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A CMC DATABASE FOR USE IN THE NEXT GENERATION LAUNCH VEHICLES (ROCKETS)

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INTRODUCTION

Ceramics Matrix Composites are being envisioned as the state-of the-art material capable of handling the tough structural and thermal demands of advanced high temperature structures for programs such as the SSTO (Single Stage to Orbit), HSCT (High Speed Civil Transport) etc. as well as for evolution of the industrial heating systems.

Particulate, whisker and continuous fiber ceramic matrix (CFCC) composites have been designed to provide fracture toughness to the advanced ceramic materials which have a high degree of wear resistance, hardness, stiffness and heat and corrosion resistance but are notorious for their brittleness and sensitivity to microscopic flaws such as cracks, voids and impurity.

THE BEHAVIOR OF CFCC

CFCCs have been singled out as the most efficient one for the more demanding projects because the fibers can control crack propagation by dissipating the crack tip energy. Fracture toughness[1] measured in terms of K_{IC} (or K_Q) values for CMCs have caught up with the lower limit (30 MPa $m^{1/2}$) of that for tough metals (30-200 MPa $m^{1/2}$). WOF (Work of Fracture) for unidirectional long fiber CMCs tends to vary from a few KJ/m^2 to about 100 KJ/m^2 whereas for monolithic structural ceramics it is just a few $Joules/m^2$.

Also the scatter in strength, measured in terms of the Weibull Modulus has shown considerable improvement in the case of CFCCs (30 for SiC/Borosilicate glass and 6-8 for monolithics). This is a more desirable situation for the designer because a higher proportion of the Ultimate Strength becomes available for component design.

C/SIC AND SIC/SIC CMCS

In elevated temperature applications, C/SiC and SiC/SiC CMCs are the materials with the highest expectations because of their greater oxidation resistance compared to

Carbon/Carbon composite which oxidizes easily even at moderate temperatures. A host of studies are going on currently all over the world on C/SiC, SiC/SiC and SiC/Glass types of composites.

Matrix microcracking[2] and hence the microcracking threshold stress σ_{mc} (about 120 MPa with 0.1% strain at room temperature for SiC_f/CAS) plays a critical role in the performance of the CMC in fatigue and in oxidizing environments. C/SiC composites are weak in this aspect because it tends to have a non-existant σ_{mc} (the stress-strain behavior is a non-linear one right from the beginning of loading). This is caused by the fact that the carbon fibers have a CTE (coefficient of thermal expansion) mismatch ($\alpha_m > \alpha_f$) with the SiC matrix forcing the material to have microcracks in the matrix during the cooling from a high temperature in the fabrication process.

SOME RECENT TESTS ON C/SIC CMC

A. An attempt at taking a C/SiC composite[3] to a temperature range of $1770^{o}c$-$1810^{o}c$ with the hope of finding a better material for the TPS system TOPHAT led to the conclusion that the C/SiC material (with fiber and matrix volumes of 40% and 60% respectively) failed mainly due to full oxidation of a thin SiC coating at the fabric holes as well as processing flaws. Oxidation occurs internally and progresses to expose carbon fibers directly to the oxidizing material.

Suggestions such as (1) a continuous and thicker coating in the holes of the fabric; (2) reduction of misalignment of fabric plies; (3) use of a fabric with smaller tows and a denser weave so as to reduce the size of the voids as well as distribute them more homogeneously through the thickness and also have a more uniform surface with holes easier to fill by a polymer assisted CVD/CVI SiC processing technique have been made.

B. Higher fiber volume and higher densities have been shown by Headinger et al[4] to correspond to higher tensile strength and/or shear strength in an investigation, sponsored by the Air Force, on the dependence of the mechanical properties of C/SiC turbine rotors. While density had greater influence on tensile strength, higher fiber volume seemed to improve toughness with no clear effect of density observed.

C. The development of a C/SiC turbine rotor[5] published in the NASA-CP 3235 reports a good correlation between coupon testing and spindisk testing. The material, when designed to have higher oxidation resistance will enable the design of a rotor which will not require cooling resulting in an improved thrust and reduced fuel consumption.

A CMC DATABASE: THE SUMMER PROJECT

The database has specifically aimed at data on C/SiC and SiC/SiC CMCs due to the fact that these materials tend to maintain their mechanical properties even at high temperatures and exhibit greater resistance to oxidation in comparison with other structural materials. However, considerable work seems to be in progress on glass ceramics also.

The following companies and institutions have been contacted for CMC data:
DuPont, B. F. Goodrich, Amercom, Pratt & Whitney, McDonnell Douglas, SEP, Dow-Corning, LTV, NASA Lewis, Boeing, Williams International, Oakridge Laboratory, University of Michigan, Southern Research Institute, Wright Patterson AFB, NIST, General Electric, Grumman, FMI/EMTL, United Technologies Research Center. So far data have been provided by : DuPont, Williams International, Southern Research Institute (reports), B. F. Goodrich, NASA Lewis, University of Michigan, Amercom, WPAFB + McDonnell Douglas (yet to arrive), Dow - Corning (promised) and Boeing (promised).

The rest have either referred to the above or are in the process of generating data.

VISITS : A trip was taken to Southern Research Institute to visit their labs and also to look into the possibility of acquiring current data on CMCs. The test organization was impressive. They are in the process of testing several CMCs for various clients; but do not have the proprietary rights to make those available to NASA/MSFC yet.

THE DATABASE SYSTEM : The MAPTIS and the M/VISION systems have been analysed for advantages and disadvantages.

