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ROYAL AEROSPACE ESTABLISHMENT

**Technical Memorandum**

January 1991

# CRAG Working Group on Alternative/Equivalent Materials for Components Cleared Primarily by Structural Testing

by

The Composites Research Advisory Group



Procurement Executive, Ministry of Defence
Farnborough, Hampshire

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## CRAG WORKING GROUP ON ALTERNATIVE/EQUIVALENT MATERIALS FOR COMPONENTS CLEARED PRIMARILY BY STRUCTURAL TESTING

by

The Composites Research Advisory Group

SUMMARY

This Report describes the conclusions and recommendations of the CRAG Working Group on Alternative/Equivalent Materials for Components Cleared Primarily by Structural Testing. Enquiries about the work of the Group should be addressed to the CRAG Secretary, Dr M. J. Pitkethly, Materials and Structures Department, R50 Building, RAE Farnborough.

## LIST OF CONTENTS

## 1 INTRODUCTION

The requirement for the Working Group arose from the identification that due to insufficient understanding of composite behaviour, the introduction of an alternative material to a composite structure seldom occurred as extensive re-testing is required. This clearly reduces the cost effectiveness of composite structures as the commercial advantages of multi-sourcing cannot be attained.

It was also identified that the classification of the structure was a major factor in the case of alternative material selection and introduction. Therefore, two Working Groups were established.

(i) Components cleared primarily by structural testing

These gain airworthiness clearance by testing (and calculation). Full re-qualification of the structure would be required for an alternative material unless a thorough understanding of the material and structural behaviour can be demonstrated, thereby reducing the pyramid of tests required for clearance.

(ii) Components cleared by calculation

The introduction of an alternative material is a procedural problem. The properties used in a calculation to clear the structure can be determined and it should be ensured that the alternative material has acceptable properties and that the processing route is similar.

This Report details the conclusions of the Working Group on Equivalent and Alternative Materials for Composite Components Cleared Primarily by Structural Testing.

## 2 ORGANISATION

The Working Group comprised of:

Mr R. T. Potter RAE, (Chairman)
Mr B. Hamill, Short Brothers
Mr R. Pickard, Rolls Royce
Mr I. Gurnell, Ciba-Geigy
Dr G. Gould, Courtaulds
Dr R. Robinson, Courtaulds
Ms L. Allger, BAe (MAL), (Secretary)

Six meetings were held between 7 April 1989 and 30 January 1990.

## 3 TERMS OF REFERENCE

The Terms of Reference were agreed to be "To identify and prioritise the research required to minimise the (cost of) testing required to substantiate the use of an equivalent or alternative material".

## 4 SCOPE

The following ground rules were established:-

(i) It was not the function of the Working Group to define what constitutes an alternative/equipment material or to define acceptable limits. The aim of the research identified in this Report is to quantify structural differences resulting from the substitution of another material. This will then permit the designer to assess whether the material differences are significant for the component(s) under consideration.

(ii) The Working Group would only consider structural performance, *ie* not EMC, Stealth, etc.

(iii) Generally, the material changes considered would involve replacement within a generic material group, *ie* thermoset replaced by thermoset.

(iv) The concept of the testing pyramid would be used but detailed differences as a function of application would be ignored.

## 5 APPROACH

In general, the levels of the testing pyramid shown in Fig 1 were defined as:-

(i) Constituents (fibre, matrix, prepreg).
(ii) Ply properties.
(iii) Laminate properties.
(iv) Structural elements/features.
(v) Sub-components.
(vi) Major test.

It was agreed to concentrate on the first four levels of the pyramid since, if the behaviour was understood at these levels, the performance of sub-components and major tests could be inferred from these.

A comprehensive list of mechanical, physical and chemical properties was compiled which would characterise each level of the pyramid. It was then possible to assess whether current knowledge would permit the influence of a property change at one level on higher levels to be quantified.

