INCH-POUND

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DEPARTMENT OF DEFENSE
TEST METHOD STANDARD

PARTICLE / SAND EROSION TESTING OF ROTOR BLADE PROTECTIVE MATERIALS

AMSC N/A **FSC 1615**

FOREWORD

1. This standard is approved for use by all Departments and Agencies of the Department of Defense.

2. The purpose of this standard is to provide a standardized test for particle/sand erosion resistance of materials used in leading edge erosion protection systems of helicopter rotor blades. This standard does not duplicate the real flight environment. The test measures the amount of material eroded from a stationary specimen by particles accelerated in a high-speed gas jet. These materials can be but are not limited to elastomers, other polymers (including reinforced plastics and composites), metals (including metal matrix composites), ceramics and coatings.

3. This pre-screening test does not, on its own, qualify a material for application onto a rotorblade. Many other material characterizations should be required to qualify a material. They may include but are not limited to additional erosion testing (whirling-arm sand, rain and/or combined particle/sand/rain), adhesion, large particle impact, impact (simulated tree strikes), hydrolysis, solar radiation, oxidation, extreme temperatures, temperature shock, fungus, salt fog, electromagnetic compatibility, thermal conductivity, fluid compatibility, radar cross section and integration onto an aircraft. Operational experience has shown that a variance exists between the two erosion mechanisms of particle/sand and rain. Therefore, additional qualification tests for combined particle/sand and rain erosion tests are suggested. The qualifying organization will define the specific requirements to fully qualify a material for overall acceptance.

4. The need for this standard is due mostly to the deployment in hot-arid regions and the effects the desert particle/sand has on current rotor blade protective systems. The development and selection of erosion resistant protective materials for rotor blades directly impacts aircrew survivability and mission completion. The availability of a standardized test to better assess the durability and repairability of rotor blade materials in these environments is needed. It is anticipated that this test standard will significantly increase the ‘time on wing’ of protective systems thereby increasing the duration between repair intervals and reducing the frequency of removal and replacement procedures – all of which are labor and material cost intensive.

5. Comments, suggestions, or questions on this document should be addressed to: Director, U.S. Army Research Laboratory, Weapons and Materials Research Directorate, Materials Manufacturing Technology Branch, Specification and Standards Office, Attn: RDRL-WMM-D, Aberdeen Proving Ground, MD 21005-5069 or emailed to rsquilla@us.army.mil. Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at https://assist.daps.dla.mil/.

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1. SCOPE

1.1 Scope. This standard describes a test method for testing the materials used as erosion protective systems of helicopter rotor blades for resistance to solid particle/sand erosion. These materials can be but are not limited to elastomers, other polymers (including reinforced plastics and composites), metals (including metal matrix composites), ceramics and coatings.

1.2 Purpose. The purpose of this standard is to provide a standardized test method for particle/sand erosion resistance of materials used as erosion protective systems of helicopter rotor blades. The test measures the amount of material eroded from a stationary specimen by particles accelerated in a high-speed gas jet.

1.3 Application. The various helicopter rotor blades that will be utilizing these coatings/appliqués are numerous. However, this test method is only one of many that is required to determine the acceptability of these coatings/appliqués, such as additional erosion testing (whirling-arm sand, rain, and/or combined particle/sand/rain), adhesion, impact, hydrolysis, solar radiation, oxidation, extreme temperatures, temperature shock, fungus, salt fog, electromagnetic compatibility, thermal conductivity, fluid compatibility, radar cross section and integration onto an aircraft.

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3, 4, or 5 of this standard. This section does not include documents cited in other sections of this standard or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3, 4, or 5 of this standard, whether or not they are listed.

2.2 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

ASTM INTERNATIONAL

ASTM E11	-	Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves
ASTM F1864	-	Standard Test Method for Dust Erosion Resistance of Optical and Infrared Transparent Materials and Coatings

(Copies of these documents are available from www.astm.org or ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.)

2.3 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 Erodent. The erodent is the sand particles used in the testing apparatus.

3.2 Erosion. Erosion is the progressive loss of original material from the surface of a test sample under investigation due to mechanical interaction between that surface and a stream of impinging solid particles.

