Catalytic Ignition of Cold O_2/H_2 Mixtures for Space Propulsion Applications

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Introduction

Catalytic ignition of cold H_2/O_2 mixtures could be used for launcher upper stage engines: (i) small thrust engine (class 10 -100 N) using the gas contained in O_2 and H_2 tank's ullage settle the liquid in the tanks during ballistic coast phases; (ii) larger LO_2/LH_2 cryogenic engine with restart possibility. In both cases, catalytic ignition allows combustion initiation at low temperatures, in the range 180-300 K, without the need of a spark delivered by high voltage electrical discharges. A dedicated test bench has then been designed and developed by Air Liquide (Fig. 1) and test campaigns have been performed to study catalytic ignition of cold H_2/O_2 mixtures. Approximately 600 ignition tests have been performed on more than 20 catalyst samples. For all samples, the active phase is deposited onto a honeycomb-type ceramic monolith after specific wash-coating procedures (Fig. 2). Several preparation parameters have been examined: nature of the base monolith ceramic, channel density, wash-coating method, nature of metal deposited onto the monolith, catalyst metal mass fraction.

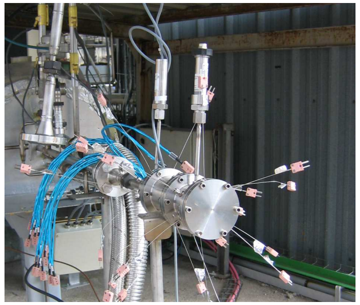

Figure 1. Catalytic ignition reactor installed in Air Liquide test area.

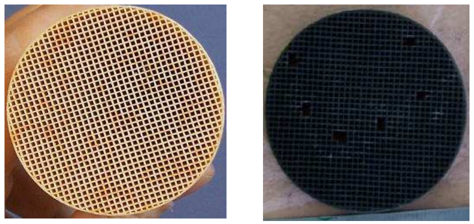

Figure 2. Cross-section of a 400 cpsi cordierite monolith before washcoat and after tests. Holes correspond to thermocouple positions inside the catalyst (length 10 cm, diameter 5 cm).

Materials and Methods

Monolithic supports (mullite or cordierite, 100 or 400 cpsi) have been specially manufactured by CTI Company (Céramiques Techniques et Industrielles, Salindres, France) [1]. Two washcoating procedures have been used (wash-coat mass percentage: 6 to 13 wt.-%) and four active phases deposited (Pt, Ir, Pd and Rh) [2]. The surface area of the washcoated support is between 10 an 22 m^2 (g-monolith)$^{-1}$, depending on the coating procedure. The loading level of the metal is between 15 and 40 wt.-% of the washcoat mass [3]. Dedicated apparatus have been developed for the impregnation and drying steps, in order to obtain a homogeneous distribution of wash-coat or impregnation layers.

Pre-tests and post-tests chemical analyses and characterizations have also been performed to verify the characteristics of catalysts using different methods: X-Ray Diffraction, Transmission Electron Microscopy, specific surface area determination, elemental analyses of active phase.

Results and Discussion

The cold catalytic ignition tests led to the selection of the most efficient noble metal catalysts (Ir) and to the characterization of the reactant mixture temperature limit as regards to ignition, according to several parameters, including the mixture mass flow rate, the O_2/H_2 mixture ratio, the catalyst bed length and the catalyst metal mass fraction. Most test conditions were representative of a small propellant settlement engine application (low O_2/H_2 mixture ratio, below 1), but some tests were also conducted at oxidizing mixture ratios, i.e. in conditions more representative of a combustion chamber igniter application.

For two of the most efficient catalysts in low flow conditions and hydrogen rich mixtures, more than 100 ignitions and 6 h of combustion have been accumulated without significant degradation of the cold mixture temperature limit as regards to ignition. Starting from this first set of results, deeper investigations are currently being held which aims at better characterizing kinetic parameters at low O_2/H_2 mixtures temperatures, and at optimizing catalyst preparation method. These activities mainly concern test conditions at low H_2/O_2 mixture ratios, and could be useful for the potential future development of a small thrust upper stage engine for propellants settlement during ballistic coast phases.
In parallel, new activities will be launched soon to try to define best suited catalysts in oxidizing conditions for a combustion chamber igniter application. Previous tests showed that the most efficient catalysts in hydrogen rich conditions (Ir-based) are not the best suited for oxidizing conditions (Pd-based).

Significance

This study represents the first application of monolithic-based noble metal catalysts for low temperature ignition reactions. The possible extension to H_2-CH_4 mixtures would be of great interest.

References

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