METAL AND POLYMER MATRIX COMPOSITES

Jonathan A. Lee and Donald L. Mykkanen

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by

Jonathan A. Lee and Donald L. Mykkanen

BDM Corporation
Huntsville, Alabama

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Foreword

This book describes the status of research on metal and polymer matrix composite systems by government and commercial laboratories. It presents data on mechanical, thermal, and physical properties of these advanced metal matrix and polymer matrix systems.

Metal matrix composites (MMCs) have advantages over monolithic metals which include better fatigue resistance, better wear resistance, better elevated temperature properties, higher strength-to-density ratios, higher stiffness-to-density ratios, and lower coefficients of thermal expansion. MMCs also have advantages when compared to polymer matrix composites, including higher functional temperatures, higher transverse strength and stiffness, no moisture absorption, better conductiveness, and better radiation resistance. MMCs also have disadvantages including high costs, newer technologies, complex fabrication methods, and limited service experience.

Polymer matrix composites are highly anisotropic. Strength and stiffness are high parallel to the fibers, but low perpendicular to the fibers. PMCs have stress-strain curves that are generally linear to failure. Polymer matrix materials result in composites that have higher specific tensile strength and stiffness properties. Polymer composites are more advanced in fabrication technology and have lower raw material and fabrication costs.

The information in the book is from *Advanced Materials Research Status and Requirements. Volume I—Technical Summary,* and *Volume II—Material Properties Data Review,* prepared by Jonathan A. Lee and Donald L. Mykkanen of BDM Corporation, for the U.S. Army Strategic Defense Command, March 1986.

The table of contents is organized in such a way as to serve as a subject index and provides easy access to the information contained in the book.

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NOTICE

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PART II
MATERIALS PROPERTIES REVIEW

Part I

Technical Summary

The information in Part I is from *Advanced Materials Research Status and Requirements. Volume I—Technical Summary,* prepared by Jonathan A. Lee and Donald L. Mykkanen of BDM Corporation for the U.S. Army Strategic Defense Command, March 1986.

1. Introduction

1.1 Purpose. This document is Volume 1 of a two-volume report describing the status and requirements of the advanced composite materials research in government and commercial laboratories. This task consists of reviewing and evaluating the advanced composite materials which might provide a major step forward in the performance of strategic defense interceptors. This task focused on the application and use of the available and near-term (5 plus years) advanced composite materials. Because of the time limitation, the scope of the technical material goals examined is restricted to advancements in composite materials with polymer and metal matrices. The cost analysis herein is limited to an estimation of the expected raw material costs in the five-year time period. The information contained in this study is the result of a thorough search of the Defense Technical Information Center (DTIC) literature, contractor reports, the Metal Matrix Composites Information Analysis Center (MMCIAC), and open literature. The material examined covers the period from 1975 to mid-1984. Volume II presents data on the mechanical, thermal, and physical properties of general interest advanced metal matrix and plastic (polymer) systems. Because advanced composite materials are in a state of evolution in terms of property improvements, it is not possible to provide final property values in the same sense as those now available for conventional metal alloys. However, Volume II is intended to inform the reader in general terms rather than to serve as a standard sourcebook for the advanced composite systems.

1.2 Applications. This document provides a review of several of the most prominent metal matrix and polymer matrix composite materials. The systems that have been chosen for this study are being seriously considered for engineering structural application to U.S. Army Strategic Defense Command (USASDC) advanced material systems. Figure 1-1 shows the advanced materials examined in this study.

Graphite, boron, Kevlar, silicon carbide, and fiberglass are the principal reinforcement materials considered. Although not truly an advanced reinforcement, fiberglass is included because it is used extensively in military and commercial systems and products. Aluminum, magnesium, and titanium are the most important metal matrices. Epoxy, phenolic, and polyimide are the most important polymer matrices.