3.3 Erosion failures.

3.3.1 Cracking. Cracking is generally a result of fatigue. Evidence of cracks exceeding established limits in the erosion protective system or blade requires replacement.

3.3.2 Debonding. Debonding is most prevalent with non-metallics. Any evidence of debonding that exceeds established limits of the erosion protection system or substrate requires repair or replacement.

3.3.3 Pitting. Pitting has the same basic criteria as surface wear. Careful inspection is required to ensure that complete penetration to the substrate has not occurred.

3.3.4 Surface wear. Surface wear is when the blade erosion protection system surface is worn. Metals generally wear smooth, whereas nonmetals usually wear rough. If the blade erosion protection system contour has been changed it should be checked to determine if it is within the established variation allowances. Even if the blade erosion protection system contour is satisfactory, once the substrate is exposed, the blade shall be repaired or replaced.

3.3.5 Wrinkling. Wrinkling is most prevalent with ductile metals that are worn to a specific minimum thickness. Once this occurs, repair or replacement is required.

3.4 Impingement. Impingement is a process resulting in a continuing succession of impacts between sand particles and a solid surface under test.

3.5 Impingement angle. An impingement (impact) angle that is normal to the stream of the dust jet shall be considered an angle of 90 degrees, and any deviation from this angle shall be measured countercurrent to the stream as shown in Figure 1. This angle may vary between 20^{o} and 90^{o} for the instrument shown in Figure 2.

3.6 Mass load. The mass of particle/sand per unit of total exposed surface area (including the sample holder) that impinges on the specimen. (See ASTM F1864).

3.7 Particle/sand erosion rate. Particle/sand erosion rate is equal to the mass loss (mg) divided by the erodent mass (g).

3.8 Volume loss. Volume loss is equal to the erosion rate divided by the density of the material and is reported in 10^{-3} g/cm^3.

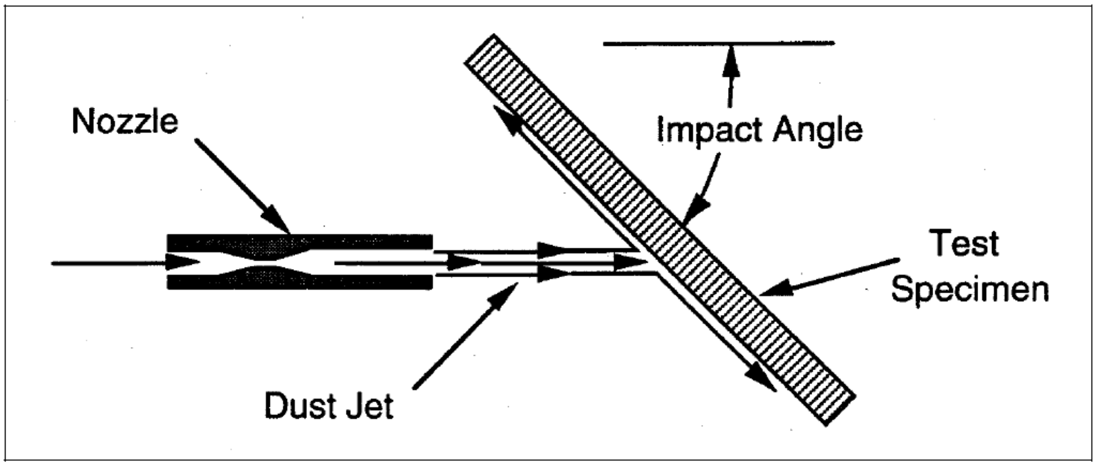

Figure 1. Sand Particle Erosion Schematic.

