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Novel infrared methodologies for material emissivity and temperature determination for space atmospheric re-entry

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Abstract

The Thermal Protection Systems (TPSs) of space vehicles, in the atmospheric re-entry phase, have to withstand high thermal fluxes and high temperature and their emissivity is one of the main parameters to be characterized. Thermography combined to other devices, such as pyrometers and thermocouples, allows to characterize the emissivity of the material when it is heated in a high temperature furnace. Furthermore the use of the thermography performed during a hypersonic Plasma Wind Tunnel test allows to obtain information about temperature and emissivity of the material in an environment similar to the one characterizing the atmospheric re-entry phase. Since the emissivity for innovative materials can be an unknown parameter, in order to obtain temperature maps free from emissivity, a new technique based on the dual color principle applied to the thermographic devices has been analysed [1].

1. Introduction

The materials employed as TPS of space vehicles must satisfy different mechanical and thermophysical characteristics. The TPS must ensure that the wall temperature is not excessively high, even during re-entry into the atmosphere, when high aerothermal loads occur.

One of the crucial parameters related to the ability of materials to heat up is emissivity. In particular those employed in the TPS should be classified as high emissivity class materials in order to guarantee, for the same heat fluxes, surface temperatures as lower as possible. For this reason in the choice and design of the materials to be used as TPS, the use of optical techniques able to determine the spectral and global emissivity of the material is crucial. Therefore, the spectral variation of the emissivity is an important information both for the materials characterization and for radiometric applications.

Several authors addressed the experimental characterization of surface emissivity [2-6]. Different set-up configurations have been developed to characterize the spectral emissivity in several spectral bands and large temperature ranges. This work focuses about three main aspects connected to the experimental characterization of the materials employed for TPS:

- the spectral emissivity characterization of the Ceramic Matrix Composites (CMC) ISiComp®, an innovative CMC with long C fibres and SiC matrix, developed by the Italian Aerospace Research Centre (CIRA) and PETROCERAMICS. This characterization allowed to determine the spectral and global emissivity of the ISiComp® material through laboratory tests performed in medium high temperature range.
- the use of the thermography for the monitoring of the material constituting the TPS during the hypersonic tests performed in Plasma Wind Tunnel (PWT), for the detecting of the two dimensions temperature map and of the emissivity in an environment similar to the one determined in the re-entry phase.
- the development of a technique able to obtain two dimensional free emissivity maps applied to the thermographic devices useful in the analysis of the thermal stresses of the samples due to the interaction with hypersonic plasma. The emissivity is not a foregone parameter to be known for innovative materials tested in PWT and this parameter, in thermographic measurements, affects dramatically the value of the temperature measured during the experimental test. The application of the dual color technique to the thermography has been analysed [7-11].

2. Techniques for the emissivity and temperature characterization of a typical material used in the atmospheric re-entry phase of a space mission

2.1. Experimental characterization of the ISiComp® emissivity in medium high temperature range

A novel set up for the detection of the spectral emissivty of the ISiComp® material has been used. The ISiComp® is a new CMC with long C fibres and SiC matrix, developed by the Italian Aerospace Research Centre (CIRA) and PETROCERAMICS. The ISiComp® is presently used for the design and manufacturing of the Thermal Protection System of the ESA funded Space Rider Re-entry Module. The set up used in this work consists of an ISiComp® sample with a circular shape characterized by a diameter of 12.7 mm and a width of 4 mm inserted in a black body cavity set at three different temperature (450 °C, 650°C and 850 °C). In Fig. 1 an image of the optical devices used to obtain the spectral emissivity of the analysed material has been showed. The optical devices used are: a pyrometer working in dual color and single color modes, a camera working in LW (Long Wavelength) spectral range and a camera working in the MW (Medium Wavelength) spectral range. A thermocouple was placed at the center of the sample and an analysis to get the best reference, as real temperature, has been performed. The analysis of the tests allowed to obtain the emissivity from NIR (Near InfraRed) spectral range up to LW spectral range and the global emissivity.