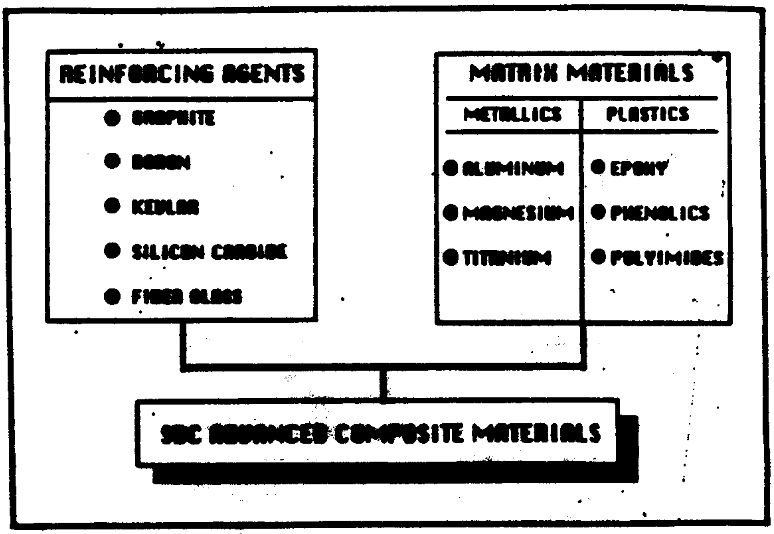

Figure 1-1. Advanced composite materials selection for USASDC material program study.

Figure 1-2 shows how metal matrix composite (MMC) materials may be applied to advanced endoatmospheric interceptor structures. The key advanced endoatmospheric interceptor forebody design requirements include high body bending frequency, minimum body deflections, light weight, and hardness to nuclear and directed energy weapons. The attributes of the MMC materials needed to meet these key design requirements are high specific stiffness and strength at high elevated temperatures, and high thermal and electrical conductivity.

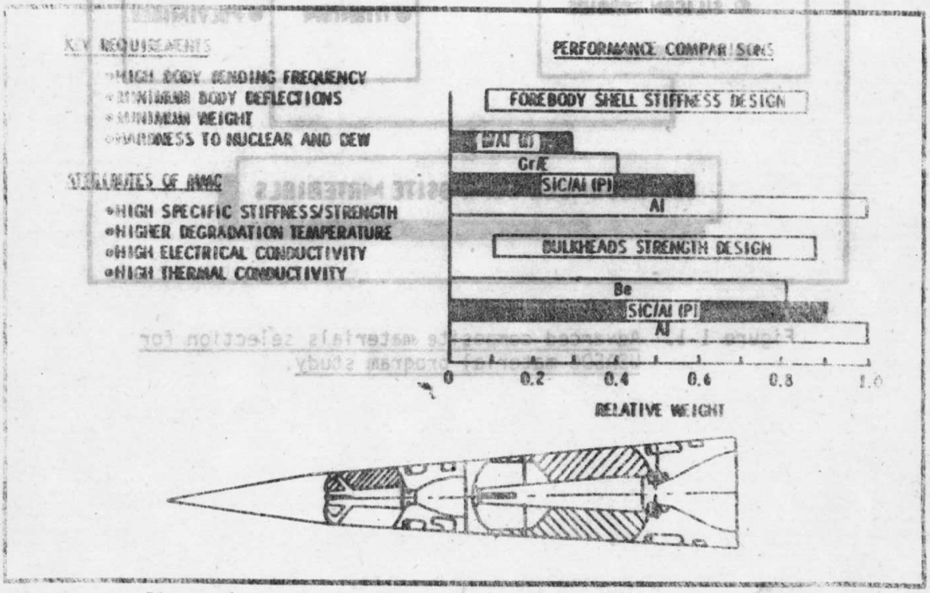

Figure 1-2. Application of metal matrix composites for advanced endoatmospheric interceptor structures.

Figure 1-3 shows how MMC materials may be applied to advanced exoatmospheric interceptor structures. Key requirements for exo interceptor structural design include minimum body weight, high body stiffness, hardness to nuclear and directed energy weapons (DEW), and low cost. Potential uses of MMC materials for exoatmospheric interceptor structures can also be found in kill vehicle (KV) external and sensor internal structures.