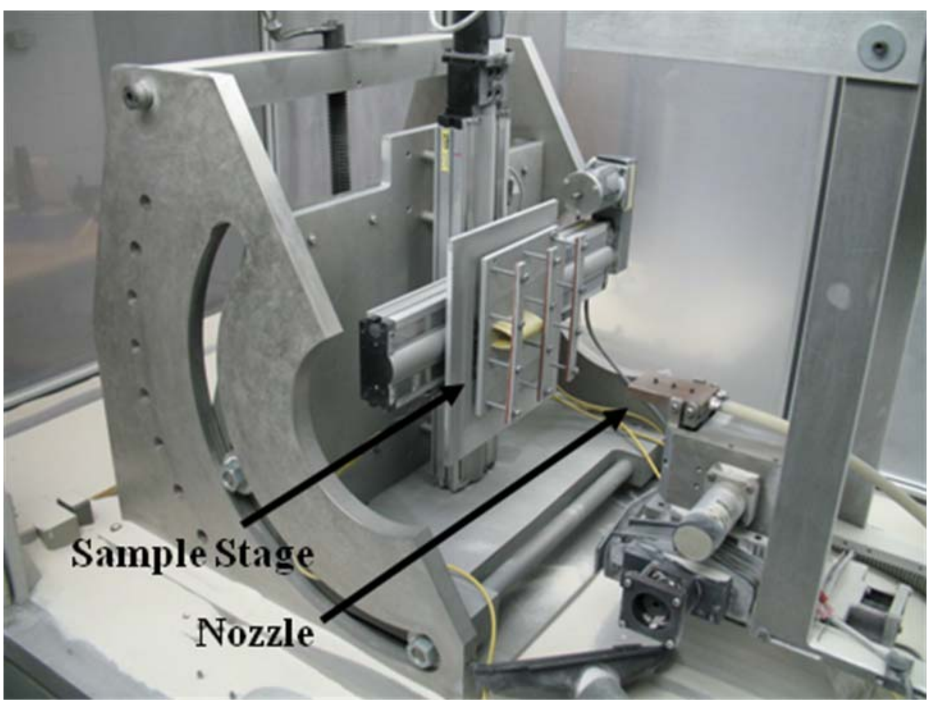

Figure 2. Particle / Sand Erosion Chamber

4. GENERAL REQUIREMENTS

4.1 Application. All materials developed to protect the exterior surfaces of the rotor blade shall be tested to the methods of this standard. The erodent for hot-arid regions encountered by rotor blade erosion protective systems in DoD unique military environments shall be simulated in the test apparatus specified in this standard. Although this test method only generates results that approximate relative particle/sand erosion resistance, these qualitative and quantitative results allow the Procuring Activity to determine which product may provide better particle/sand erosion resistance in hot-arid regions.

4.2 Testing apparatus. The testing apparatus shall be capable of simulating the effects of flight through a concentration of airborne particles/sand. See Section 5 for a description of the testing apparatus.

4.2.1 Standard test conditions. The values listed for the various test conditions (velocity, load, etc.) were determined by measuring each condition on actual rotor blades during takeoff and landing. Caution should be taken to ensure that the same types of materials are tested with the same parameters. The standard test conditions shall be as follows.

4.2.1.1 Pre-conditioning test specimens. All test specimens shall be pre-conditioned to the following requirements for at least 24 hours prior to testing: 75° F (23° C) and 50% Relative Humidity (RH). The tolerance shall be ± 5° F and ± 5% RH unless otherwise specified in the contract or purchase order (see 6.2).

4.2.1.2 Testing temperature and humidity. Unless otherwise specified in the contract or purchase order (see 6.2) for the specific material being tested, the testing shall be conducted at a temperature of 75° F ± 5° F and at a Relative Humidity (RH) of 50%. (see 5.2.3 and 6.5). The temperature and RH shall be measured within the test chamber prior to testing.

4.2.1.3 Erodent. A synthetic mineral quartz sand formed by the fracture of quartz pebbles shall be the erodent. Shattering or crushing quartz pebbles is the source of the high degree of sharpness that makes this sand uniquely suited for this standard. There are currently no acceptable substitutions for this particle/sand. Sources for golf trap or bunker sand are available and shall be acceptable for use if they are made by the fracture of quartz pebbles. Quartz sand not prepared by crushing is not guaranteed to have an acceptable degree of sharpness and angularity for this standard. The prepared particle/sand must not be water-washed but may be water sprayed during processing and handling for dust control. A water-washed particle/sand will not produce acceptable erosion results for this standard.

4.2.1.3.1 Erodent sieve size. An industrial bulk sieve (in accordance with ASTM E11) using a single size cut is the preferred method of preparing the size fraction. The particle/sand shall be evenly distributed across the size range of 240 to 550 microns (µm) in diameter in the as-sieved condition. Mixing of size cuts can be used to achieve the 240 to 550 micron (µm) size distribution provided there is an even distribution of size through this range. This size of erodent is comparable with particle/sand collected in the plane of the rotor blades during desert hover and low-level flight testing. Sand composed of particle sizes smaller than 200 microns (µm) sieve diameter is unacceptable. Hand sieving is not an acceptable preparation method due to typical poor size control. A recommended source for this un-sieved synthetic particle/sand is listed in paragraph 6.7.

