Convective Reflow Emulation (CRE) Module Testing Protocol/Best Practices

1 Introduction

The Convective Reflow Emulation (CRE) Module is a thermal solution for the Akrometrix AXP warpage measurement equipment. The CRE enables enhanced emulation of thermal conditions seen in production reflow ovens, surpassing all previous temperature dependant warpage measurement tools. Advantages of the CRE module include:

- increased sample temperature uniformity
- increased sample heating rates
- improved handling of shadow moiré working distances
- improved handling of sample outgassing effects on warpage measurements

Testing correlation with standard IR heating based systems is an immediate concern when comparing data from the CRE with data from an IR radiation based warpage system. On the whole, a level of correlation between IR and CRE based systems should be viable, though research by Akrometrix has indicated some offset in CRE and IR heated sample warpage behavior. With all other variables equal, in cases showing offset between warpage data taken with the CRE and IR based systems, the CRE should be considered the more accurate representation of actual warpage behavior seen in production.

In order to achieve comparable testing results between different CRE systems, a fully defined test protocol is required. The goal of this test protocol is to specify important test parameters that, when set up similarly in different CRE modules, will allow those machines to capture similar results. While the following recommendations are a good starting point, different samples may require different setups to optimize the captured data. Where different, users should communicate exact test conditions.

This best practice protocol is written assuming the user already has familiarity with Akrometrix's Die and Package Testing Protocol/Best Practice. In particular, sections on Calibration, Data Acquisition, Data Analysis, and Reporting still apply to shadow moiré use with the CRE Module.

2 Hardware Setup

The CRE Module installation is described in Section 2.1 of the CRE User Manual. Critical details and recommended options are described in more detail in the points below.

- **CRE Orientation:**

- Make sure to center the triangle mark on the grating, so that grating lines run vertical to the system line light. Check to make sure the grating has not shifted between opening and closing the grating and installing/uninstalling the CRE. Improper alignment can cause measurement error.

- Make sure to install the sample support to match **Figure 1(a-b)**. For an addition check on orientation the name of the sample support should be facing the user.

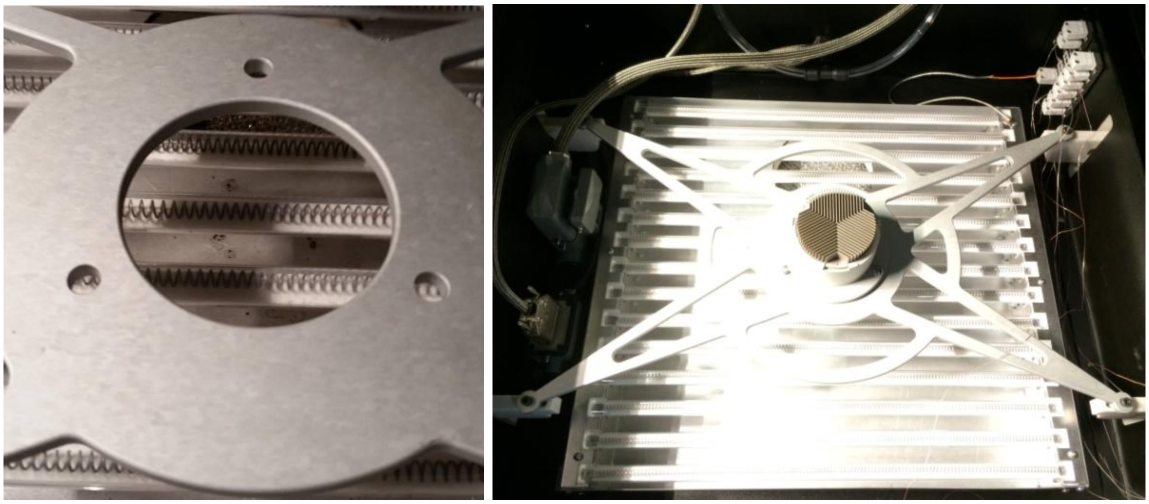

Figure 1(a-b). CRE Sample Support Orientation

- **Airflow:** Airflow in the CRE Module is measured in psi (pounds per square inch), taken on an air pressure gauge installed on the side of the AXP system. Increasing the pressure on the gauge will increase the airflow of the system. Two different pressure settings can be read from the pressure gauge, one setting for when air is flowing to the CRE and one setting when it is not. Some variation between gauges is expected. Airflow should be recorded from the “air on” state to be most accurate. Airflow can be turned on manually by using a red button near the gauge. When reading the gauge hold the red button for at least 5 seconds before reading the gauge, to allow the pressure to stabilize. The pressure gauge and the airflow button are highlighted in **Figure 2** below.

