Variability in the Performance of MIL-STD-810 Sand Testing

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ABSTRACT

Exotic Electro-Optics (EEO) recently completed a series of MIL-STD-810F, Method 510.4 sand erosion tests at multiple commercial testing sites. During this testing process, it became apparent that no two environmental test vendors are alike, even if MIL-STD-810F is specified in all cases. Three different test laboratories performing the same Method 510.4 sand test on identically fabricated samples yielded three different results. Ultimately, it is the responsibility of the Engineer to confirm that the test vendor's equipment, processes, and procedures produce a test environment that is applicable and a result that is accurate based upon the customer specified test requirement and the MIL-STD-810 methodology. Some critical factors that determine the utility of a test are particle concentration, air velocity, particle size and composition, and the ability to maintain these parameters over a test duration of up to 90 minutes. EEO has identified a number of parametric details critical to maximizing the stability and accuracy of MIL-STD-810F, Method 510.4, Procedure II sand testing. These strategies will be presented.

Keywords: sand, testing, MIL-STD-810, particle, erosion.

1 INTRODUCTION

As a supplier of optics to the Defense, Aerospace, and Homeland Security industries, EEO frequently receives requests for quotes that include requirements for solid particle erosion blowing sand testing per MIL-STD-810. This requirement is common to both ground based and airborne applications. It was during a recent qualification test program that EEO discovered a significant difference in the methods, equipment, and thus, the results when a standard MIL-STD-810F, Method 510.4 Blowing Sand test was performed at three different environmental test vendors. Table 1 presents common test parameters for the performance of the blowing sand test.

Table 1. Blowing Sand Test Parameters

Impact Angle (degrees)	Particle Size (µm)	Velocity (mph)	Concentration (g/m^3)	Chamber Temperature	Duration (min)
90	150-850	40	2.2	Ambient	90

The parameters specified were very routine MIL-STD-810 sand test parameters. The range of sand particle sizes, the distribution, and the composition were defined in MIL-STD-810F. The air velocity is at the low end of the range specified that will support particles of this size. The particle concentration is the most severe of the three recommended levels and reflects the concentration of particles found in the vicinity of a helicopter operating over an unpaved surface. The ambient chamber temperature was specified by the customer. The test duration is the minimum recommended by MIL-STD-810F. All three environmental test vendors were very familiar with these parameters and had performed many similar tests prior to these specific runs.

All three sets of test samples were manufactured in a consistent fashion. All had the same exterior coating and all were inspected before and after sand exposure in a consistent fashion and were exposed to a nominally identical blowing sand environment. A minimum of two samples were tested in the run at each of the facilities. The samples were scanned in a spectrophotometer at EEO to establish a pre-exposure transmittance value. After the samples were exposed to the

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environment, the samples were gently cleaned and re-scanned in the same way at the same wavelengths to determine the post-exposure transmittance. The normalized transmittance loss was calculated as,

$$T_{nor}[\%] = \{1 - (T_{post}[\%] / T_{pre}[\%])\} \times 100$$

Where T_{post} = the post exposure transmittance in percent
T_{pre} = the post exposure transmittance in percent

Table 2 presents the normalized transmittance loss at a series of wavelengths for the three test vendors. These wavelengths range from around 0.7 to 5 mm, increasing from A to F. A to D are in the NIR region and E to F are MWIR.

Table 2: Average transmission loss after Particle Erosion Testing

	LAB 1 - AVE	LAB 2 - AVE	LAB 3 - AVE
Wavelength (µm)	Normalized Transmission (or average) Loss (%)	Normalized Transmission (or average) Loss (%)	Normalized Transmission (or average) Loss (%)
A	8.8	23.4	19.7
B	9.4	22.9	19.4
C	6.5	21.5	17.8
D	4.5	14.7	12.8
E	7.2	4.9	4.7
F	6.9	4.0	3.8

There was as much as 70% difference in the transmittance loss of the samples when comparing the values obtained. Three nationally known environmental test vendors performing the "same" test per MIL-STD-810F on samples prepared in a consistent fashion produced significantly different results. Is one lab's result more "correct" than those of the others? Can these results be repeated? How can the responsible engineer ensure that the test is performed in a fashion that is consistent with MIL-STD-810F, Method 510.4, and Procedure II? The rest of this paper will attempt to provide the answers to these questions.