4.2.1.3.2 Reuse of erosion media. The sharpness and angularity of the particle/sand will be reduced during use and contamination of the particle/sand is likely, therefore the reuse of the erosion media is not permitted.

WARNING

Refer to a quartz sand Material Safety Data Sheet (MSDS) or equivalent for health hazard data, e.g., exposure to silica can cause silicosis; other material may cause adverse health effects. See 6.3.1.

4.2.1.4 Velocity. Unless otherwise specified in the contract or purchase order (see 6.2) for the specific material being tested, the mean velocity of the erodent measured at a distance of four (4) inches from the nozzle tip shall be 730 ft. /sec. ± 35 ft. /sec. (see 5.2.3.2). This velocity is representative of helicopter rotor tip speeds during landing and takeoff conditions.

4.2.1.5 Impingement angle. The impingement angle for flat 1" square coupons shall be dependent on the material being tested (see 5.2.3.3). The specific angle(s) shall be specified in the contract or purchase order (see 6.2).

4.2.1.6 Sand particle mass load. Unless otherwise specified in the contract or purchase order (see 6.2), the sand particle mass load shall be between 30 and 50 grams/cm^2 (see 5.2.3.4). This value was determined to be effective to separate performance of a wide range of test samples.

4.3 Materials. Each material submitted for testing must include a description that includes the class of material (metallic or elastomeric), chemical composition, material density, type of coating or treatment, if applicable (polysiloxane, CARC, etc.), and coating thickness. Caution should be taken to ensure that the same types of materials are tested with the same parameters specified in previous contracts or purchase orders (see 6.2). Provider of test samples shall disclose any hazardous or toxic components.

4.4 Preparation of test specimens. Test specimens shall be made from the same material and assembled in a manner intended to represent the rotor blade erosion protective system(s). The size of the test specimens shall be as specified in Section 5.2.2. When applicable, the test specimens shall be cut from the actual production item.

4.4.1 Sampling and inspection. Unless otherwise specified in the contract or purchase order (see 6.2), sampling, inspection, and testing shall be in accordance with Section 5 of this standard.

4.4.2 Cleaning test specimens. A procedure for cleaning the specimen surface prior to testing, shall be specified in the contract or purchase order (see 6.2).

4.5 Erosion resistance.

4.5.1 Pre-test inspection. Unless otherwise specified in the contract or purchase order (see 6.2), test specimens shall show no gross mechanical damage of any kind prior to the testing (see 3.3.1 to 3.3.5).

4.5.2 Mass loss. The test specimen shall be weighed by the test equipment operator before and after the test to the nearest 0.001 gram. The impingement area shall also be determined before the test. Mass loss is defined as the difference between the initial and final weights. Mass loss must be adjusted (normalized) for test specimens with non-standard area.

4.5.2.1 Anomalous mass change. Care should be taken when weighing the test specimen after testing. Therefore, the contract or purchase order shall specify the applicable cleaning method for the specific material after testing (see 6.2). Sand particles can become entrapped in elastomeric and ductile metals, adding to the weight of the test specimen. Some polymeric materials can absorb atmospheric moisture, also adding to the weight of the test specimen.

4.6 Testing facility. Test specimens shall be forwarded to an independent facility that can perform testing as described herein.

4.7 Test report. A detailed test report shall be forwarded to the customer. The test report shall include the test conditions (temperature and humidity), raw data, applicable test parameters (mass load, sand particle size, sand particle velocity, and impingement angle) and sand erosion rate, if applicable, and a summary of any visual evaluations. Raw data shall consist of but not be limited to the weight of each test sample before and after testing and the area before testing. If the customer requires additional information, such as, storage conditions, it shall be so noted in the contract or purchase order (see 6.2)

5. DETAILED REQUIREMENTS

5.1 General. The detailed formats for testing candidate materials are listed in this section.

5.2 Test method.

5.2.1 Test apparatus. The test apparatus shall conform to the requirements of the test apparatus specified in ASTM F1864 except as noted below.

