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# MATERIALS EVALUATION TECHNIQUES

MATERIALS ADVISORY BOARD



National Academy of Sciences—
National Research Council
Washington, D.C.

# MATERIALS ADVISORY BOARD
## DIVISION OF ENGINEERING
## NATIONAL ACADEMY OF SCIENCES-NATIONAL RESEARCH COUNCIL

# MATERIALS EVALUATION TECHNIQUES

Prepared by the
Materials Advisory Board
Division of Engineering - National Research Council

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and
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## ABSTRACT

Guidelines for materials evaluation are not now available. The need for a Materials Advisory Board study of the subject was considered and endorsed.

The proposed study would identify systems, components, environments, design criteria, and relate these factors to test techniques and trade-off approaches. This could permit guidelines to be drawn on recommended approaches to materials evaluation, trade-off studies, development of test techniques, and detail design data generation. The materials evaluation considerations will cover all structural materials except composites and the classically brittle materials.

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MATERIALS EVALUATION TECHNIQUES

## Introduction

New or improved materials are rapidly being developed for a broad range of applications. Many current and near term applications involve the use of materials in environments for which there is little if any previous design experience. To meet this critical situation, materials evaluation studies are being conducted on a broad scale. The producers, the Services, and the users are each conducting materials evaluations. Some of these evaluations duplicate each other; some omit measurements of significant properties; others invest too heavily in materials which, in fact, have little prospect of use. In the absence of some well considered guidelines for materials evaluation, we can only look forward to increasing confusion, lost time, and waste of funds.

Following recommendation of Air Force personnel at the December 8-9, 1965, meeting of the Materials Advisory Board (Appendix XI of the Minutes, p. 54, copy attached Appendix 4), an informal Ad Hoc MAB Panel met on March 15, 1966, to discuss the materials evaluation problem and if appropriate, to formulate an outline of activities for a formal MAB Committee which could develop guidelines for directing materials evaluations programs. A list of those attending the Panel meeting is attached as Appendix 1. After thorough discussion, the need for an MAB Committee on Materials Evaluation Techniques was enthusiastically endorsed.

The outline of activities for this proposed committee is somewhat difficult to communicate because the subject has many facets and there is often confusion over the terms which are used. Appendix 2 contains a glossary of terms.

## Scope of Recommended Committee

The first objective of the Committee should be to develop a base from which to operate. This base is an organized description of the structures and components, the design conditions (including environment) and the materials properties which are needed for the future applications which are anticipated. This part of the committee's work can begin with consideration of the recently completed work of the MAB Aerospace Applications Requirements Panel*. This effort can be concluded quickly because of the prior work but if the Committee is directed to assume a broader scope than aerospace, it will then be necessary to expend additional effort on defining the scope of the total effort. Consideration should be given to assure inclusion of components which will demonstrate various types of design criteria patterns.

Composites and the classically brittle materials should not be considered in this study. The field of composites, which is extremely active at present, comprises a subject in itself, requiring special treatment. It does appear that the standardizing of test methods for composites will soon be appropriate. Brittle materials such as ceramics were excluded because with the variability of properties which they exhibit they do not lend themselves to statistical analysis. In addition, our ability to design efficient load-bearing members of non-ductile materials is poorly developed.

The proposed study should not be considered as limited to metals. The same considerations and problems exist in designing for structural organics as apply for metals, and the need for the evaluation criteria is at least as urgent.

The make-up of the Committee should be expanded if more than aerospace materials evaluation problems are to be considered. The Committee needs to be directed in this regard though the outline of activities need not be changed.

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*MAB-200-M(AAR-1) Volume I, "Systems Requirements Operations & Environmental" (U) Objective I, Classified, September 30, 1964.

MAB-200-M(AAR-2) Volume II, "Design Requirements" (U) Objective II Classified, September 1965.

MAB-200-M(AAR-3) Volume III, "Manufacturing Development Requirements" Objective III, Unclassified, October 1965.

MAB-200-M(AAR-4) Volume V, "Summary of AARP" (U) Classified, May 1966.

Next, the Committee would develop a matrix of component types versus design criteria and indicate the relative importance of the various types of materials data needed for each of the combinations of component type and design criteria. This aspect of the study relates materials property data requirements to the structures that must be designed and it establishes the order of importance of these requirements.

Having defined the types of data which are needed, it will then be necessary to consider the suitability of the known methods available for obtaining these data. This part of the study should be concluded with comments on the suitability of present evaluation techniques and specific recommendations for the development of new or improved techniques that may be required. The recommendations would, of course, be related directly to the end use of the data.

