AFRL-AFOSR-VA-TR-2018-0345

Combined Mechanical and Optical Experimental Setup (CMOES) to enable configurable characterization of a wide variety of materials

Cassandra Degen
SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY RAPID CITY
501 E SAINT JOSEPH ST
RAPID CITY, SD 57701

09/20/2018
Final Report

DISTRIBUTION A: Distribution approved for public release.

Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/RTB2
Arlington, Virginia 22203
Air Force Materiel Command

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
31-05-2018	FINAL TECHNICAL	Sept 2016 - Feb 2018

4. TITLE AND SUBTITLE
Combined Mechanical and Optical Experimental Setup (CMOES) to Enable Configurable Characterization of a Wide Variety of Materials

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-16-1-0303

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Degen, Cassandra, M
Ellingsen, Marius, D
Robinson, Marc, J
Katzenstein, Kurt, W
Crawford, Grant, A

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
South Dakota School of Mines and Technology
501 East Saint Joseph Street
Rapid City, SD
57701-3901

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Office of Scientific Research
875 North Randolph Street, RM 3112
Arlington, VA
22203-1954

10. SPONSOR/MONITOR'S ACRONYM(S)
AFOSR/RTB2

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution A - Approved for Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report summarizes the acquisition, development, and capabilities of the equipment and instrumentation corresponding to the Combined Mechanical and Optical Experimental Setup (CMOES) acquired through the Air Force Office of Scientific Research DURIP Grant FA9550-16-1-0303. The CMOES is housed within Dr. Cassandra Degen's JMP Laboratory (http://jmp.sdsmt.edu/default.html) on the SD Mines campus in Rapid City, SD. The CMOES is a collection of various equipment working in concert with one another for the purpose of collecting real-time mechanical and optical information pertaining to the characterization and evaluation of various materials.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Degen, Cassandra M
					19b. TELEPHONE NUMBER *(Include area code)*
Unclassified	Unclassified	Unclassified	UU	14	605-394-2496

Combined Mechanical and Optical Experimental Setup (CMOES) to Enable Configurable Characterization of a Wide Variety of Materials

South Dakota School of Mines and Technology

Dr. Cassandra Degen[1], Dr. Marius Ellingsen[2], Dr. Marc Robinson[3], Dr. Kurt Katzenstein[4], Dr. Grant Crawford[5]

[1] Mechanical Engineering, [2] VRC Metal Systems, [3] Civil and Environmental Engineering, [4] Geology and Geological Engineering, [5] Materials and Metallurgical Engineering

Air Force Office of Scientific Research
DURIP Grant FA9550-16-1-0303

Final Technical Report
May 31, 2018

Submitted by:

Cassandra M. Degen
Assistant Professor, Mechanical Engineering
South Dakota School of Mines and Technology
501 E. St. Joseph Street
Rapid City, SD 57701
Phone: (605) 394-2496
Fax: (605) 394-2405
Email: Cassandra.Degen@sdsmt.edu

Period Covered by the Report: September 1, 2016 – February 28, 2018

PROJECT SUMMARY

This report summarizes the acquisition, development, and capabilities of the equipment and instrumentation corresponding to the Combined Mechanical and Optical Experimental Setup (CMOES) acquired through the Air Force Office of Scientific Research DURIP Grant FA9550-16-1-0303. The CMOES is housed within Dr. Cassandra Degen's JMP Laboratory (http://jmp.sdsmt.edu/default.html) on the SD Mines campus in Rapid City, SD. The CMOES is a collection of various equipment working in concert with one another for the purpose of collecting real-time mechanical and optical information pertaining to the characterization and evaluation of various materials. An overhead view of the CMOES is shown in Figure 1 below. The setup contains six subsystems which are listed in Table I and discussed below in greater detail.

