The Status of Titanium in 1961—A New Structural Metal Starting Its Second Industrial Decade

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TITANIUM as a structural material was introduced industrially in the United States during the early 1950's ; the major use of this material at that time was in the military jet aircraft. During the 1950's, the amount of titanium used for this application increased steadily. However, with the advent of missiles, less emphasis has been placed on manned military aircraft ; therefore, the demand for titanium for this application has declined.

But the future of titanium is undimmed. It will play a more and more important role in the advanced air and space craft structures and chemical ware of the future. There are various reasons for titanium's finding an important place in industry. First, titanium is the fourth most abundant metal in the earth's crust, the order being aluminium, iron, magnesium and titanium. Second, ductile titanium has very attractive mechanical properties both at low and high temperatures. Third, titanium is one of the fairly light metals ; its density is about half-way between those of aluminium and iron.

Titanium has two allotropic forms : (1) a body centred cubic or beta phase, above 1625°F and (2) hexagonal close-packed, or alpha phase, below 1625°F. It is to be noted that the low ductility usually associated with hexagonal metals is not characteristic of titanium. Hot working can be performed both below and above the transformation temperature ; pure titanium can be cold rolled up to 95% before cracking occurs. At the same time, titanium has desirable work-hardening characteristics.

Titanium exhibits extremes in its chemical behaviour. At relatively low temperatures, it is completely inert. At high temperatures it is quite reactive and readily absorbs oxygen, nitrogen and hydrogen ; the absorption may significantly alter its properties.

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All alloying elements added to titanium either lower or raise the temperature of its allotropic transformation and thus can be described as either alpha stabilisers or beta stabilisers.

The alloys of titanium are of three main types : alpha, beta, and alpha-beta alloys. Crucible Steel Company introduced the ABC classification of titanium-base materials as a simple means of describing all titanium alloy systems. In this classification, A denotes the class of alpha alloys, B the beta alloys, and C the combined alpha-beta alloys. This ABC system is used as Crucible's code designation of all titanium alloys.

In general, the A (alpha) alloys have
(1) good weldability,
(2) high strength and toughness both at low and high temperatures, and
(3) resistance to bending stresses.

The B (beta) alloys have
(1) good bend ductility, and
(2) high strength both at low and high temperatures, but are vulnerable to contamination.

The C (alpha+beta) alloys compromise these properties. They have
(1) good strength at low temperatures but are weak at high temperatures,
(2) good bend ductility,
(3) moderate contamination resistance, and
(4) excellent forgeability.

Because of the special procedure required in the manufacture, the price of titanium was fairly high in the early days. Fig. 1 shows relationship between the price and production of titanium during the 1950's. This shows that the price of titanium declined steadily

