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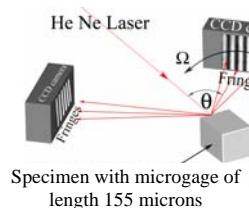
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Background / Objectives

- Microsystems consisting of structures, sensors and actuators on the microscale have leveraged favorable miniaturization scaling laws improving performance and increasing functionality.
- Reliable measurements of micromaterial mechanical properties is required as design complexity and optimization progresses.
- The *Interferometric Strain / Displacement Gage* (ISDG) has established itself as a robust direct strain measurement technique for microscale tension or compression tests.
- As size scale is reduced, previously negligible errors in measurements can become significant requiring improved instrumentation, accuracy and precision.
- Recent advances in digital image processing and data analysis have enabled improvements to the ISDG.
- This work presents recent advances at UMBC to the ISDG technique to meet the demands of microscale mechanical material property testing.
- Coefficient of thermal expansion (CTE) of various materials with microscale gage lengths were measured to demonstrate the system's capabilities.

The Principle of ISDG



- The beam from a Helium-Neon laser (632.8 nm) source is used to illuminate two reflective markers on the sample surface.
- Resultant interference fringes are captured on a pair of Charged Couple Device (CCD) cameras 800 X 600 pixels with individual pixel dimension of 4.65 μm square.
- Fringe motion is captured and the corresponding fringe phase shift is proportional to the strain in the specimen through the following equation [1]:

$$\epsilon = \frac{(\Delta\phi)}{2\pi} \frac{\lambda}{d_0 \sin \theta}$$

Variables in the equation are defined as:
 θ - the angle between laser source and the resultant fringe pattern
 λ - the wavelength of the incident laser
 d_0 - the initial gage markers spacing
 $\Delta\phi$ - the phase shift

Uncertainty Analysis

Fringe Pattern Processing

- Historically, fringes have been captured on a linear diode array (1 x 512 pixels), sampling only a small portion of the available optical fringe pattern.
- In this work, a window of 120 x 512 pixels is used to capture a two dimensional map of the fringe pattern allowing for optical averaging.
- The total uncertainty in the strain measurement is determined using a standard root sum squared uncertainty analysis and can be represented by [2]:

$$U_\epsilon = \sqrt{\sum_{b=1}^n \left(\frac{\partial f}{\partial X_b} U_b\right)^2}$$

$$\text{where } U_b = \sqrt{B^2 + (tP)^2} \text{ and } P = S_z = \frac{S}{\sqrt{N}}$$

U_b is the measure of individual uncertainty of each term in the strain equation, B is the bias limit of the instrument being used, t is a function of the system's degrees of freedom and P is the precision error index.

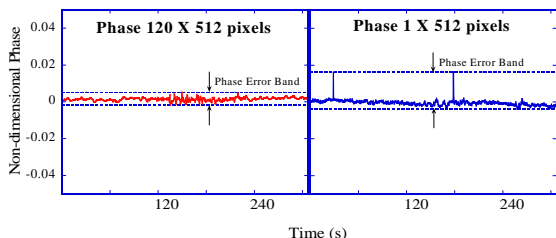
- Thus total uncertainty in strain and CTE measurements are as follows:

$$U_\epsilon = \sqrt{\left(\frac{\partial \epsilon}{\partial \phi} U_\phi\right)^2 + \left(\frac{\partial \epsilon}{\partial \lambda} U_\lambda\right)^2 + \left(\frac{\partial \epsilon}{\partial d_0} U_{d_0}\right)^2 + \left(\frac{\partial \epsilon}{\partial \theta} U_\theta\right)^2}$$

