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PRODUCTION OF TITANIUM ALLOY INGOTS BY CONSUMABLE ELECTRODE ARC MELTING

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SUMMARY OF RESULTS

The experiments showed that titanium alloy ingots having adequate mechanical properties and without appreciable inhomogeneities could be produced in the laboratory arc melting furnace by either a single or a double melting operation.

It was found that losses of volatile constituents, such as manganese, were considerable when melting in vacuum or at low pressures.

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(3 tables, 9 illus.)

INTRODUCTION

Titanium and its alloys cannot be melted by normal techniques because the reaction between molten titanium and all known refractory materials leads to contamination of the melt with consequent deterioration in mechanical properties. A special technique (consumable electrode arc melting) has been developed for melting reactive metals, such as titanium, by means of an electric arc in a water-cooled copper mould. Under these conditions the outer skin of the ingot solidifies and the molten metal is contained by material of the same composition. Contamination from the container is thus avoided.

A consumable electrode arc melting furnace was designed and constructed at the Mines Branch in 1955 and has been described by Rylski and Kinsey(1). This furnace has been used extensively for melting nickel(2,3), sponge titanium(4), and steel(5), but has not been used previously for preparing alloy ingots from raw materials.

Some difficulty has been experienced by commercial firms in producing homogeneous alloy ingots of uniform properties. Holladay(6) has investigated this problem and shown that, apart from minor microsegregation, inhomogeneity of titanium alloy ingots is more likely to be due to faulty preparation of electrodes than to freezing segregation in the ingots. The preparation of electrodes is important, for the whole ingot is not molten at the same time in consumable electrode arc melting furnaces and thus major inhomogeneities in the electrodes may appear as inhomogeneities in the ingot. To reduce this problem, commercial ingots are often remelted and the homogeneity is greatly increased.

The present experiments were designed to show that ingots of satisfactory homogeneity, soundness and mechanical properties could be produced in the laboratory by consumable electrode arc melting. For this purpose a commercial alloy composition (titanium-4% aluminium-4% manganese) was chosen and the properties of the experimental alloy ingots were compared with those of commercially available material of the same nominal composition.

MATERIALS AND EXPERIMENTAL PROCEDURE

Materials

The basic titanium used in preparing electrodes was sponge titanium, produced by the Kroll process and having a hardness of 140 Brinell in the as-cast condition. This sponge was separated into two size ranges ($\frac{1}{4}$ in. to $\frac{1}{2}$ in. and $\frac{1}{2}$ in. to 1 in.) for incorporation into electrodes.

Alloy additions were made by means of titanium-42% aluminium and titanium-25% manganese master alloys. These master alloys were in

the form of sintered pellets 3/8 in. in diameter and 3/8 in. long.

Preparation of Electrodes

Electrodes were fabricated from pressed compacts, each of which contained the correct proportions of sponge titanium and master alloy pellets (Figure 1). These components were mixed together when loading the compacting die. With the press working at maximum load (500 short tons), working pressures were obtained of 50 tons per square inch (tsi) when pressing compacts 8 in. x 1¼ in. x 1 in. and 31 tsi when pressing compacts 8 in. x 2 in. x 5/8 in. (Figure 2).

These compacts were welded together in a step-wise fashion to produce electrodes with a cross section 2 in. x 1¼ in. The welding was done manually with a tungsten electrode within a "dry box". The dry box was first evacuated and then filled with argon to atmospheric pressure, so that no contamination of the titanium electrodes occurred.

On attempting to melt these electrodes in the arc furnace, trouble was experienced due to breaking of the electrodes as they passed between the drive rolls and the contact shoes(1). This type of failure occurred in alloy electrodes fabricated from compacts 2 in. x 5/8 in. in section as well as from compacts 1 in. x 1¼ in. in section, but did not occur in pure titanium electrodes. In Figure 3 it can be seen that the failure of the alloy compacts is associated with a group of master alloy pellets, and the effect of these pellets on the load to failure in a bend test is given in Table 1.