2 RECOMMENED TESTING APPROACH

EEO has developed a sound approach to sand testing that can be summarized in the following statement; survey a number of vendors, select two with whom you are the most confident, and work with them until you are satisfied that their equipment and procedures comply with MIL-STD-810, method 510.4, procedure II, and that their quality system will ensure repeatable testing. As an example, a competent test vendor will understand the differences in the various revisions of MIL-STD-810F, use equipment that is calibrated, demonstrate a solid understanding of all the critical parameters associated with sand testing, and have a certified quality system. Once you have selected your primary test vendor and have established that they are performing the test per the specification, it is a good idea to run a series of tests on various substrates and coatings using differing test parameters. EEO recommends using a combination of transmittance loss and visual inspection as the measure of performance of the substrate and coating. The visual inspection will determine if the coating and/or substrate has been damaged and to what extent (scuffed, pitted, partial or completely delaminated coating). The comparison of the pre and post test transmission scans provides an indication of the optical loss that can be expected due to exposing the optic to the specific environment (scatter due to damaged coating, increased reflection due to lost coating, etc.). When performing a sand test, EEO always uses a minimum of two samples just in case there is an issue with one. The samples are scanned at the wavelengths of interest prior to testing. EEO recommends actually testing a number of samples at varying exposure durations. This allows one to generate a plot of transmittance loss versus exposure duration. Figures 1 and 2 show typical post testing visual inspection photos. Chart 1 shows a typical plot of transmittance loss versus exposure duration for the same set of test wavelengths from Table 2.

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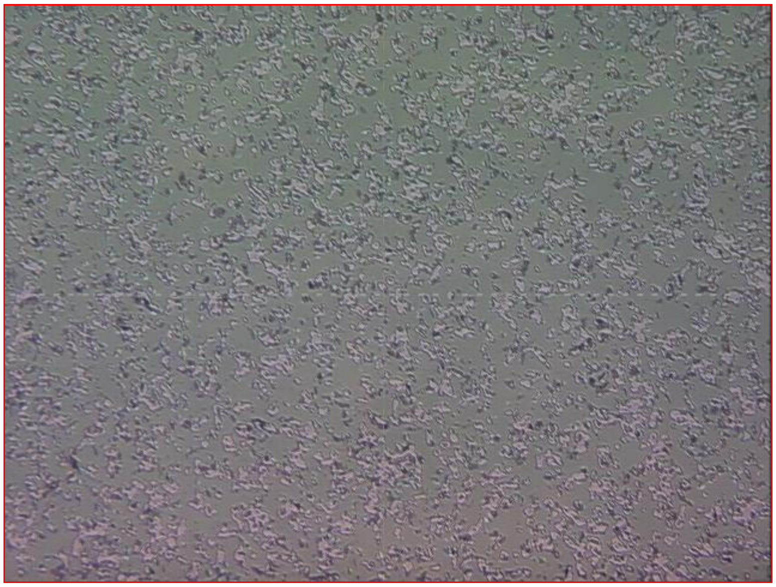

Figure 1: Typical Post-Test Visual Inspection Picture
(Sample @ 50x magnification after 40 mph blowing sand)

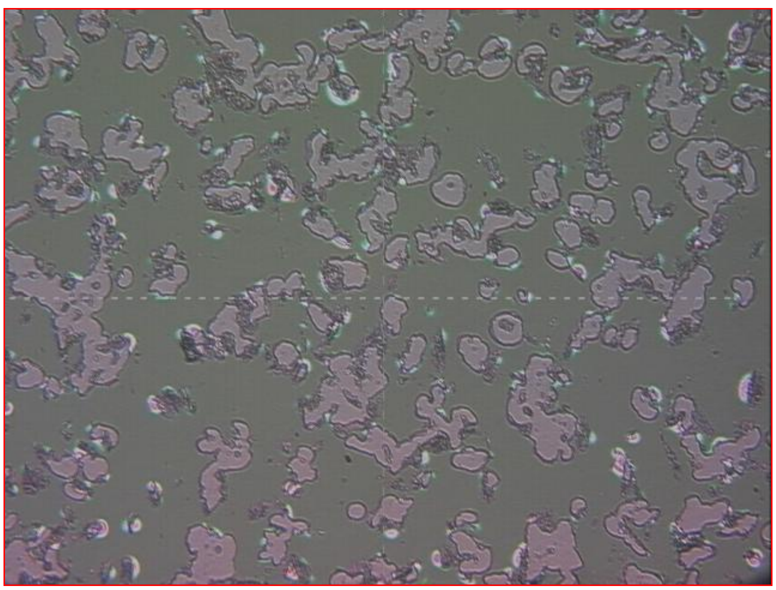

Figure 2: Typical Post-Test Visual Inspection Picture
(Sample @ 200x magnification after 40 mph blowing sand)