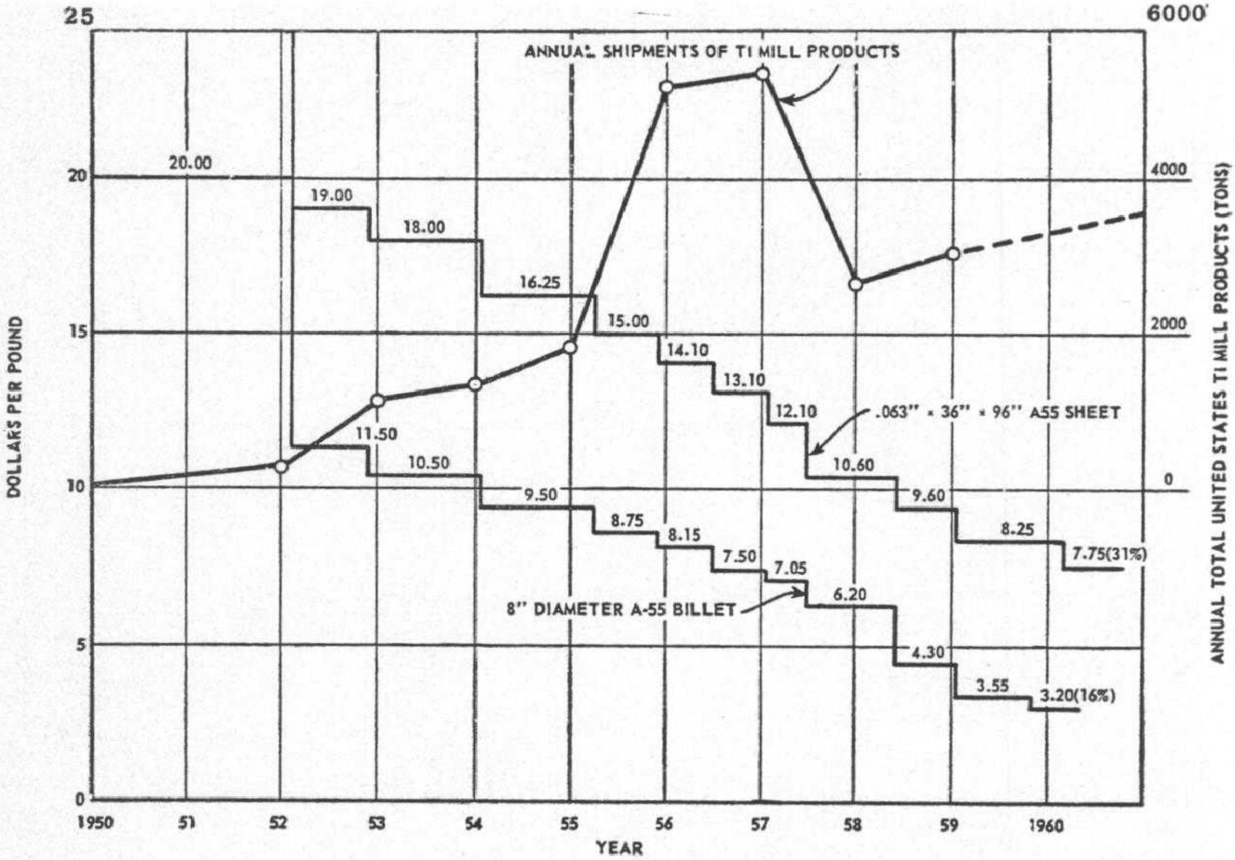


Fig. 1.
Price history of commercially pure titanium mill products.

as the production methods were improved. The price of titanium finished mill products in 1959 was only 31% of the 1952 price, and the total production in the United States was about 2500 to 3000 tons.

In the early days of titanium, it was only possible to make small ingots of titanium and titanium alloys; however, at the present time, titanium ingots as large as 8000 pounds have been produced at Crucible.

In 1959, Crucible made a major advance in the technology of titanium alloys by developing a new all-beta titanium alloy known as B120VCA. With a nominal composition of 13% vanadium, 11% chromium, and 3% aluminium, this new alloy has a completely beta structure upon solidification and cooling to room temperature. This alloy has excellent formability; because of the beta structure, it can be aged to high strengths at relatively low temperatures, thus making it a promising material in the aircraft field.

Advanced aerospace vehicles must be light-weight structures capable of operating from liquid helium temperature—423°F to re-entry temperatures of 4000°F. This is best attained by using the highest strength-to-weight metal sheets of minimum gauge, welded or brazed together with a minimum of joints. Besides the strength-weight considerations, dozens of other criteria are of controlling importance in the selection of materials for these uses.

The wide spectrum of structural sheet materials ranging from the light metals aluminium, magnesium, beryllium, and titanium through the heavy metals tantalum and tungsten and the correspondingly wide time-temperature-stress combination over which each material is serviceable are shown in the iso-plastic-strain diagram of Fig. 2. Since a rather large amount of qualitative information has been introduced, this graph gives a schematic broad, overall aerospace metal picture and cannot be used for quantitative purposes.

The comparison in Fig. 2 is based on the familiar Larson-Miller parameter:

