

# Standardization in Coating Evaluation: A Universal System for Repair Coatings

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With the many Original Equipment Manufacturer's (OEM's) criteria for evaluation of thermal spray materials, laboratories are forced to have multiple criteria/systems to test and analyze coatings. As airlines/repair shops are moving towards overhaul of more variable engine types/models in their shops, the need to have a common evaluation system has been identified and is currently being addressed. A sub-committee of the European Airline Committee for Materials Technology is currently working to formulate this common system for coating evaluation. Participants are from GEAE, Pratt & Whitney, Rolls Royce, SNECMA and KLM Royal Dutch Airlines. The progress and goals of this group will be documented and reported.

## 1 Introduction

Standardization of testing and manufacturing processes is a very important goal as all industries become more global in both the technical and business sense. The processes involved in the repair of aircraft engines are no exception to this world-wide trend. With this in mind, a subcommittee of the European Airline Committee for Materials Technology (EACMT) has been working on the testing aspects of thermal spray coatings since April 1997.

### 1.1 Why is it critical to address this issue?

The current state of testing in the aerospace repair industry is a variety of Standard Practice Manuals (SPM's) from the major OEM's with many different requirements. Each major manufacturer uses different rating systems, definitions of characteristics, and acceptance criteria. This is really the status of testing for many industries that use thermal spray coatings but obviously the requirements in many cases are not as stringent as aerospace limits. With the lack of a common framework, it means a repair shop has to put more effort, time and money fulfilling all the different requirements, resulting in the impossibility for a repair shop to develop a universal system for thermal spray coating evaluation. As more shops repair multiple engine types across many OEM lines, the impetus for a more universal system has increased. For those not familiar with the EACMT, the committee was formed by some AEA (Association of European Airlines) members to discuss together issues associated with repair of aircraft components. The first working group meeting was held in 1967 in Hamburg. In due time, the OEM's were invited to participate in the working group. The main emphasis of the committee is on surface treatments (like plating, shotpeening, NDT,

gritblasting, etc...) and special processes such as heat treatment, welding, etc. The proven success of the group (34 Airlines are members of the EACMT from which 8 are steering group members: KLM Royal Dutch Airlines, Lufthansa, British Airways, Iberia, Jugoslavia Airlines, Finnair, Swissair and SAS) has been a willingness to pool resources in attacking special process problems with the OEM's (GEAE, Pratt & Whitney, Rolls-Royce, SNECMA, Boeing, Airbus, British Aerospace)

### 1.2 What are the major goals of this effort?

There are four simple goals of this effort: Standardization, Simplification and Savings in both Time and Money. A standardized system will normally lead to a more simplified approach as the most efficient portions of all systems are incorporated. With this increased efficiency, analysis should be more rapid and less costly. This paper will summarize the general procedure for addressing this issue and provide a short synopsis of some but not all work performed to date.

## 2.0 General Procedure

In 1997, the EACMT working group defined the objectives for the sub working group for reviewing the total evaluation system of thermal spray coatings. Those objectives were:

- ⇒ recommend one set of requirements and evaluation methods per coating/process
- ⇒ establish uniform criteria for physical and mechanical test specimens
- ⇒ simplify extent of QC evaluation
- ⇒ standardize test intervals
- ⇒ define uniform metallographic preparation and evaluation

The formed sub working group was named: 'EACMT Subcommittee for Standardization of Quality Control Procedures for Plasma Sprayed Coatings' and the subcommittee members were originally comprised of representatives of all the OEM's, airframers and engine manufacturers alike, with representation from two European airlines, KLM Royal Dutch Airlines and Lufthansa. However, with the passage of time and changes of personnel and assignments, the working committee has evolved to members of engine manufacturers and KLM Royal Dutch Airlines. In addition, there are numerous technical experts who are called upon by each of the OEM's to provide metallurgical support in this very specialized area.

## 2.1 Achieved Objectives

In general, the scope of the EACMT subcommittee was to standardize how thermal spray coatings are evaluated. As with any standardization task, the initial difficulty is to define a scope when looking at such a tremendous amount of information to review. With the EACMT subcommittee, the process has evolved into the following steps:

- a) Identify the common requirements in all systems
- b) Review the evaluation methods within the systems and
  - I. Eliminate out of date methods or methodologies which are difficult to control
  - II. Critique and question the need for unique requirements and identify for possible deletion
- c) Develop a common and agreed upon framework/format to document and manage the standardization
- d) Identify initial goals that provide early success to move the effort forward

Commonality in the systems is relatively easy to identify with regard to test types used. Table 1 lists the general tests which were identified in review of the major OEM's participating in this program.

**Table 1 General List of Aerospace Thermal Spray Coating Tests**

Metallography	Cup Test *
Tensile Bond Strength Testing	Stamp test *
Macrohardness	Scratch Hardness *
Microhardness	Bend Testing *
Lap Shear Testing *	

The right hand column of the table lists the QC tools used as fast go/no-go in shop determination tests. The left hand column represents QC tools used in the labs for more accurate determination tests. The committee's progress with identification and

elimination of out dated or hard to control test methods resulted in eliminating the tests marked with a \*. Those test types have or are in the process of being eliminated as requirements in the SPM's of all committee OEM participants.

