate service conditions well nor predict field performance adequately. Cycle tests used to partly simulate service conditions are apparently less damaging than the normal static tests. Dr. Bomberger's paper goes on to discuss the results of some of the research that has been done on this phenomenon. Data are presented to illustrate the effect of hot salt corrosion on the tensile properties of Ti-6Al-4V alloy. A table of standard free energy changes for possible reactions in the salt corrosion of titanium is also presented.

6. "Titanium Alloy Structural Forgings - Status Report, 1966" - J. E. Coyne

In this paper, the author points out that the state-of-the-art of forging titanium alloys is well advanced, but that it has not yet reached the no-draft design. This will come with increased use of titanium in airframe structural hardware. Titanium alloys are rated as being less forgeable than 5% Cr die steels and stainless steels, but more readily forgeable than iron-base and nickel-base super alloys. Mr. Coyne goes on to discuss the manner in which forging practice has to be adapted to suit the metallurgical characteristics of titanium alloys and also to discuss the metallurgical factors that must be utilized for quality control of titanium forgings.

The paper also discusses specific examples of titanium alloy forgings that are now being used in aircraft construction. One outstanding example is a bulkhead forging supplied on a production basis in 4340 steel. In the same dies these bulkhead forgings have been produced in Ti-6Al-6V-2Sn and Ti-8Al-1Mo-1V alloys. The author suggests that for many shapes the more forgeable titanium alloys can now be supplied to the same refinement now being purchased in the alloy steels.

One of the newer developments in forging titanium alloys is forging at temperatures above the beta transus. In the past, this has been considered to be bad forging practice. However, research now being conducted into this aspect of forging would suggest that, when fully developed, beta forging of alpha-beta alloys such as the Ti-6Al-4V alloy will prove to be more advantageous with regard to both properties and cost.

The author concludes his paper by observing that considerable sophistication can be achieved in design, provided adequate tooling is used. There are several avenues that offer considerable promise for further refinement; among these is beta forging. However, exploration in this area will be wasted effort unless coordinated with airframe builders.

7. "Titanium Extrusion - Status Report, 1966" - J. J. Shaw

This paper is a well illustrated presentation of the wide variety of extrusions available in titanium alloys that are being produced by the author's company for use in airframe structures. Mr. Shaw observes that titanium extrusion to-day stands at the position of the aluminum extrusion industry approximately 25 years ago, when it was on the threshold of large-scale production for the airframe industry. The process has proved itself adaptable to the extrusion of all classes of titanium alloys and therefore should meet any advancement in alloy development that may come about.

8. "Critical Aspects of Forming Titanium Alloys" - W. W. Wood and R. E. Goforth

The authors of this paper point out that the early growth of the titanium metal industry was handicapped by lack of fabricating and processing "know-how". To a large extent this situation has now been rectified. Fortunately, it has been possible to devise techniques whereby titanium can be processed economically with existing fabricating equipment.

Much of the forming work, to date, involving titanium is contracted for on a short-run basis, thus precluding the development of equipment designed specifically for the metal. Forming can be performed successfully by most standard processes, but the equipment must be modified for hot forming and hot sizing, and must provide the necessary atmosphere protection.

It is the purpose of this paper to present some of the effects of external variables, such as temperature, pressure and forming velocity, on the formability of various titanium and other high-strength alloys. Much of the information summarized in the paper is based on data generated by Ling-Temco-Vought under Air Force contracts which had the general objective of providing a source of formability information for many of the new alloys and serving as a guide in the development of future forming equipment.

Forming technology has developed to such a complex state that scientific analysis, rather than trial-and-error and past experience, is required for solving many of the present-day problems. One of the problems that has gained prominence in the aerospace industry is that of measuring the forming characteristics of various materials by some simple means short of the production process itself. Under a U.S. Air Force contract AF33(616)-6951, "Theoretical Formability", a concept of predicting formability limits based on geometric parameters, mechanical properties and forming process was developed. Predictability equations were formulated for several conventional forming processes and basic part shapes. The paper discusses in some detail the various aspects of theoretical formability and pays particular attention to elevated temperature forming, brake forming, stretch forming, deep drawing, and pressure effects encountered in rubber forming processes.

9. "The Machining of Titanium" - C. T. Olofson

This paper discusses, in a condensed form, the various types of problems that have arisen in the machining of titanium and its alloys, and the types of steps that have been taken to overcome these problems. The paper discusses such subjects as relative costs of machining titanium, general machining requirements, recommended planning operations where titanium is being machined, safety precautions, general machining characteristics of titanium, and specific machining processes. The basic requirements for machining titanium are summarized in a full-page table in this paper.