$$\text{Parameter} = \text{Temperature}\ (\text{Constant} + \log \text{Time})$$

This parameter permits the consideration of the

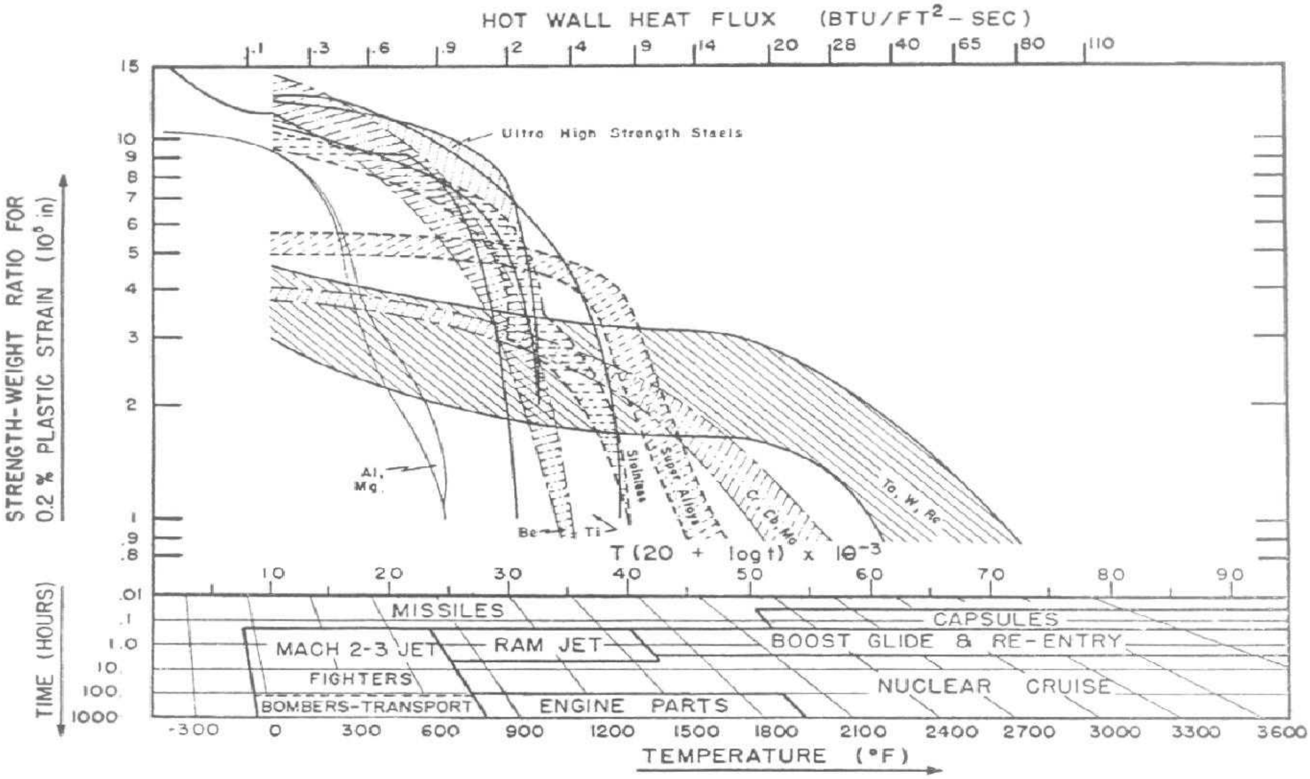
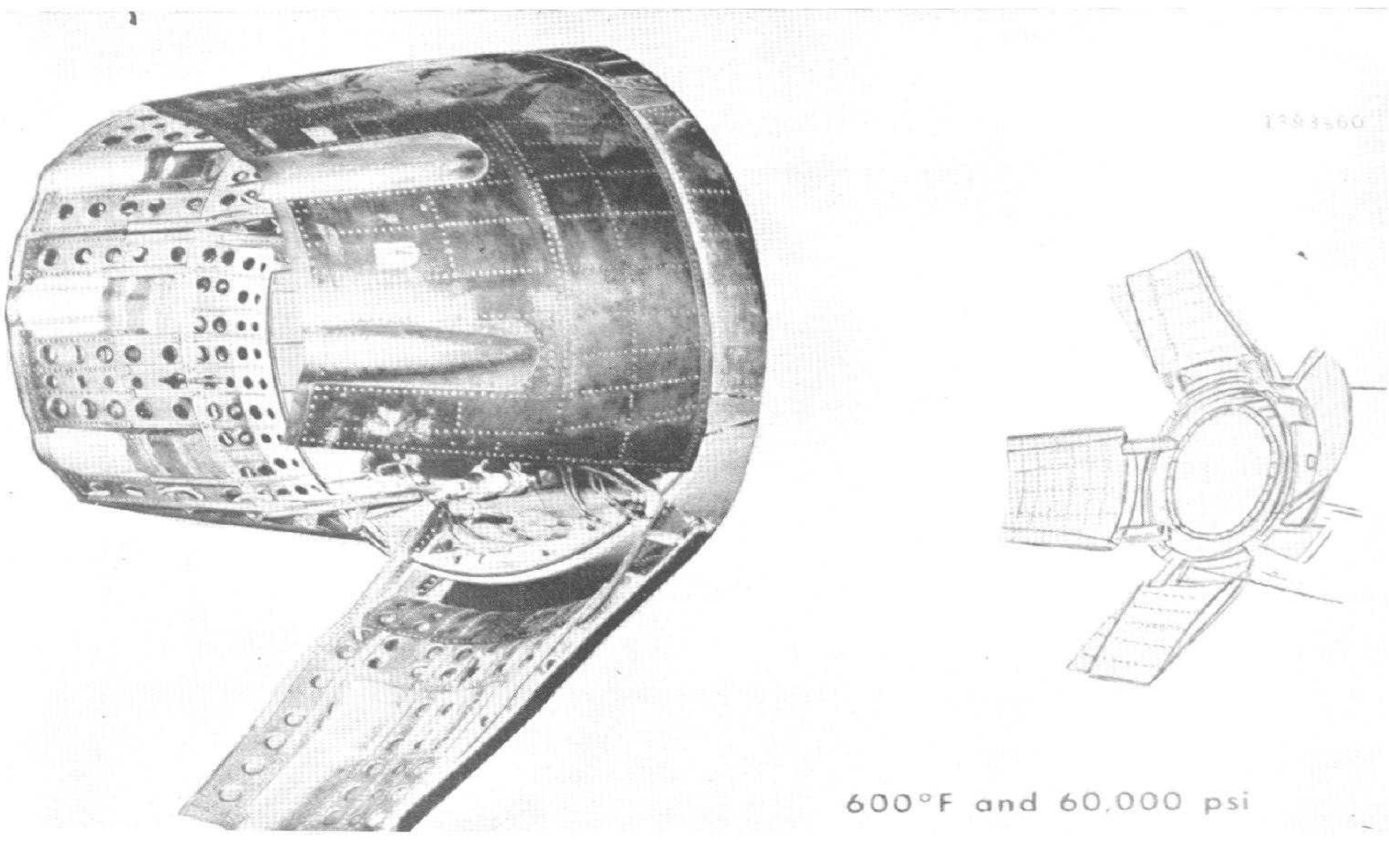