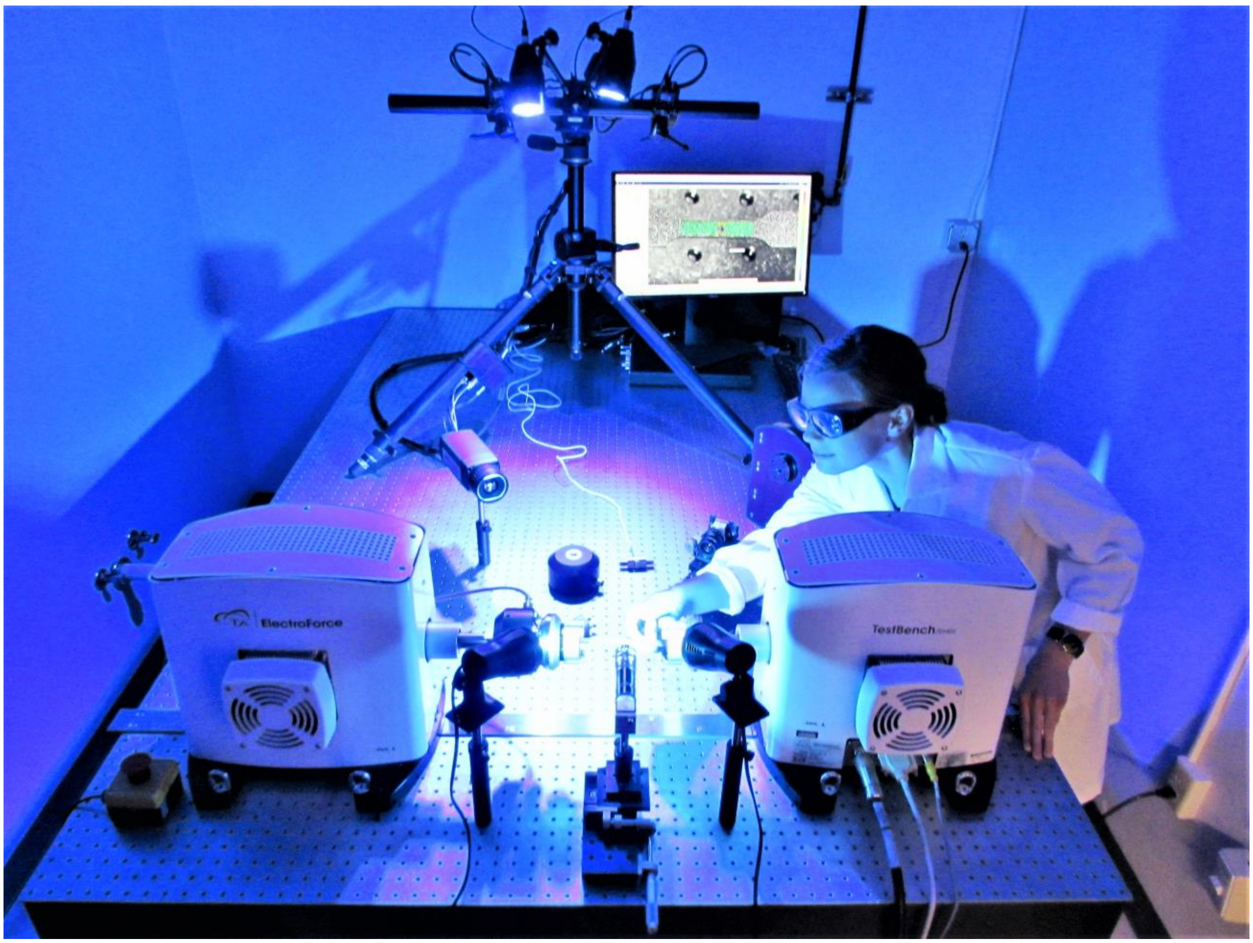

Figure 1. Overhead view of the CMOES in Dr. Degen's lab at SD Mines.

Table I. List of subsystems incorporated in the CMOES.

Subsystem	Specific Functions in the CMOES
Vibration Isolation Optical Table	Dampen vibrations for steady imaging on small scales
Dual Actuated Load Frame	Mechanical testing of materials
Infrared Camera	Capture full-field thermal images
3D Digital Image Correlation System	Capture full-field 3D displacement information
CMOS Cameras, Lenses, and Filters	Capture various images (color, black and white, fluorescence)
Data Collection Correlation Hardware and Software	Control entire system and correlate collected mechanical testing data to collected images

CMOES SUBSYSTEMS

Vibration Isolation Optical Table

The base of the CMOES is a 5 ft. x 8 ft. x 8 in. thick Integrity 4 VCS vibration isolation optical table from the Newport Corporation. This table was chosen as the base for the CMOES for 2 main reasons: 1) mounting hole placement for flexibility of location of mechanical testing and optical equipment, and 2) vibration isolation for image quality when working with small fields of view. The specifications for the Integrity 4 VCS are listed below in Table II.

Table II. Specifications for the Newport Corporation Integrity 4 VCS vibration isolation optical table.

Optical Table Quality	Specifications
Mounting hole type	• ¼-20, 1 in. grid with 0.5 in. borders • Easy clean non-corrosive high impact polymer conical cup, 0.75 in. deep
Maximum payload	• 2150 lb, 800 lb per isolator • Deflection under load: <5.0 x 10^{-5} in.
Working surface	• Surface flatness of ±0.004 in. over 2 ft^2 • 3/16 in. thick 400 Series ferromagnetic stainless steel skins with integrated damping layer • Working surface height: 36.7 ±0.5 in.
Core design	• Trussed honeycomb, vertically bonded closed cell construction, 0.010 in. steel sheet materials, 0.030 in. triple core interface
Broadband damping	• Constrained layer core, damped working surface and composite edge finish
Tuned damping	• 2 narrowband precision tuned dampers • Maximum air pressure: 85 psi
Max. dynamic deflection coefficient	• <0.8 x 10^{-3}
Max. relative motion value	• <8.0 x 10^{-9} in.
Horizontal amplification at resonance	• 6 dB
Horizontal isolation	• 10 Hz: 98%, 5 Hz: 88%. Resolution: 1 Hz
Vertical amplification at resonance	• 9 dB
Vertical isolation	• 10 Hz: 98%, 5 Hz: 88%, Resolution: 1.5 Hz

Dual Actuated Load Frame

Mechanical testing within the CMOES is achieved through a TA Instruments ElectroForce TestBench. This TestBench system contains 2 actuators (movers), enabling specimens to be tested in tension or compression with grip movement from both sides. The advantage of a dual actuated system is that during testing, the center of the sample stays in the same location, allowing imaging of the sample to take place without the need for movement of the imaging detector. Dual actuation during testing is particularly useful for materials that undergo significant deformation during testing, such as polymers and biomaterials.

The TA Instruments TestBench that was chosen for the CMOES has the capability to test materials in both tension and compression. Each mover is individually controlled in either displacement control or load control and is capable of either static or dynamic movement. Additionally, because each of the movers is separately controlled, the movers can be programmed to follow different commands to accommodate a wide range of testing protocols.

The two sets of interchangeable wedge grips on the TestBench allow for testing of specimens 0 mm – 8 mm thick. The TestBench is also equipped with 3 different interchangeable load cells, 100 N, 250 N, and 1000 N, allowing for testing of materials with a wide range of stiffnesses. The system is equipped with a conversion kit and separate power supply that allows the system to have higher precision at both ends of the loading spectrum. The total available displacement of the grips during testing is 50 mm. The maximum displacement rate of the movers during static loading is 6350 mm/sec, and the range of frequencies of the movers during dynamic loading is 1 x 10^{-5} Hz – 100 Hz. The full list of specifications of the TA Instruments ElectroForce TestBench is listed in Table III and an image of the system is shown in Figure 2.

Table III. Specifications for the TA Instruments ElectroForce TestBench dual actuated load frame.

