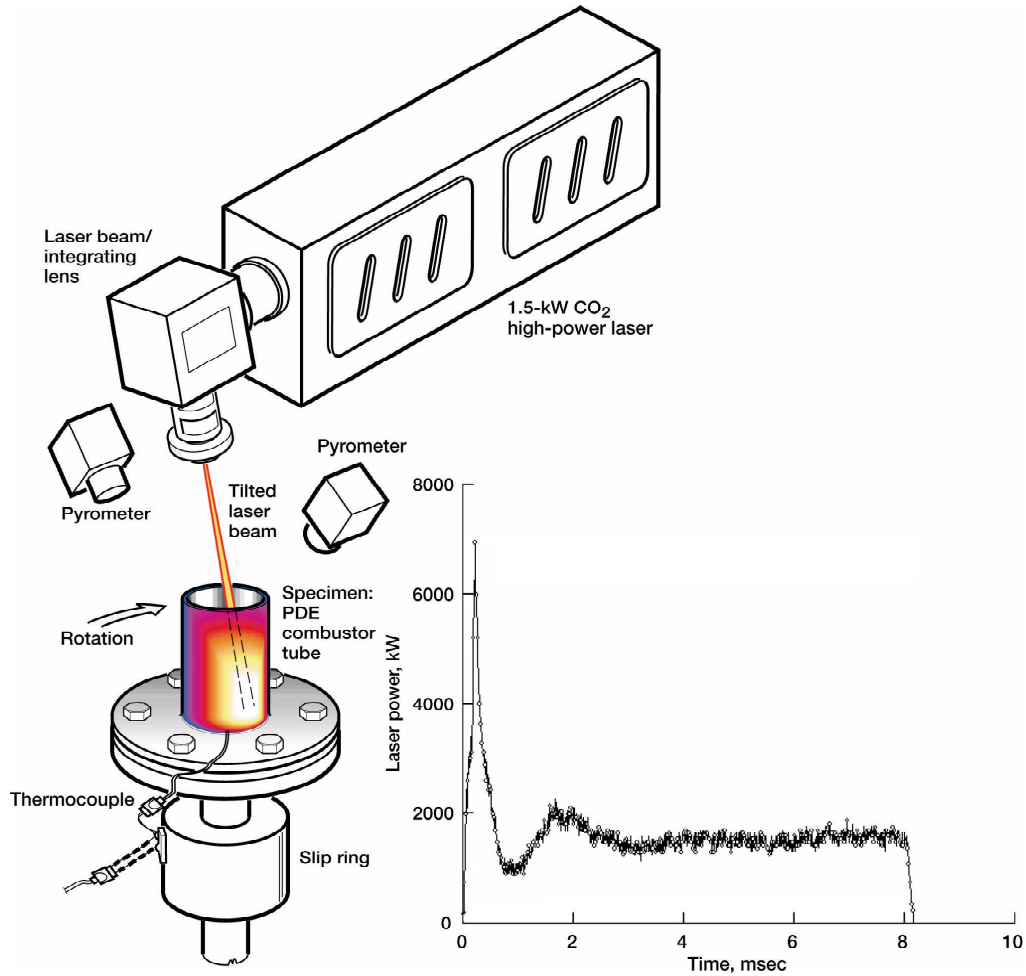


Laser High-Cycle Thermal Fatigue of Pulse Detonation Engine Combustor Materials Tested

Pulse detonation engines (PDE's) have received increasing attention for future aerospace propulsion applications. Because the PDE is designed for a high-frequency, intermittent-detonation combustion process, extremely high gas temperatures and pressures can be realized under the nearly constant-volume combustion environment. The PDE's can potentially achieve higher thermodynamic cycle efficiency and thrust density in comparison to traditional constant-pressure combustion gas turbine engines (ref. 1). However, the development of these engines requires robust design of the engine components that must endure harsh detonation environments. In particular, the detonation combustor chamber, which is designed to sustain and confine the detonation combustion process, will experience high pressure and temperature pulses with very short durations (refs. 2 and 3). Therefore, it is of great importance to evaluate PDE combustor materials and components under simulated engine temperatures and stress conditions in the laboratory.

