Design, Development, and Applications of Structural Ceramics, Composites, and Nanomaterials

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Ceramic Transactions
Volume 244

The American Ceramic Society
WILEY

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Also available as an e-book

ISBN 978-1-118-77094-8

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A Collection of Papers Presented at the 10th Pacific Rim Conference on Ceramic and Glass Technology
June 2–6, 2013
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Published by John Wiley & Sons, Inc., Hoboken, New Jersey.
Published simultaneously in Canada.

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Library of Congress Cataloging-in-Publication Data is available.

ISBN: 978-1-118-77094-8
ISSN: 1042-1122

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

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Preface

The 17 papers in this volume were presented during the 10th Pacific Rim Conference on Ceramic and Glass Technology, June 2–6, 2013 in Coronado, California in the following five symposia:

- Engineering Ceramics and Ceramic Matrix Composites: Design, Development, and Applications
- Advanced Ceramic Coatings: Processing, Properties, and Applications
- Geopolymers – Low Energy, Environmentally Friendly, Inorganic Polymeric Ceramics
- Multifunctional Metal Oxide Nanostructures and Heteroarchitectures for Energy and Device Applications
- Advanced Characterization and Modeling of Ceramic Interfaces

We would like to thank the members of the symposia organizing committees, for their assistance in developing and organizing this vibrant and cutting-edge meeting. We are grateful to the staff of The American Ceramic Society for their efforts in ensuring an enjoyable conference and the high-quality publication of this proceeding volume.

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ADVANCED CHARACTERIZATION AND MODELING OF CERAMIC INTERFACES

Engineering Ceramics and Ceramic Matrix Composites: Design, Development, and Applications

DESIGN AND TESTING OF A C/C-SIC NOZZLE EXTENSION MANUFACTURED VIA FILAMENT WINDING TECHNIQUE AND LIQUID SILICON INFILTRATION

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ABSTRACT

Nozzle extensions made of ceramic matrix composites (CMC) have the potential to improve the performance of liquid fueled rocket engines. Gas permeability and delamination have been reported to be still critical aspects in the manufacture of CMC nozzle structures. This work shows the development and manufacture of a radiation cooled C/C-SiC nozzle for a full ceramic thrust chamber. The green body was produced via advanced wet filament winding technique using multi-angle fiber architectures which were adapted to reduce the affinity of delamination during succeeding high temperature processing steps. In order to improve the final gas-tightness additional efforts were made to adjust the carbon matrix by re-infiltration for complete conversion to a dense SiC matrix with reduced amount of residual silicon after liquid silicon infiltration process.

Microstructural characterization and flaw detection were performed by computer tomography and scanning electron microscopy analysis. Prototype nozzle extensions were manufactured and preliminary results of the structural characterization before the hot firing tests are presented.

INTRODUCTION

Carbon-fiber-reinforced silicon carbide matrix composites are still considered to be one of the most promising material candidates to replace heavy refractory superalloys in future rocket propulsion applications, e. g. rocket nozzle extensions, due to their excellent thermal and mechanical properties in high temperatures and its much lower material density to increase the payload capacity[1-11].

A variety of different CMC processing routes, like chemical vapor infiltration (CVI)[12-16], liquid polymer infiltration and pyrolysis (PIP)[17, 18] and reactive melt infiltration (RMI)[19-25] or combinations of those have been studied intensively in the last decades. In the field of carbon-fiber-reinforced silicon carbide matrix composites for future rocket nozzle structures the DLR focuses on the development of competitive C/C-SiC materials using the liquid silicon infiltration route (LSI) in combination with effective fiber preform techniques like filament winding which is indispensable for axis-symmetric structures. The possible use of adapting fiber architectures result in novel LSI-based C/C-SiC materials with different final microstructures and mechanical properties which are currently studied.

Processing costs and times are significantly high using CVI or PIP fabrication routes. The latter CMC materials require a complex fiber coating to accomplish damage tolerant fracture behavior and they additionally show high open porosities due to their specific processing. The LSI-based composite materials are featured by short processing times (3 weeks) and cheap raw materials (C-fiber, C-precursor and silicon) which are commercially available. Within advanced LSI-based C/C-SiC materials no fiber coating is needed because carbon filaments are embedded in a dense carbon matrix which is surrounded by silicon carbide, which results in low open porosities which is favorable because dense CMC materials are usually required for most aerospace nozzle applications.

In the last years the DLR worked intensively on developing rocket thrust chambers based on transpiration cooled inner combustion chamber liners made of porous ceramic matrix composites[26-29]. A basic design sketch of DLRs thrust chamber is depicted in Figure 1 showing its general assembly and functionality. This experimental combustion chamber has been successfully tested in several hot gas tests without a full nozzle structure. It is operated with gaseous hydrogen and liquid oxygen at a combustion chamber pressure of about 60 bar.

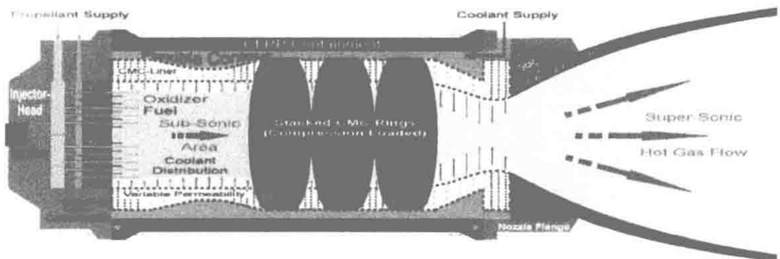

Figure 1. Design principle of DLRs composite thrust chamber assembly[26].

Lately the DLR extended its CMC propulsion development to demonstrate the operation of an experimental full ceramic thrust chamber with a radiation cooled double walled CMC nozzle extension. The development of double walled CMC nozzle extensions corresponds to an active patent procedure[30]. The design, fabrication and preliminary results of the material characterization of dense radiation cooled C/C-SiC nozzle structures are described in this publication.

NOZZLE CONTOUR DESIGN

Based on the operational parameters of the combustion chamber the divergent nozzle wall contour was calculated as a truncated ideal contour (TIC) by DLRs Institute of Space Propulsion in Lampoldshausen, Germany. Truncated ideal contour nozzles show no shock unsteadiness systems like free shock separation (FSS) and restricted shock separations (RSS) as it appears in overexpanded thrust optimized parabolic nozzles (TOP) during start up and shut down sequences which cause intense side loads that could reach 10% of the nominal thrust[31].

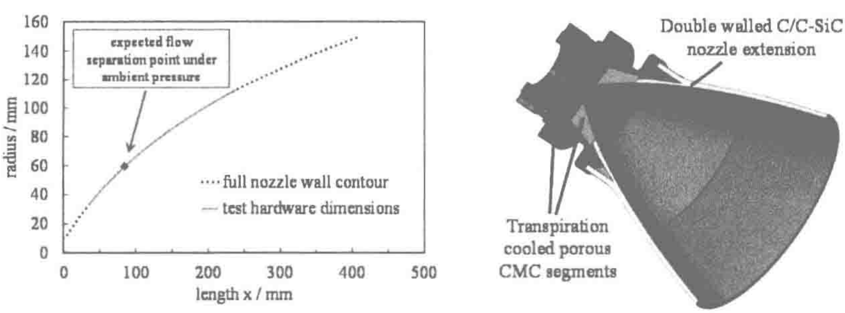

Figure 2. TIC nozzle wall contour (left) and CAD sketch of the nozzle extension structure (right).

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