TestBench Quality	Specifications
Base system	• Dual LM2 TB 8x2 PCI ElectroForce TestBench with Dual 3000 N Axial 230 V
Load cells	• 100 N, 250 N, 1000 N interchangeable load cells
Displacement sensors	• 2 total – one on each actuator
Reaction base	• 610 mm x 1524 mm reaction base with reaction bracket
Control and software	• WinTest Digital Control System input and 2 output channels • WinTest Software • Dynamic Link Library functionality to allow customer-written programs using external programs to access test system data and functions. Compatible programs include LabView, MatLab, Visual Basic
Adaptability	• Conversion kit that converts performance of an ElectroForce 3330 (3 kN) test instrument to an ElectroForce 3310 (1 kN) test instrument • Power supply • Cables
Grips	• Tension/Compression wedge grips • Fatigue rated • Suitable for use in temperatures from -150 °C to 350 °C • Wedge jaws for flat specimens from 0 mm – 19 mm thick and 25 mm wide or round specimens 4 – 19 mm diameter

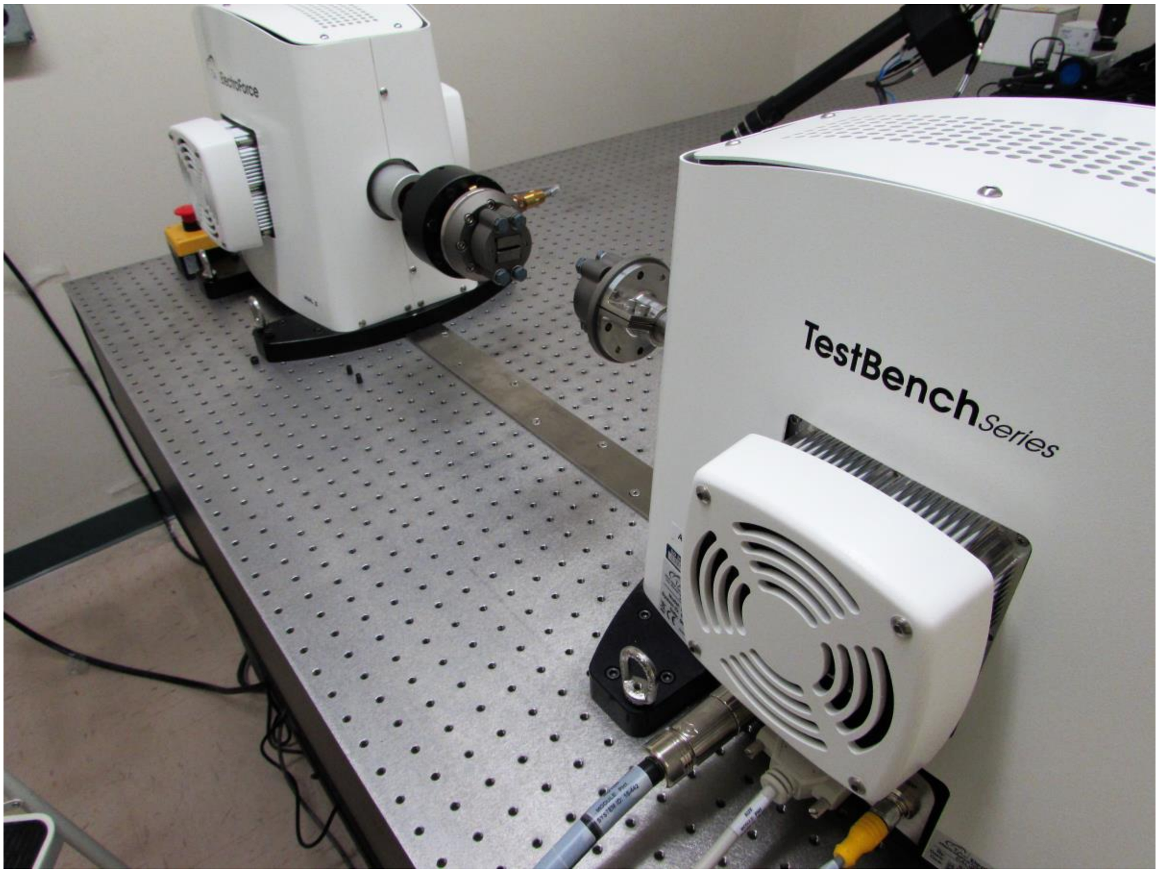

Figure 2. TA Instruments ElectroForce TestBench dual actuated load frame installed in the JMP Lab.

Infrared Camera

The imaging capabilities of the CMOES allow for real time collection of various information during the prescribed deformation of the material. The first image collection subsystem is an infrared (IR) camera to collect full field thermal profiles. The IR camera is a FLIR A655sc with a close up lens for a field of view of 64 mm x 48 mm. The temperature range detectable with this camera is -40 °C to 650 °C, making the camera exceptionally versatile. The IR camera's versatility will make it useful in the CMOES system for measuring heat lost or gained during deformation, particularly in cases where single point measurements are inadequate, or thermocouples cannot be placed. A full list of the FLIR A655sc specifications are listed in Table IV and the camera is shown in Figure 3.

Table IV. Specifications of the FLIR A655sc infrared camera.

Infrared Camera Quality	Specifications
Detector type	• Uncooled microbolometer
Spectral range	• 7.5 – 14.0 µm
Resolution	• 640 x 480
Detector pitch	• 17 µm
NETD	• <30 mK
Time constant	• <8 ms
Frame rate (full window)	• 50 Hz
Subwindow mode	• User-selectable 640 x 280 or 640 x 120
Maximum frame rate (@ min. window)	• 200 Hz (640 x 120)
Dynamic range	• 14-bit
Digital data streaming	• Gigabit ethernet (50/100/200 Hz) USB (25/50/100 Hz)
Command and control	• Gigabit ethernet, USB
Standard temperature range	• -40 °C to 650 °C
Accuracy	• ± 2 °C or ± 2% of reading
Camera f/#	• f/1.0
Lens	• 24.6 mm (25°)
Focus	• Automatic or manual (motorized)
Close-up lens	• 100 µm, FOV 64 mm x 48 mm (5.8x)
Digital data	• Via PC using ResearchIR software
Operating temperature	• -15 °C to +50 °C
Storage temperature	• -40 °C to 70 °C
Encapsulation	• IP 30 (IEC 60529)
Bump/vibration	• 25 g (IEC 60068-2-29) / 2 g (IEC 60068-2-6)
Power	• 12/24 VDC, 24 W absolute max.
Weight	• 0.9 kg
Size (L x W x H) w/o lens	• 216 x 73 x 75 mm
Mounting	• ¼” – 20 (on three sides), 2 x M4 (on three sides)

Figure 3. FLIR A655sc infrared camera with close-up lens.