With the common test *types* identified and reviewed/deleted, the next and more difficult step was discussion of test *methodology/procedures*-how is the evaluation actually performed?

In reality, this is the true issue for standardization. Varied issues concerning methodology before the committee in different states of resolution are:

- The thickness requirements for test specimens covering metallography, tensile and hardness
- The list of approved adhesives and bonding fixtures used for tensile bond testing
- The number of hardness readings required for macro and micro hardness and the pattern of indentations on the specimens
- The type of material which should be used for fabrication of the varied test specimens

Resolution of the listed issues and many others is necessitating research of past history and the technical justification of how or why certain steps or requirements were added to a method. The process also identifies the strengths/weaknesses of each OEM's methodology and the need for improvement. This is found to be especially applicable to metallography as covered in the next section.

## 3.0 Current Progress

### 3.1 Metallography

In the thermal spray community and within the subcommittee, it is recognized that metallography is the single test which provides the most valuable information concerning thermal spray quality. Unfortunately, it is also the group consensus that metallography is one of the most difficult procedures to control and can provide misleading information when applied incorrectly. This area has therefore been a major focus of the committee.

The subcommittee realized the critical item for consideration was the system of framework required to process and evaluate the sample from beginning to end. As the varied systems were reviewed, many questions were identified:

- Metallographic training

With regard to training in the aerospace industry, there is a growing awareness of the need to have educated and competent lab technicians due to the difficult nature of this work. A number of courses are available that deal with this subject. To develop synergy between European and American working groups that support this training, different rep-

representatives have been contacted about the efforts of the committee. The goal of this synergy is that major portions of the revised and universal evaluation system might be included in future educational materials.

- **Metallographic Preparation**
  - Suggested mounting methods for varied coatings
  - Recommended grinding/polishing methods
  - Role of consumables in preparation
  - Repolish rules
  
- **Microstructural Evaluation**
  - Definition of characteristics (unmelts, delamination, etc.)
  - Use of photostandards vs. percentage rating
  - Recommended magnifications for evaluation

With this in mind, the committee developed the common framework in Figure 1.

*What is the current status of this metallographic effort?*

Tremendous progress has been made in Section 2 on metallographic preparation and Section 3 on definition of rules/characteristics for microstructural evaluation. Figure 2 represents the consensus on cleaning and mounting of coating samples for preparation of aerospace thermal spray coatings. The current definition of common microstructural characteristics is shown in Figure 3.

One engine OEM has already incorporated the referenced changes into the current revision of the SPM. The other major OEM's will soon follow. The committee's continued progress will be reported in upcoming thermal spray conferences in the future.

### 3.2 Test frequency

Frequency of testing can vary from a sample set with every part sprayed for very critical applications to bi-monthly testing in shops where Statistical Process Control (SPC) shows excellent consistency and reproducibility. However, when reviewing the SPC methods employed by each OEM, the procedures and acceptance limits can result in very different requirements.

At this moment, the subcommittee is busy establishing test frequencies in 3 major areas:

- initial qualification
- requalification
- on-going qualification

This covers qualification of equipment, thermal spray operators, consumables, coatings and aircraft parts.

### 3.3 Metallographic atlas

In evaluation of coatings, a universal atlas would be an invaluable tool for assisting the laboratory technician. It is the wish of the EACMT airline members to

strive for this goal but this is still part of discussions with the OEM's.

In focusing on the task of identifying attainable goals for the committee, the initial target of the group was to identify and develop metallographic methods/requirements for the three coatings as listed in Table 2. The committee's ultimate goal is to address all coatings but a small representative segment was chosen as a starting point.

<p><b>Standardized SPM Section 1 (Scope)</b></p> <ul style="list-style-type: none"> <li>- Scope (content &amp; summary)</li> </ul> <p><b>Standardized SPM Section 2 (Equipment and Metallographic Preparation)</b></p> <ul style="list-style-type: none"> <li>- Equipment (strong recommendations for semi-automatic)</li> <li>- Qualification of the metallurgist/metallographer</li> <li>- Qualification/certification of the Control Laboratory</li> <li>- Metallographic preparation</li> </ul> <p><b>Standardized SPM Section 3 (Metallographic Atlas for Specific Coating Features/Characteristics)</b></p> <ul style="list-style-type: none"> <li>- Definitions including example picture(s) 200X or 500X of Section A</li> <li>- There will be single or multiple pictures for each characteristic as required</li> <li>- The characteristics covered will be: <ul style="list-style-type: none"> <li>- Unmelts</li> <li>- Oxides</li> <li>- Separation</li> <li>- Delaminations</li> <li>- Cracks</li> <li>- Voids</li> <li>- Others as required</li> </ul> </li> <li>- Rules for Metallographic Evaluation of Coated Test Samples</li> </ul> <p><b>Standardized SPM Section 4 (Metallographic Atlas for Specific Coatings)</b></p> <ul style="list-style-type: none"> <li>- Specific examples of coating conditions in words and/or single/multiple pictures:</li> <li>- Typical pictures of the coating</li> <li>- Specific conditions of the coating with arrows and legend.</li> <li>- Acceptable/rejectable pictures of the coating</li> <li>- Acceptables/rejectables/ratables in words</li> </ul>
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**Figure 1 Common Framework for SPM Metallography**

