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Laboratory, On-ground and In-flight Investigation of Ultra High Temperature Ceramic Composite Materials

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ABSTRACT

The capsule SHARK (Sounding Hypersonic Atmospheric Re-entering ”Kapsule”) was designed and realized for testing in real flight conditions a ZrB_2-based Ultra High Temperature Ceramic (UHTC) Nose Tip. The capsule was instrumented with accelerometers, rate and pressure sensors, and thermocouples of which three were inserted inside the UHTC Nose Tip.
The capsule was launched by the European Space Agency (ESA) rocket MAXUS-8 performing an atmospheric re-entry after a parabolic trajectory with an apogee at 700 km of altitude.
The temperature profile recorded by the thermocouples inserted inside the Nose Tip reported a discontinuity at about 762 s after the release from the rocket, revealing the failure of the ceramic component during the flight. The capsule was recovered and the Nose Tip was found damaged: the fore half was missing while the inner part, fractured in three pieces, was recovered.
The fractographic analysis of the three recovered fragments was carried out by optical microscopy techniques which allowed identifying the main fracture marks, such as fracture mirror, hackle lines, arrest lines, and Wallner lines.
The fracture dynamic has been outwardly reconstructed and the stress at fracture was evaluated by means of the Orr’s equation involving the measurement of the fracture mirror radius. Then applying the Griffith’s relationship, the flaw size was estimated. The origin of the main fracture was identified on the edge of the hole manufactured by Electrical Discharge Machining (EDM) to lodge thermocouples inside the nose tip, causing the strength-limiting flaw.
Thermal shock was recognized as the probable failure cause as already observed by on-ground tests performed in the Plasma Wind Tunnel (PWT) “Scirocco” by the Italian Aerospace Research Centre (CIRA) on a similar UHTC Nose Tips manufactured with the same machining technology.

Keywords: ceramic matrix composites; optical fractography; aerospace vehicles.