Table 1

Bend Strength of Electrodes Fabricated from Compacts

Type of Compact	Cross Section of Compacts (in.)	Cross Section of Electrode (in.)	Breaking Load in a Bend Test (lb)
Sponge titanium	2 x 5/8	2 x 1¼	440
" " + master alloy	2 x 5/8	2 x 1¼	170
" " + master alloy	1¼ x 1	2 x 1¼	240

Because it was impossible to avoid clusters of master alloy pellets in these compacts, it was decided to modify the electrode feeding mechanism of the arc furnace.

Modifications to the Furnace

The modified electrode assembly and feeding mechanism are shown schematically in Figure 4. The electrode is now supported only from its upper end and does not pass through the drive rolls and contact

shoes. The new electrode consists of compacts 8 in. x 2 in. x 2 in. welded end to end and finally to a threaded titanium adaptor which screws into the electrode stub. Since the making of these modifications no failures have resulted from breakage of the electrode.

The following advantages have also resulted from these modifications:

(i) Removal of the drive rolls and contact shoes from within the furnace makes it much easier to clean the furnace.

(ii) Since the drive rolls and contact shoes formerly sat directly over the mould and acted as a restriction to gas flow from the mould, their removal leads to more efficient removal of gas from the mould during vacuum melting.

(iii) The number of compacts required for a given weight of ingot is greatly reduced (e.g. only four compacts are needed for a 12 lb titanium ingot whereas twenty were needed prior to the modification).

(iv) Electrodes of complex cross-section are easily handled once they are welded to the threaded adaptors.

Operation of the Furnace

The first essential in melting titanium is that the furnace be free of leaks, to avoid contamination of the melt by oxygen and nitrogen. Real leaks were located with the aid of a helium-sensitive mass spectrometer, and the presence of virtual leaks was checked by isolating the furnace from the vacuum pumps and noting the rate of pressure rise in the furnace. The location of virtual leaks was difficult, but they could be avoided by thoroughly cleaning the interior of the furnace after each operation.

Electrodes were melted in two types of atmosphere, argon and vacuum. For argon melting the furnace was first evacuated and argon was admitted to the desired operating pressure (usually 300 mm Hg). During vacuum melting the furnace was evacuated continuously by means of a 4 in. oil booster pump backed by a mechanical pump. This combination had a through-put of approximately 3000 micron litres per second at a pressure of 20 microns Hg, and when melting titanium this was sufficient to keep the pressure in the furnace at less than 20 microns Hg.

A pad of loose titanium sponge, weighing 100 g, was placed on the bottom of the mould, and, with the power supply switched on, the electrode was lowered until contact with the starting pad caused arcing and melting to commence. The progress of melting was observed and regulated from a remote control panel. Corrections in the rate of electrode feed were made to maintain a satisfactory arc length, which was deduced by observing the changes in the pattern of a direct current cathode ray oscilloscope connected across the current leads of the arc furnace. The desirable arc length being very short, droplets of metal passing from the electrode to the melt create momentary

"dead shorts", and it was the presence or absence of these momentary "dead shorts" which the operator observed on the oscilloscope. Because the arc length was so short and the surface of the molten pool was depressed by the arc, it was necessary to allow the arc to lengthen slightly, prior to the termination of the melt; otherwise, on extinguishing the arc the electrode would freeze into the top of the ingot.

When it was desirable to double-melt an alloy, the ingot from the first melt was quartered longitudinally and the pieces welded end to end to form a new electrode for the second melting operation.

RESULTS

Contamination of the Ingots

Oxygen and nitrogen contamination of ingots produced by consumable electrode arc melting can result from real and virtual vacuum leaks, and such contamination may seriously affect the mechanical properties of the ingots. Oxygen contents of this alloy, as determined by the vacuum fusion method, were subject to large inaccuracies due to volatilization and condensation of manganese from the alloy and were not reported. The nitrogen content (determined by the Kjeldahl method) of the ingot melted in argon at a pressure of 250 mm Hg was 0.030 wt %, and after remelting in vacuum this increased slightly to 0.031 wt %.

The nitrogen contents were rather higher than those of commercial alloys (0.01 wt % N) but this was due to the high gas content of the master alloy additions used in preparing the alloys. The very small change in nitrogen content on remelting was of more importance, for if appreciable real vacuum leaks were present, the nitrogen (and oxygen) content would then increase considerably. However, it is possible that contamination by oxygen alone may result from a virtual vacuum leak of water vapour, although the low furnace pressure before and during remelting (0.5 and 10 microns Hg respectively) suggested that no appreciable vacuum leaks (real or virtual) were present.

