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A PROSPECTIVE IN-SITU ARC MELTING FURNACE (IAMF) TO PRODUCE TITANIUM ALUMINIDES INTERMETALLIC COMPOUNDS

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ABSTRACT
Intermetallic alloys are an emerging class of materials which may serve in a variety of structural materials applications. One of processes to develop the materials is via melting/casting route. Using an in-situ arc melting furnace (IAMF), titanium aluminides are expected to form. Some tests are carried out, i.e. XRD test, Density test, and Hardness test, to make sure that the designed IAMF has the ability to develop intermetallic compounds such as titanium aluminides.

Keywords: intermetallic compounds, titanium aluminides, in-situ arc melting furnace, heat treatment

INTRODUCTION
Intermetallic alloys are an emerging class of materials which may serve in a variety of structural materials applications. Unfortunately, for all new structural materials, the time periods necessary for the technical inventions which lead to a new technology, as well as the developments associated with introducing a new engineering technology, are quite expensive when measured by time, money, and risk [1].

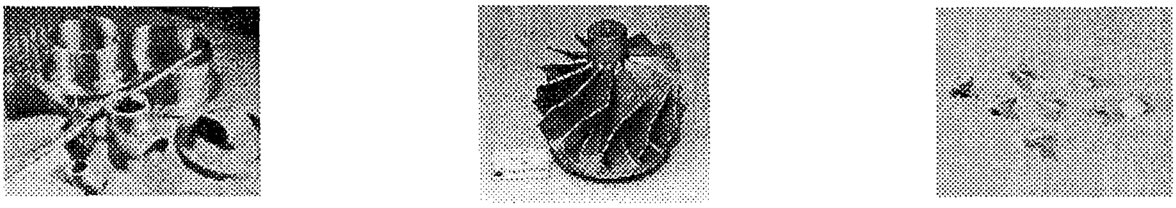
From the viewer point, only three classes of intermetallics have actually matured sufficiently to offer an emerging competitive balance of properties in the structural materials arena: the $L1_2$ structured nickel aluminides, the B_2 structured iron aluminides, and the $L1_0$ structured gamma titanium aluminides. Among these only gamma titanium aluminides alloys (gamma alloys) appear to be successfully advancing toward structural applications within the next decade [1]. And nowadays, there have been significant interests and intensively investigated in titanium aluminides as potential replacements for conventional nickel-, cobalt-, and iron- based superalloys components at high temperature in aerospace and automotive-engine applications[2,3,4,5]. Such applications are turbine blades, turbine wheels, impellers, exhaust valves, and turbocharger rotors as shown in Figure 1 [2].

There are many processes available to make titanium aluminides, such as melting/casting route, wrought alloy technology, powder metallurgy (PM) processing i.e. hot pressed and hot isostatic pressing (HIP) technique, combining the processes of combustion synthesis (CS) and solid freeform fabrication (SFF) method, etc. Melting is the most economical processes for making intermetallic compounds of titanium aluminides for research and commercial request. [6,7,8].

Realizing the necessity of critical equipment for research at School of Materials and Mineral Resources Engineering – Universiti Sains Malaysia (USM), we decided to assemble an in-situ arc melting furnace (IAMF). An IAMF using a welding machine as its energy source offers not only an opportunity to conduct investigation on some intermetallic compounds alloys but also cost saving in terms of time and money in the future investigations in this area.

TITANIUM ALUMINIDES ALLOYS
Intermetallics in Ti – Al system have potential in a wide range of high temperature applications due to their attractive and specific characteristics such as low density, good corrosion resistance and excellent mechanical properties. The excellent mechanical properties include high temperature strength, high specific modulus, high creep resistance, good fatigue strength and high fracture

toughness. According to some literatures, titanium aluminides have ± 4.00 gr/cm^3 for specific weight or density, while its hardness (HVN number) is 350 – 700 [4,9,10].