Fig. 2.
Iso-plastic-strain diagram of materials used for advanced aerospace vehicles.

Fig. 3.
Speed brake doors on the Republic F 105 Jet aircraft.



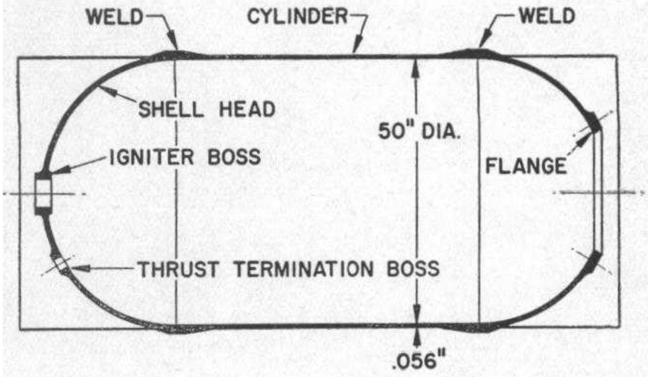
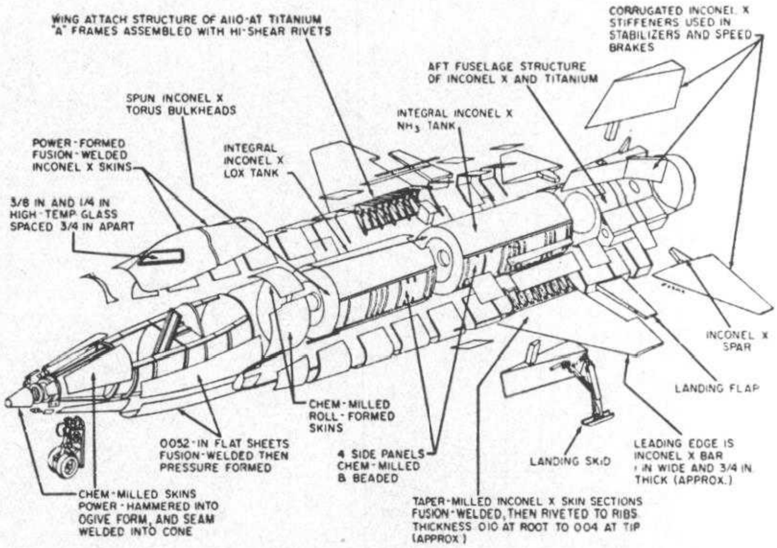


Fig. 4.