Homogeneity of the Ingots

The homogeneity of the ingots was determined by taking samples for chemical analysis from a longitudinal section of an ingot melted in argon at a pressure of 250 mm Hg, and from a longitudinal section of an ingot melted in argon and then remelted in vacuum at a pressure of approximately 10 microns Hg. The results of these analyses are shown in Figure 5 and Table 2.

In both cases the homogeneity was satisfactory and at least as good as that obtained by other workers[7] in ingots of similar size. The actual composition of the ingot melted in argon at 250 mm Hg pressure was approximately the same as the nominal composition of the electrode, and this showed that there was no preferential loss of any component. However, on remelting in vacuum there was a marked decrease in manganese content whereas the aluminium content remained practically unchanged. This was not unexpected, for at a given

Table 2

Chemical Analyses of Alloy Ingots

Sample No.	Ingot melted in argon at 250 mm Hg		Ingot melted in argon and then remelted in vacuum at 10 microns Hg	
	Al (wt %)	Mn (wt %)	Al (wt %)	Mn (wt %)
1	3.74	4.46	3.98	2.98
2	3.86	4.59	3.96	2.89
3	3.84	4.58	3.97	2.81
4	3.84	4.49	3.95	2.91
5	3.89	4.50	3.75	2.76
6	3.84	4.57	3.91	2.85
7	3.83	4.53	3.92	2.97
8	3.75	4.53	3.85	2.93
9	3.70	4.60	3.91	2.75
10	3.81	4.40	3.81	2.79
11	3.81	4.45	3.89	2.78
12	3.82	4.33	3.84	2.78
Average	3.81	4.51	3.90	2.85

temperature manganese has a considerably higher vapour pressure than has aluminium. For example, if manganese and aluminium are in ideal solution in titanium at 2000°K, then the equilibrium partial pressure of manganese over the alloy is 3.4 mm Hg pressure and that of aluminium 0.4 mm Hg. When the alloy is melted in argon at 250 mm Hg pressure, the argon suppresses the evaporation of manganese. During remelting in vacuum, however, evaporation may readily occur and condensation of manganese may take place on the cold surfaces of the furnace. Had this condensation occurred in the mould, then, as the ingot built up, some manganese might have re-entered the alloy and given rise to higher manganese contents in the skin of the ingot; but this effect was not found in the present experiments.

Tensile Properties of the Alloys

The tensile properties of the alloys were determined by testing at room and elevated temperatures. Test specimens, with a gauge section 3/8 in. in diameter and $2\frac{1}{2}$ in. long, were prepared from bar which was produced by forging the ingots at 925°C (1700°F) to 2 in. square and then rolling to $\frac{3}{4}$ in. thickness and 2 in. width at 815°C (1500°F). Specimens were strained at a rate of 0.005 in./in./min up to the yield point and then at a cross-head speed of 0.05 in./min until failure.

The properties of the alloys after melting in argon and after remelting in vacuum are compared, in Figures 6, 7, 8 and 9, with those of a commercial alloy of the same nominal composition. The differences in properties, which are within commercial specifications for this

alloy, can be explained by differences in the chemical composition of the alloys, such as the low manganese content of the vacuum-remelted alloys.

Further evidence of the homogeneity of the alloys produced in the laboratory is shown in Table 3, which gives the results of triplicate tensile tests at room temperature.

Table 3

Tensile Properties of Ti-4% Al-4% Mn Alloy at Room Temperature

	0.2% Yield Strength (kpsi)	Ultimate Tensile Strength (kpsi)	Elongation (% in 2 in.)	Reduction in area (%)
Melted in argon at pressure of 250 mm Hg	138.0 140.0 140.3	148.5 148.9 150.6	22.7 20.7 21.3	38.2 38.2 39.6
Remelted in vacuum at pressure of 10 micron Hg	136.7 138.7 139.0	145.3 145.6 145.6	22.7 19.3 20.0	36.1 34.5 29.6

