Study of Thermo-mechanical properties of NiCoCrAlY bond coats using Micro-tensile samples and 2D-DIC

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Abstract. Bond coats are used in high-temperature sections of gas turbine engines to provide oxidation protection to the substrate. The study of the thermo-mechanical properties of these coatings requires the ability to carry out mechanical tests on samples of less than 1mm in thickness. The present work shows measurement of these properties by performing uniaxial tension tests on very small size samples (total length ~10 mm, width ~5mm, thickness ~1mm) at temperatures up to 750°C, using Digital image correlation (DIC).

Introduction

Bond coats, which are used protect the substrate from oxidation and corrosion in high-temperature sections of gas turbine engines, are either a) diffusion based or b) overlay coatings. The overlay coatings are often termed as MCrAlY coatings (where M is Ni, Co, or Ni-Co), as they are primarily composed of these elements. MCrAlY coatings are generally 0.1-0.2mm thick but thickness up to 0.7mm can also be applied. The coating for the present study is made from commercially available 'Amdry 386-2' (composition by wt.%, Ni-47.1%, Co-22.1%, Cr-16.8%, Al-12.6%, Y-0.59%) using High-Velocity Oxy Fuel spray (HVOF) [1].

Investigations into the thermo-mechanical properties of coatings have generally been carried out using experimental techniques like, bending and indentation. Few researchers have tried developing miniaturized tensile testing [2,3]. However, a comprehensive method for tensile testing of free-standing bond-coats is still lacking. This study attempts to bridge this gap by leveraging advanced imaging technique to capture strains in small sample using Digital Image Correlation (DIC).

Experimental Set-up

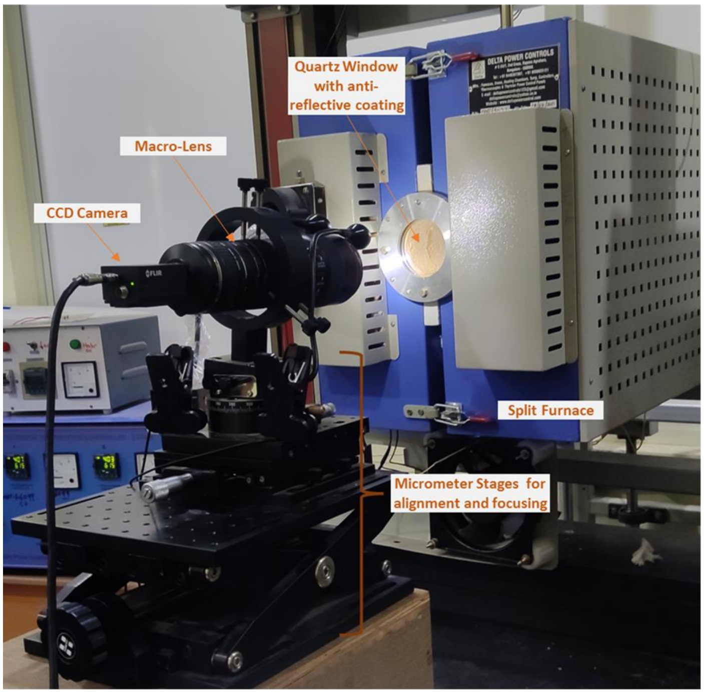
The experimental set-up consists of

1) Zwick AllroundLine Table-top UTM
2) Split Furnace with max temperature of 1100 °C, temperature stability +/- 1°C, equipped with Quartz window for viewing
3) Monochrome CCD camera (FLIR Grasshopper 3) integrated with 1:1 Macro-lens

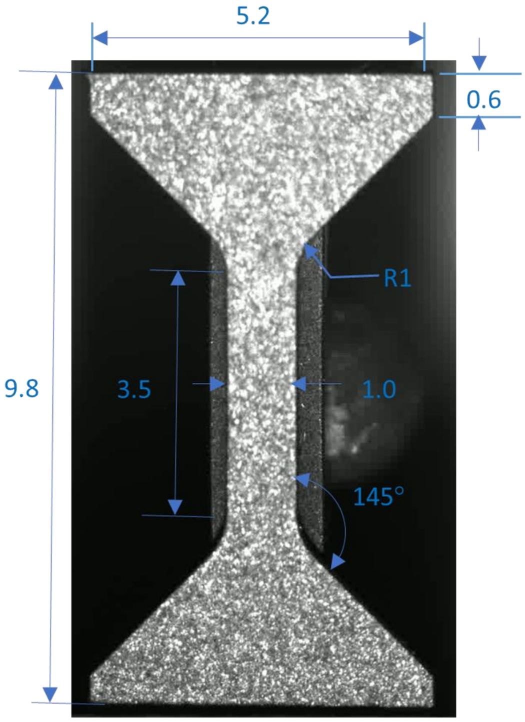
The experimental set-up is shown in Figure 1a below. Focus and alignment play a crucial role in strain measurement. A combination of linear micrometre stages, rotation stage, and goniometer is used to achieve well aligned image of the sample. For low noise and high contrast, a CCD monochrome camera is used. Canon EOS 180mm 1:1 Macro enables us to capture small region from a distance. In addition, lens elements like extension-tubes and focal length extender have been used to achieve the required magnification.

The standalone bond coat is obtained by removing the coating from the substrate using wire-EDM. The coating thus obtained was annealed to 800°C for 2 hours. The tensile sample used in the study is based on the design reported by M. Zupan, et. al [4]. However, the profile needed modification as the sample was found to fail in the grip region. Poor surface contact with the grip resulted in stress concentration at the triangular corners in the grip region. The geometry was therefore modified to avoid sharp corners. With the modified sample geometry, as shown in Figure 1b, failure moved to the gauge section. This geometry is wire cut from the annealed coating. The thickness of the samples ranges from 0.7 to 0.9mm. The speckle pattern on samples was created using 0.3mm airbrush. Peeling of paint at high temperature is a common problem. This was addressed by using a primer first and using a three-step baking process for the paint (Rustoleum high-heat paints). The paint was found to sustain reasonably well for more than 24hrs at 700°C, which enabled creep testing.

This test methodology was verified using commercially pure copper. The properties measured on copper were a) Young's Modulus 137.8 GPa, b) Poisson's ratio 0.334, c) CTE 1.78 x 10^{-5} /°C (between 100 to 200 °C). These properties are found to match within 5% range of the properties quoted in literature [5].



a) High Temperature DIC Set-up



b) Sample Dimension (in mm)

Fig. 1 High temperature DIC set-up and Micro-tensile sample geometry

Results

These coatings are brittle at room temperature, but show a brittle to ductile transition around 600 °C. The elastic properties measured at room temperature shows a modulus of ~130 GPa, and Poisson's ratio of 0.26. The fracture stress was found to be ~600 MPa, with elongation of 0.5%. At 700 °C the elongation increased to 3.5%, but the fracture stress dropped to ~500 MPa. The CTE was found to be constant around 1.5 x 10^{-5} /°C. The creep stress exponent was found to 4.8, and the activation energy 243kJ.

References

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