10. "Welding of Titanium Alloys" - K. C. Wu

This paper is a review of the "state of the art" of welding of titanium alloys. The author briefly reviews the arc-welding and resistance welding processes in general, and then discusses the inert-gas shielded-arc welding process and the resistance spot welding process, with particular attention to those parameters that are critical in the welding of titanium alloys. For example, the factors that must be observed in providing adequate gas shielding and the significance of electrode geometry are discussed. The importance of selecting the proper back-up bar material for a specific type of weldment and type of titanium alloy is dealt with. There is also an introductory discussion of energy input and thermal cycle as applied to the arc-welding process. The significance of surface treatment, electrode geometry, electrode force and welding time in the resistance spot welding of titanium alloys is discussed. The paper then goes on to deal briefly with the welding metallurgy of the following titanium alloys: Ti-5Al-2½Sn, Ti-8Al-1Mo-1V, Ti-6Al-6V-2Sn, Ti-6Al-4V, and Ti-13V-11Cr-3Al.

Finally, the paper gives several examples of how problems characteristic of typical titanium alloy weldments have been handled. Some details of both the arc-welding processes and the spot-welding processes are presented. There is a brief discussion of the results of using commercially pure titanium filler wire in the arc welding of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-6Al-6V-2Sn alloys. Fusion zone properties can be improved by adding dissimilar filler metals and the heat-affected zone properties can be adjusted by knowing the continuous cooling transformation kinetics. Residual stress distribution in a weldment, particularly in a thick member, should be evaluated, because it may accelerate the reaction of stress-corrosion cracking.

11. "Diffusion Bonding and Brazing" - R. R. Wells

Brazing and diffusion-bonding processes and the application of these processes to joining titanium alloys are dealt with in this paper. Solid state diffusion bondments are theoretically as strong as the base alloy. However, the author points out that this theoretical strength is seldom attained, because voids can remain after the bonding process. The reason for the existence of these voids, and the steps that can be taken to either eliminate or minimize this problem when using solid state diffusion bonding for the fabrication of titanium alloy airframe components, are discussed.

A brief discussion of conventional brazing as applied to titanium alloys is then presented. The author refers to a braze metal composition of Ag-5Al as being one of the best braze alloys developed. This alloy flows onto titanium at 1790°F.

He then describes a process called "thin film diffusion brazing" of titanium that has been developed at Nordair. This process depends upon the formation of small quantities of liquid which behave as a braze alloy. Subsequent diffusion then drastically alters the alloy composition, resulting in a metallurgically compatible titanium joint. It is claimed that the process is a combination of diffusion bonding and conventional brazing. During the process a liquid interface between the titanium components is formed. As the process continues, diffusion causes solidification to take place. The process requires that the components be diffusion-treated until the desired final composition is reached in the joint. Thin film diffusion brazing of titanium does impose close fit-up requirements and also the need for close metallurgical control of the process.

The paper presents a comparison of the three joining systems discussed and as a result of this comparison claims that the thin film diffusion brazing process is the best of the three for the fabrication of titanium honeycomb alloys. It is claimed to have good thermal stability with regard to identical properties after long-time service temperature exposure, and fracture toughness of the titanium sheet is not impaired. The results of core shear tests, beam flexure tests, peel tests and acoustic fatigue on a thin-film-bonded honeycomb panel consisting of Ti-8Al-1Mo-1V face sheets and Ti75A titanium core are presented. In closing, the author claims that by proper application, thin-film-bonded titanium panels could be used to reduce the weight of an aeroplane by replacing aluminum components.

12. "Adhesive Bonding of Titanium" - S. R. Breshears

The adhesive bonding of load-carrying airframe structures is dealt with. The major advantages of using adhesive bonding in aircraft are summarized. The author then goes on to discuss adhesive bonding of titanium in general, titanium surface treatments necessary to good adhesive bonding, and adhesive development. Adhesive development is discussed in some detail, particular attention being paid to thermal degradation mechanisms, the effect of oxygen on degradation, contact catalytic effect of metals on degradation, and a review and evaluation of the adhesive state of the art. The method of applying adhesives and developing bonds, and the types of materials that may be bonded together, are briefly discussed. The testing of adhesives and bonded structures is also mentioned.