## 4.0 Conclusions

The need for standardization of evaluation for thermal spray coatings in the aerospace industry has been

identified and the EACMT sub-committee is addressing all aspects of this issue. Excellent progress has been made in elimination of non-value added test methods and special emphasis is being placed on defining a system for preparation of metallographic specimens and microstructural evaluation. A complete revision of the thermal system is targeted for year end 2002 and will hopefully be presented at the next ITSC in 2003.

**Table 2 Coatings for EACMT Review**

<b>Name</b>	<b>Typical application</b>
Nickel Aluminum 95/5	Bondcoat or dimensional restoration
Tungsten Carbide Cobalt 88/12	Anti-wear coating (low temperatures)
Chrome Carbide Nickel Chrome 75/25	Anti-wear coating (high temperatures)

Cleaning

Cleaning is an important step after sectioning:

- a. to remove all contaminants from the surface of the specimen
- b. to remove any fluids that may have penetrated into the coating especially for porous materials.

Recommended methods may include the following or any combination thereof:

- a. Washing with soap and water
- b. Brushing or soaking of sample in solvent like materials such as acetone/alcohol followed by application of heat with possibly a heat gun or hotplate to drive off any internal absorption
- c. Cleaning of sample by performing an initial/extra vacuum step (if using vacuum impregnation in mounting) to volatilize any entrapped materials

Mounting

Mounting is a very critical step for metallography of coatings because this procedure serves to hold the sample together during grinding /polishing especially for porous materials.

Methods for mounting of coating materials are suggested below and sometimes used together:

- a. Hot Mounting (in a press)
- b. Cold Mounting (can be assisted by heat, vacuum impregnation or pressure impregnation)

Suggested mounting materials for coatings are:

- a. Hot mount epoxies
- b. Cold mount epoxies

Choice of mounting procedure/material should be driven by:

- a. Time available for mounting
- b. Size of porosity and level of voids in coating and degree of interconnected porosity
- c. Required viscosity of epoxy for impregnation of porosity if important
- d. Hardness of coating vs. mounting material

For porous coatings like abrasives, thermal barrier coatings (TBC), and other materials, cold mounting with vacuum impregnation alone and/or pressure impregnation is recommended. The viscosity of the cold mount epoxy will be important if porosity in the coating is small and difficult to impregnate.

A well impregnated sample will also show less tendency towards pullout of phases and microstructure damage.

For the choice of mounting method/material, it is critical to maintain written procedures and identify the critical parameters requiring control for consistent techniques.

**Figure 2 Mounting Excerpt from SPM Section on Metallographic Preparation**

*Interface Contamination*

Embedded foreign particles or contamination between the base metal and the coating. This contamination may be in the form of base metal oxides, grit, or residual coating remaining from previous stripping operations.

*Coating Contamination*

Foreign material present in the coating. This contamination may be in the form of metallic or ceramic particles. These particles may come from nozzle hardware, contaminated powder feed systems, etc.

*Transverse Crack*

A linear, or branched, separation with random direction within the coating that must be greater than .001 inch (25  $\mu\text{m}$  or 1 mil) to be ratable.

*Delamination*

A separation or horizontal defect that follows, or is associated with, contour of the laminar build-up or coating layers that must be greater than .005 inch (125  $\mu\text{m}$  or 5 mil) to be ratable. For linear interface defects, see Separation.

*Grit Blast Inclusion*

Embedded abrasive particle associated with the substrate surface preparation.

*Integrity*

Overall coating quality associated with oxides porosity and unmelted particles.

*Layering*

Stratification of coating components or features.

*Oxide*

Oxidized coating constituent.

*Oxide Clusters*

Concentration of oxides that must be greater than .003 inch (75  $\mu\text{m}$ ) to be ratable.

*Oxide Stringers*

Linear oxides

*Porosity*

Holes within a coating.

*Pull-out*

Mechanically induced damage associated with metallographic preparation.

*Separation*

A defect that follows, or is associated with, the contour of the interface-must be longer than .005 inch (125  $\mu\text{m}$ ) to be ratable. For linear intracoating defects, see Delamination.

*Unmelted Particles*

Unreacted powder particles contained within the coating matrix. These particles have a round or globular appearance (3:2 ratio), not adhered to the surrounding coating matrix by any more than 25% and greater than .002 inch (50  $\mu\text{m}$ ) in any direction.

*Uniformity*

Homogenous distribution of coating constituents (e.g. phases, porosity, oxides, etc.).

**Figure 3 General Definitions for Microstructural Characteristics**