STRUCTURAL INTEGRITY OF ADVANCED COMPOSITES

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The University of Plymouth is unique in having European Community funded research projects in all three composite material matrix systems (ceramic, metal and polymer), with partners in the majority of EC countries. The University has also a strong Technology Transfer unit, operating under the name Advanced Composites Manufacturing Centre, which services the continuing professional development needs of Europe in its widest sense.

INTRODUCTION

This paper reports recent work in advanced composites at the University of Plymouth, England. A new School of Manufacturing, Materials & Mechanical Engineering (SMMME) has been established (1991) in the new University of Plymouth. The principal research thrust in ceramic matrix, metal matrix and polymer matrix composites covers enhanced performance and manufacturing aspects in an integrated way. The School is well funded via three BRITE Projects:

1. INNOVATIVE MANUFACTURING, DESIGN AND ASSESSMENT OF ALUMINIUM MATRIX COMPOSITES FOR HIGH TEMPERATURE PERFORMANCE. Co-ordinator: Professor David Taplin. BRITE EURAM Project BE3398 (BREU-75). Commenced January 1990. Collaborating bodies: University of Oxford, University of Birmingham, Polytechnical University of Madrid, Ecole Centrale de Paris. Sponsors: Aerospatiale, Alcan, Pechiney, Peugeot, Renault, T & N.

2. ENGINEERED FIBRE STRENGTHENED CERAMIC COMPOSITES: STRUCTURAL INTEGRITY AND PERFORMANCE IN ENERGY CONVERSION AND PROCESSING SYSTEMS. Co-ordinator: Professor David Taplin. BRITE EURAM Project BE4610-90. Commenced 1 March 1992 for 42 months. Collaborating bodies: Warwick University, Leuven University, EOLAS Dublin. Sponsors: British Gas, Brown Boveri, Pilkingtons, Rolls Royce.

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3. SIMULATION OF THE RESIN TRANSFER MOULDING PROCESS FOR EFFICIENT DESIGN AND MANUFACTURE OF COMPOSITE COMPONENTS. Co-ordinator: Dr. John Summerscales. BRITE EURAM II Project BE5477. In negotiation for November 1992 start, anticipated duration 3 years. Collaborating bodies: British Aerospace Airbus Ltd., Brochier SA, Inasco Hellas, Inasmet, Intracom SA, Short Bros. Plc., Sonaca SA, TNO Plastics and Rubber Research Institute. Sponsors: Tech Textiles Ltd.

INNOVATIVE MANUFACTURING, DESIGN AND ASSESSMENT OF ALUMINIUM MATRIX COMPOSITES FOR HIGH TEMPERATURE PERFORMANCE.

The project began in January 1990, following preliminary work which started in January 1988. The basic objectives of this project are derived from recent developments in processing technology, which have enabled the manufacture of aluminium based composites of high structural integrity, thus opening the possibility of major new industrial applications in automotive and aerospace applications. The essential objective of this project is to underpin industrial progress through a materials science research consortium focused on:

- shape, size and volume fraction of reinforcements in the microstructure.
- interface reactions for selected reinforcements.
- the influence of thermal expansion mismatch within the composite on elevated temperature performance.
- the evaluation of microstructural damage and performance parameters for life prediction under monotonic and cyclic load at a range of temperatures and under various environmental conditions.

A second objective of the research is to optimize manufacturing processes to produce microstructures which possess excellent elevated temperature performance in selected aluminium alloy systems and allow predictive engineering design of components for European Industry. The central aim is to develop a thorough understanding of the performance characteristics of high temperature aluminium metal matrix composites (MMC's) in terms of their microstructures as influenced by the various routes of manufacturing and constituent reinforcements and alloy matrices. The overall approach in performance analysis is one of micromechanicistic damage parameters and micromechanicistic modelling. The development of micromechanical mechanism models has been identified as the key specific objective of the project. It is only through the development of such physically based models that significant advances in the design of materials for specific components can be attained.

The specific task of the University of Plymouth is on creep damage processes, under uniaxial and multiaxial loading at temperatures up to 300°C, plus environmental effects. Uniaxial creep studies designed to provide benchmark data and damage evolution information on a selection of materials have been conducted using standardized creep testing equipment coupled with electron metallography of damage. Notched creep testpieces using the same basic solid cylindrical dimensions, as for uniaxial creep testing incorporating circumferential Bridgeman type double notches, have been employed. These double notch testpieces provide information on the detailed micromechanisms of damage evolution while this type of test is the simplest technique for assessing predictive models.

Creep data on the materials tested in this experimental programme have been entered in a CRISPEN [1] computer software system designed for the prediction of creep performance of nickel base superalloys. The experimental curves for these aluminium based MMCs show great similarity to those of nickel base superalloys upon which CRISPEN is based and, therefore, reasonable agreement of the CRISPEN simulations with the experimental data would be expected. While the physical mechanisms of deformation for these materials have not yet been determined in detail, the good simulation yielded by the exponential formulation suggests that strain softening is a dominant deformation mechanism [2]. Since CRISPEN has been scheduled in a modular fashion [3], physically based models for the tertiary damage mechanisms relevant to these composite materials could be incorporated in this software package and thus extend its predictive capacity to incorporate creep of particulate reinforced MMCs.

ENGINEERED FIBRE STRENGTHENED CERAMIC COMPOSITES: STRUCTURAL INTEGRITY AND PERFORMANCE IN ENERGY CONVERSION AND PROCESSING SYSTEMS

U.S. markets for advanced structural ceramics are estimated to have an annual growth rate of 22% from 1990 to 1995, followed by an 18% annual growth to the year 2000. The total market should reach $2.6 billion by the end of this decade. It is envisaged that CMCs, with their improved toughness, will find a significant niche in this market.