3D Digital Image Correlation System

The second imaging system on the CMOES is a Trilion Quality Systems ARAMIS digital image correlation system. Digital image correlation (DIC) is a non-contact experimental evaluation method that is applicable to a wide variety of testing scenarios. This technique utilizes images of a specimen prior to, and during, deformation of the specimen and tracks the position of the reference and deformed images. To achieve this result, a speckle pattern is applied to the area of interest of the test specimen prior to deformation, and the movement of these specks is the metric of measurement utilized by the method. DIC is an exceptionally useful technique for measurement of displacement and calculation of strain particularly for soft materials which experience significant deformation, for cases where displacement is non-uniform and a full-field analysis is desired (rather than a single point, i.e. strain gauge), and for scenarios where more traditional contact methods (strain gauges, extensometers, and nanoindentation) are unsuitable.

DIC can be employed in both 2D and 3D. In 2D applications, a single camera is pointed at the speckled surface of the specimen and images from a single surface (for example the x-y plane) are collected during deformation of the material. The analysis of these images allows for tracking of speckle movement in 2 dimensions, in the x-y plane, and therefore allows for calculation of strain in 2 dimensions. The major limitation of this method is that if any significant out of plane deformation occurs, the camera can only detect this deformation as a de-focus of the collected image, and analysis of the sequence of images can give poor strain data. In 3D, two cameras set at known angles and distance from the specimen are employed. The setup of the 3D system relies on principles of stereo-vision to capture not only displacements in a single plane (x-y plane), but also any out of plane displacements (in the z-direction). Using this principle, 3D DIC is able to capture displacements in 3 dimensions and therefore calculate strains in all 3 directions simultaneously.

The ARAMIS adjustable base system by Trilion Quality Systems was chosen for the flexibility it provides when used in conjunction with the overall CMOES. The adjustable base and calibration from any distance or position relative to the specimen makes it adaptable for many applications. The full specifications of the ARAMIS system are shown in Table V. One positioning setup of the ARAMIS system on the vibration isolation table is shown in Figure 4.

Table V. Specifications of the Trilion Quality Systems ARAMIS adjustable base DIC system.

ARMAIS DIC System Quality	**Specifications**
Base system	• Dual high-resolution 2.3 Megapixels imaging system
Frame rate	• 130 fps at full resolution (1936 x 1216 pixels) • 250 fps at half frame rate (1936 x 608 pixels) • 500 fps at quarter frame rate (1936 x 304 pixels)
Field of view / lenses	• Broad range of field of view with capability for adding focal length extenders and using different lenses • C-mount high precision lenses
Calibration	• Certified calibration panel • Calibration object holder
Data collection	• 8 channel testing controller and data logger
Lighting	• Integrated advanced LED illumination package
Mounting	• Stable sensor tripod stand
Computer and software	• High-end image processing workstation • ARAMIS 3D professional software • Unlimited basic analysis software licenses – GOM Correlate
Support	• Complete on-site installation and initial training (2 day) • Dedicated online training course (4x half-day) • 1-year warranty and Trilion Gold support

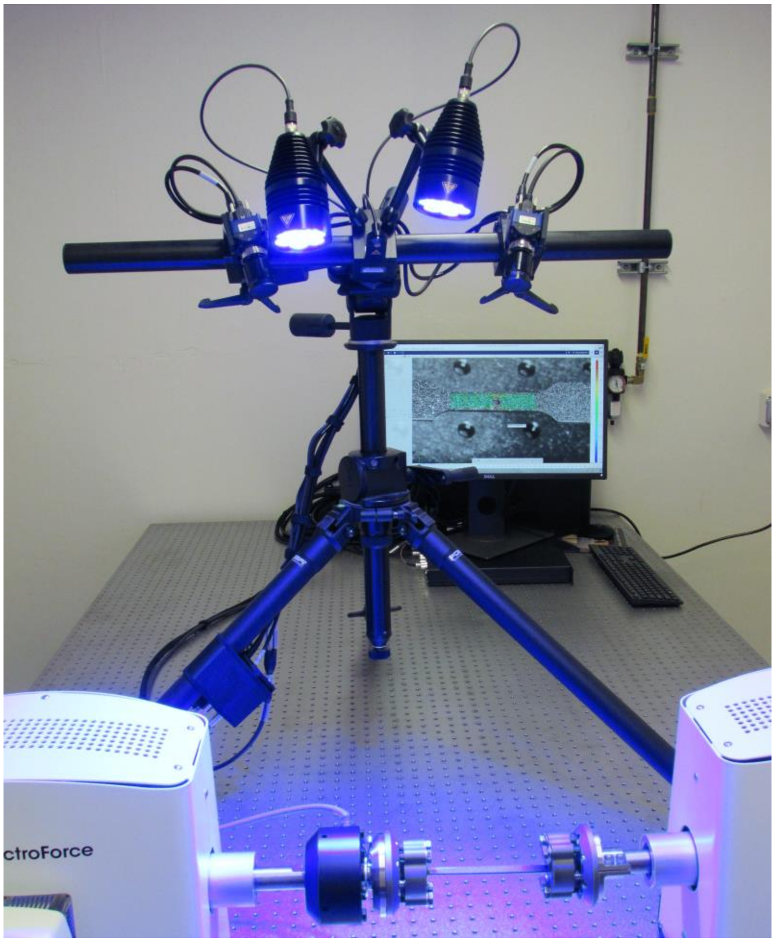

Figure 4. ARAMIS adjustable base DIC system setup for use with the TestBench on the vibration isolation table.