(a) (b) (c)

Figure 1. Some applications of titanium aluminides: (a) fittings and valves, (b) turbine wheel, (c) high-pressure compressor blades for aircraft engine

There are some different intermetallic compounds phases in Ti – Al system such as $Ti_3Al(\alpha_2)$, $TiAl(\gamma)$, $TiAl_2$, and $TiAl_3$ (see Figure 2). Type of phases can affect the properties of the intermetallic compounds. The properties of Ti – Al alloys are strongly composition and microstructure-dependent. It's possible to obtain four types of microstructures in the system [3,11]:

- near γ, with equiaxed grains and α_2 particles at the grain boundaries and triple points,
- duplex, consisting of γ grains and lamellar colonies of alternating layers of γ and α_2 phase,
- nearly lamellar, the size of the lamellar ($\alpha_2 + \gamma$) grains is larger than that of the γ grains,
- fully lamellar, with coarse lamellar ($\alpha_2 + \gamma$) grains.

The duplex and equiaxed gamma give rise to high strength and some ductility but poor creep resistance, low fatigue strength and low fracture toughness. However, the fully lamellar microstructure, composed of thin γ and α_2 lamellae, seems to be better than the other by offering high strength, high creep resistance, good fatigue strength and high fracture toughness, but generally with somewhat lower ductility than the duplex, so the fully lamellar that shows superior mechanical properties is more desired in the Ti – Al system [4].

DESCRIPTION OF THE IAMF

The high melting point of titanium (about 1670°C) and the highly reactive nature of the element to make the melting and casting of titanium-base materials an intrinsically difficult problem. As early 1939, Kroll, who was the first to investigate the technological problems involved in the preparation of consolidated titanium metal, discovered that molten titanium reacted violently with all the usual refractory materials. And nowadays, copper block is commonly used as the hearth or mould of the melting furnace. Kroll also observed the now well-known fact that at temperatures above a few hundred degrees Centrigade, titanium will absorb the common gases oxygen, nitrogen and hydrogen, all of which have a deleterious effect on the mechanical properties of the materials [7]. For more details about IAMF, see Figure 3 of this paper. Generally, the furnace can be divided into three parts, i.e.:

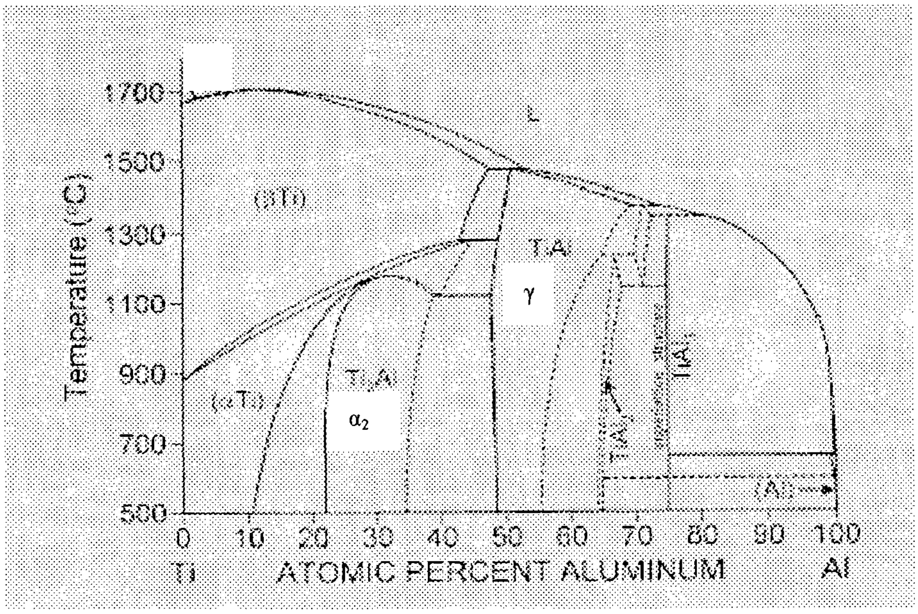


Figure 2. Binary phase diagram of system Ti – Al

Furnace atmosphere

In melting titanium, it is absolutely essential that no oxygen and nitrogen should be permitted to come into contact with the molten metal, and hence protective inert gas atmospheres are used within the apparatus. In our IAMF, inert gas that is used is pure argon. The inert gas must be completely purified, since any contaminating elements present therein will be absorbed by the molten titanium aluminides. The inert gas is passed continuously through the furnace, and thus the entrance of oxygen and nitrogen by diffusion through any small leaks which may exist in the apparatus is impeded by the out-flowing gas stream. It can be seen from Fig.ure 4 that the IAMF has gas inlet and outlet of gases.