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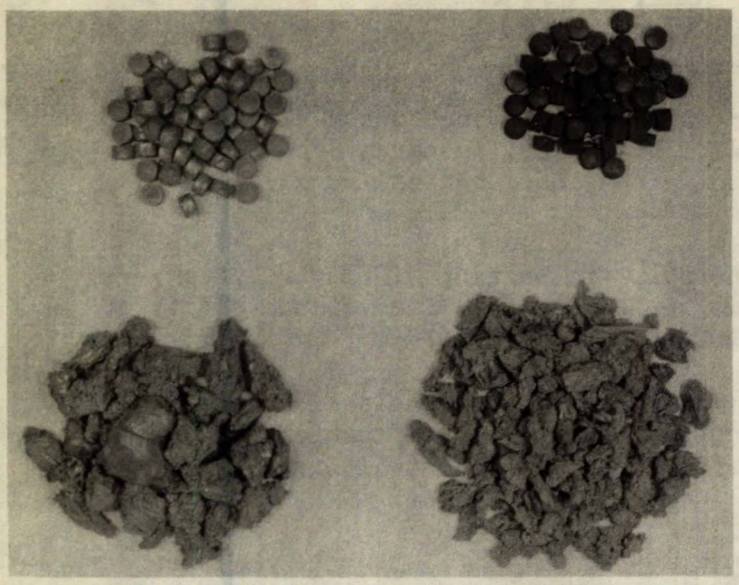

Fig. 1 - Master alloy pellets and sponge titanium for the 8 in. x 2 in. x 5/8 in. compacts.

(Approx. 1/3 size)

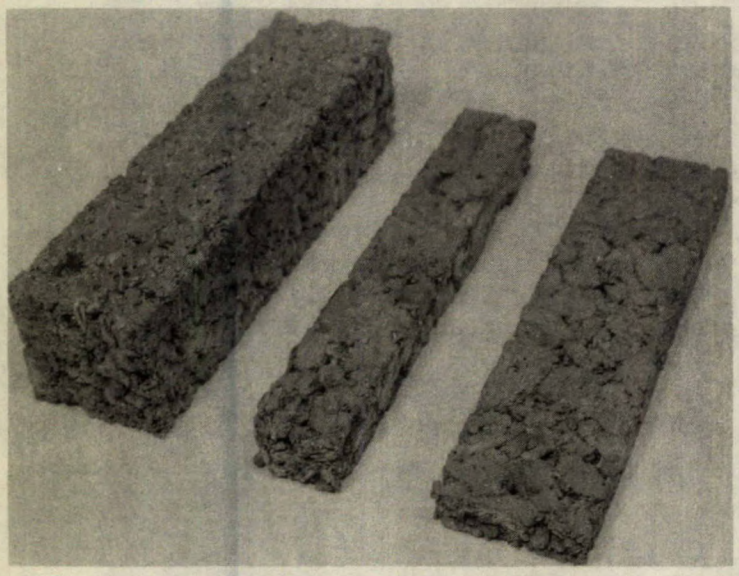

Fig. 2 - Compacts for fabricating electrodes. Left to right: 8 in. x 2 in. x 2 in., 8 in. x 1¼ in. x 1 in., 8 in. x 2 in. x 5/8 in.

(Approx. 1/3 size)

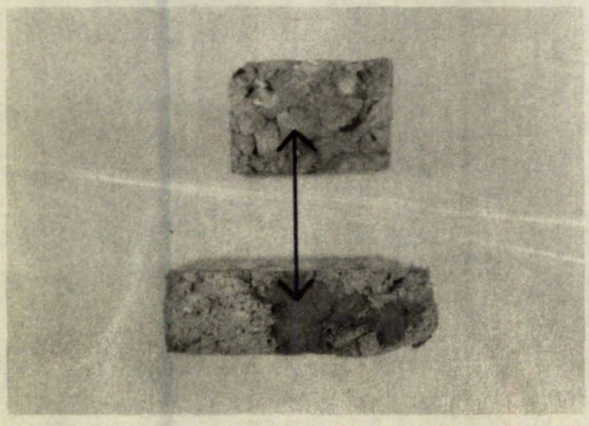

Fig. 3 - Fracture surface of alloy compacts. Clusters of master alloy pellets are shown by arrows.