Typical rocket motor casing used in solid fuel rockets.

the individual strength values reported to date for representatives of each of the classes, in many cases just laboratory samples. It is anticipated that today's best individual laboratory values will be the '70's typical

North American X-15 rocket ship ready to land



Exploded view showing material of construction

effects of time and temperature as interchangeable, insofar as time and temperature affect such rate processes as recovery, recrystallisation, creep and stress-rupture. The design criterion used in the iso-plastic-strain diagram is 0·2% plastic deformation taking place over time periods varying from 0·01 hour to 1,000 hours (for longer times than about the 0·01 hour required for a tensile test, this could be termed 0·2% plastic creep). For metals and alloys having the same constant in the Larson-Miller parameter,* the Larson Miller relationship states that the stress which a particular alloy can withstand for a short time at a high temperature (while only plastically deforming 0·2%) is the same as that which it can withstand for longer times at lower temperatures. It is recognised that this use of Larson-Miller may lead to serious error if precipitation, ageing, or grain growth are taking place. The assumption made here is that structural aerospace alloys will not exhibit such instability in service, and accordingly we will make use of the convenience of this parameter.

As indicated below the abscissa (temperature horizontally and time vertically), a number of important aerospace vehicle time-temperature regions† can be identified and related to the load-supporting capabilities of the various classes of alloys.

Thus, the iso-plastic-strain diagram outlines the typical service stresses which all aerospace structural sheet metals can withstand for temperatures up to about 3,000°F and for times up to 1,000 hours. The lower limit of each of the eight bands is composed of the typical 1960 values for the best production sheet materials in each class; the upper limit is composed of

* This has been experimentally determined for a number of metallic elements and their alloys to be in the neighbourhood of 20; further, for the purposes of the iso-plastic-strain diagram, it is assumed that the best aerospace alloys in the '60's and '70's will also show parameter constants of about 20.

† W. S. Pellini and W. J. Harris, Jr., "Materials Requirements of Thermal Protection Systems for Thermospheric Flight", presented at the ARS Semi-Annual Meeting, June 8–11, 1959, San Diego, California.

Tabulation of NAA X-15 X-15 components using titanium

Total and list of components using titanium:

Wing (all internal structure between front and rear spars)	372 lb
Horizontal Tail (trailing edge ribs after the spars) ...	20 lb
Upper Fin (fittings)	15 lb
Lower Fin (fittings)	13 lb
Fixed Fins (upper and lower fittings)	13 lb
Fuselage (bulkhead webs and fittings)	503 lb
Landing Gear (fittings)	19 lb
Surface Controls (incl. power system fittings) ...	23 lb
Engine Mounting Seal and Fire Wall	8 lb
Fixed Equipment	2 lb
Propulsion Group (pressure vessels)	446 lb
	1,524 lb

This total amounts to 17·2 per cent of the total flyweight of the X-15.

Fig. 5.

Use of titanium in the X-15 rocket ship.