The results, shown in Tables 1 to 3 represent the best opinions of the members of the Working Group and have been annotated as follows:-

it is highly probable that there will be an influence;

it is highly probable that there will not be an influence;

? unknown;

? () some uncertainty, but likely influence shown in parenthesis.

## 6 ASSUMPTIONS MADE

The following assumptions were made:-

(i) A change in a property in the left hand column assumes all other properties in that column remain constant.

(ii) A change in modulus (fibre, matrix, ply or laminate) will result in a load re-distribution and hence will alter the strength properties in the the level above.

(iii) Environmental effects, non-linear behaviour and fibre volume fraction Vf, were not addressed as separate items as they are fundamental to full material characterisation.

(iv) Defects were not included since, if an alternative material had a different defect behaviour, this would be apparent from properties such as fracture toughness, notch sensitivity, etc.

## 7 RESULTS

The results are presented in Tables 1 to 3, when reading these tables the following notes should be taken into consideration.

### Table 1

The numbers of the notes below correspond to the numbers in brackets in Table 1.

(1) There could be an effect using Aramid fibres.

(2) Process control has been included as there are other physical and chemical properties that cannot currently be identified. This is the reason why material specifications control the manufacturing route.

(3) Physico-chemical testing will detect any further changes which cannot be identified provided there is test method standardisation and full definition of the critical tests for different materials.

(4) This assumes that a constant Vf is achieved by bleeding excess resin to obtain the desired Vf .

(5) All properties will be affected if transfer of release agents from the protective or prepreg backing paper to the prepreg occurs.

**Table 2**

(1) It is assumed that environmental effects are included to cover "worst case".

(2) Non-linear behaviour is assumed to be part of the full ply or laminate characterisation and is therefore not included independently.

(3) Processing has not been included as physico-chemical characterisation will determine control of processing provided research is aimed at evaluation of physico-chemical properties.

(4) Gc = interlaminar.

(5) Notch sensitivity = in plane.

**Table 3**

(1) Gc = interlaminar.

(2) Notch sensitivity = in plane.

(3) When considering stiffened panels, ribs/spars and honeycomb structures holes and specific features have been neglected.

## 8 ANALYSIS OF RESULTS

### 8.1 Relationship between constituents and ply properties (Table 1)

To summarise Table 1, in the majority of cases it can be established whether or not a change in a constituent property would influence ply properties. However, with the possible exception of moduli, it would not be possible to quantify the effect.

The major areas of uncertainty are:-

(i) Process control of the fibre.

(ii) Physico-chemical properties of the resin and prepreg.

As far as possible, a comprehensive list of constituents which could influence ply properties has been defined. However, there are other parameters which cannot currently be defined which could have an influence. It is because of this uncertainty that material specifications contain "no change" clauses, which prevent an equivalent/alternative material from being used.

There are several individual areas where there remains considerable uncertainty.

### 8.2 Relationship between ply and laminate properties (Table 2)

The major areas of uncertainty are:-

(i) The correlation between third direction ply properties and laminate properties.

(ii) Quantifying the effect of ply property changes on laminate behaviour.

There are good plain laminate strength and stiffness prediction methods but work is still required to improve notch and impact strength prediction.

(iii) Laminate creep behaviour.

### 8.3 Relationship between laminate properties and structural elements/features (Table 3)

The major areas of uncertainty are:-

(i) The ability to quantify changes. There are numerous methods enabling stress distributions around features to be established, but there is a lack of failure criteria for uniaxial and multiaxial loading.

(ii) The significance of changes in laminate creep properties on structural performance.

## 9 CONCLUSIONS

Tables 1 to 3 detail the many areas in which research is still required in order to substantially reduce the amount of testing required to qualify an alternative/equivalent material for components cleared primarily by structural testing. However, the major areas in which research is required are detailed below.

### 9.1 Failure criteria

The area of research considered to have highest priority is the development of soundly based failure criteria for uniaxial and multiaxial loading. Development of suitable criteria will directly benefit all the higher levels which are the most costly part of the airworthiness testing pyramid.