(Approx. 1/3 size)

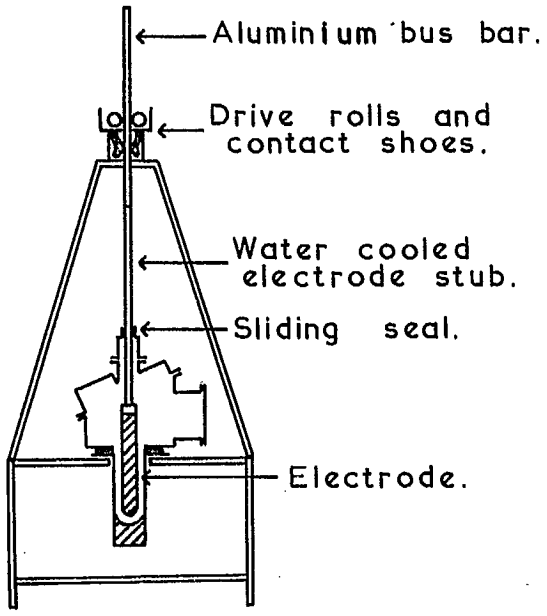

Fig. 4 - Modified furnace assembly.

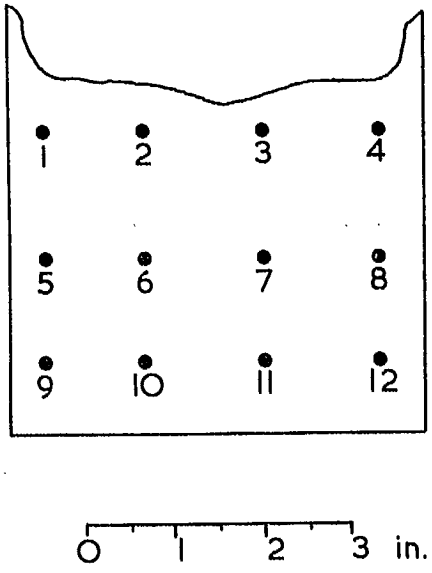

Fig. 5 - Location of samples in alloy ingots for chemical analyses.

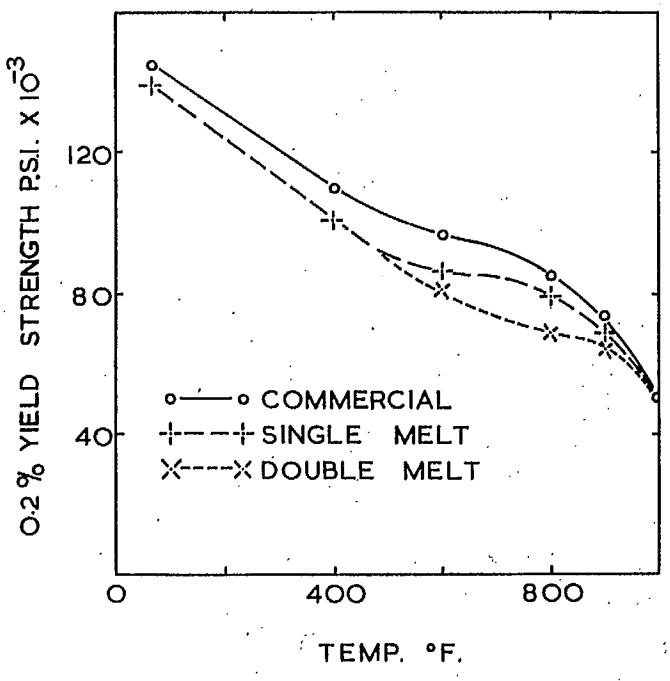

Fig. 6 - Effect of temperature on the 0.2% yield strength of alloy melted in argon, alloy double-melted in argon and vacuum, and commercial alloy.