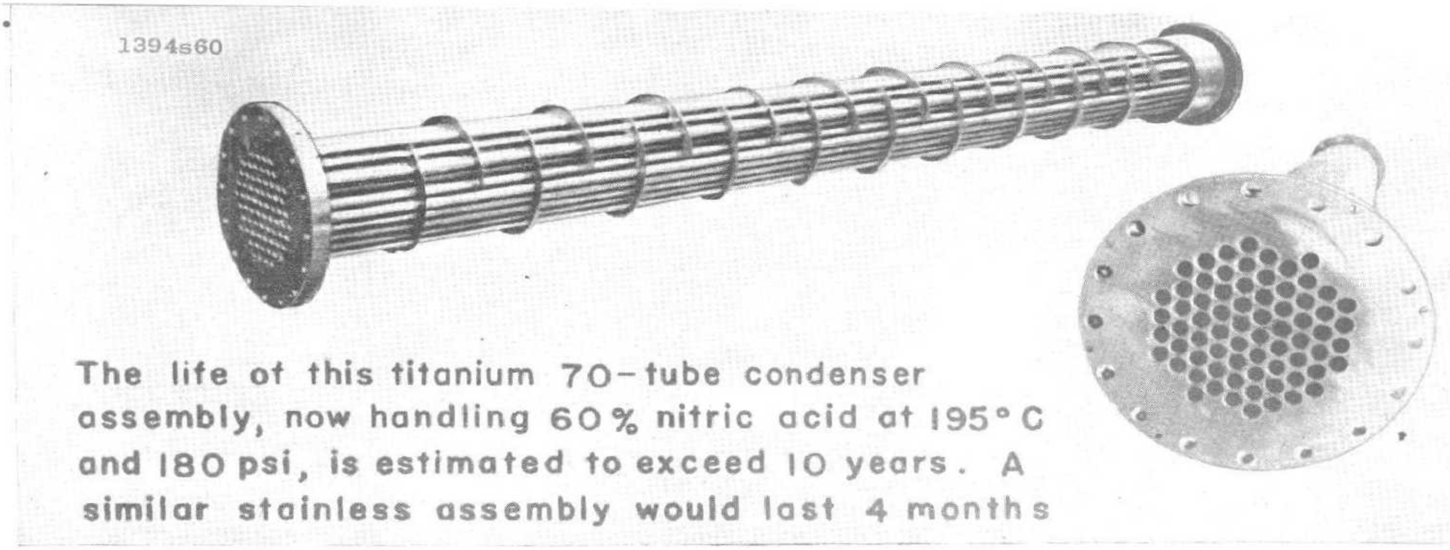
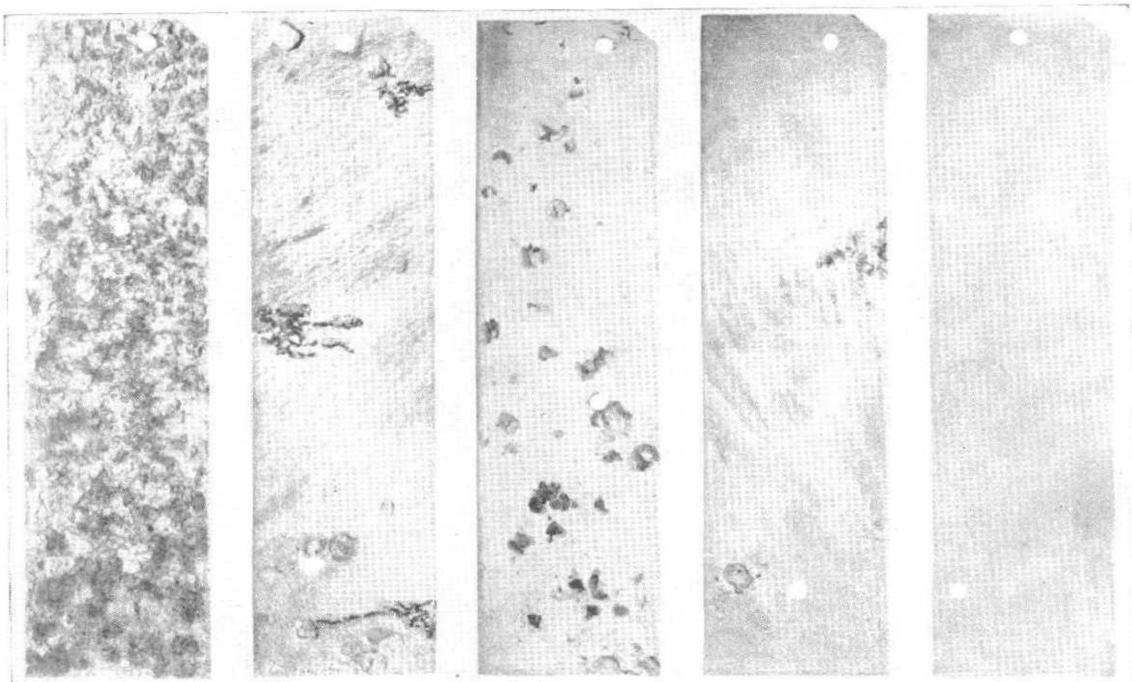


Fig. 6.
Condenser assembly handling 60% nitric acid.



Material	A	I	S2	S16	A-70 Ti
Corrosion Rate mpy	0·857	0·164	0·117	0·063	C·0008
			1·0 mpy=0·001 inches per year		
Maximum Depth-in	Perforated	Perforated	·060	·050	None

Fig. 7.
Effects of flowing sea water (5 years at 3 feet/second) on several structural metals.

production values. The widths of the bands, therefore, cover the range of typical strength values for each alloy base as a function of both time and temperature from today (lower limit) to the '70's (upper limit).

The major comparative features of Fig. 2 are as follows:

(1) As is well known, the strengths of all the structural materials plotted fall off with increasing temperature and increasing time. Aluminium and magnesium drop most sharply; tantalum, tungsten and rhenium, the least.