Electrodes

In arc melting furnaces, the hearth or crucible, and the charge in contact with it, act as one electrode. The other electrode may be either consumable or non-consumable, i.e. it may be composed of the same materials the charge, and melt down with it, or it may consist electrode holder tipped with a material which will not melt when the arc is struck. Although consumable electrodes are to be preferred for a number of reasons, such as the complete absence of any danger of contaminating the melt with impurities from the electrode, their application is hindered by formidable practical difficulties. The electrode material, for instance, must be available in rod form, and must be continuously fed into the furnace without permitting the entrance of air.

The choice of a suitable tip material for non-consumable electrodes is severely limited by the requirement that such a material must have a high melting point, good electron emission, high thermal and electrical conductivity, adequate mechanical strength and resistance to thermal shock, and be capable either of being machined or of being joined to the electrode by brazing or welding. Thoriated tungsten which melts at 3400°C and graphite which is stable until it begins to vaporize at about 4000°C are the only two available materials which fulfil these conditions, since the high melting point nitrides and carbides of the transition metals are too brittle to be joined satisfactory to the electrode assembly, and also have very low resistance to thermal shock. And in the IAMF depicted in Figure 4, tungsten is used as tip of electrode one as cathode while copper block as molten mould tobe anode.

Power supply

Theoretically, either alternating or direct current may be used in arc melting furnaces, although direct currents are normally used for melting titanium at present. For larger furnaces, however, the provision of generators or rectifiers capable of supplying the high direct curents required involves heavy capital expenditure, and there would be obvious advantages in the application of alternating currents. Direct currents, on the other hand, produce a more stable arc, and are to be preferred for smaller furnaces in which the supply of a sufficiently large direct current presents no difficulties. In a direct current arc the heat generated at the anode is roughly double that generated at the cathode. Therefore, to maintain the largest possible molten pool at the upper surface of the ingot, the crucible or hearth serves as the anode. In the IAMF, the current is supplied by an Inverter ITG 202P welding machine.