The ultimate objective of materials evaluation testing is to assist in the selection of the correct material for a specific application. The Committee should not select specific materials for any application but, instead, develop approaches for materials selection. The task of obtaining the necessary data involves using the proper evaluation techniques and then recognizing and conducting the necessary tests at the proper time. Another important step involves making the correct selection of material once the data are in hand. This brings us to the subject of trade-off studies. It is intended that the Committee will develop approaches for conducting materials selection trade-off studies. It is anticipated that the recommended approaches will be dependent upon the class of component and its operating environment. One or more examples will be detailed to demonstrate the approach. The Committee should not, however, concern itself with the detail design data tests which are usually necessary after a material selection is made.

The final objective of the Committee would be to summarize and relate to each other the previous outputs. This could take the form of recommendations for the approach and timing of:

Screening and detail evaluations

Material selection trade-off studies
Evaluation techniques development
Detail design data generation

as they relate to component types, vehicles or devices. The final recommendations which will be made in the complete report of the Committee could provide guidelines for the Services and all others involved in materials evaluation.

The foregoing comments describe in general terms the proposed activities of an MAB Committee for Materials Evaluation Techniques. Appendix 3 describes the activities of the Committee in more complete detail and delineates ten steps to the final objective. This report, including the appendices, constitutes the recommendations of the Ad Hoc Panel which met on March 15, 1966.

## Summary

It is recommended that an MAB Committee on Materials Evaluation Techniques be formed as soon as possible. The task is a large and important one which may require 12 to 18 months to complete.

It will be noted that the proposed approach is applications oriented rather than materials oriented. This is deemed to be an important distinction which will enable the committee and those who use the report to concentrate upon obtaining data which have direct application as opposed to performing materials comparison studies which are often not as useful.

The make-up of the Committee will be very important. The types of experience most needed are:

a. Structures Design
b. Systems Analysis
c. Materials Evaluation
d. Fabrication

The best justification for the formation of the Committee is stated in the objective which is contained in Appendix 3, i.e., "To develop guidelines and recommendations for increasing the cost effectiveness of the materials evaluation dollar". This would be achieved by:

1. Establishing the relative importance of the various types of tests which could be conducted for a given application.
2. Commenting on the value of present evaluation techniques as they relate to selection of materials for use in specific applications.
3. Making specific recommendations for development of new or improved materials evaluation techniques.
4. Making recommendations of the types of approach to be used for materials selection.
5. Summarizing the whole scheme of materials evaluation and recommending the approach and timing for obtaining the necessary materials information.

## APPENDIX 1

Attendees
March 15, 1966

Ad Hoc MAB Panel on
Materials Evaluation Techniques

Members

Bryce King, Brush Beryllium Co. (Chairman)
John L. Arnquist, Boeing Co.
Calvin H. Conliffe, General Electric Co.
David L. Grimes, Whittaker Corp.
Stanley A. LaFavor, McDonnell Aircraft Corp.
Alan V. Levy, Aerojet-General Corp.
G. Alan Starr, Ling-Temco-Vought

Liaison & MAB Staff

John Barrett, Department of Defense
Harry J. Boertzel, Navy, Bureau of Weapons
Joseph R. Lane, MAB Staff
Fred J. Peck, Jr., Federal Aviation Agency
Norman L. Reed, Army Materials Research Agency
D. A. Shinn, Materials Lab., Wright-Patterson AFB

## APPENDIX 2

### Glossary of Terms

1. Materials Evaluation - A general term denoting the testing conducted at any stage of materials development or usage, for the purpose of learning something about the applicability of a material for some structurally useful purpose.

2. Materials Development Evaluation - Those tests conducted during the development of a new material for the purpose of measuring only those few properties which will indicate whether the material has potential for any application.

3. Materials Screening Evaluation - Those tests conducted on established materials which will indicate which material(s) will have potential for specific applications.

4. Materials Detail Evaluation - Those tests conducted to obtain the data needed for various stages of design. These data can be of two kinds:

   (a) Engineering Data - Those data obtained on materials for the purpose of assessing the reaction of the material to various environments, which data are not sufficiently precise for final design, but may be useable for some designs in the absence of more suitable information.

   (b) Design Data - Those data, including allowables, obtained on materials for the purpose of sizing or selecting materials for the final design of items. These data are either analyzed for statistical probability or have a high degree of accuracy.

5. Design Criteria - Those guides and controls (for materials) which describe the conditions and boundaries under which a material must operate in an item in service.

6. <u>Materials Evaluation Criteria</u> - Those guides and controls, deduced from design criteria, which establish the conditions and boundaries under which materials must be tested, especially when obtaining Design Data.

## APPENDIX 3

### A Proposed Approach for a Material Evaluation Techniques Committee

**Objective**

To develop guidelines and recommendations for increasing the cost effectiveness of the material evaluation dollar.

**Approach**

1. Identify the Types of Vehicles or Devices to be Considered in the Study

The Committee will have to decide (or be instructed) whether the scope of its work is to be restricted to materials for airframes and propulsion devices or whether a broader spectrum of military applications is to be considered.