### 9.2 Through-thickness properties

The second highest priority is the study of through-thickness properties and their significance in structures. Experience has shown that a number of unpredicted failures can be attributed to the lack of understanding in this area. There is already a CRAG Working Group on test specimens for measurement of through-thickness properties but there is a need to develop analysis techniques and failure criteria.

## 9.3 Physico-chemical properties

There is a need for research to evaluate potential relationships between physico-chemical properties and mechanical and structural performance of composites. A CRAG Working Group has been tasked with the investigation of standard test methods and to examine their potential for predicting mechanical properties.

Additionally, work is required to establish fibre parameters, other than those already identified, which may affect ply properties. These are currently assumed to be governed by process control and are the reasons for "no change" clauses in specifications.

## 9.4 Impact

It is not currently possible to predict impact performance and residual strength of structures on the basis of coupon data. Research is required on this to give a rational method for damage tolerant design.

## 9.5 Creep and fatigue

There remains some uncertainty as to the significance of creep and fatigue in relation to structural response, particularly for new toughened materials. Research is required to establish the significance of these phenomena.

Table 1

RELATIONSHIP BETWEEN CONSTITUENTS AND PLY PROPERTIES

| CONSTITUENTS \ PLY PROPERTIES | | 1 DIR TENSILE STRENGTH | 1 DIR TENSILE MODULUS (INITIAL) | 2 DIR TENSILE STRENGTH | 2 DIR TENSILE MODULUS (INITIAL) | 3 DIR TENSILE STRENGTH | 3 DIR TENSILE MODULUS (INITIAL) | 1 DIR COMP STRENGTH | 1 DIR COMP MODULUS (INITIAL) | 2 DIR COMP STRENGTH | 2 DIR COMP MODULUS (INITIAL) | 3 DIR COMP STRENGTH | 3 DIR COMP MODULUS (INITIAL) | SHEAR STRENGTH | SHEAR MODULUS (INITIAL) | CREEP | FATIGUE | Gc | Tg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FIBRE | MODULUS | ✓ | ✓ | X | X | ? (X) | ? (X) | ✓ | ✓ | X | X | ? (X) | ? (X) | ? | ? (X) | ✓ | ✓ | ✓ | X |
| | STRENGTH | ✓ | X | X | X | ? (X) | ? (X) | ✓ | X | X | X | ? (X) | ? (X) | X(1) | X | ?(✓) | ✓ | X | X |
| | GEOMETRY | ? (X) | X | ✓ | ?(✓) | ?(✓) | ?(✓) | ✓ | ?(✓) | ✓ | ?(✓) | ?(✓) | ?(✓) | ✓ | ? (X) | ? | ? | ✓ | X |
| | SURFACE TREATMENT | ✓ | X | ✓ | X | ✓ | X | ✓ | X | ✓ | X | ✓ | X | ✓ | X | ✓ | ✓ | ✓ | X |
| | SIZE | ✓ | X | ✓ | ? (X) | ✓ | X | ✓ | X | ✓ | ? (X) | ? | ? (X) | ✓ | ? (X) | ✓ | ✓ | ✓ | ✓ |
| | CRYSTAL STRUCTURE | ✓ | X | ✓ | X | ✓ | X | ✓ | X | ✓ | X | ✓ | X | ✓ | X | ✓ | ✓ | ✓ | X |
| | SURFACE ELEMENTAL ANALYSIS | ✓ | X | ✓ | X | ✓ | X | ✓ | X | ✓ | X | ✓ | X | ✓ | X | ✓ | ✓ | ✓ | X |
| | PROCESS CONTROL (2) | ← ? → | | | | | | | | | | | | | | | | | |
| MATRIX | CHEMICAL TYPE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | MODULUS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X |
| | TENSILE ELONGATION | ✓ | X | ✓ | X | ✓ | X | ? (X) | X | ? (X) | X | ✓ | X | ✓ | X | ✓ | ✓ | ✓ | X |
| | TOUGHNESS | ✓ | X | ?(✓) | X | ? (X) | X | ? | X | ? | X | ? | X | ?(✓) | X | ? | ✓ | ✓ | X |
| | VISCO-ELASTICITY | ? (X) | X | ? (X) | ? (X) | ? (X) | ? (X) | ? (X) | ? (X) | ? (X) | ? (X) | ? (X) | ? (X) | ? (X) | ? (X) | ? (X) | ✓ | ✓ | ? |
| | PHYSICO-CHEMICAL PROPERTIES (3) | ← ? → | | | | | | | | | | | | | | | | | |
| PREPREG | PLY THICKNESS | ? | ? (X) | ? | ? (X) | ? | ? (X) | ?(✓) | ? (X) | ? | ? (X) | ? (X) | ?(✓) | ? (X) | ? | ? | ?(✓) | ?(✓) | X |
| | RESIN CONTENT (4) | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| | PROTECTIVE (5) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | PHYSICO-CHEMICAL PROPERTIES (3) | ← ? → | | | | | | | | | | | | | | | | | |