13. "Titanium Fasteners" - L. H. Stone

This paper deals with mechanical fasteners that may be used for joining dissimilar metals, heavy sections and components not amenable to the high temperatures required for diffusion bonding, brazing, or welding. It is claimed that titanium fasteners offer several advantages over steel and aluminum fasteners currently being used in the aerospace industry. They are lighter than steel fasteners, and possess higher strengths and greater fatigue life than aluminum fasteners. They can also be used at higher elevated temperatures than aluminum fasteners. The first extensive use of titanium fasteners in airframe fabrication dates back to 1953, when the B-52 SAC bomber was fabricated with thousands of titanium fasteners. The paper goes on to briefly discuss various aspects of the use of titanium fasteners in the aircraft industry.

14. "Designing with Titanium" - R. E. Pearson

The author discusses in some detail the underlying principles and philosophy that, if adopted, are most likely to result in the successful and economic utilization of titanium in airframe structures. He states that a 20% reduction in structural weight may be achieved using titanium in lieu of steel and/or aluminum, and suggests that any airframe design in which extensive use has been made of titanium that does not show this weight reduction is not an efficient design and cannot be justified from the point of view of economics. This implies, for example, that although the actual production cost of a titanium airframe may be higher than its equivalent steel or aluminum airframe, the advantages obtained, namely weight reduction, improved fuel mileage, better fatigue performance, increased corrosion resistance and reduced maintenance, will result in a lower total system cost over the projected life of the aircraft in spite of the fact that the initial investment cost may be somewhat higher.

The author points out that the designer specifying titanium must recognize the over-all effect of this material in the conceptual design state if he is to successfully obtain the desired design and cost effectiveness. One sure way to invite high costs without realizing improvements in structural efficiency is to substitute titanium into a design calling for aluminum or steel. The result is a higher end item cost, with little or no weight saving or product improvement to offset the higher raw material and processing costs, on a total system cost basis. The basic requisites of titanium design may be categorized under the following headings:

1. Selection of optimum raw material type and form.
2. Maintenance of extensive raw material utilization.
3. Efficient use of material strength.
4. Use of simplified concepts compatible with material limitations and processing capabilities.
5. Good cost effectiveness.

The proper titanium or titanium alloy in its optimum raw material form for a specific job should be used for the part. The part should not be made of titanium when lower-cost materials would do an equal or better job. Part design should maintain extensive raw material utilization. A large percentage of the purchased raw material should be found in the end item, not in a scrap barrel as chips. As an example of this, the author cites the case of a forging that, when properly designed from the point of view of material utilization, resulted in a net part cost of $38.50 per pound, as compared with a cost of $110.00 per pound when a poorly designed forging was used. Detailed parts and complete design must be compatible with processing requirements and manufacturing capabilities. The designer must avoid complex forming and machining operations, and marginal manufacturing operations, by following simplified design concepts well within the physical limits of the material and its processing methods. A minimum reduction in weight of 20% as compared to aluminum or steel structures must be achieved in weight-sensitive applications. The finished part must be producible at a practical dollar:pound ratio of finished weight if it is to be economically competitive with alternative materials.

The designer must acquire enough basic knowledge of mill production methods, mill processing limitations, current and future product availability, and mill product cost factors, to intelligently design parts from titanium, using the best mill product shapes available at the lowest cost. He must become familiar with available materials forms, projected technology improvements, and the influence of material shape and size on cost. He should continuously and effectively apply value engineering, using and integrating all disciplines available. The cost analyst is an excellent aid in achieving competitive economics. He can point out areas of high cost that may be eliminated or substantially reduced through good design.

Basically, designing of titanium components requires practical and continuous application of value engineering by the designer to achieve favourable cost effectiveness: a dollar per pound value must be assigned to structural components, and the designer must evaluate the proposed designs before proceeding, to ensure compatibility with the total end item. An evaluation of a good prospective titanium design should show a 20% weight improvement over comparable aluminum or steel design. If it does not, the material strength is not being utilized effectively and other design concepts should be considered. The author considers all of these points in some detail.

REVIEWER'S GENERAL COMMENTS

The papers which have been collected and published in DMIC Memorandum 215 entitled "Titanium, 1966", and which have been reviewed on the foregoing pages, form a very useful review of the "state of the art" in titanium and titanium alloy technology. This DMIC report is available to "qualified requesters", who may obtain copies from the Defence Documentation Center (DDC), Cameron Station, Building 5, 5010 Duke Street, Alexandria, Va. 22314, U.S.A.

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