EXAMPLES OF THE DATA COLLECTED : DuPont (Nicalon/SiC, Enhanced SiC/SiC with a matrix enhancement and T-300/SiC); B. F. Goodrich (Nicalon/SiC, T-300/SiC); Williams International (data from various sources on SiC/SiC, C/SiC, $SiC_{p\&f}/Al_2O_3$, NiC/SiC); the University of Michigan (Fatigue, High Temp. Creep, Environmental behavior of CMCs).

FUTURE WORK : The data will have to be evaluated for quality prior to putting them in the database. The criteria for evaluation are to be established based on a thorough study of the factors affecting the pedigree of the data, information supplied by the manufacturers as well as using theoretical models and softwares based on the micromechanical behavior of CMCs.

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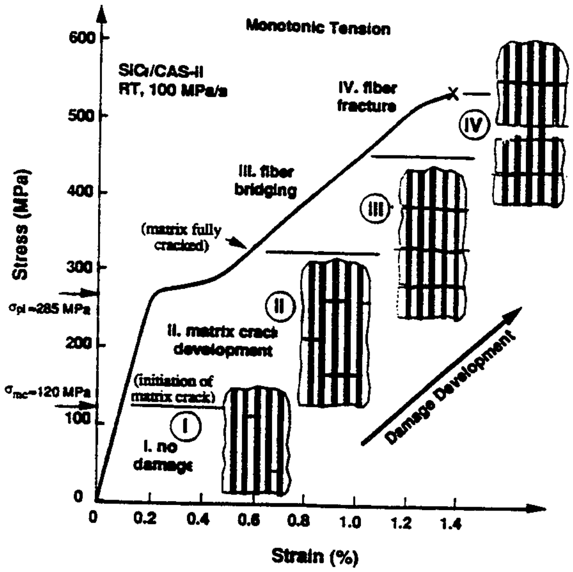
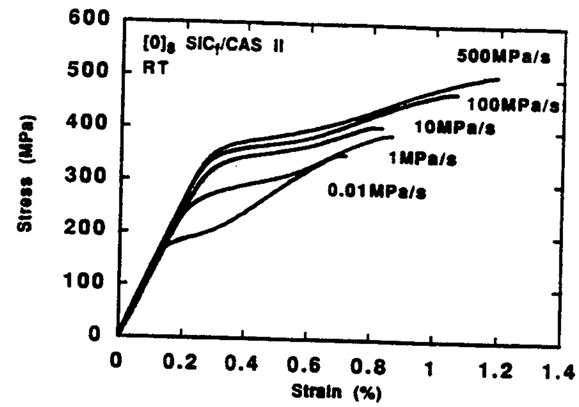
4. M. H. Headinger, R. W. Klacka, S. L. Bors and W. R. Moschelle, "The Effects of Density and Fiber Volume on the Mechanical Properties of SiC Matrix Composites Reinforced with T-300 fibers", NASA - CP 3235, May, 1994, P 567-582.
5. R. W. Klacka, M. H. Headinger, W. R. Moschelle and J. D. Farr, "C/SiC Turbine Rotor Development", NASA - CP 3235, May, 1994, p 855-862.

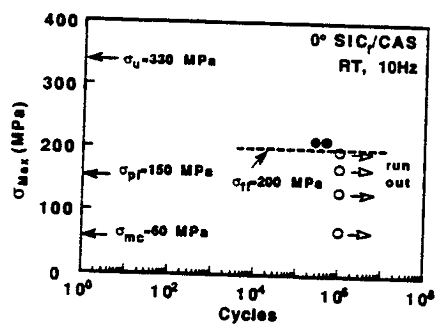
Characteristics of Monotonic and cyclic loading[2] :



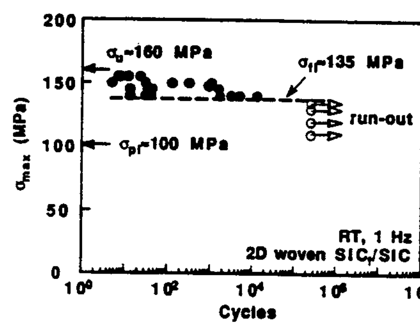
Monotonic stress-strain behavior of unidirectional SiC_f/CAS.



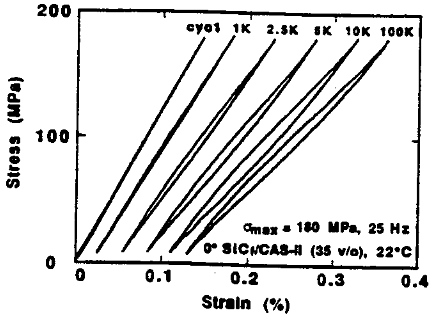
Influence of loading rate on the monotonic stress-strain behavior of SiC_f/CAS-II in air at 20°c.



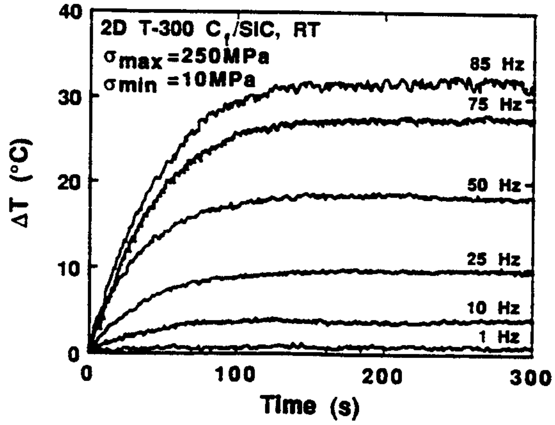
Fatigue life diagram



SN curve at room temperature



Changes in hysteresis behavior during fatigue



Influence of loading frequency on the surface temp rise during tension-tension fatigue