CARBON - CARBON FOR NOZZLES

G. W. Driggers and H. S. Starrett
Southern Research Institute
Birmingham, Alabama 35205

Application Environment

Missile and space launch systems using solid propellants are setting demanding new requirements on materials to be used in nozzles. Missile systems are projected to use propellants with gas stagnation temperatures exceeding 6000°F and highly reducing constituency. Design chamber pressures of 1000 to 3000 psi are common in advanced systems. At the other extreme, the Space Shuttle Interim Upper Stage and various solid propellant space motors are incorporating relatively benign propellants with long burn times. The current premium on reliability, weight savings and potential performance gains is substantial.

Carbon-Carbon Nozzle Programs

It has been suggested by Ellis (1974) that a carbon or graphite reinforcement in a carbonaceous matrix (carbon-carbon composite) could provide a near optimum nozzle material. The tailorability, potential ablation resistance and probable higher reliability of a one piece c-c nozzle compared to complex multi-piece nozzles made the proposal attractive.

A subsequent program, sponsored by the Naval Surface Weapons Center, (NSWC), was conducted by Chemical Systems Division (CSD) of United Technologies, Inc. to investigate the c-c Integral Throat and Entrance (ITE) concept experimentally. The four c-c ITE's were examined at the micro- and macro-structure level to determine what material and surface characteristics potentially affected ablation performance. Additionally, mechanical and thermal properties were determined to the extent possible considering material quantity limitations. These investigations were conducted at Aerospace Corporation and Southern Research Institute.

Current efforts in carbon-carbon nozzle components and ITEs are in progress under the sponsorship of both NSWC and the Air Force through a series of joint AFML/AFRPL programs. The Carbon Nozzle Opportunities (CNO) program is firing both multipiece and ITE nozzles with a nominal seven inch I.D. throat section. The NSWC program and USAF C/CAN efforts will fire a variety of nominal 1.96 inch throat diameter subscale nozzles. Selected mechanical, thermal and surface removal phenomena characterizations are in progress on the CNO and C/CAN programs with similar efforts planned for the new NSWC program.

Observations to Date

The amount of characterization to date has been limited due to the small number of firings and the availability of materials and funds. Sufficient work has been done, however, to develop a series of observations and hypotheses on relationships between construction parameters and process characteristics (such as nature of porosity, permeability, etc.) and thermo-mechanical or ablation performance. In addition, work in recent years on c-c materials for nose tips and heat shields has yielded data and information on the impact of construction anomalies relative to mechanical and thermal behavior. The strength of a c-c in a given direction, for example, can be tied to the extent and type of damage experienced by the reinforcement during weave and process. Filament breaks and kinks, yarn waviness and malalignment as well as matrix to filament bonding have correlated to modulus, strength and thermal expansion anomalies.

On axis tensile and compressive properties are directly related to the properties of the reinforcement for the three-dimensional orthogonal constructions. Therefore construction anomalies of any extent can affect the on axis properties. For example, initial compressive failure at low temperatures occurs as a result of local buckling of yarn bundles. This buckle precedes shear failure and occurs at nominal stress levels less than one-half those where tensile failure normally occurs. If these are bowed, wavy, or kinked reinforcements, then the stress levels are further reduced. This could become an important consideration in materials with cylindrical weaves where the successful manufacture of parts without wavy circumferential yarn bundles is difficult.

The wavy circumferential yarn bundles in cylindrical weaves can also have a pronounced affect on the hoop tensile strength of these materials. Recent data have shown tensile strength reductions of 75% and greater on cylindrical materials with weave distortions versus material with relatively straight yarns.

Ref. [1]Ellis, R.A., "Nozzle Efficiency Improvement With Advanced Materials", Presented JANNAF Propulsion Meeting San Diego, October, 1974