5.2.1.1 Test apparatus description. Sand particles are accelerated in a small diameter (approximately 0.125-inch) high-speed gas jet and directed onto a test specimen as illustrated in Figure 1. Since the diameter of the dust jet is smaller than the test specimen area, the test specimens are translated past the jet while the jet is oscillated so the dust covers the test specimen in a uniform manner. This combination of movements provides a uniform sand particle loading (sand mass intercepted per unit surface area). The test chamber containing the nozzle and articulating stage is shown in Figure 2. Compressed air (or nitrogen) provides the transport gas stream with regulators and pressure transducers to measure and control the pressure at the nozzle. The air or nitrogen that is utilized shall be from a dry, filtered (20 micron (µm)) source. Sand particles are metered into the transport gas stream from a pressurized screw feeder system (Figure 3). Since the screw feeder provides a very accurate and uniform sand flow, the sand particle mass applied to the specimen is determined by the run time based on prior screw feeder calibration intervals. Sand particle size, velocity and impingement angle can be controlled independently.

Figure 3. Pressurized Screw-Feeder Sand Plenum.

5.2.1.2 Sand erosion facility. The test apparatus described herein and in ASTM F1864 differs from the real flight environment and whirling-arm sand erosion testing in several aspects. The specimen is stationary and the sand particle transport stream is moving at the specified mean velocity. When moving different size sand particles in a transport stream, it is normal for the larger mass sand particles to travel slower than less massive ones. In the flight environment and whirling-arm testing, the material impacts all sand particles at the same velocity, regardless of sand particle mass. Also the material is under stress caused by centrifugal force of the whirling blade. These differences are not expected to have any significant effect on ranking the erosion resistance of various materials. Whereas the key parameters in the flight environment are the sand cloud mass concentration (mass or volume of sand particles per unit volume) and velocity, in the sand particle erosion facility the key parameters are the sand particle mass loading and velocity. The relationship between the mass loading in the test facility, and the sand cloud concentration, impact velocity, and time in the flight environment is as follows:

Mass Load = [sand cloud concentration] x [impact velocity] x [time]

5.2.2 Test specimens. Test specimens shall be made from the same composition and fabricated in the same manner as the specific design of the rotor blade appliqué or coating being tested. The size of the test specimen shall be 1" x 1" x 0.25", unless otherwise specified in the contract or purchase order (see 6.2). See Figure 4.

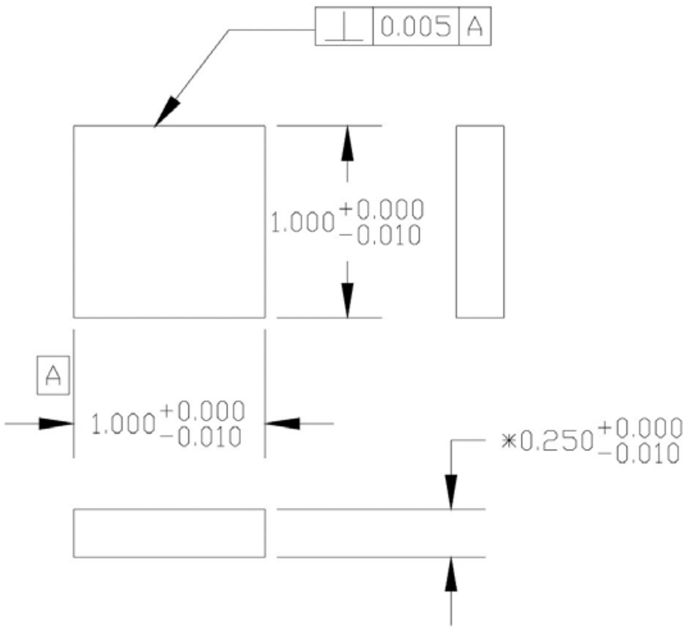

Figure 4. Standard Square Test Specimen
NOTE: Dimensions are in inches (see 5.2.2).

5.2.3 Test conditions. Test conditions consist of five independently variable parameters (see 5.2.3.1, 5.2.3.1.1, 5.2.3.2, 5.2.3.3, and 5.2.3.4) that define the exposure environment for the sample to be tested. The testing temperature shall be as specified in paragraph 4.2.1.1.