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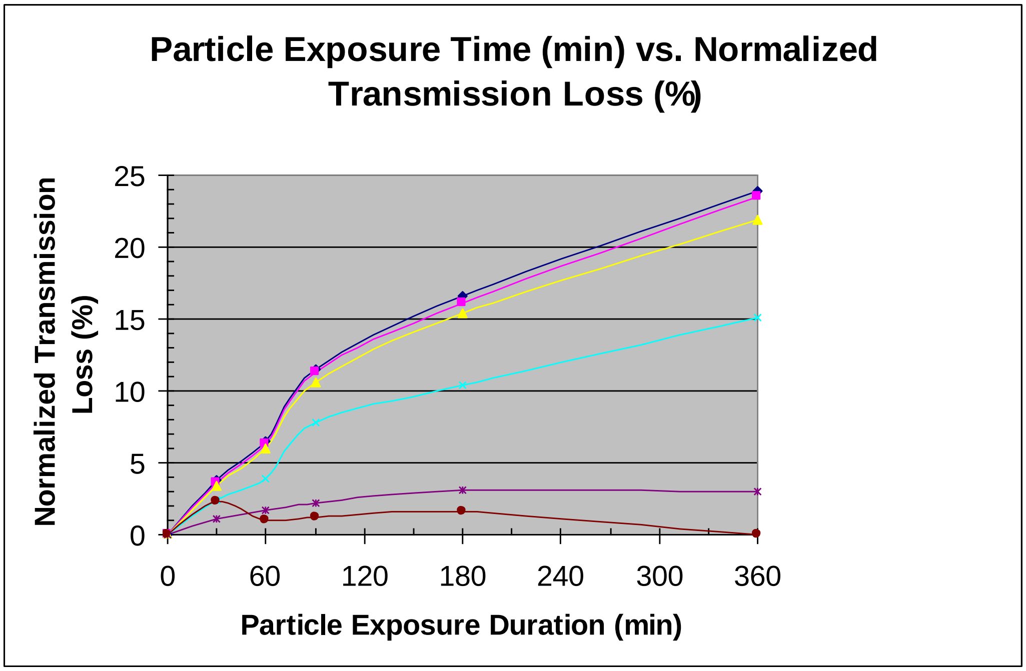

Chart 1: Typical Post-Test Plot Generated

3 CRITICAL TEST PARAMETERS

Reducing the variability in performance of MIL-STD-810 blowing sand testing begins with understanding each test parameter. The following is a discussion of these parameters including ideas as to how to control them.

3.1 Chamber Configuration

It is important that the chamber size be appropriate for the size sample being tested. The guidelines presented in MIL-STD-810F provide limits defining the ratio of sample size to the cross-sectional area (< 50%) and volume (< 30%) of the chamber. Remaining below these limits helps ensure proper circulation in the chamber. Care needs to be taken when testing small samples in a large chamber. Under such conditions, the correct concentration cannot be applied to the samples. Figures 3 and 4 show a blowing sand test chamber.

3.2 Air Stream Velocity

Most environmental test facilities generate a stream of air using a blower connected to ducting. The ducting then connects to the environmental chamber. The sand particles are introduced into the air stream and blown into the sample. Once you and the test vendor have determined the exact location of the samples in the chamber, place a digital turbine anemometer in the sample location and measure the air speed at that location in the chamber. This reading will be a good indication of the air speed and thus sand speed at sample impact. Note the range that the air speed varies as it is measured (the value will fluctuate as it is held in the stream). This fluctuation is an indication of the nature of the air flow in the chamber (laminar versus turbulent). An air speed variance of ± 100 ft. /min. represents a reasonably stable air stream. Beware of test facilities where the air stream varies by greater than this amount. EEO recommends witnessing this measurement or at a minimum have the test vendor record it along with the tolerance. Make sure that the anemometer has been calibrated.

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Figure 3: Example of a blowing sand test chamber
(Photograph courtesy of National Technical Systems – Santa Clarita Facility)

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Figure 4: Example of a blowing sand test chamber
(Photograph courtesy of National Technical Systems – Santa Clarita Facility)

3.3 Sand particle size, shape, hardness, and composition

The required particle sizes can vary based upon the MIL-STD-810 revision that is specified. Blowing sand is defined as the following:

Size:	150-850µm
Composition:	> 95% by weight SiO2
Structure:	sub angular
Krumbein number:	0.5-0.7 for both roundness and sphericity
Hardness factor:	7 mhors
Distribution (810F):	90 ± 5% by weight smaller than 600µm and larger than 149µm, at least 5% by weight > 600µm.