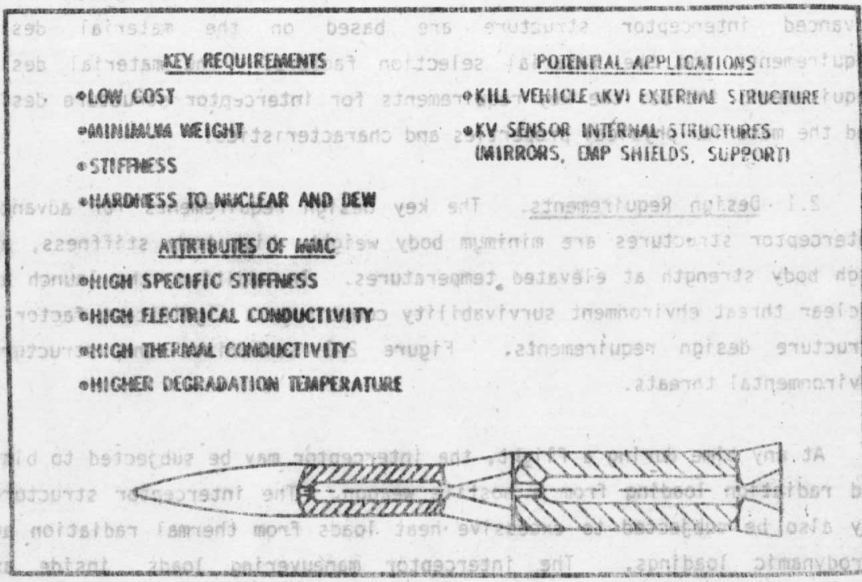

Figure 1-3. Application of metal matrix composites for advanced exoatmospheric interceptor structures.

2. Material Selection Criteria

The material selection criteria of a composite material system for an advanced interceptor structure are based on the material design requirements and the material selection factors. The material design requirements include the key requirements for interceptor structure design and the material physical properties and characteristics.

2.1 Design Requirements. The key design requirements for advanced interceptor structures are minimum body weight, high body stiffness, and high body strength at elevated temperatures. In addition, the launch and nuclear threat environment survivability constitute a significant factor in structure design requirements. Figure 2-1 summarizes the structural environmental threats.

At any time during a flight, the interceptor may be subjected to blast and radiation loading from a hostile weapon. The interceptor structures may also be subjected to excessive heat loads from thermal radiation and aerodynamic loadings. The interceptor maneuvering loads, inside and outside the atmosphere, provide axial and lateral loads to the structure. Therefore, in selecting candidate materials for use in interceptor support structure, the material design requirements must be carefully evaluated to ensure adequate thermal protection, structural strength, and nuclear hardening of the interceptor structure.

The material design requirements or drivers result in materials with high specific strength and modulus to meet the minimum weight penalty. Table 2-1 summarizes the properties and characteristics of advanced composite materials for interceptor structural application. However, the material property requirements are not limited to standard mechanical characteristics such as longitudinal strength, transverse strength, shear strength, etc., but also include other required properties and characteristics such as coefficient of thermal expansion, specific heat, damping loss factor, laser hardness, etc., as shown in Table 2-1.