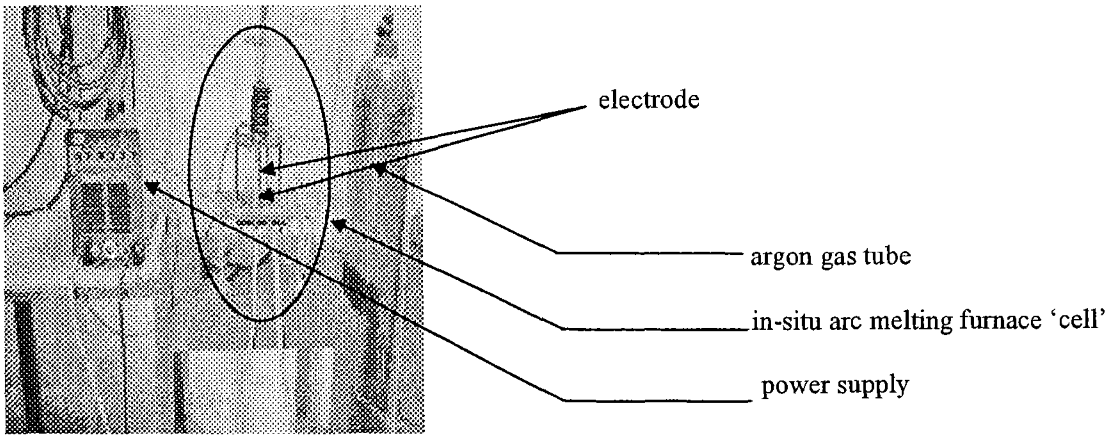


Figure 3. The IAMF apparatus

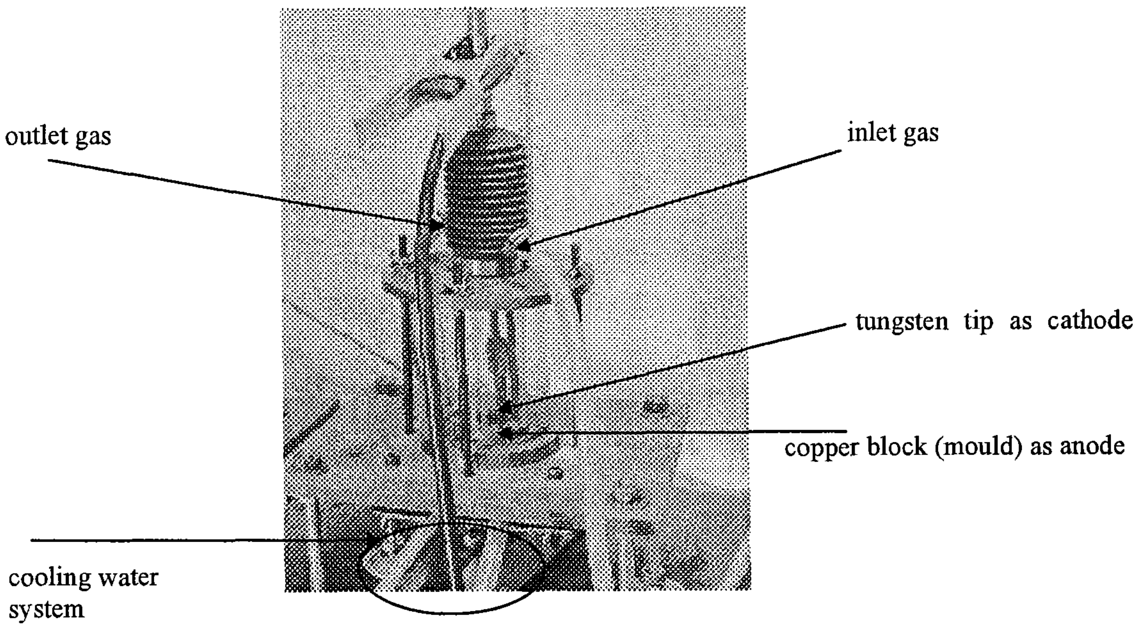


Figure 4. A 'Cell' of the IAMF

PRODUCTS DEMONSTRATION & TESTING

Metal powder that will be melted in the IAMF is prepared into a pellet before the melting process is carried out, to make sure the metal powder will not splash out. A compression setup is used to form the pellet. And then some pellets are put in the copper block mould for the melting processes. Selecting the compositon in this demonstration is related with the composition that can form alumina protective oxide-scale on the titanium aluminides. This paper is a part of a main research project about oxidation resistance of titanium aluminides.

Sample of titanium aluminides that was obtained using the IAMF are characterized to identify the development phases. The desired intermetallic compounds phases in Ti – Al system, as explained before, are γ-TiAl (tetragonal phase) and $Ti_3Al(\alpha_2)$ (ordered hexagonal phase), for their specific properties. Tests that were conducted include XRD, Density test, Hardness test. And the important one is the XRD tests results, because it can show what phases are in the samples. Results of that tests are given below:

Density and Hardness test

Hardness test was carried out using Vickers Hardness Tester, while density hardness was done using Micromeritics AccuPyc 1330, Gas Pycnometer.