5.2.3.1 Erodent. The total amount of erodent used for each test shall be determined to calculate the sand erosion rate for the test sample.

5.2.3.1.1 Sand particle size. Standard particles consist of dry silica sand (see 4.2.1.3) that has been sieved to the sand particle size ranges (µm) as described in 4.2.1.3.1. Sand particle sizes are uniformly distributed within the 240 – 550 micron (µm) size range.

5.2.3.2 Velocity. Mean sand particle stream velocity shall be as specified in 4.2.1.4.

5.2.3.3 Impingement angle. Impingement angle is dependent on the material being tested (see 4.2.1.4). The specific angle(s) shall be specified in the contract or purchase order (see 6.2). See Figure 1.

5.2.3.4 Sand particle mass load. Sand particle mass load shall be as specified in 4.2.1.6 (see 6.2).

5.2.4 Test procedures. Weigh each test specimen before test. Confirm sand feed rate is appropriate to deliver the required mass for the test. Mount the specimens in the sample holder and report their positions in the log. Specimens are always oriented vertically by name or arrow mark when placed in the holder. The samples shall be returned to the same position and orientation in the holder if they have been removed for an intermediate weigh step before restarting the test. If needed, adjust the translation stage to the specified impingement angle. Load sample holder plate. Close the test cabinet, put on personal hearing protection, and turn on the dust collection system. Bring the air pressure up to that required for the test and turn on nozzle oscillation. Begin feeding the erodent into the pressurized air flow. Visually confirm that erodent is being fed to the system. Begin the specimen translation program and visually confirm that the sample holder is moving and continue the exposure until the desired mass load is achieved. At the end of the exposure, stop the erodent flow and the nozzle oscillation. Turn off dust collector and stop air flow. Remove the sample holder plate from the test chamber and unload the specimens and carefully dry-wipe the specimens clean (a blow-off gun can also be used, if necessary). Reweigh each specimen and calculate its mass loss. Repeat this process for each test specimen in the machine. Adjust to specified impingement angle. Bring the machine up to pressure. Introduce the erodent into the flow. Begin translating the dust jet in front of the specimen(s); continue until the desired mass load is achieved. Stop the flow of air and erodent, remove specimens, carefully clean and reweigh each specimen, and calculate the mass and volume loss. Adjust (normalize) calculations for specimens with non-standard area. Repeat this process for each test specimen.

5.3 Data Analysis.

5.3.1 Volume loss. The erosion performance of the material shall be assessed based on comparison with the baseline rotor blade materials. The maximum acceptable volume loss shall be as specified in the contract or purchase order (see 6.2). Failure of any averaged series of test samples to meet the requirements shall constitute rejection of the specific material being tested.

5.3.2 Ranking of the various materials. For a specific type of material, such as, elastomers of similar density, a particle/sand erosion rate for that material can be calculated by dividing the number of grams of coatings that were removed (Mass loss, see 4.5.2) by the amount of particle/sand used (see 5.2.3.1). A lower value indicates better particle/sand erosion resistance.

5.3.3 Failure of a coating. Debonds, cracking, pitting, or wrinkling during testing shall constitute failure of a coating.

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use. This standard attempts to simulate the desert environment, specifically SW Asia, that rotor blades experience in flight, and to provide an evaluation of candidate materials that may perform better in that environment. The specific simulation requirements include approximate particle sizes from 240 to 550 microns (μm), particle mass loads of 30 grams/cm^2, particle velocities of 730 ft. /sec., and impingement angles from 20 to 90^o. Candidate materials include but not limited to elastomers, other polymers (including reinforced plastics and composites), metals (including metal matrix composites), ceramics and coatings. These design appliqués and coatings should be in the form of insert, leading edges, paints, overlays, coatings, or other surfacing techniques that protects the base material from its environment. The following services and associated rotorcrafts will have immediate interest in this standard: the Air Force (MH-53, HH-60, UH-1, CV-22), the Army (CH-47, OH-58, UH-60, AH-64, UAV), the Navy (H-1, H-46, H-53, H-60, V-22), and the US Coast Guard (HH-3, HH-60, HH-65).