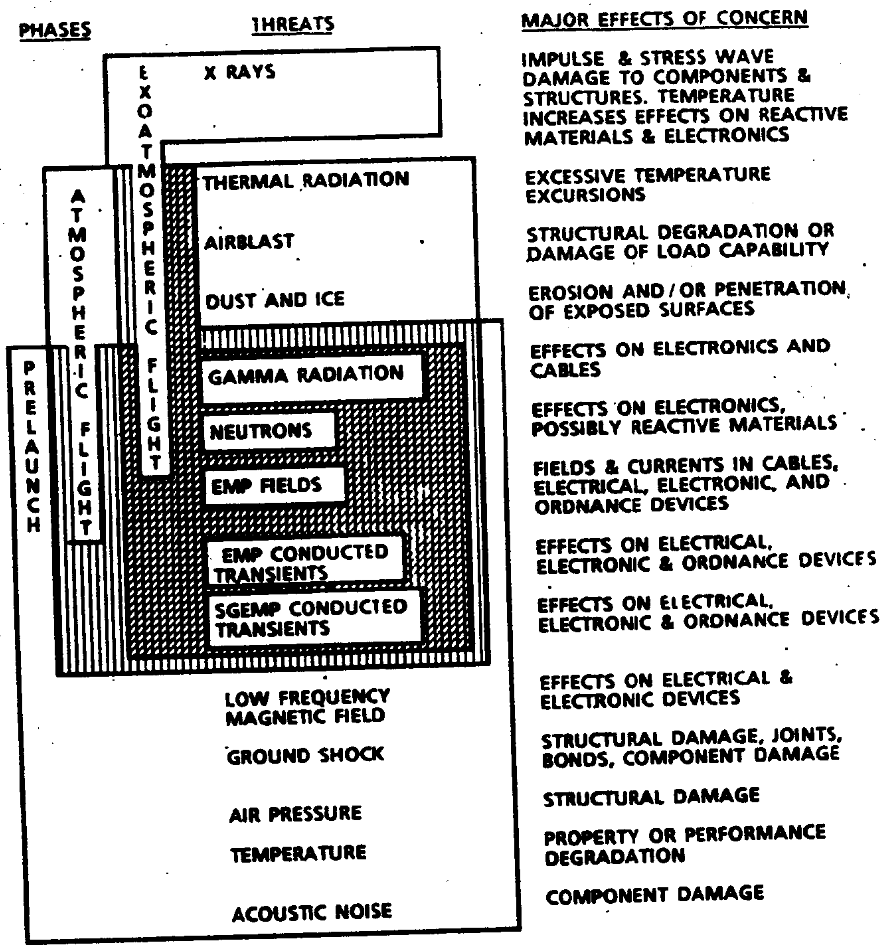

Figure 2-1. Interceptor structural environmental threats. (Reference 1)

TABLE 2-1. Material Selection Properties and Characteristics.

STATIC CHARACTERISTICS
- LONGITUDINAL STRENGTH
- TRANSVERSE STRENGTH
- SHEAR STRENGTH COMPRESSION
- YOUNG'S MODULUS
- POISSON'S RATIO

FATIGUE CHARACTERISTICS
- HIGH LOAD
- LOW LOAD/EXTENDED LIFE
- CONSTANT AMPLITUDE LOAD
- SPECTRUM LOAD

FRACTURE CHARACTERISTICS
- FRACTURE TOUGHNESS
- FLAW GROWTH CHARACTERISTICS

DAMPING CHARACTERISTICS
- LOSS FACTOR

THERMAL PROPERTIES
- COEFFICIENT OF THERMAL EXPANSION
- HEAT TRANSFER COEFFICIENT
- SPECIFIC HEAT

MANUFACTURING METHODS
- PRODUCIBILITY
- PROCESSING CHARACTERISTICS
- MINIMUM HANDLING THICKNESSES
- JOINING TECHNIQUES
- NDI METHODOLOGY
- QUALITY ASSURANCE

HOSTILE ENVIRONMENTS
- MOISTURE
- TEMPERATURE
- NUCLEAR HARDNESS
- LASER HARDNESS
- BEAM WEAPON HARDNESS

2.2 Selection Factors. The second material selection criterion is the material selection factors. The selection factors for an advanced composite material system are summarized in Table 2-2. As an example, some critical selection factors include an available data base, material availability on demand, and low material cost. For the available data base factor, it should be noted that some of the material data are specific to certain applications and perhaps not necessarily of interest to USASDC. However, a complete material data base will include the material design, analysis, processing, and mechanical properties. At the present, an important factor for the material data base is the general lack of information provided for the samples being tested and reported. The quality and properties of a material vary not only with processing conditions, but also with time and probably some undefined variables.

Another important selection factor is the composite material cost. Presently, high cost is a primary barrier to large scale use of advanced composite material systems. It results from high cost and structural fabrication cost of raw reinforcement materials. It is expected that significant cost reduction will occur in the material quality control inspection and manufacturing of composite hardware with increased production. These cost reductions will occur primarily because of increased automation, decreased raw material cost, and decreased cost as a result of the learning curve.

TABLE 2-2. USASDC Advanced Material Selection Factors.

- AVAILABLE DATA BASE
  - DESIGN
  - ANALYSIS
  - PROCESSING
  - MECHANICAL PROPERTIES
- MATERIALS AVAILABLE ON DEMAND
- LOW MATERIAL COSTS
- EASY TO MAKE
- RELIABLE
- EASY TO INSPECT
- HIGHER STRENGTH / DENSITY
- HIGHER STIFFNESS / DENSITY