The utilisation of monolithic ceramics is restricted primarily by their limited integrity (maximum fracture toughness of $10MPam^{1/2}$). Increased activity in development of ceramic matrix composites (CMCs) is the subject of scientific research at the University of Plymouth, co-ordinators of the research consortium. The current research program involves the creation of closely engineered structural ceramic composites based upon: (a) glass ceramic matrices, and (b) chemical vapour infiltration, with continuous SiC fibre reinforcements. Work is being conducted to improve understanding and enable precise characterisation in order to achieve accurate predictive life criteria for model-based design purposes. Three classes of material are to be studied with the main focus on the first two (near-commercial) classes and later work in the third class:

- Class I: Pyrex glass type matrices with SiC fibres and useful up to 550°C.
- Class II: Glass ceramic matrices reinforced with SiC fibres and useful up to 900°C.
- Class III: SiC matrix, SiC fibre-reinforced composite potentially useful up to 1200°C.

Work on Classes I and II is of particular benefit through the ability to operate progressive refinements of the materials through an industrial manufacturing feedback loop. These classes of material have been selected based upon an advanced understanding of in-situ interface formation and matrix crystallisation providing basic guidelines for reasonable confidence in their commercial potential. The material will be in the form of both unidirectionally reinforced composites as well as laminated or woven composites with the fibre architecture in two or more directions (2-D and 3-D). The industrial sponsors of this project have already identified potential applications where the composites may find favour: in energy conversion systems and chemical processing systems. Specific examples are:

-(Rolls Royce + Brown Boveri) - Final stage compressor blades in turbines (lower rotational inertia/higher temperature).

-(British Gas)-Heat exchanger tubes (higher temperature/improved heat transfer/longer life).

Designing such components clearly necessitates a more sophisticated understanding and detailed materials data. These requirements will be met upon completion of the work programme objectives, which involve:

- environmental degradation in a range of relevant hostile environments;
- uniaxial monotonic high temperature mechanical degradation;
- uniaxial cyclic degradation mainly at high temperature;
- creep-fatigue interaction at high temperature (low-cycle fatigue);
- thermal cycling/thermal shock;
- creep-fatigue-oxidation synergisms;
- damage analysis and interface studies;
- CRISPEN-type modelling.

The composites developed are expected to display superior properties to metallic alloys in terms of their high specific stiffness and strength, high hardness, wear resistance, oxidation and chemical resistance combined with relatively high melting or decomposition temperature.

SIMULATION OF THE RESIN TRANSFER MOULDING PROCESS FOR EFFICIENT DESIGN AND MANUFACTURE OF COMPOSITE COMPONENTS.

Research on resin transfer moulding (RTM) has been undertaken at Plymouth for over ten years [4 - 6].

It is intended to develop analytical techniques for the simulation of the RTM process. Since the process involves the introduction of a thermoset resin into a permeable fibre reinforcement, there is the possibility that either pockets of air will be entrapped in the moulding or that the resin will start to cure before the moulding is completely filled. The design of the process to ensure complete filling of the mould is currently based upon past experience which resides in a number of specialist organisations. The selection of suitable materials and the location of the resin inlet and outlet ports has been based upon trial and error requiring modifications to tooling and resource wastage before the manufacturing route is perfected. While RTM is cost effective when the manufacturing route is developed, for organisations with either a small volume or a wide range of components to be manufactured, the cost of developing individual production items becomes expensive. Analytical techniques to predict the process events would therefore assist in improving the lead time and reducing costs in introducing the manufacturing technique into production. It is intended to improve the opportunity for introducing RTM into production by providing predictive techniques. The improvement in design knowledge will be realized through:

- improved materials characterisation through the acquisition of accurate fabric permeability data and improved resin characterisation.
- materials characterisation to take into account the deformed shape of the fabric in the component and the performing route by which the shape is produced.
- development of an improved software code, to model three-dimensional resin flow and the use of analytical capability to predict the process events.
- validation of the process simulation software against a series of representative test pieces incorporating increasingly complex features.
- development of an Intelligent Knowledge Based System (IKBS) incorporating the data from this programme to assist with process design and material selection.

Potential costs reductions for RTM are estimated to be in excess of 30% compared with existing composite manufacturing routes. The development of these analytical techniques will significantly increase the entry of RTM into the manufacturing market and, as a result, it is expected that there would be a 50% reduction in the scrap rate and 20% reduction in the energy required during production.

In addition to European funded research, the following projects are current:

- Use of nuclear magnetic resonance spectroscopy and tomography for the non-destructive evaluation of composites.
- Simulation and design optimisation for resin transfer moulding.

- Resin transfer moulding of ballistic panels.
- Resin transfer moulding of marine products.

TECHNOLOGY TRANSFER

In 1987, with UK government funding from an Advanced Manufacturing Technology Initiative, the Advanced Composites Manufacturing Centre (ACMC) at the University of Plymouth was formed to provide Continuing Professional Development (CPD) through technology transfer Short Courses and Discussion Meetings for the reinforced plastics and composites industries. By the end of April 1992 such meetings had been attended by 783 delegates from 11 of the EC countries, plus EFTA, Israel, Japan, South Africa, North America and Brazil.

In 1990 the University became the only UK further education establishment to offer a named Bachelor of Engineering degree in Composites Engineering. The basis for development of this degree is the close links forged with industry through the ACMC CPD unit. The course may be undertaken full time in three years, or preferably as a sandwich degree with one year industrial experience between years 2 and 3. The degree will be available in modular format under CATS (Credit Accumulation Transfer Scheme) from September 1992, running in 6 semesters of 15 weeks each.

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