CCD Cameras, Lenses, and Filters

Additional imaging components are available with the CMOES for color, monochrome, and fluorescence imaging of specimens during deformation. The current capabilities include one color camera and one monochrome camera, which can be used in concert with each other. The system also has filters that can attach to the light source and either camera such that only certain wavelengths of visible light are collected by the camera. The cameras, lenses, and filters are all compatible with each other in their mounting setup (c-mount) so that all pieces are interchangeable. Additional filters for other ranges of light collection, additional lenses, and other optical components will be simple to add to the system in the future if needed, further increasing the imaging capabilities. The specifications of the additional imaging components are listed in Table VI and shown in Figure 5.

Table VI. List and specifications of the various individual imaging equipment.

Imaging Component	Specifications
Basler ace acA1300-200uc USB3 color	• c-mount • USB 3.0 video output • ½" camera sensor format, 1.3 megapixel resolution • 1280 x 1024 pixels (H x V), 4.8 x 4.8 µm pixel size (H x V) • Dimensions: 29.3 x 29.0 x 29.0 mm • Freely programmable exposure control • 203 fps maximum frame rate • 0 – 50 °C operating temperature • Synchronized via external trigger or free-run • Progressive scan CMOS sensor type, color camera
Basler ace acA2500-60um monochrome USB 3.0	• c-mount • USB 3.0 video output • 1" camera sensor format, 5 megapixel resolution • 2590 x 2048 pixels (H x V), 4.8 x 4.8 µm pixel size (H x V) • Dimensions: 29.3 x 29.0 x 29.0 mm • 60 fps maximum frame rate • CMOS sensor type, monochrome camera
Edmund optics 13 mm C series lens	• c-mount • fixed focal length lens, focal length = 35 mm • 2/3" camera sensor format • Aperture f/1.65 – f/22 • 165 mm - ∞ working distance and 39.3 mm, 14.3° field of view • M25.5 x 0.5 filter thread
Kowa HC lens	• c-mount • 1" (12.5 mm) megapixel lens • Manual focus and aperture, f1.4 – f16 aperture range • 12.5 mm focal length • Horizontal angle: 1/2" 28.7°, 2/3" 39.1°, 1" 55.6° • M35 x 0.5 filter thread
Shortpass filter	• 25.0 mm diameter, 3.5 mm thickness • Cut-off λ = 550 nm • Transmission region (T>90%); 400 – 543 nm • Rejection region (OD>5); 557 – 1200 nm
Longpass filter	• 25.0 mm diameter, 3.5 mm thickness • Cut-on λ = 600 nm • Transmission region (T>90%); 609 – 2150 nm • Rejection region (OD>5); 200 – 1591 nm
Filter mounts	• Thor Labs lens mount with retaining ring • Adapter with external M25.5 x 0.5 and internal SM1 threads
Lens tubes	• 0.03" thread depth, with one retaining ring • c-mount focal length extender
Optical post	• 0.5" diameter, 8-32 setscrew, ¼"-20 tap, 4" length, stainless steel
Tripod	• Professional 72" tripod
Lights	• Externally powered, repositionable blue light illumination

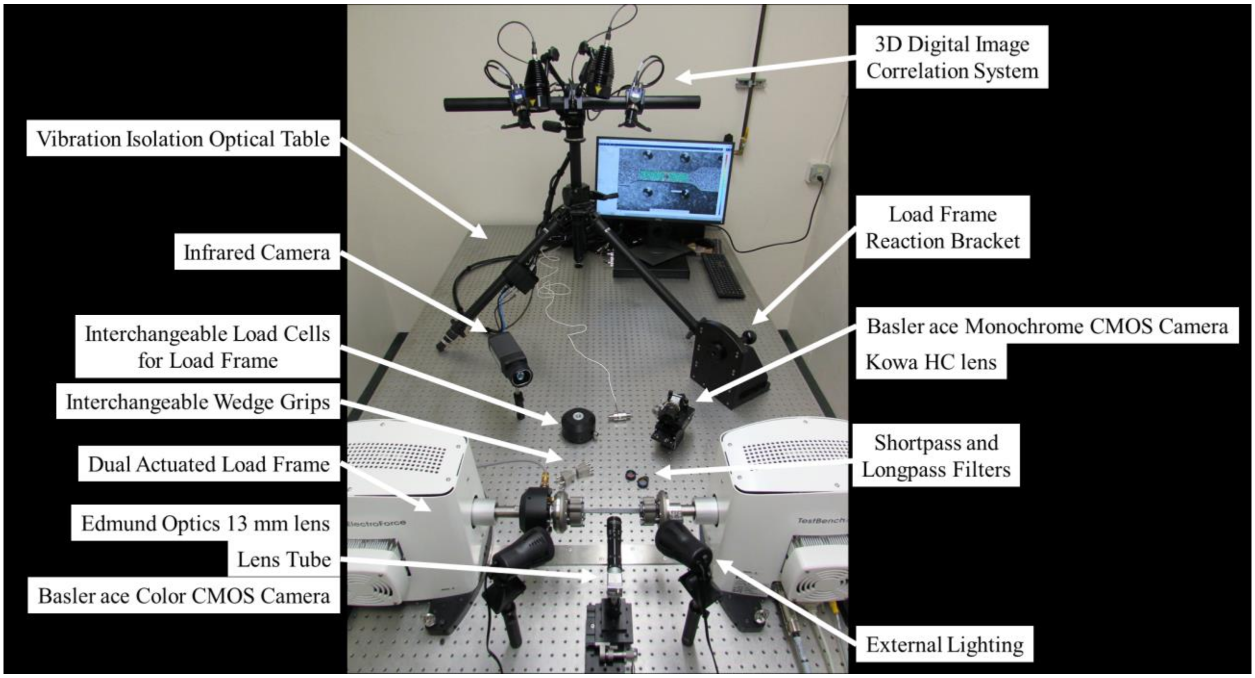

Figure 5. Individual imaging components available for use with the CMOES.

Data Collection Correlation Hardware and Software

The final components of the CMOES include both hardware and LabView software from National Instruments. The hardware and software are used to trigger each individual piece of equipment described above to run and collect data simultaneously. The correlation of information from all individual pieces of equipment is necessary for post data analysis.