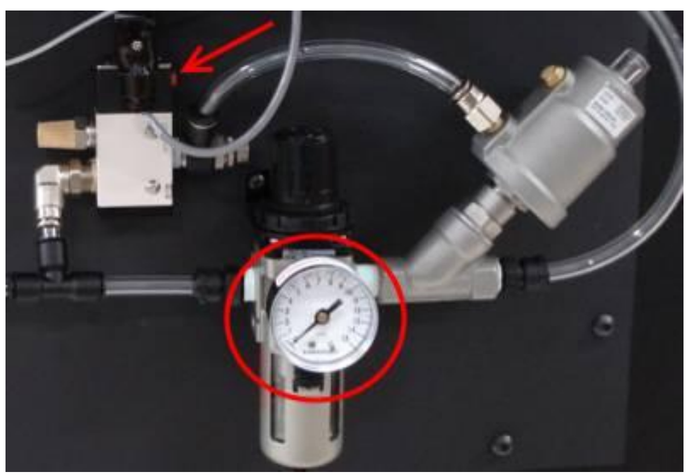

Figure 2. CRE Airflow Hardware

The following table summarizes air on and air off pressures for the CRE. The table also shows positive and negative effects of using higher and lower air pressure settings. Small differences between running and static pressures are expected from each pressure gauge.

Airflow Type	Running Pressure	Static Pressure	Positives Effects	Negative Effects
Minimum	~4.0	~8.25	Increased sample stability	Reduced Heating and Cooling Rates
Typical	~5.0	~10.0	N/A	N/A
Maximum	~6.25	~12.0	Improved Heating and Cooling Rates	Thinner samples may "flutter" or move during test

- **Grating Choice and Zoom:** An Akrometrix TherMoiré AXP with CRE Module is used for optimal surface characterization. The correct grating and field of view choice is critical for achieving optimal warpage measurements. Recommended grating choice is primarily dependent on sample dimensions.

  The AXP comes with a variable zoom lens installed. The amount that the user can zoom-in on the sample affects the data density of the measurement (essentially the number of camera pixels in a given area) and is directly dependent on the installed grating. The CRE Module comes standard with 3 gratings differentiated by grating pitch (though named as the inverse of pitch) written in lines per inch (LPI): 100 LPI, 200 LPI, and 300 LPI. The tighter pitch grating provides improved Z resolution and enables increased data density. However, tighter grating pitch decreases the working distance of the measurement capability. For this reason the 300 LPI grating is the tightest pitch grating offered.

  Grating choices can be made based on sample outer dimensions and maximum possible warpage levels. Special attention should be paid to what field of view is chosen for each test. Because zoom lenses have no detents, it is especially important to use the same size ROI between systems. Field of view should generally be maximized relative to the grating in use.

  The following table summarizes shadow moiré characteristics in relation to grating pitch.

Grating (LPI)	Warpage Resolution	Max Data Density	Maximum Working Distance	Max Measured Coplanarity
100	2.5 µm	16 pixels/mm^2	~8 mm (315 mils)	~4 mm
200	1.25 µm	64 pixels/mm^2	~2 mm (80 mils)	~1 mm
300	0.85 µm	144 pixels/mm^2	~0.9 mm (35 mils)	~0.25 mm

Warpage resolution and data density numbers above assume optimal setup. Working distance and max measured coplanarity numbers are approximate values only and the gratings can at times be used beyond these values.

More general recommendations for grating choice based on sample dimensions are shown in a further table. The numbers are again approximate and overlap, by design. If both dimension criteria are not met in the table, use the more coarse grating pitch.