2.2. Experimental tests of the ISiComp® material in Plasma Wind Tunnel facility

Laboratory tests are essential to determine the class in terms of emissivity of the material. The emissivity obviously depends on the wavelength and the temperature, but the analysis in the medium-high temperature range allows to verify if the material with high emissivity at room temperature maintains its characteristics when it is heated. Once the good characteristics of the material in terms of emissivity have been ascertained in laboratory tests, it is necessary to carry out the experimental tests in an environment closest to the re-entry phase. For this reason, experimental tests have been performed in the PWT at hypersonic conditions. During these tests the sample can be monitored through the thermography. This diagnostic technique allows to simultaneously monitor the sample and obtain two dimensions temperature maps and information about the emissivity of the target on a specific spot by crossing thermographic data with the ones coming from a dual color pyrometer. In Fig. 2 the ISiComp® sample subjected to the hypersonic jet framed by IR camera has been showed.

2.3. Analysis and experimental test of the dual color thermography

The emissivity is not always a parameter known for innovative material such as the ones employed in TPS and it can change with temperature and also with the chemical reactions of the plasma with the surface of the analysed target that can change its mechanical and chemical features. A wrong emissivity setting can lead to wrong temperature measurements. For this reason, the development of a technique able to determine two dimensions temperature maps free from emissivity can be extremely useful. In this work the dual color technique applied to the thermography has been analysed. The best combination of the two working wavelengths to be applied in the ratio principle compatible with the thermal camera working spectral range have been determined [7-11]. Preliminary results have been showed. In particular in Fig. 3 a two dimensions map of the temperature free of emissivity of an ISiComp® sample heated in a black body cavity has been showed.

3. Figures

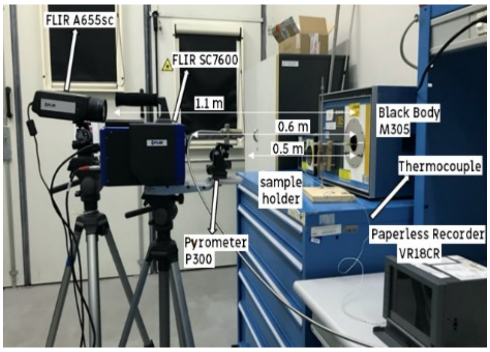

Fig. 4. *Experimental set up for ISiComp® emissivity in medium high temperature range*

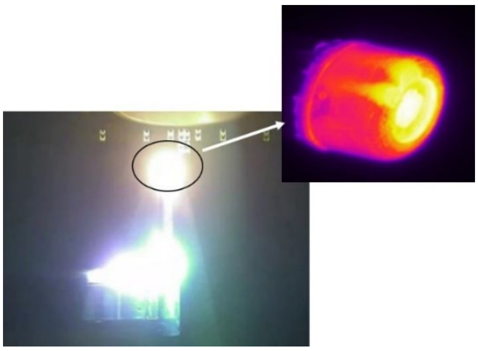

Fig. 5. *Experimental test performed in PWT*

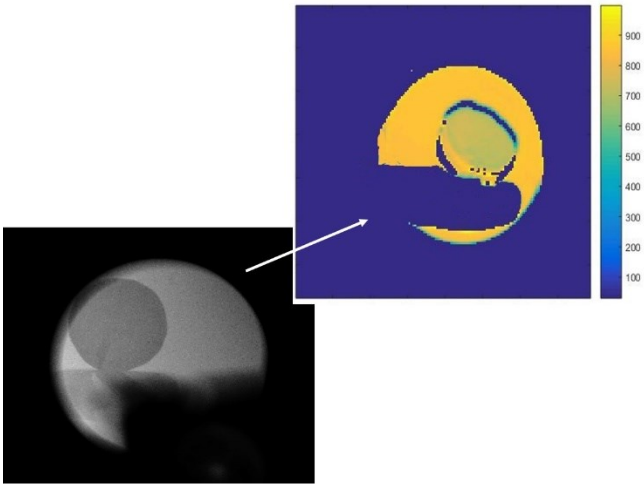

Fig. 6. *Two color map of an ISiComp® sample in a black body cavity (temperature in Celsius degrees)*

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