After looking into the various options, EEO recommends using U.S. Silica #1 Q-ROK unground silica (1) right out of the bag. Using this sand unaltered reduces the variability associated with having individual test vendors sieve the sand. Once used in a test, the sand cannot be reused due to either a change in shape or potential contamination.

3.4 Sample orientation relative to the sand particle stream

There are three main concerns in this area: the distance between the sand injection point (into the air stream) and the samples, the x-y location of the samples in the stream, and the distance of the samples from the chamber back wall or outlet duct. MIL-STD-810 states that the injection point of the sand into the air stream should be no closer than 10 feet from the sample to allow the particles time to get up to the air stream velocity. Placing the center of the sample area in the center of the inlet duct does not necessarily guarantee that the samples will see a uniform sand stream of particles. Gravity, as well as chamber air flow effects, can and will move the particles in the stream prior to impacting the samples. In order to counteract this effect, a simple test needs to be done to determine the correct x-y location. Place a sheet of soft material (soap stone, etc.) into the chamber in front of the center of the sand stream at the correct distance from the injection point. Turn on the air and sand for a short duration. Turn off the air and sand and visually inspect the material to determine the pattern and location of the impacts. The goal is to find the area that has the most uniform pattern. This is the side-to-side (x) and the up-down (y) location for the samples. The last concern is one of secondary strikes. Secondary strikes happen when the sand particles bounce off something in the chamber (fixturing, chamber walls, etc.) and get kicked back into the sand stream. This is a problem because these particles can increase the impact concentration plus the particles may not be the correct shape. In order to minimize this concern, make sure that the samples are far enough away from all chamber walls and the outlet duct. If this is not possible, place a board of some sort behind the samples. Angle the board down so as to direct the particles down to the floor of the chamber so they will not have a tendency to join the sand stream.

3.5 Sample mounting

Any means of holding the samples securely at the correct angle of impact for the entire test duration without distorting the air stream is acceptable. Care must be taken not to hold the sample on the coated surface. Most test vendors are not familiar with handling and mounting optics. EEO would highly recommend mounting the samples into a fixture yourself and bringing the entire fixture to the test vendor's facility. Then the only concern would be location, orientating, and supporting that fixture in the chamber. If samples are going to be removed at various exposure intervals (in order to generate a plot of transmittance loss vs. exposure duration), be sure to allow for removal of the outer most samples without disturbing the rest of the set-up. Figure 5 shows an approach to sample mounting.

3.6 Chamber Temperature

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The chamber temperature should be defined by the customer's requirements. MIL-STD-810 recommends conducting the test with the test item at the high operating or high storage temperature. If a temperature other than ambient is specified, the tolerance must be defined. Ambient temperature is defined as 25 ±10°C. Most environmental test vendors will monitor the chamber air temperature by inserting thermocouples into the chamber. Make sure that the thermocouples are in working condition and the temperature monitor is calibrated. Have the environmental test vendor provide a chart of the chamber temperature over the entire test duration so the temperature can be verified.

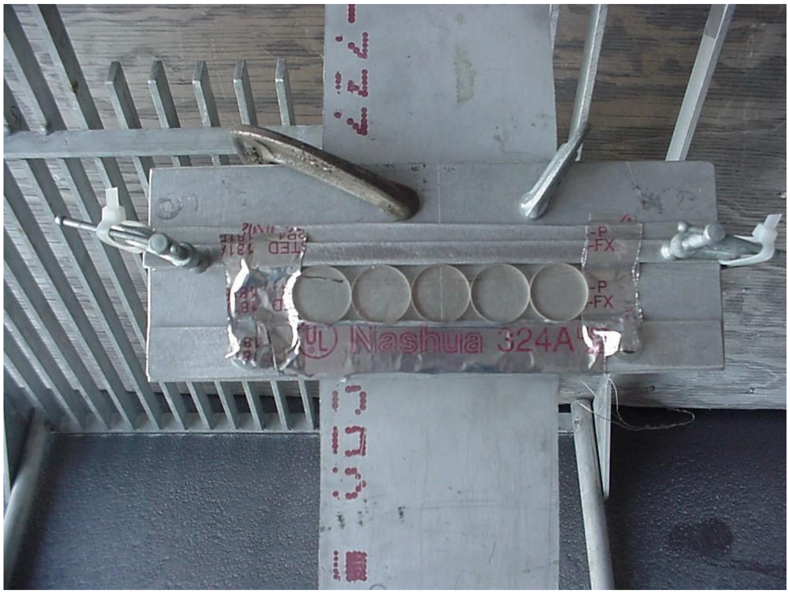

Figure 5: Example of a way to mount the test samples (samples shown are property of EEO)
(Photograph courtesy of National Technical Systems – Santa Clarita Facility)

3.7 Chamber Humidity

The relative humidity inside the chamber must remain below 30% per MIL-STD-810F. Most environmental test vendors will monitor the chamber air humidity by inserting a probe into the chamber. Make sure that the probe is in working condition and the humidity monitor is calibrated. Have the environmental test vendor provide a chart of the chamber humidity over the entire test duration so the humidity can be verified.