Grating (LPI)	Sample Lateral Size	Sample Expected Coplanarity
100	> 20x20mm	> 80 microns
200	10x10mm – 60x60mm	< 250 microns
300	3x3mm – 16x16mm	< 125 microns

3 Sample Characteristics

The CRE is designed around reflow profile simulation of mobile packaging. With that said, the improved top/bottom uniformity of the system allows for thicker packaging applications to also benefit from the CRE module's heating uniformity. Minimum sample sizes are defined by how small and thin a sample can be without being moved by the minimum airflow settings of the CRE. Maximum sample size is limited to the 70mm diameter circle of the convection chamber.

4 Sample Placement and Lateral Uniformity

A critical design point for the CRE Module is optimization of both lateral and top/bottom temperature uniformity. Top/bottom temperature uniformity is primarily dependent on working distance and airflow rates discussed in section 6. Working distance and airflow rates have a more passive effect to influence lateral uniformity. Lateral uniformity more largely depends on the locations of the samples. The CRE is designed for air to flow in from 3 nozzles surrounding the sample support (**Figure 3**).

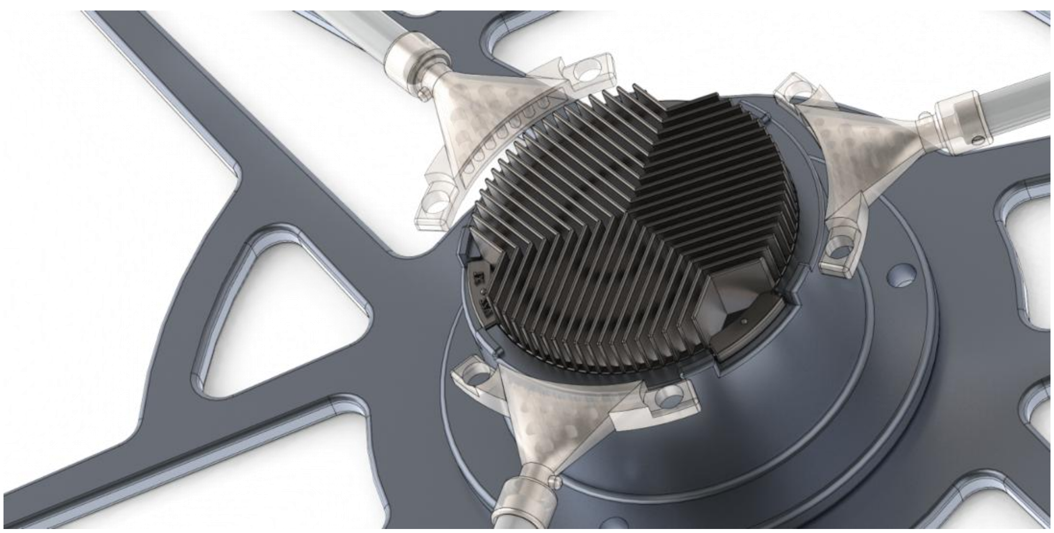

Figure 3. CRE Sample Support and Nozzle Drawing

Creating strong lateral uniformity in the CRE requires careful attention to sample placement. Samples should be placed with symmetry around the nozzles. The closer to the nozzle the higher heating rates, thus samples should be placed with the same orientation and distance from each nozzle. See the examples in **Figure 4(a-d)** below. All images are shown taken from the user's perspective, such that the bottom of the image would be closest to the user when looking into the AXP. Notice that quantities of 3, 6, and 9 samples are chosen to optimize symmetry in the 3 heater system.