6.2 Acquisition requirements. Acquisition documents should specify the following:

a. Title, number, and date of the standard.
b. If a different tolerance is specified (see 4.2.1.1).
c. If a different temperature and/or relative humidity is specified (see 4.2.1.2 and 6.5).
d. If a different mean velocity is specified (see 4.2.1.4).
e. The specific impingement angle (see 4.2.1.5 and 5.2.3.3).
f. If a different sand particle mass load is specified (see 4.2.1.6 and 5.2.3.4).
g. Caution should be taken to ensure that the same types of materials are tested with the same parameters used in previous contracts or purchase orders (see 4.3).
h. If sampling size, inspection or testing is different (see 4.4.1).
i. A procedure for cleaning the specimen surface prior to testing (see 4.4.2).
j. If gross mechanical damage of any kind is acceptable (see 4.5.1).
k. A procedure for cleaning the specimen surface after testing (see 4.5.2.1).
l. If additional information is required by the customer (see 4.7).
m. If a different test specimen size is specified (see 5.2.2).
n. The maximum acceptable volume loss (see 5.3.1).
o. If a MSDS should be included with each unit of issue of material covered by this specification (see 6.3).

6.3 Material safety data sheets (MSDS). The contracting activity should be provided a material safety data sheet for each part at the time of contract award. The MSDS should be provided in accordance with OSHA section 1910.1200, 29 CFR Chapter XVII and found as part of FED-STD-313. OSHA section 1910.1200 requires reporting threshold criteria for known or suspected human carcinogens on MSDS 0.1 percent or greater, and 1 percent or greater for other health hazards. The MSDS should be included with each unit of issue of material covered by the specification, when specified (see 6.2). Contracting officers will identify those activities requiring copies of completed material safety data sheets prepared in accordance with FED-STD-313. The pertinent Government mailing addresses for submission of data are listed in FED-STD-313.

6.4 Erosion resistance of an elastomer. The failure of the elastomer occurs when the erosion reaches the substrate. However, some entrapped air bubbles, localized adhesion loss or physical defects in the specimens may contribute to early failure at isolated sites. It is therefore very important to observe the degree of erosion across the entire surface. In general, if only isolated sites are eroded to the substrate while the rest of the surface remains undamaged, the elastomer is likely to have some physical defects inside. On the other hand, if widespread erosion damage is observed, it is the inherent nature of a poor solid particle erosion resistant elastomer.

6.5 Testing temperature. The contract or purchase order should consider the temperature of the environment that the test item (i.e. rotor blades) will be used / operated, plus any additional considerations. It should be noted that the color of the rotor blades does have an effect on the temperature of the rotor blades. It is quite likely that the temperature on stationary (non-whirling) black rotor blades may reach 200° - 220° F, or higher, in a hot arid environment. See Paragraphs 4.2.1.2 and 6.2.

6.6 Recommended post-test metallographic examination. Samples may be prepared in accordance with ASTM E3 and photographed at the required magnification in accordance with ASTM E883. Samples are prepared by sectioning the 1" x 1" squares in half in the direction perpendicular to the impingement plane. This sectioned face can be metallographically prepared to examine at higher magnifications to determine such conditions as sand entrapment in a coating, coating integrity, coating adhesion, and surface effects resulting from solid particle impingement

6.7 Source for the un-sieved synthetic particle/sand . A source for the un-sieved synthetic particle/sand reference in this standard is R. W. Sidley, P.O. Box 150 Painesville, OH 44077, phone 800-536-9343. Their Internet website is at www.pro-angle.com. Their product is called "Pro-Angle White Bunker Hydrosand" and is referred to as "golf sand" in this standard. Alternate sources may become available in the future.

6.8 Subject term (key word) listing.

Aircraft
Coatings
Design appliqués
Rotorcraft

CONCLUDING MATERIAL

Custodian:
Army - MR
Navy - AS
Air Force - 11

Preparing activity:
Army - MR

Project 1615-2006-001

Review activities:
Army – AV
Navy – CG, NP
Air Force – 84, 99

NOTE: The activities listed above were interested in this document as of the date of this document. Since organizations and responsibilities can change, you should verify the currency of the information above using the ASSIST Online database at https://assist.daps.dla.mil/.