(2) No alloy base possesses the highest strength-weight ratio over the entire service temperature range. Titanium has the highest strength-weight values at—423°F and is forecast to be either the highest or the closest-to-the-highest strength-weight material to over 1,000°F. Although beryllium holds promise for being the highest strength-weight material at ambient and moderately elevated temperatures, titanium and the hot-work steels possess the highest strength-weight values up to about 1,200°F. The superalloys, which have somewhat lower stength-weight values up to about 1,200°F, possess the highest values from about 1,200°F to approximately 1,700°F. The heavyweight refractory metals titanium, tungsten, and rhenium similarly start with still lower strength-weight values at lower temperatures but are pre-eminent above about 1,800°F and are the only useful metal bases above perhaps 2,700°F. The light-heavyweight refractory metals chromium, columbium, and molybdenum fall generally within the tantalum, tungsten, rhenium band but are at the high side up to about 1,200°F and fall gradually out of it above approximately 2,300°F.

(3) The rather close overlapping of the beryllium, titanium and steel bands up to about 1,200°F has the paradoxical effect of minimising the primary importance of highest strength-weight in that temperature range. The forecast is that these general classes of alloys will attain about the same level of strength-weight; therefore it can be concluded that in the future, as is often the case at present, the selection of one alloy for a particular application will depend upon which one offers the best combination of secondary properties or characteristics.

The second largest application of titanium (next to its use in aircraft) is in the manufacture of chemical processing equipment. Here advantage is taken of the excellent corrosion resistance of titanium. The use of titanium in this application has been increasing during the 1950's and in 1959 amounted to 70 tons. The future outlook is about 260 to 300 tons per year will be used for this purpose by 1961 in the United States. Surprisingly, in Japan, about 250 tons of titanium were used in corrosion-resistant processing equipment in 1959.

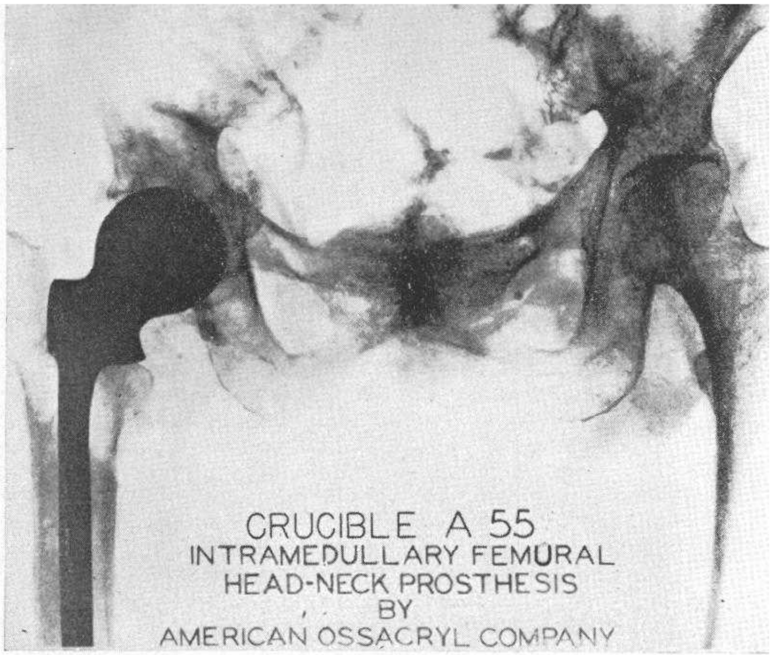


Fig. 8.
Use of titanium in prosthetic devices.

The following examples illustrate some present-day uses for titanium. In the field of jet aircraft and missiles, Fig. 3 shows the use of titanium for speed brake doors on jet aircraft. This application requires a material of high strength-to-weight ratio to be used at 600°F and 60,000 psi. Fig. 4 shows a rocket motor casting used in solid propellant missiles. Here again, the need is for the highest strength-weight material, and titanium is a very likely metal to be used in such applications. Fig. 5 shows an exploded view of the X15 rocket ship and the materials used in making this ship. Again, it is seen that titanium plays an important role.

As an example in the chemical processing field, Fig. 6 shows the use of titanium in a condenser assembly handling 60% nitric acid at 195°C and 180,000 psi. This assembly is expected to outlast a stainless assembly by 30:1. Fig. 7 shows the effects of flowing sea water on several structural materials and shows the possible use of titanium in applications where salt water corrosion is an important factor. In fact, titanium is currently being considered as a potential candidate in the construction of submarine hulls.