3.8 Concentration (means of achieving and calibration)

The sand concentration is specified by the customer. That value is actually used to determine the required mass flow rate as follows:

MFR = CON x CSA x VEL (1)

where

MFR = Mass Flow Rate [g/min] (calculated and measured)

CON = Concentration [g/ft^3] (specified by the customer)

CSA = Cross-sectional area of the sand stream [ft^2] (determined by the chamber configuration)

VEL = Air speed [ft/min.] (specified by the customer and measured)

Example Calculation: The customer specifies a blowing sand test with the following parameters:

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Concentration = 2.2 g/m^3, Speed = 40 mph, Angle of impact = Normal, duration is 90 minutes.

Based upon these specifications, the required mass flow rate can be calculated:

CON = 2.2 g/m^3 = 0.063 g/ft^3

CSA = 1 ft^2 (defined by test vendor's inlet duct dimensions)

VEL = 40 miles/hr = 3,520 ft / min.

MFR = (0.063 g/ft^3) x (1 ft^3) x (3520 ft/min.) = 222 grams /min. or 0.49 lbs/min.

Based upon this result, the test vendor can not only set the correct MFR but also calculate the amount of sand required to complete the test.

Sand = 0.49 lbs/min x 90 minutes = 44 lbs. of sand.

The basic operational assumption is that the concentration will be maintained in the chamber if the mass flow rate and air speed are maintained over the entire test duration. Implicit in that assumption is that all the sand particles must fall out of the stream after passing the samples (no secondary strikes). Methods to monitor the mass flow rate will be discussed in the mass delivery system section.

3.9 Mass delivery system and sand introduction method

The method of mass delivery is important since it plays a key role in maintaining the mass flow rate which establishes the sand concentration. Most environmental test vendors use some type of automated equipment such as an auger to introduce the sand into the air stream. The key item to look for here is consistent mass flow over the entire test duration. Ask the test vendor to verify the flow rate by decoupling the feed tube from the chamber and measuring the output mass of sand per unit time. This verifies that the mass delivery system is introducing the correct rate of sand into the stream. Also recommended is to have the vendor take periodic readings of the flow rate during a 90 minute duration to determine the stability of the flow rate. This data will provide the engineer with the confidence that the rate is correct and maintained over the entire test duration. Figures 6 shows an auger used to introduce the sand into the chamber. Figure 7 shows the mass flow rate verification test set-up. Beware of gravity fed mass delivery systems. The flow rate can be reduced if the valve clogs (usually a ball valve) or increased due to vibration of the chamber. These types of systems may pass the initial verification test but have problems maintaining a consistent and stable mass flow rate over the entire test duration.

4 OTHER CONSIDERATIONS

There are three additional characteristics of a test vendor that can affect the accuracy and repeatability of the performance of sand testing: technical capability, quality system, and customer relations. The presence of technically competent people overseeing the engineering and performance of the test equipment is critical. Asking some very simple questions during an introductory on-site visit will reveal quite a bit about their understanding and familiarity with the requirements. Make sure that the test vendor is certified and has an established quality system in place. This will help ensure that equipment is regularly calibrated and that standard processes and procedures are followed. Lastly, it is very important to select a test vendor that is willing to work with its customers. Some vendors do not really appreciate technical scrutiny to the level required to ensure that this type of testing is done properly. Others welcome your questions and are very willing to incorporate your constructive suggestions.

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Figure 6: Example of a mass delivery system
(Photograph courtesy of National Technical Systems – Santa Clarita Facility)

Figure 6: Example of a mass flow rate calibration set-up
(Photograph courtesy of National Technical Systems – Santa Clarita Facility)

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5 CONCLUSION

The fact that small particles of sand at relatively low speed (Mach 0.1) produce observable damage in diamond implies that sand erosion is a problem for all infrared window materials (3). With this said, all suppliers of optics to the Defense, Aerospace, and Homeland Security industries need to have the capability of evaluating the solid particle erosion performance of coatings and substrates. Recognizing the potential for variability in the performance of a blowing sand test, it is imperative that the responsible engineer take the suggested steps presented in this paper to reduce variability, ensure the correct performance, and increase the repeatability of MIL-STD-810 blowing sand testing.

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