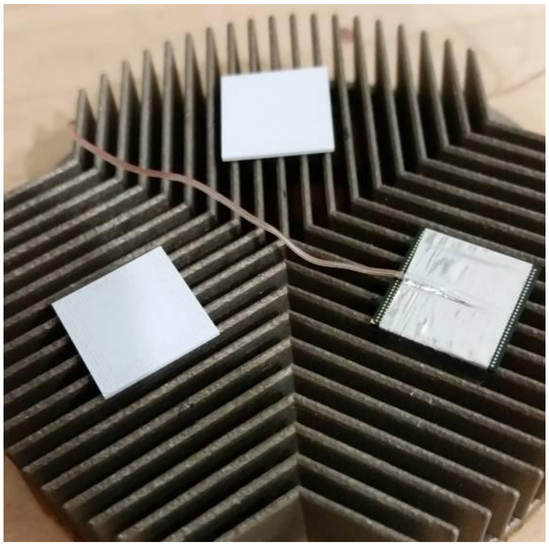

Figure 4(a). Typical 3 sample setup

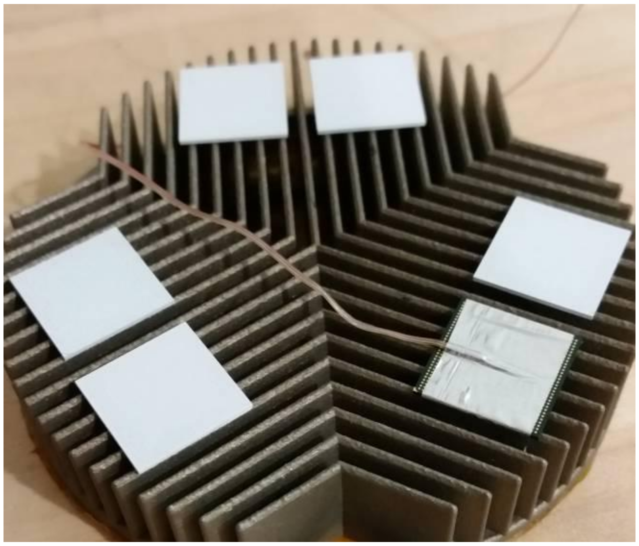

Figure 4(b). Typical 6 sample setup

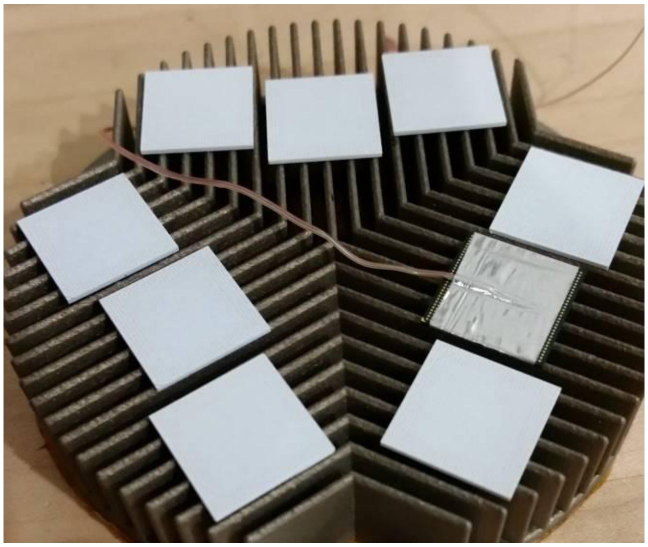

Figure 4(c). Typical 9 sample setup

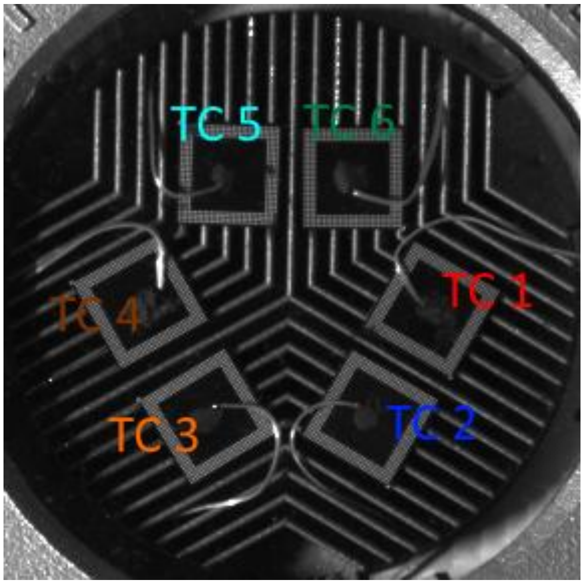

Figure 4(c). 6 sample lateral uniformity test

Figure 4(a-d). Example sample setups

5 Thermocouple Placement

The recommended method for thermocouple attachment in the CRE is to use a single piece of, 1” wide and 4 mil thick extreme high temperature, aluminum tape. While Kapton tape is still the recommended tape for IR based Akrometrix systems, the aluminum tape is a better fit for the CRE. The tip of the thermocouple should be coated with a small amount of thermal grease. The piece of aluminum tape should be used for, both thermocouple to sample attachment, as well as sample to sample support attachment. The tape holds the thermocouple to the center of the top of the sample. The aluminum tape should be attached to the vertical walls of the sample support struts. A 0.05” Allen key can be used to reach between the vertical struts and secure the tape against the vertical walls of the sample support. A close up of this attachment is shown in **Figure 5**.