Another minor but important use of titanium, shown in Fig. 8, is in the making of prosthetic devices, where the combination of corrosion resistance and high strength of titanium make it a very promising material.

DISCUSSIONS

Dr. B. R. Nijhawan, NML : I would like to enquire from Mr. Chandhok the reasons for the decrease in the production targets of titanium. At one time titanium was made out to be the wonder metal and the production figures touched 10,000 and 15,000 tons per year. From the correspondence I have lately with some of the leading overseas research organisations, it has been indicated that it was not the wonder baby it was claimed to be. From the data that we come across in the technical literature and the discussions we have had about the properties of titanium and its strength to weight ratio and high temperature properties as a material for fuselage for jet aircraft, etc. where the skin temperature rises to 400–500°C, it would appear undoubtedly to be the material which will hold sway for a very long time to come. But the production of this metal has of late declined in spite of the fact that the cost of production and selling price have also been brought down. I believe it used to be $3 per lb but it is 1·5 $ now. There are certain factors which have adversely worked against titanium but I cannot lay my hands on specific data as such which would indicate its deficiency. Perhaps Mr. Chandhok may be able to throw some light on this aspect.

Mr. Vijay K. Chandhok (Auhtor): Dr. Nijhawan's question is a very worthwhile one, and might be summarised as asking why the sales of titanium have not matched the promise of its properties, which are unmatched for aircraft in the 400–500°C range. Basically, the answer to this question is that the production of titanium has paralleled the rise and relative fall of military jet aircraft during the past decade. During the first half of the 1950's, jet aircraft ruled the skies and the increasing amounts of titanium went into advanced jet airframes and jet engines. During the latter half of the 1950's, however, missiles began to take over many of the military tasks performed formerly by high performance jet aircraft. Since the initial problem in missiles was "to get the bird to fly", rather than to get the last bit of performance out of it, standard structural materials were employed in early missile models. Titanium production, therefore, dropped in the 1957–1959 period.

Gradual inclusion of titanium in missile designs, the continuing increased use of titanium in both jet and commercial aircraft, and the growing use of titanium in chemical processing equipment, resulted in 1960 in a 60% increase in the tons of titanium shipped over 1959, and it appears that 1961 will show an increase of 10% or 20% of titanium tons shipped over 1960.

Mr. M. B. Shankar, Hindustan Aircraft Limited, Bangalore : The author has pointed out that the emphasis on titanium as a metal in U.S.A. for airframe has diminished. May I attempt to put the case in its perspective ?

Titanium, by virtue of its high strength-to-weight ratio (midway between aluminium and steels as regards density), high temperature stiffness, resistance to oxidation up to 450°C and superior corrosion resistance, is considered an outstanding structural metal for supersonic aircrafts, aero-engine components in compressor sections. Its increasing uses (1) for alloying as a stabilising element in the production of super alloys and "Nimonics" ; (2) in the chemical industry for pipe fittings, tanks, etc. and (3) for naval applications, by virtue of its superior corrosion resistance, are well known. With the speeds of aircraft now exceeding sonic levels, proven conventional high-strength aluminium alloys are found to suffer unacceptable deterioration under skin temperature exceeding 200°C. Under speeds exceeding Mach No. 2 (i.e. twice the speed of sound) intense heating problem of aircraft skins and bodies are experienced. Under such conditions, Ti-alloys seem to be the next light weight material known. But the cost of titanium although coming down, is still prohibitive. Side by side development of new additional Ti-alloys are under progress, together with efforts to overcome several problems of fabrication. This may be the reason for present virtual lull in the wide use of the alloys. Today supersonic military aircraft and missile fields may be seeking stainless steels. But, use of stainless steel is confronted with many problems of production (viz., large size sheets with high standard of flatness, surface finish and problems of fabrication) apart from primary weight hurdles. These factors yield an assured place to Ti-alloys as the material for future aircraft. Side by side, with rapid and vast researches, "Inconel" also appears to be a running mate to steel for higher supersonic (research) aircraft as has become evident from the latest researches in U.S.A.

Airborne equipment is another promising field of application for titanium. From these circumstances, no phenomenal growth in titanium alloy consumption seems to have taken place.

Still the high cost of titanium restricts promising applications for civilian aircrafts and naval uses at present. Such considerations apart, titanium seems to have lost no ground as a "wonder" metal.

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