APPLICATIONS AND INITIAL USES OF THE CMOES

The goal of the CMOES equipment was to construct a system that was applicable for a wide variety of applications. The flexibility of the placement of each subsystem as well as the flexibility of the loading and imaging capabilities will allow this setup to be useful for many faculty on the SD Mines campus as well as collaboration on projects that extend beyond our campus.

The main project to-date that the CMOES equipment has been used for was a research project funded by the state of South Dakota. This project's goal was to use both experimental techniques and computational methods in concert to describe the behavior of thermoplastic matrix composite materials and ultrasonic spot welds of the composite material. The CMOES system was used to collect experimental information about the chopped glass fiber thermoplastic matrix composite material used in the work. The experimental results obtained from the CMOES system were then used to build a computational model that will guide the development of a more complex model to predict ultrasonic spot weld performance. Additionally, the CMOES system was used to validate the initial computational model.

Experimental strain fields were collected for a composite material specimen with a hole through the center. The hole was placed to represent a stress concentration or a simplified ultrasonic spot weld. Additionally, a single hole through a specimen in tension has a well-known solution for stress distribution (and therefore strain distribution using linear elastic assumptions) and can be used to validate the experimental 3D digital image correlation method. The composite specimen with a hole was tested in tension at a constant displacement rate of 0.085 mm/sec and the full field distribution of strain just before sample failure is shown below in Figure 6. Of interest for this project was the difference in material behavior with fiber orientation in the composite. Because of the manufacturing process, the composite material used for this work had a strong fiber alignment in a single direction. The specimen used in Figure 6 was manufactured such that the fiber orientation was in the direction of loading (x-direction). Figure 7 shows the full field strain distribution just before failure of a specimen tested in tension at 0.085 mm/sec that was manufactured such that the fiber orientation was perpendicular to the direction of loading (x-direction). The differences in behavior of the specimens in Figure 6 and Figure 7 were then used to evaluate the orthotropic nature of the composite material for computational modelling.

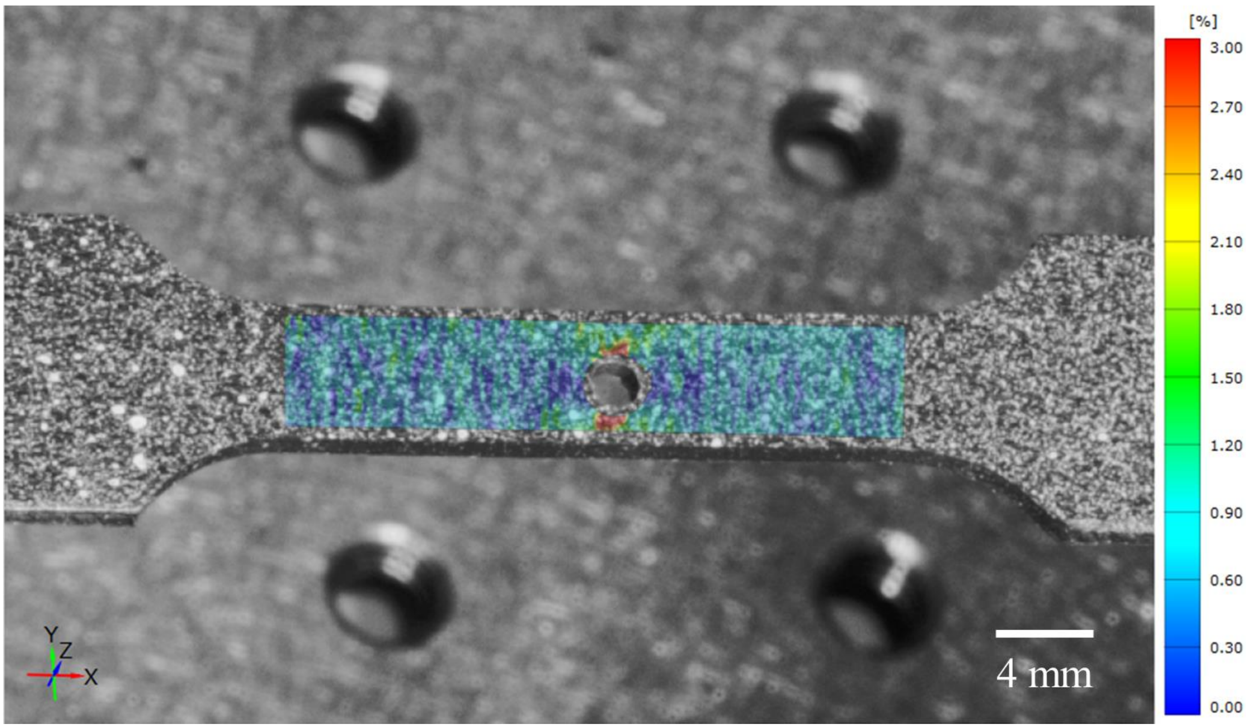

Figure 6. Full field strain (ε_x) distribution just before failure in a composite sample with fibers oriented parallel to the loading direction (x-direction). Sample was loaded in tension at 0.085 mm/sec.

