Fritz Appel, Jonathan D. H. Paul, and Michael Oehring

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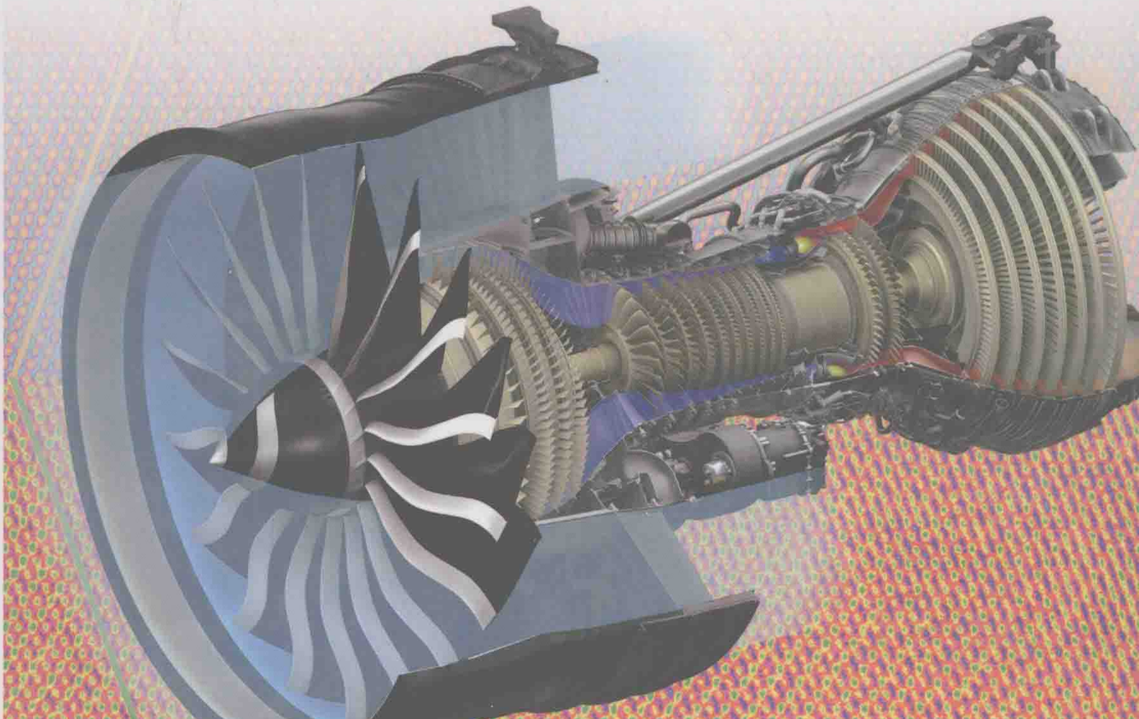

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Preface

There is an ever-increasing demand for the development of energy-conversion systems towards improved thermodynamic efficiency and ecological compatibility. Advanced design concepts are based on higher service temperatures, lower weight, and higher operational speeds. For example, the operating efficiency of a gas-turbine engine will increase by over 1% for every 10 °C increase in the turbine-inlet temperature. Substantial fuel savings in aircraft and power generation can be achieved through the introduction of new materials that can provide higher temperatures or reduced component weight. The conventional metallic systems that are currently in use have been developed over the last 50 years to near the limits of their capability. If further advances are to be made, new classes of materials will be required.

Titanium aluminide alloys based on the intermetallic gamma phase are widely recognized as having the potential to meet the design requirements mentioned above. Undoubtedly, the development of such a material system has important implications for spin-offs to other high-temperature technologies, as well as for the general economy. For example, General Electric has recently made public that its most recent engine, the GEnx, includes the use of titanium aluminide as a blade material. This is a significant milestone for a relatively new, advanced engineering material.

Although there is a vast body of TiAl literature going back over 20 years, there have only been a few review articles published in the recent past, the latest nearly a decade ago. Since that time, considerable advances have been made, both in the basic understanding of the physical metallurgy and in processing technology. It is our intention that the publication of this book will, for the first time, give a wide-ranging interpretation and discussion of the voluminous amounts of data documented in the literature. For TiAl to be successfully employed as a structural material requires a comprehensive understanding of the complex microstructures, down to the nanometer scale, and knowledge concerning how the structure–property relationships are determined by, for example, the atomic details of interface-related phenomena.

The overview of all relevant research topics that are presented in this book is intended to form a link between scientific findings and alloy development, material properties, industrial processing technologies, and engineering applications.

The metallurgy of TiAl alloys undoubtedly has several features in common with other intermetallic system. Thus, in that we have chosen to emphasize the scientific principles, the book will provide a treatment of the subject for researchers and advanced students who need a more detailed coverage than is found in physical metallurgy textbooks. We expect that our compilation of the current state of titanium aluminide science and technology will not only serve as a guide through the huge body of literature to the TiAl community, but will also be of interest to materials scientists, engineers, and technical managers who are involved in areas where low-density, high-temperature resistant materials are required. The detailed description of interfaces and interface related phenomena will certainly be of interest to an extended scientific community.

It would not have been possible to write such a book without the help and support from numerous people and organizations. First, we would like to acknowledge the generous support and the excellent research conditions provided by the Helmholtz-Zentrum Geesthacht (formerly GKSS) under its Scientific Director Prof. Wolfgang Kaysser, Prof. Andreas Schreyer as the Director of the Institute for Materials Research, and Prof. Florian Pyczak as group leader.

We also thank the BMBF (German Ministry for Education and Research), DFG (German Science Foundation), Helmholtz Gemeinschaft (Helmholtz Association), Rolls-Royce Deutschland, and CBMM (Companhia Brasileira de Metalurgia e Mineração) for financial support through their funding of numerous research projects.