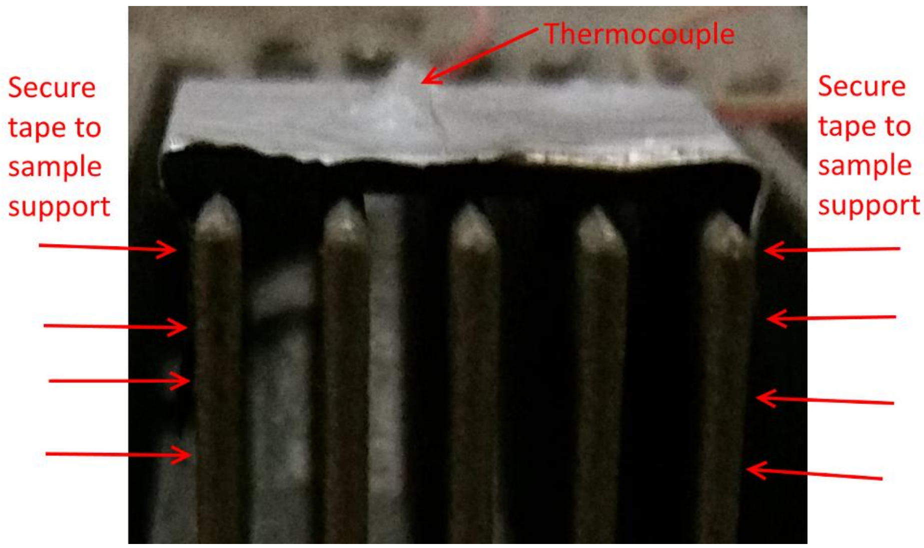

Figure 5. Aluminum tape thermocouple attachment

Alternatively JB Weld Epoxy can be used to attach thermocouples to the top of the sample surface. This is a reliable attachment method but requires overnight curing of the epoxy before use and generally slightly reduces thermal response in comparison to the aluminum tape.

With either thermocouple attachment type the thermocouples should be routed away from the front of the nozzles where air is entering the system. A thermocouple very close to the incoming air may be damaged during testing. The thermocouples can be taped to the surrounding sample support structure to route as needed.

6 Optimizing Heating Rates and Top/Bottom Uniformity

- **Maximum Thermal Operating Conditions:** The specified maximum operating temperature for the CRE Module is 275°C. Running sample temperatures beyond 275°C or soaking more than 40 seconds at 275°C has the potential to damage the CRE hardware.

  The temperature control scheme for the CRE Module has built in protection for the CRE Module hardware. Thermal profiles exceeding 160 consecutive seconds with internal heater air temperatures above 400°C will trigger a reduction in the maximum power output of the system. Users seeing a sudden reduction in heating rates at higher temperatures are likely reaching this safety trigger. The system will continue to heat but at a reduced input power.

- **Effects from Airflow:** Section 2 covers the general positive and negative effects of increasing airflow. Generally airflow can be increased to a level such that the samples remain stable in the CRE module. Above the listed maximum flow rate at 6.25 psi running pressure, benefits on increasing heating rates will plateau as the heaters inside the CRE will be begin to produce lower air temperatures with increasing flow rate. Airflow changes effect top/bottom uniformity, but no direct correlation between uniformity and airflow rates has been observed.
- **Effects from Working Distance:** Heating rates in the CRE Module are maximized around 250-300 mil working distances. Heating rates will be reduced gradually as working distance decreases. The maximum heating rate range enables only the 100LPI grating for measurement.

  Working distance is the largest contributing variable to top/bottom temperature uniformity. Working distance for optimal sample uniformity is sample dependent, but the uniformity can be easily optimized by adjusting working distance. Decrease working distance to increase the bottom sample temperature. Increase working distance to increase the top sample temperature.
- **Effects from Thermal Mass:** While not directly controlled by the user, sample thermal mass is mentioned here, as undoubtedly more samples and greater sample thermal mass can generally slow heating rates and play a role in top/bottom temperature uniformity.