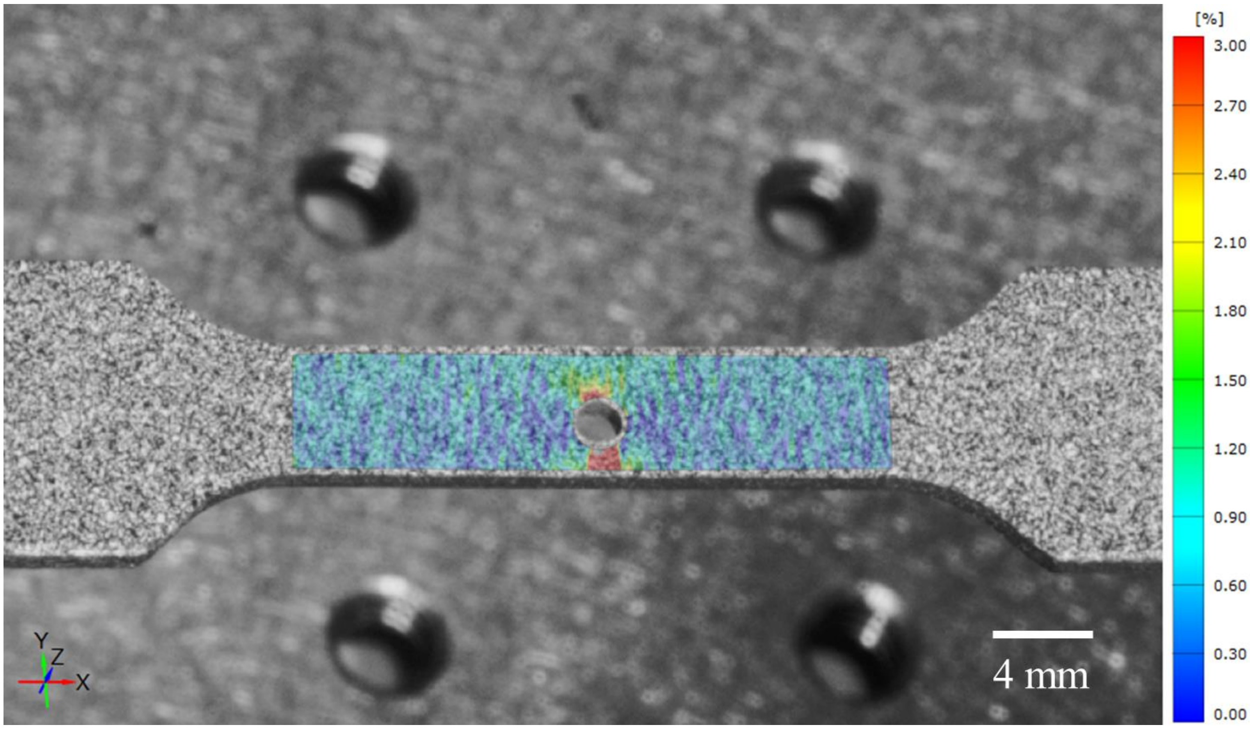

Figure 7. Full field strain (ε_x) distribution just before failure in a composite sample with fibers oriented perpendicular to the loading direction (x-direction). Sample was loaded in tension at 0.085 mm/sec.

The overarching goal of this project was to move towards predictions of performance of ultrasonic spot weld lap shear specimens. Earlier in the project, it was realized that there was significant out of plane material deformation during the testing of lap shear specimens. Prior to the CMOES equipment, these lap shear specimens were pulled in tension on a MTS 858 hydraulic load frame. Important to characterization was the collection of load and displacement data during testing. On this testing setup, displacement information was collected from grip displacement, and because of the significant out of plane deformation and non-uniform strain distribution, these displacement data were extremely inaccurate. The CMOES was useful to correct this inaccuracy by testing lap shear specimens with the TestBench and imaging with the ARAMIS system. The CMOES allowed for the collection of 3D displacement and strain information, providing a full field distribution of displacement and strain across the lap shear specimen. The significant out of plane displacement was captured and is shown in Figure 8 as displacement in the z-direction of the lap shear specimen just before failure. The analysis software provided with the ARAMIS system is capable of accounting for this out of plane displacement and correcting for the actual deformation in the loading direction. Figure 9 shows the full field calculated strain in the loading direction across the lap shear specimen. This particular project shows the utility of the CMOES where two subsystems, dual-actuated well-controlled loading and 3D digital image correlation, were necessary for accurate characterization.

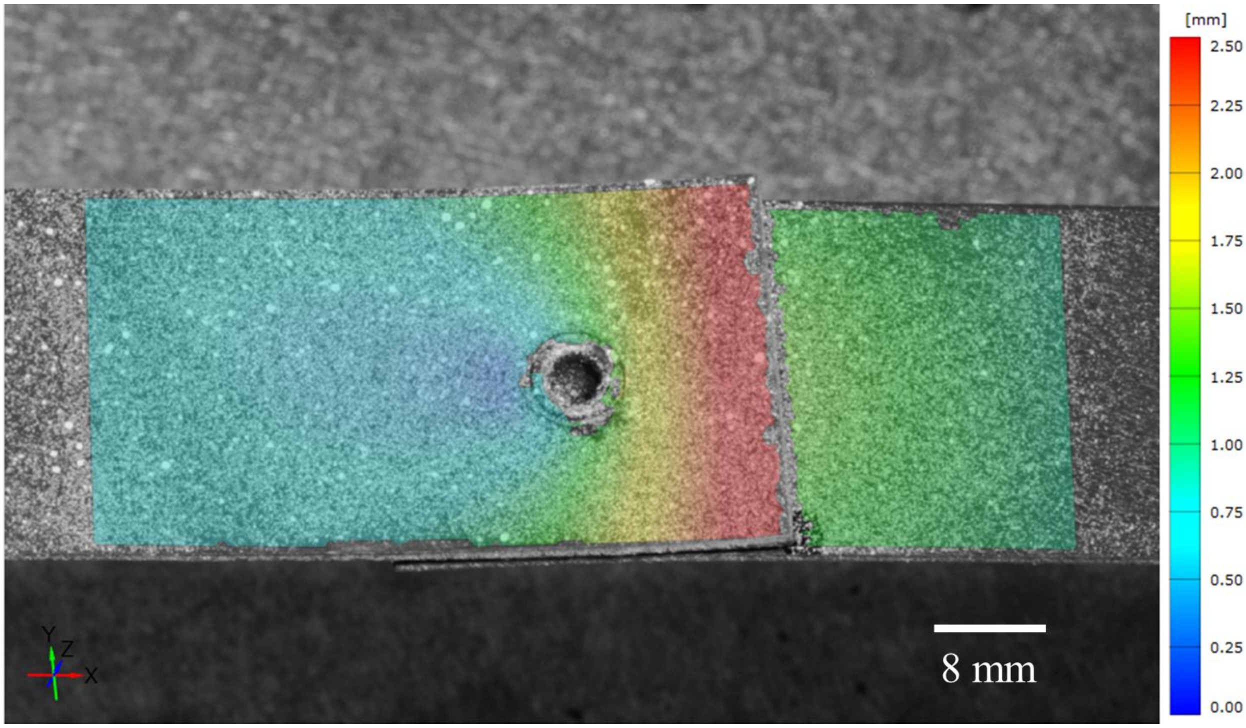

Figure 8. Full field out-of-plane (δ_z) displacement captured by the ARAMIS 3D DIC system during tensile loading of an ultrasonic spot welded composite lap shear specimen. Sample was loaded at 0.085 mm/sec along the x-direction.