We would particularly like to thank Prof. Richard Wagner (now Director at the Institute Laue-Langevin, Grenoble, France) who initiated the work on TiAl in the late 1980s while he was director of our institute. Additionally, we would like to thank our colleagues and former students, Ulrich Brossmann, Stefan Eggert, Dirk Herrmann, Roland Hoppe, Ulrich Fröbel, Viola Küstner, Uwe Lorenz, the late Johann Müllauer, Thorsten Pfullmann, and Ulf Sparka for their interest, support, and for contributing to an excellent group atmosphere. The generous help from the HZG library personnel is also acknowledged.

A very special mention must be made to acknowledge Dr. Young-Won Kim (Universal Energy Systems, Dayton, USA) for his achievement in keeping the titanium aluminide community together for very many years and his friendship. Fritz Appel would like to thank his wife, Bärbel, for her support. Finally, the authors would like to expresss their gratitude to Wiley-VCH for the opportunity to write the book and in particular gratefully acknowledge the patient support by Waltraud Wüst and Ulrike Werner and careful copyediting of Bernadette Cabo.

Geesthacht, January 2011

Fritz Appel
Jonathan David Heaton Paul
Michael Oehring

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G. Hug, PhD Thesis, Université de Paris-Sud, France, 1988.	Figure: 5.9.

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Cover
Foreground shows the General Electric GEnx-1B engine (photo courtesy of General Electric). The background is an artificially colored high resolution TEM image of a deformation twin/matrix interface in TiAl.

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1
Introduction

The reason why gamma TiAl has continued to attract so much attention from the research community including universities, publicly funded bodies, industrial manufactures, and end-product users is that it has a unique combination of mechanical properties when evaluated on a density-corrected basis. In particular, the elevated temperature properties of some alloys can be superior to those of superalloys.

Dimiduk [1] has assessed gamma TiAl with other aerospace structural materials and shown that new capabilities become available on account of its properties. The most important pay-offs involve

- high melting point;
- low density;
- high specific strengths and moduli;
- low diffusivity;
- good structural stability;
- good resistance against oxidation and corrosion;
- high ignition resistance (when compared with conventional titanium alloys).

Figure 1.1 shows how the specific modulus and specific strength of gamma TiAl alloys compare to other materials. As a result of these properties TiAl alloys could ultimately find use in a wide range of components in the automotive, aero-engine and power-plant turbine industries.

For a material to be ready for introduction, the whole production chain and supplier base, from material manufacture through processing and heat treatment must have achieved "readiness". This includes detailed knowledge of how component properties are related to alloy chemistry, microstructure, and processing technology. In addition, TiAl-specific component design and lifing methodologies need to be developed and give reliable predictions [2]. At the implementation stage no unforeseen technical problems concerning the processing route or component behavior, which may be very costly to remedy, should arise. In 1999, a time when fuel costs were relatively low compared to the current day, Austin [3] discussed how introduction of gamma would depend on economic viability. This was identified as the chief obstacle for the use of gamma, with marketplace factors dominating implementation decisions.

Gamma Titanium Aluminide Alloys: Science and Technology, First Edition. Fritz Appel, Jonathan David Heaton Paul, Michael Oehring.

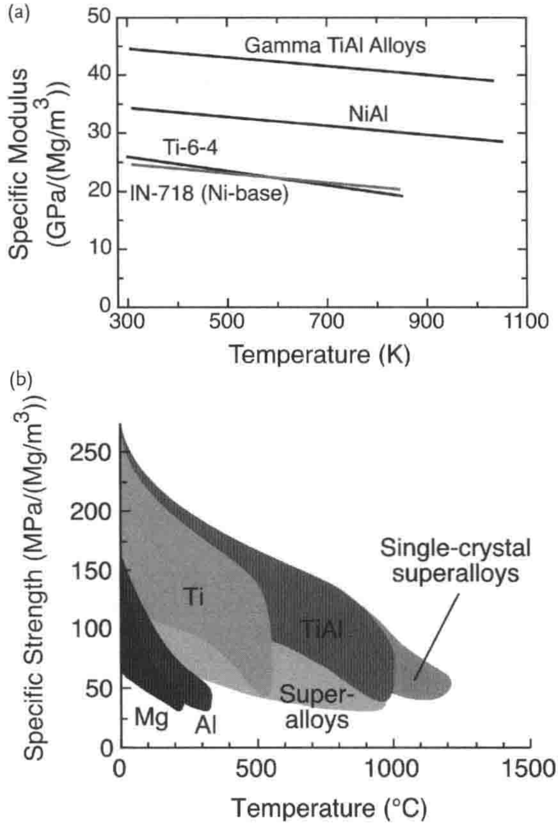

Figure 1.1 Graphs showing the (a) specific moduli and (b) specific strengths of TiAl and other structural materials, as a function of temperature [1]. The data indicates that TiAl compares favorably with the other materials. The data has been redrawn based on the original diagrams.

Due to its intermetallic nature, the complex constitution and microstructure, and the inherent brittleness, the physical metallurgy of TiAl alloys is very demanding. Nevertheless, we will attempt to discuss the broad literature that has been published over the last two decades concerning synthesis, processing and characterization. In our opinion, significant advances have been made, in particular General Electric has made public its intention [4, 5] to use gamma TiAl in its latest engine, the GEnx-1B (Figure 1.2), which best illustrates the present state that has been achieved in TiAl technology. Gamma TiAl has also been successfully introduced into at least one automotive series production, used in formula 1 racing engines, and a variety of components have been manufactured and successfully tested. In the following chapters we will present a comprehensive assessment of both the science and the related technology that has enabled TiAl to be used in the real world.