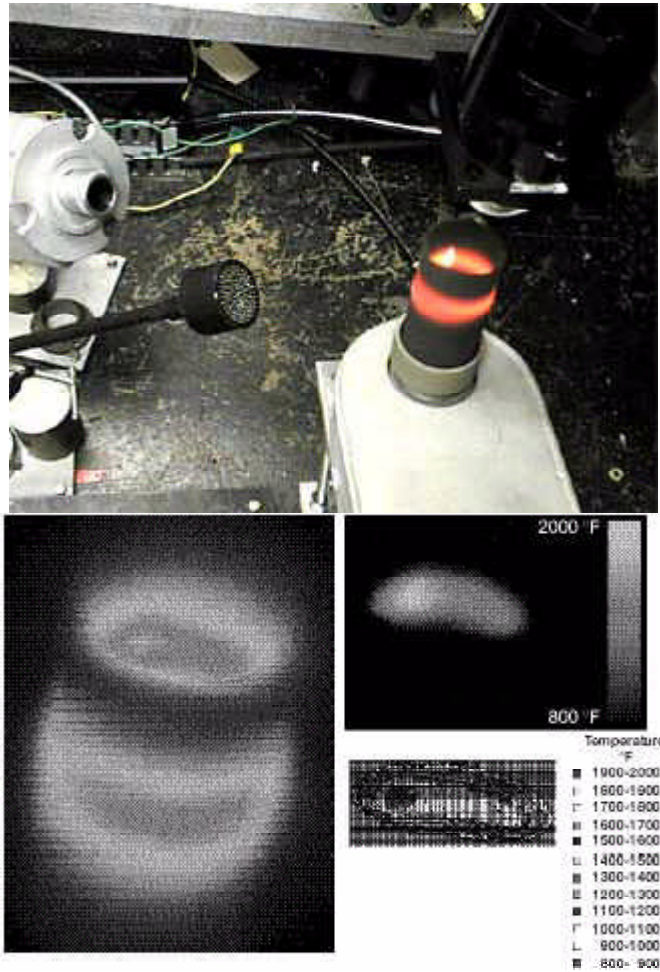
In this study, a high-cycle thermal fatigue test rig was established at the NASA Glenn Research Center using a 1.5-kW CO₂ laser. The high-power laser, operating in the pulsed mode, can be controlled at various pulse energy levels and waveform distributions. The enhanced laser pulses can be used to mimic the time-dependent temperature and pressure waves encountered in a pulsed detonation engine. Under the enhanced laser pulse condition, a maximum 7.5-kW peak power with a duration of approximately 0.1 to 0.2 msec (a spike) can be achieved, followed by a plateau region that has about one-fifth of the maximum power level with several milliseconds duration. The laser thermal fatigue rig has also been developed to adopt flat and rotating tubular specimen configurations for the simulated engine tests. More sophisticated laser optic systems can be used to simulate the spatial distributions of the temperature and shock waves in the engine.

Pulse laser high-cycle thermal fatigue behavior has been investigated on a flat Haynes 188 alloy specimen, under the test condition of 30-Hz cycle frequency (33-msec pulse period and 10-msec pulse width including a 0.2-msec pulse spike; ref. 4). Temperature distributions were calculated with one-dimensional finite difference models. The calculations show that that the 0.2-msec pulse spike can cause an additional 40 °C temperature fluctuation with an interaction depth of 0.08 mm near the specimen surface region. This temperature swing will be superimposed onto the temperature swing of 80 °C that is induced by the 10-msec laser pulse near the 0.53-mm-deep surface interaction region.