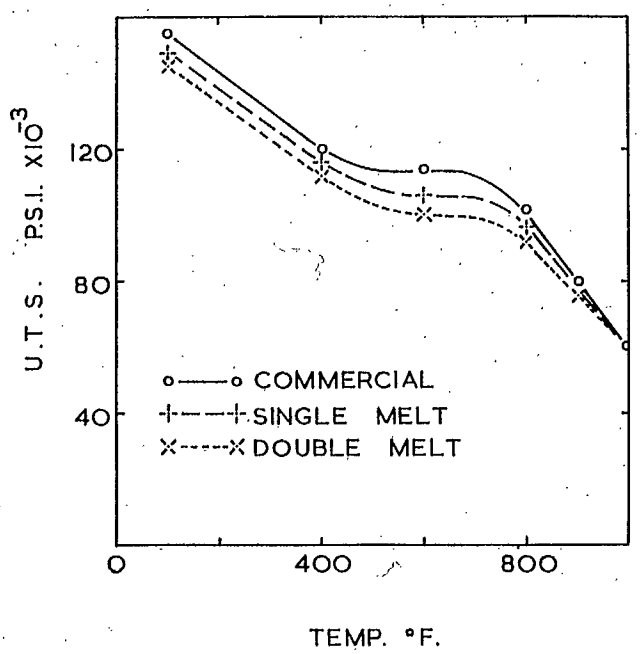

Fig. 7 - Effect of temperature on ultimate tensile strength of alloy melted in argon, alloy double-melted in argon and vacuum, and commercial alloy.

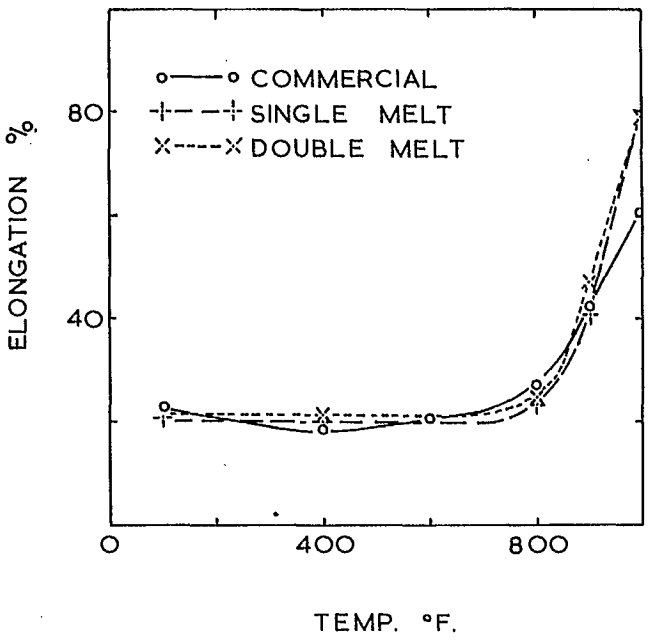

Fig. 8 - Effect of temperature on elongation of alloy melted in argon, alloy double-melted in argon and vacuum, and commercial alloy.

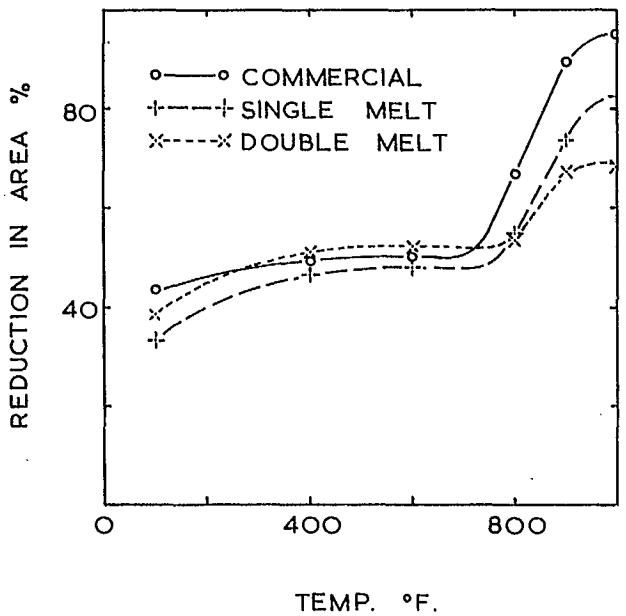

Fig. 9 - Effect of temperature on reduction in area at fracture, of alloy melted in argon, alloy double-melted in argon and vacuum, and commercial alloy.

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