In the event the scope is restricted to airframes and propulsion devices (for both atmospheric and space flight), it is suggested that the recently completed work of the MAB Aerospace Applications Requirements Panel could be an excellent starting point. The vehicles identified in this study cover the complete spectrum of vehicles known to be of future interest to the Air Force. By using this study as a starting point, additional value is received by the Air Force for the money already expended.

2. Identify the Vehicle (or Device) Components to be Considered

The MAB AARP reports identify those typical components that were expected to be critical from a manufacturing methods point of view. Some additional components may require identification for the purposes of this committee; specifically, those for which possibly unique material evaluation criteria exist. In any event, it is suggested that the MAB reports will form a good basis for an expanded listing of components for specific vehicles. It should be noted that the AARP group formulated a complete checklist of all components. This checklist could prove useful to the Committee.

3. <u>Identify Component Design Environment</u>

The MAB AARP reports also describe the design environments for selected components and vehicles. These environments consider such factors as:

- type of environment, i.e., thermal, acoustic, corrosion, radiation, stress, etc.
- type of loading, i.e., static tension or compression, fatigue, biaxial, pressure, thermal stress, etc.

In the event additional components beyond those listed in the AARP reports are identified in Step 2, further development of the environments will be needed.

At this point we have identified a broad range of components and environments for which evaluation criteria are needed. The next phase of the effort is to consider the available evaluation criteria and to determine where the deficiency areas are.

4. <u>Identify (or summarize) Total Design Criteria (Both Screening and Detail Types) and Group into Several Major Categories</u>

For example, major categories into which the design criteria might be grouped could be:

- Static Strength Criteria
- Fatigue Criteria
- Thermal Stress Criteria
- Fabricability Criteria
- Surface Protection Criteria
- Other

For each major category the several physical, mechanical and metallurgical characteristics of interest can be listed.

5. <u>Relate the Applicable Design Criteria of Step 4 to Components and their Design Environments and their Material Types. Assign Priorities to Evaluation Criteria</u>

This step represents the first significant input of the new committee. Steps 1, 2, 3 were essentially extensions of prior work. Step 4 is just a comprehensive check list. This step requires some expertise to be certain that those design criteria that are most pertinent are properly related to typical components.

The output of the effort represented by this step should be a matrix of component types versus design criteria. An attempt should be made to indicate the relative importance of the several criteria for the component in question.

6. Identify Present Evaluation Test Techniques Used and Note Shortcomings, Limitations or Problems

For each of the criteria listed in Step 4, there is, presumably, a laboratory test (or tests) designed to measure a quantity that will indicate the performance of the material. These test techniques should be identified, suitably referenced, classified and comments noted as to their suitability. The latter effort may prove to be more difficult than it sounds since not all test techniques are universally accepted, nor is there complete agreement as to the usefulness of many that are. Nevertheless, it would be valuable to summarize the situation with the intent that "problem areas" that are identified could be referred to some appropriate group for further action. A case in point is the lack of correlation which has been observed between laboratory tests and service experiences in problem areas such as stress corrosion.

7. Recommend Needed New or Improved Evaluation Techniques and Relate to Component and Material Type

Step 6 has been done independently of Steps 1, 2, and 3. At this point, however, the requirements developed in Step 5 are compared with the available test techniques as identified in Step 6. The main purpose is to determine which of the many evaluation test techniques are applicable to which component, and of those, which appear to require improvement. It may be, for some components, that no satisfactory evaluation test technique exists. In this case, it would not be the task of the Committee to devise an acceptable technique but rather to identify the need for one. Attention could be given to assessing the trade-off between accuracy, speed, and cost of testing for various types of design criteria.

8. Discuss Trade-Off Factors and Their Relative Importance Pertinent to Specific Components

Most trade-offs in the design application of materials can be reduced to an effect on weight, fabrication cost, material cost, product life and maintenance cost. The effect on weight can ultimately be converted to an effect on system cost. Obviously, the Committee cannot attempt specific trade-offs. However, the Committee can identify the factors that must be considered in the general case. Further, it can discuss these factors and indicate which factors are likely to be most important for a specific type of component. A member of the Committee functioning in his role as an expert consultant can for a specific class of components, prepare a knowledgeable discussion of the interplay and importance of the several factors that would be involved in a specific design trade-off without, in fact, performing the trade-off.

9. Recommend Trade-Off Approaches for Particular Classes of Components and Materials

The recommendations will, of course, be generalized as a consequence of the detailed discussions generated in Step 8. One purpose of these recommendations will be to indicate, if such be the case, the differences in trade-off approaches as affected by the design application. One or more examples will be detailed to demonstrate the approach.