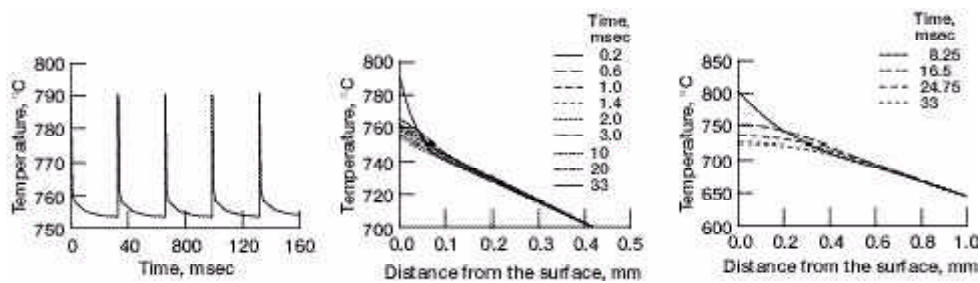


High-power CO₂ laser rig developed for testing PDE combustor materials and components under simulated engine temperature and stress conditions. The insert shown is a measured laser pulse waveform from the pulse signal of a 1.5-kW CO₂ laser using an oscilloscope. The laser pulse width is 8 msec, and a maximum laser power 7.5-kW can be achieved over about 0.2-msec duration at the pulse enhancement mode.

Specimen failure modes were also studied after the laser thermal fatigue testing. Extensive surface cracking with crack depths of approximately 30 mm was observed on the flat and tubular specimens tested under enhanced laser pulses and thermal cycling.

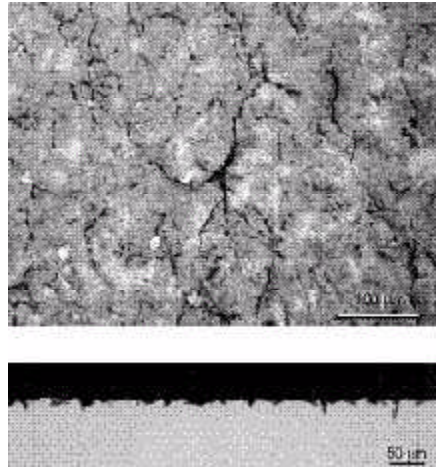


A tubular Inconel 601 superalloy specimen is being tested in the pulsed-laser high-cycle thermal fatigue rig (100-Hz laser pulse frequency; 10-msec pulse period, 5-msec pulse width including a 0.2-msec pulse spike). Enhanced laser pulses and a rotating tubular configuration are used to mimic the time-dependent temperature and pressure waves in a pulsed detonation engine. Top: Laser testing of the rotating tubular specimen. Right: Temperature distributions of the specimen determined from infrared thermography during the laser testing. Maximum surface temperature, 1950 °F; maximum back temperature, 1550 °F.



One-dimensional finite difference modeling results showing the temperature swings on a Haynes 188 specimen under the enhanced pulse condition (33-msec pulse period, 10-msec pulse width including 0.2-msec pulse spike). Left: Temperature pulses induced by

the high-energy laser pulse spike. Center: Temperature swings due to the enhanced, 0.2-msec laser pulse spike. Right: Temperature fluctuations due to the regular 10-msec laser pulse.



Surface cracking patterns of the Haynes 188 superalloy after the enhanced laser pulses and thermal cycling (10.8 million 30-hr high-cycle fatigue cycles, and 200 30-min heating-cooling cycles). Striations on the alloy and crack surfaces may reveal high-cycle fatigue mechanisms under the intense laser pulse cyclic loads. Top: Surface cracking morphologies of the tested specimen. Bottom: Cross section of tested specimen showing surface cracking penetration into the alloy.

The laser-induced severe high-frequency thermal cycles are detrimental to the potential PDE combustor superalloy materials. Preliminary results suggest that surface oxidation, alloy inclusions, grain boundaries, and surface roughness have accelerated crack initiation and propagation under intense laser-pulse cyclic loads.

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Programs/Projects: Propulsion Systems Base R&T, Pulse Detonation Technology