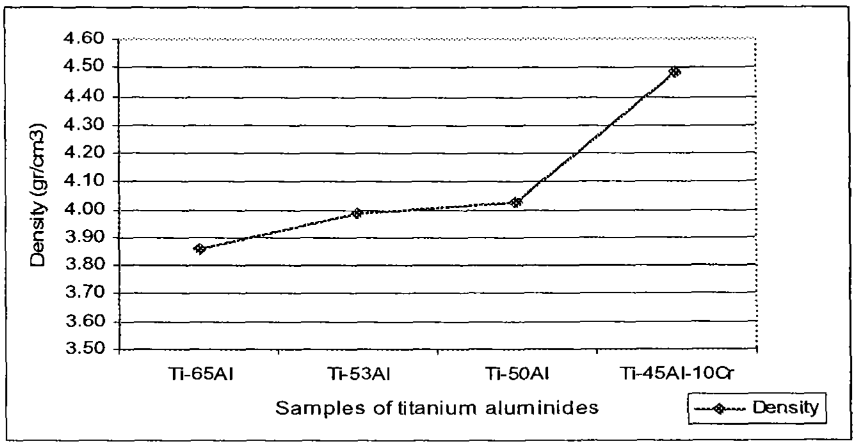


Figure 5. Density of Titanium Aluminides

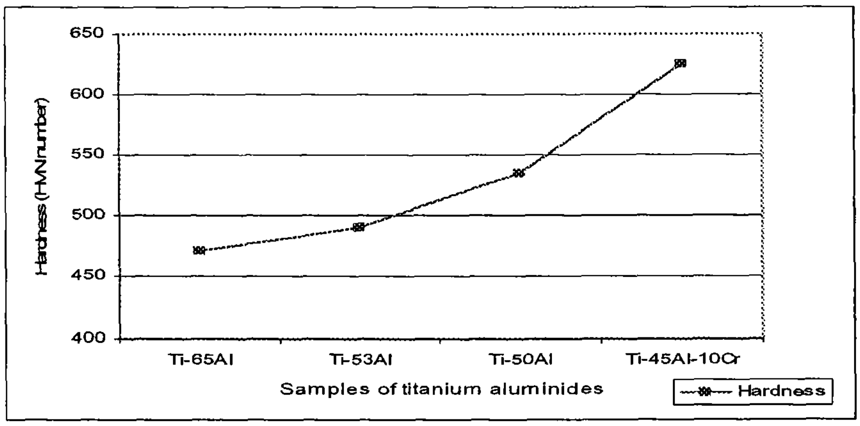


Figure 6. Hardness of Titanium Aluminides

XRD test

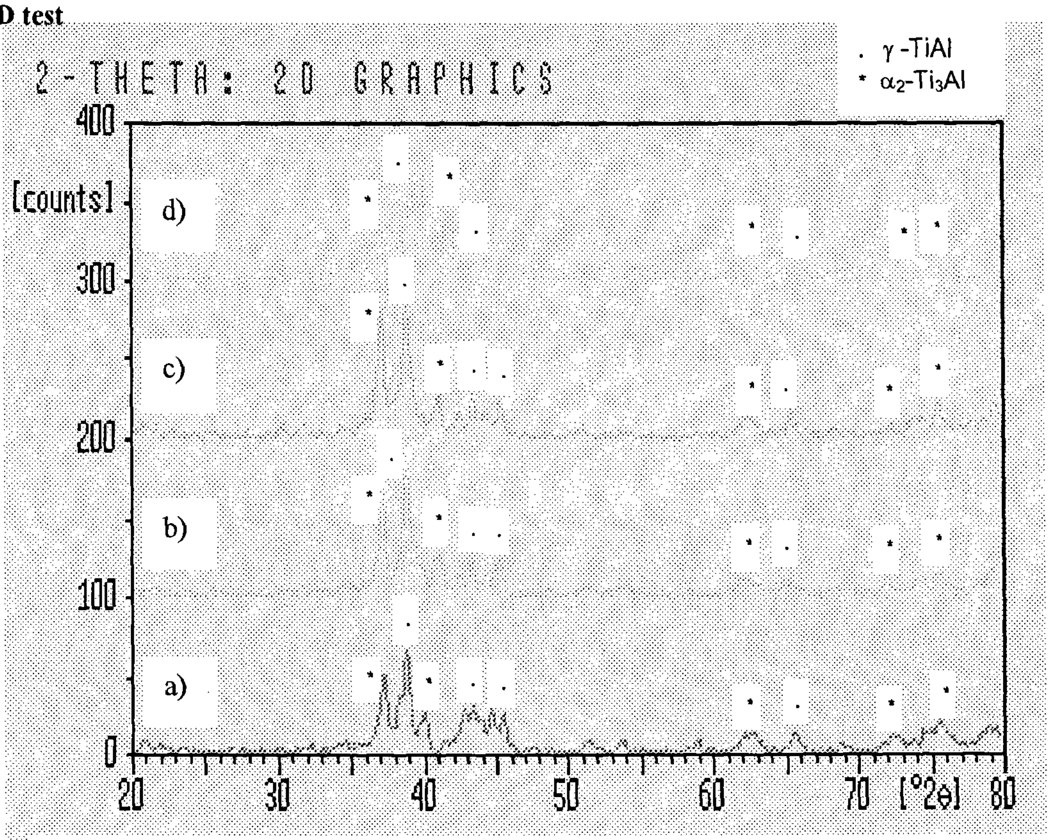


Figure 7. XRD patterns of Ti – Al system for (a) Ti – 65Al, (b) Ti – 53Al, (c) Ti – 50Al and (d) Ti – 45Al – 10Cr