## Table 2

RELATIONSHIP BETWEEN PLY PROPERTIES AND LAMINATE PROPERTIES

| PLY PROPERTIES \ LAMINATE PROPERTIES | TENSILE STRENGTH | TENSILE MODULUS (INITIAL) | COMPRESSIVE STRENGTH | COMPRESSIVE MODULUS | SHEAR STRENGTH | SHEAR MODULUS | CREEP | FATIGUE | Gc | NOTCH SENSITIVITY | IMPACT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 DIR TENSILE STRENGTH | ✓ | X | X | X | ✓ | X | ? | ✓ | X | ✓ | ✓ |
| 1 DIR TENSILE MODULUS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | ✓ | ✓ |
| 2 DIR TENSILE STRENGTH | ✓ | X | ✓ | X | ✓ | X | ? | ✓ | X | ✓ | ✓ |
| 2 DIR TENSILE MODULUS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | ✓ | ✓ | ✓ |
| 3 DIR TENSILE STRENGTH | ← | | | | | ? | | | | | → |
| 3 DIR TENSILE MODULUS | ← | | | | | ? | | | | | → |
| 1 DIR COMP STRENGTH | X | X | ✓ | X | ✓ | X | ? | ✓ | X | ✓ | ✓ |
| 1 DIR COMP MODULUS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | ✓ | ✓ |
| 2 DIR COMP STRENGTH | ?(X) | X | ✓ | X | ✓ | X | ? | ✓ | X | ✓ | ✓ |
| 2 DIR COMP MODULUS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | ✓ | ✓ |
| 3 DIR COMP STRENGTH | ← | | | | | ? | | | | | → |
| 3 DIR COMP MODULUS | ← | | | | | ? | | | | | → |
| SHEAR STRENGTH | ✓ | X | ✓ | X | ✓ | X | ? | ✓ | X | ✓ | ✓ |
| SHEAR MODULUS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | ✓ | ✓ |
| CREEP | | | | | | | ✓ | ? | | | |
| FATIGUE | | | | | | | ? | ✓ | | | |
| Gc | ✓ | X | ✓ | X | ✓ | X | ? | ✓ | ✓ | ✓ | ✓ |
| Tg | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | ✓ | ✓ |

Table 3

RELATIONSHIP BETWEEN LAMINATE PROPERTIES AND STRUCTURAL ELEMENTS/FEATURES

| LAMINATE PROPERTIES \ STRUCTURAL ELEMENTS/FEATURES | | PLY DROP OFF | BONDED JOINTS | MECHANICAL JOINTS | STIFFENED PANELS | RIBS/SPARS | HONEYCOMB STRUCTURES | CUT-OUTS/ACCESS PANELS |
|---|---|---|---|---|---|---|---|---|
| TENSILE STRENGTH | IN PLANE 1,2 | ✓ | X | ✓ | ✓ | ✓ | ✓ | ✓ |
| | OUT OF PLANE 3 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| TENSILE MODULUS | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| COMPRESSIVE STRENGTH | | ✓ | ? | ✓ | ✓ | ✓ | ✓ | ✓ |
| COMPRESSIVE MODULUS | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| SHEAR STRENGTH | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| SHEAR MODULUS | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| CREEP | | ← | | | ? | | | → |
| FATIGUE | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Gc | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| NOTCH SENSITIVITY | | X | X | ✓ | X | X | X | ✓ |
| IMPACT | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

