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High Throughput Coefficient Thermal Expansion Testing Utilizing Digital Image Correlation

Dr. Fitzgerald, a postdoc at Sandia National Laboratories, works in a materials of mechanics group characterizing material properties of ductile materials. Her presentation focuses specifically on increasing throughput of coefficient of thermal expansion (CTE) measurements with the use of optical strain measurements, called digital image correlation (DIC). Currently, the coefficient of thermal expansion is found through a time intensive process called dilatometry. There are multiple types of dilatometers. One type, a double push rod mechanical dilatometer, uses and LVDT to measure the expansion of a specimen in one direction. It uses a reference material with known properties to determine the CTE of the specimen in question. Testing about 500 samples using the double push rod mechanical dilatometer would take about 2 years if testing Monday through Friday, because the reference material needs to be at a constant temperature and heating must done slowly to ensure no thermal gradients across the rod. A second type, scissors type dilatometer, pinches a sample using a "scissor-like" appendage that also uses a LVDT to measure thermal expansion as the sample is heated. Finally, laser dilatometry, was created to provide a non-contact means to measure thermal expansion. This process greatly reduces the time required to setup a measurement but is still only able to measure one sample at a time. The time required to test 500 samples gets reduced to 3.5 weeks. Additionally, to measure expansion in different directions, multiple lasers must be used. Dr. Fitzgerald solved this conundrum by using an optical measurement technique called digital image correlation to create strain maps in multiple orientations as well as measuring multiple samples at once. Using this technique, Dr. Fitzgerald can test 500 samples, conservatively, in 2 days.

Fitzgerald then discusses the setup of her experiment. Dr. Fitzgerald used additively manufactured (AM) Kovar samples whose CTE was desired. The inherent course surface roughness of AM provides a "speckled" pattern that provides sufficient contrast for the DIC software to track and correlate. Dr. Fitzgerald then placed a grid of 10 x 5 samples on a steel plate on a hot plate. The steel plate was used to distribute heat more evenly from the hot plate. Initial tests using thermal imagery showed that there are "hot spots" across the hot plate. Using a thermal camera and an additional camera, Dr. Fitzgerald measured thermal maps and the dependent strain values. However, during initial tests Dr. Fitzgerald noticed that as the temperature increases the noise in strain values also significantly increased. After studying thermal imagery, Dr. Fitzgerald noticed that there were thermal gradients radiating from the surface of the hot plate. These thermal currents created significant noise in the DIC. To prevent this, Dr. Fitzgerald installed an air knife to provide a constant stream of air above the samples eliminating these thermal currents. This change to the experiment significantly reduced the noise in strain data, however, more precision was desired. Next, Dr. Fitzgerald noticed that the stand holding the thermal camera and DIC camera was shaking due to the on-board fan of the thermal camera. Dr. Fitzgerald then isolated the DIC camera from the thermal camera and noticed a further reduction in noise. She also added an isolation table to further reduce surrounding vibrations. These final changes significantly reduced the noise, roughly 15%. Dr. Fitzgerald was now able to determine to determine the coefficient of thermal expansion in AM Kovar. The 50 samples chosen were printed using a variety of printing parameters. The study Dr. Fitzgerald aimed to determine was whether one could affect the CTE by modifying printing parameters, such as printing power, printing speed, build height etc. By using her setup, Dr. Fitzgerald was able to determine that one was able to increase or decrease CTE just by changing printing parameters. Instead of measuring the CTE of one sample in 10 minutes, Dr. Fitzgerald is able to measure 50 samples in the same time. With the help of a colleague, Dr. Fitzgerald created a high throughput

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analysis technique as well that correlates strain imagery with thermal imagery and can calculate CTE for multiple samples.

During the question-and-answer portion of the presentation, someone asked whether 15% accuracy was sufficient for this measurement technique. Dr. Fitzgerald explained that perhaps speckling the samples prior to testing would provide a finer speckle pattern and provide more contrast to increase accuracy of DIC. I asked why Dr. Fitzgerald choose to use mono-DIC for this experiment rather than stereo-DIC. Dr. Fitzgerald stated that for ease of setup and initial prototyping, only one camera was used but the experiment could be easily adapted to stereo-DIC. Using stereo DIC, she explained, would also enable the ability to measure out of plane displacement caused by thermal expansion. Future work aims to increase the throughput by measuring more samples and additionally varying print parameters to determine what specific parameters affect CTE. Dr. Fitzgerald will present her findings at the International Digital Image Correlation conference in Boston, MA.