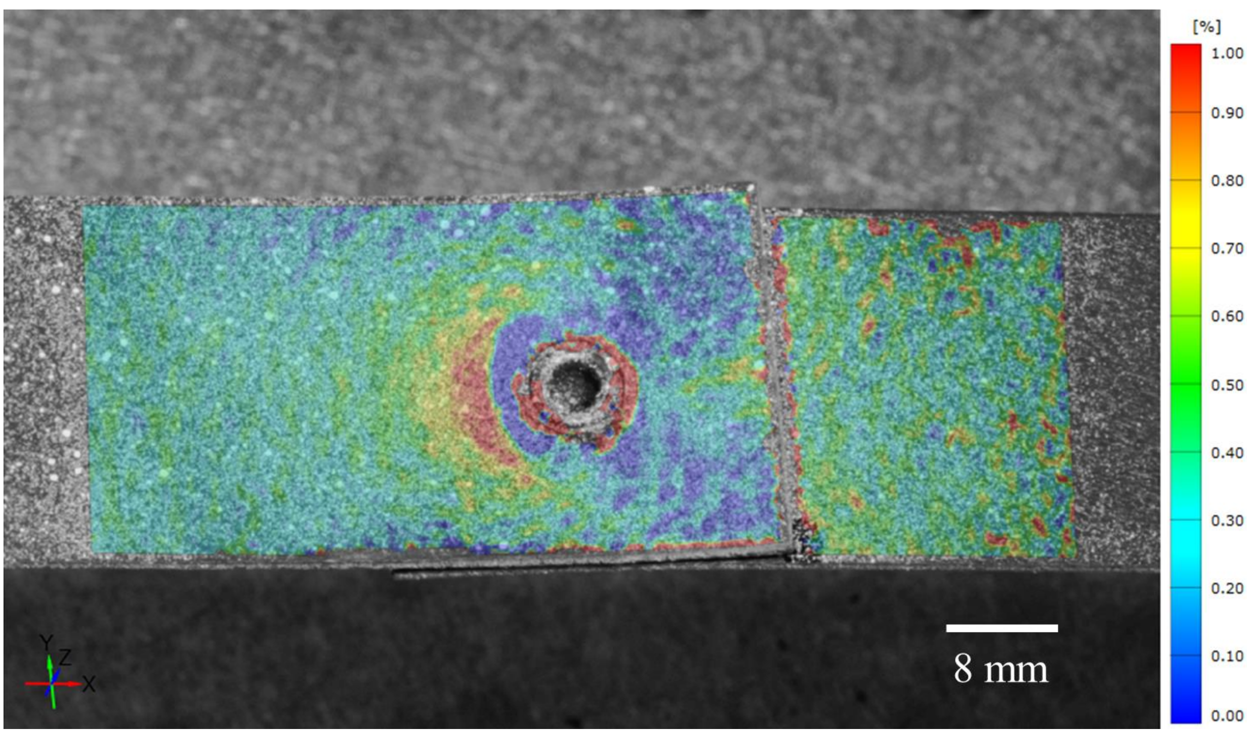

Figure 9. Full field in-plane strain (ε_x) calculated by the ARAMIS 3D DIC system during tensile loading of an ultrasonic spot welded composite lap shear specimen. Sample was loaded at 0.085 mm/sec along the x-direction.

IMPACTS OF THIS DURIP AWARD

The impacts of the equipment obtained through this award have been wide-spread in both teaching and research avenues. The PI also began teaching a new laboratory course in the Spring of 2018, Mechanics of Viscoelastic Solids. This course is a senior/graduate level course in which students are exposed to a number of experimental techniques specific for polymers. The CMOES equipment was used as a demonstration during the initial offering of the laboratory course to highlight creep, stress relaxation, and response of polymers to dynamic loading, as well as digital image correlation. The next offering of the course during the Fall of 2018 will continue to utilize the CMOES equipment as a teaching tool in this course and use will increase as new educational experiments are developed for the equipment.

The graduate student working on the project highlighted above in the initial uses of the CMOES gained valuable expertise in the DIC method as well as with experimental characterization of composites and polymers in general largely due to the equipment obtained through this DURIP award. The student graduated in May 2018 and recently accepted and began a position as a Product Development Engineer with the Engineered Films division of Raven Industries in Sioux Falls, South Dakota. He will be working on a combination of customer-oriented application work, and research and development into implementation of composite technology like that used in this work. The equipment has helped recruit a new graduate student who will work on the continuation of this project (beginning in the 2018-2019 academic year).

The equipment will also have an impact in the research education of undergraduate students and the recruitment of these students to SD Mines. The JMP Laboratory will host one undergraduate student through a NSF REU (Research Experience for Undergraduates) program and one high school student through the Army Education Outreach Program’s Research and Engineering Apprenticeship Program (REAP) during the summer of 2018. The summer projects for both students will utilize the DURIP equipment from this grant, exposing the students to the capabilities of the equipment.

The equipment has also enabled collaboration with several local industries (VRC Metal Systems and B9Creations, both of Rapid City, SD) through submission of SBIR/STTR grants and projects related to the development of technology at the companies. Additionally, campus collaboration on both the SD Mines campus as well as the South Dakota State University in Brookings, SD have stemmed from the available capabilities of the CMOES. Overall, the CMOES has significantly increased the capabilities for advanced materials characterization on the SD Mines campus and in the state of South Dakota and the PI anticipates several proposals to come from these projects and collaborations in the near future.