7 Data Acquisition

- **Sample to Grating Distance:** Grating working distances have already been discussed in section 2. However, the CRE Module improves the usability of the higher pitch shadow moiré gratings such as the 300 LPI. This is done through a new software function called “Compensate for frame warpage”. No different from other AXP setups, working distance can change as samples and the surrounding structures are heated. Unique to the CRE Module, Akrometrix is able to compensate for the changing working distance by frequent small movements of the sample stages and monitoring the temperature of the CRE frame. The optimal value for “Compensate for frame warpage” is calibrated by Akrometrix prior to CRE module shipment and will be provided by Akrometrix with the system. This setting should remain checked (on) for all CRE use.

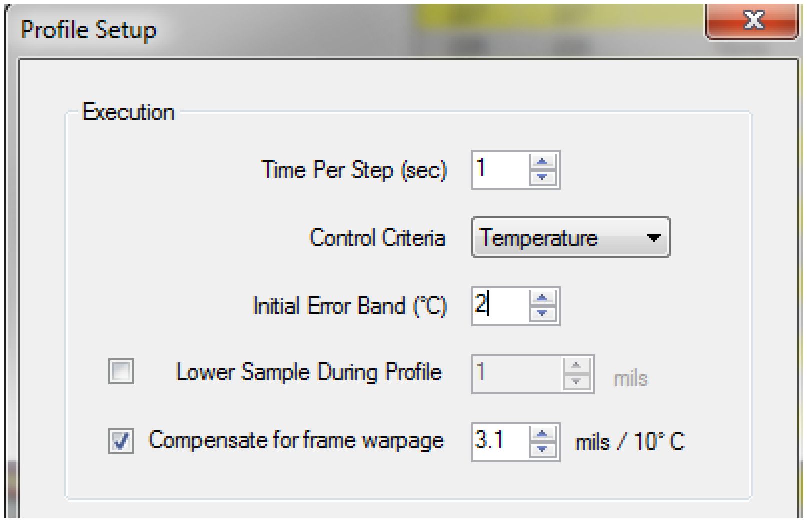

Figure 6. Software setting "Compensate for frame warpage"

- **Regions of Interest (ROI):** A circular measurement area is provided with the CRE Surface Measurement software to compliment the circular inspection area. This is a convenience and generally recommended for ease of setup.

8 Final Tips

- Some flexibility is left in the assembly/installation of the sample support. Take note to center the sample support under the CRE nozzle and grating structure as much as reasonably possible.
- The grip strength of the aluminum tape has been observed to decrease with extended exposure to open air. Leave the aluminum tape closed around its roll of tape when not in use.
- The upper CRE module structure can be raised, lowered, and tilted via the same thumbscrews that move the standard AXP grating. For optimal temperature uniformity setup the CRE grating should be setup parallel with the sample support as much as is reasonably possible.
- Calibration of the CRE Module should be done anytime the grating is removed from the CRE Module, the CRE Module is removed from the system, or anytime the user suspects that the grating has shifted.
- The following list summarizes the range of variables that may have some affect on the performance of the CRE module. The more critical variables have already been addressed earlier in this best practice document, so this exhaustive list is included for clarity only.
  - Sample Support
    - Model
    - Orientation (120° rotations)
    - Minor Rotation within fixture stand
    - Minor Shift within fixture stand
  - Device Under Test

- Number of samples
- Dimensions (x,y,z)
- Out-of-Plane Angle
- In-Plane Angle
- Sample Warpage
- Attach method to sample support (tape, epoxy)

- Thermocouple Attachment
  - Attachment Side
  - Tape/Epoxy
  - Epoxy/Tape Type
  - Epoxy/Tape Quantity
  - Air exposure of thermocouple inside epoxy
  - Location of thermocouple in the epoxy relative to sample surface
- Stage Height/Working Distance
- Compensate for Frame Warpage On/Off and amount
- Lower While Heating On/Off and amount
- Airflow (air pressure setting)
- Grating Tilt
- Incoming Heater Power Variance
- Heating Rate/Profile
- Support Base Relative to Clamshell Centering