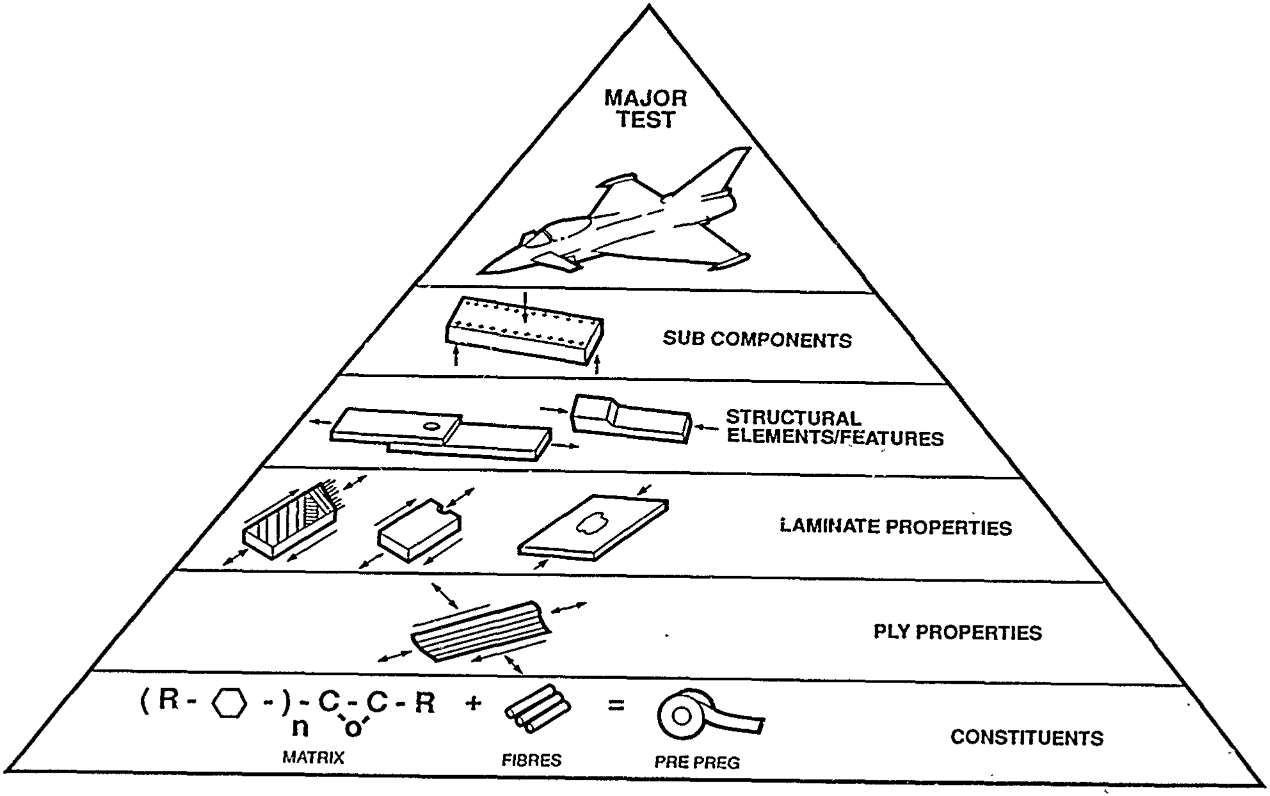


FIGURE 1 : AIRWORTHINESS TESTING PYRAMID

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17. Abstract

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