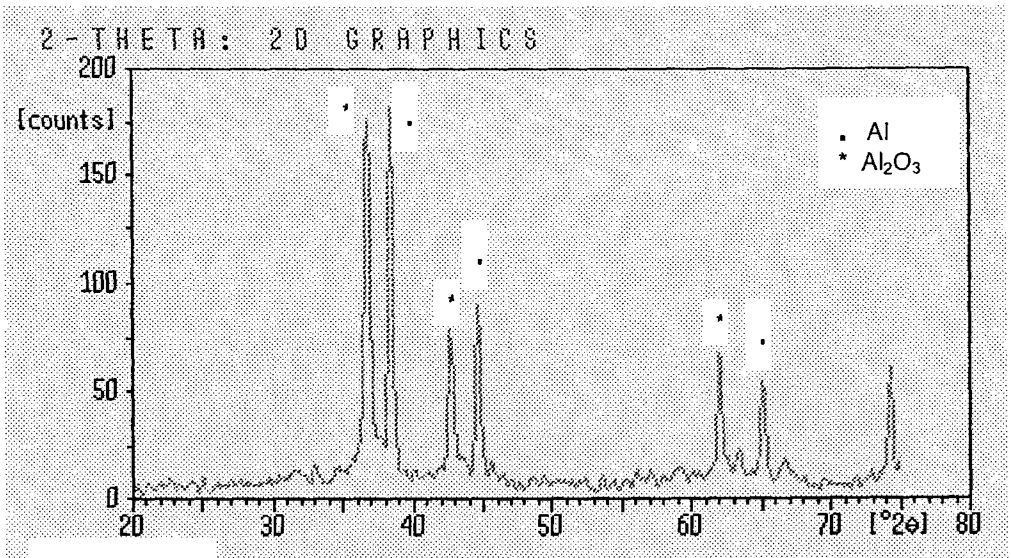


Figure 8. XRD patterns of dust as by-product of melting processes

DISCUSSION & FUTURE WORK

Figure 5 shows that density of titanium aluminides increases linearly content of aluminium decreases in the titanium aluminides. It is consistent with the theory which indicates that the volume density of material is mass/unit cell divided by the volume/unit cell. Furthermore, mass/unit cell is closely connected with the atomic/molecule mass. Reducing the content of aluminium causes the atomic/molecule mass of titanium aluminides to increase.

Aluminium is the most influential element to the alloy strength and it acts by changing the volume fraction of the α_2 phase, which is the hard phase in $\alpha_2 + \gamma$ two phase alloys. With a decrease in aluminium concentration the α_2 volume fraction is increased and so is the strength. It can be seen from the Figure 4. that the hardness value increases with the decrease of aluminium content. It is in a good agreement with other reported investigations [8,11,13].

It can be seen that some intermetallic compounds have been formed (see Figure 7). Although it is not perfect yet but generally the products that resulted from the IAMF are titanium aluminides intermetallic compounds i.e phase of γ-TiAl and Ti_3Al (α_2). Figure 8 shows that aluminium (Al) and alumina (Al_2O_3) are by-product of melting process in dust type. It is estimated that in the beginning of melting process, aluminium is splashed-out partly while alumina is obtained from flaking oxide scale of titanium aluminides when melting processes are occurred. It can be seen that Figure 8 gives sharper of XRD patterns peaks than Figure 7. It can be occurred because sample for Figure 8 in powder type while for Figure 7 still in bulk type.

The products of titanium aluminides by the IAMF can be improved with heat treatment to obtain the expected of titanium aluminides. Changing the bulk samples to powder for XRD tests will also be considered.

CONCLUDING REMARKS

The preliminary steps of producing titanium aluminides intermetallic compounds of by in-situ arc melting furnace (IAMF) was satisfactory. The results of that effort was not disappointing eventhough not perfect.

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