10. Recommend Approaches for Relative Scope and Timing of:

a. Screening and detail evaluation
b. Trade-off studies
c. Evaluation techniques development
d. Detail design data generation

as they Relate to Component Types and Vehicles (or Devices)

This is the heart of the entire effort for which all the previous steps were essentially preparatory building blocks. Much thought and discussion will be required by the Committee. It will be here that some of the answers to the philosophical questions posed by Air Force personnel will be generated, or at least, better insight and guidelines developed for how the answers might be obtained in a specific case.

Among other considerations, the "quality" of the material must be established. By this is meant the microstructure and texture inherited by the consolidation and forming processes, qualities which will vary depending on the scale of the operation. Testing, of course, should be carried on with material which has been sufficiently scaled up and on which processing has been optimized and standardized so that the results will correspond with subsequent production. Performance evaluation should also recognize that property changes can accrue from prior fabrication history. Thus the behavior of a formed part in service may not be clearly predicated upon the sheet material before undergoing the forming operation.

# APPENDIX 4

## Suggested Proposal for the Formation of an Ad Hoc MAB Panel on Design Criteria

(April 29, 1966, letter from Air Force Materials Laboratory)

1. In our effort to utilize structural materials in optimum ways in Air Force systems we are constantly plagued by a lack of agreement on what design criteria and test techniques should be used in our materials evaluation programs. While there is a substantial amount of work completed and currently underway in the technology of materials evaluation, most of this work is not suitable for our purposes as it is oriented towards materials development and comparison rather than design applications. You are aware of the new ARPA programs to couple materials producers, universities, and users. These programs should provide some progress toward tailoring a material for an application and evaluating a material more effectively. However, we don't think they will achieve much in the way of more effective evaluation of existing materials for new applications. In addition several of the technical committees have been active in some areas, notably brittle fracture. However, because of their nature these committees represent many diversified viewpoints and, consequently, seldom come up with the type of recommendations needed for planning purposes. Recommendations from the Aircraft Industries Associations, Aircraft Research and Testing Committee and several Ad Hoc MAB panels have been useful in the past, but their recommendations are generally limited to traditional mechanical properties on specific classes of materials (e.g., refractory alloys, beryllium, etc.). We know of no extensive effort directed specifically at achieving the knowledge required to apply materials efficiently to complex environments and stresses.

2. Consequently there are two basic questions that must be asked:

   a. Is there a fair proportionate share of available resources being expended on evaluation and application, as contrasted to materials research and new materials development?

b. How can we orient our materials evaluation effort for maximum interaction between the designer and the materials engineer to provide optimum results?

3. Depending on the answer to the above questions we are then more specifically concerned with the following types of things:

a. Would an ability to perform an accurate stress-analysis in a complex structure eliminate a need for complex materials evaluations programs?

b. If an accurate stress-analysis were possible, what materials data or analyses are needed?

c. What type of tests are needed for brittle materials to use them in design?

d. What type of tests are needed for composites to use them in design?

e. What is the effect of thermal stresses in complex structures (ductile and brittle) and how can they be simulated and measured?

f. What can be done about evaluating the effect of multiaxial tensile stresses?

g. What are the effects of various surfaces (in service)?

h. How should we evaluate materials for long time effects?

4. As evidence of this problem, Dr. Goldhoff who works for Dr. W. R. Hibbard, Jr., the Materials Advisory Board Chairman, has written us some helpful letters and we have received many proposals from other sources. But because of the complexity and wide range of possible approaches to the problem solution it is very difficult to intelligently judge the many avenues of attack and select those which might have the greatest payoff.

5. With the preceding comments as background, it is our purpose to solicit your advice as to a proposed course of action to provide a better perspective for the materials evaluation picture. The first step would appear to be the review and selection of those design approaches appropriate

for modern structures and environments. The area of usefulness and limitations of these approaches should be established. The tests and test procedures necessary to use the selected approaches should be defined. Finally the relative order of importance of these data with respect to the more traditional properties such as tension, compression, bearing, shear, and S/N fatigue data should also be established. If additional basic research on evaluation is needed before certain recommendations can be made, for example: effects of multiaxial stresses, then this need should be established.

6. It is obvious that recommendations of this nature would be difficult to obtain through an advisory group. However, until such recommendations are forthcoming, materials property data will continue to be obtained based on traditional analysis techniques making optimum material selection for complex environments difficult if not impossible. It is therefore suggested that an Ad Hoc Panel be formed to review the many design approaches which have been proposed and make appropriate recommendations.

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Under a contract between the Office of the Secretary of Defense and the National Academy of Sciences, the Board's present assignment is

> "...to conduct studies, surveys, make critical analyses, and prepare and furnish to the Director of Defense Research and Engineering advisory and technical reports, with respect to the entire field of materials research, including the planning phases thereof."