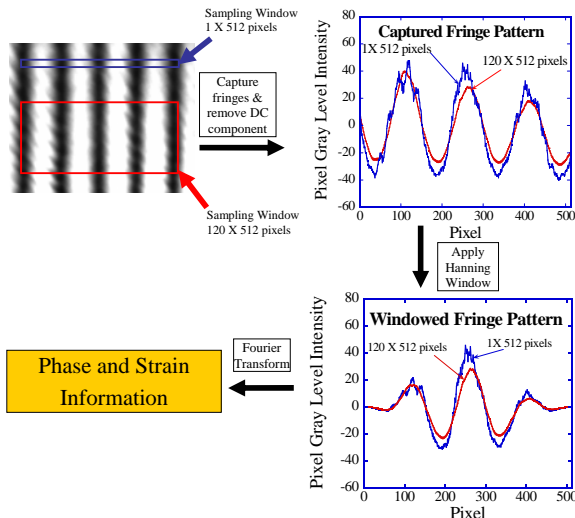
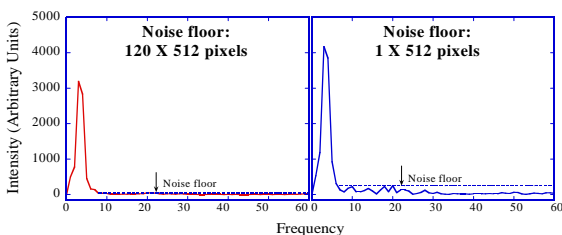
$$U_\alpha = \sqrt{\left(\frac{\partial \alpha}{\partial \epsilon} U_\epsilon\right)^2 + \left(\frac{\partial \alpha}{\partial T} U_{\Delta T}\right)^2}$$

U_ϕ is constituted of three components:

- **Physical uncertainty of the system:** Minimum number of pixels required to define a fringe normalized by measured number of pixels per fringe.
- **Noise floor:** Ratio of the Fourier transform power spectrum background noise to peak frequency magnitude.



- **System noise:** Mechanical, thermal and electrical vibrations causing drift in phase measurement.



- The components of uncertainty were determined to be

$$\begin{aligned} U_{d_0} &= \pm 6.17118 \times 10^{-6} \text{ m} \\ U_\theta &= \pm 0.420286^\circ \\ U_\lambda &= \pm 0.28 \times 10^{-9} \text{ m} \\ U_\epsilon &= \pm 8.38 \mu\text{strain} \\ U_{\Delta T} &= \pm 0.091^\circ \text{ C} \end{aligned}$$

The individual uncertainty in phase shift for 1 x 512 pixels array was determined to be $U_\phi = 5.94 \text{ rad}$.

In contrast, the individual uncertainty in phase shift for 120 x 512 pixels array was found to be $U_\phi = 1.56 \text{ rad}$.

Comparison of overall strain measurement uncertainty

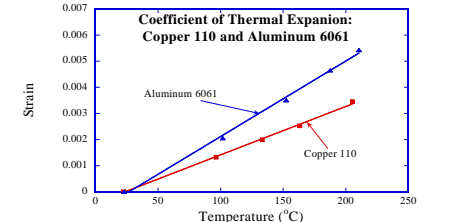
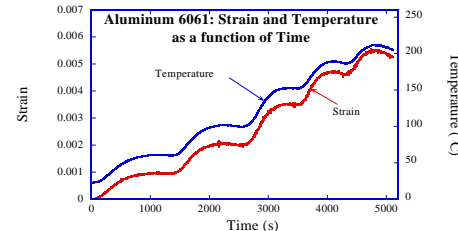
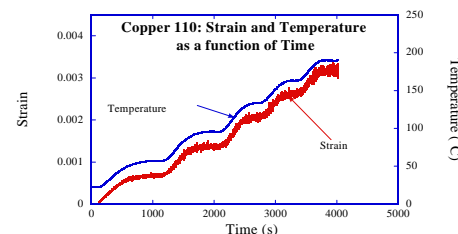
$$\begin{aligned} U_{1X512} &= \pm 30.29 \mu\text{ strain} \\ U_{120X512} &= \pm 8.38 \mu\text{ strain} \end{aligned}$$

The overall uncertainty in the measurement of Coefficient of Thermal Expansion

$$U_\alpha = \pm 0.047 \times 10^{-6} / ^\circ \text{ C}$$

Results

- CTE of Copper 110 alloy and Aluminum 6061 alloy were measured using microscale gage length of 155 microns.



Measured CTE of Copper 110: 18.14 μm/m/°C
 Measured CTE of Aluminum 6061: 27.02 mm/m/°C

Conclusions

- Two dimensional analysis of the fringe field using CCD cameras decreases the uncertainty in the strain measurement by approximately one third.
- The Coefficient of Thermal Expansion measurements for Copper 110 alloy and Aluminum 6061-T61 alloy obtained from the microscale experiments on the ISDG are in close agreement with bulk measurements.
- It is expected that the new fringe analysis technique will improve ISDG plastic strain and high temperature measurement results. The experiments on thermal expansion of materials in the microscale confirmed the theory.