Performance Assessment of Penetrant and Magnetic Particle Systems used at Hellenic Aerospace Industry

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Abstract -The Hellenic Aerospace Industry NDI facility performs Penetrant and Magnetic particles process control operations (daily, weekly, monthly, quarterly) to ensure the performance of the in-use materials. Taking into consideration that all penetrant materials shall conform to the requirements of SAE AMS 2644 and all magnetic particles materials shall conform to SAE AMS 3044 or SAE AMS 3045 or SAE AMS 3046, a conformance to the as mentioned specifications report is always required fr om the material supplier. However, even though conformance assures efficiency, performance tests of the materials prior to be used are prerequisite to assess the applicability of the systems-test parameters at HAI's NDI facility.

Keywords: NDT performance, Penetrant Inspection, Magnetic Particle Inspection, UV Inspection

1 Introduction

In the aerospace industry, Non-Destructive Testing (NDT) and Inspection (NDI) are vital functions in achieving the goals of efficiency and quality at an acceptable cost. In many cases, as in Penetrant Testing and Magnetic Particle Testing, where these functions are highly critical, the reliability of the method depends a lot on the performance of the means (penetrant and magnetic system), as well as on operator skills, knowledge and ability, because final inspection is done visually and under ultra violet light.

The widely used Liquid Penetrant Testing is a reliable, high-sensitive non-destructive method to detect open to surface discontinuities. The method is based on a plethora of physical and chemical properties, sometimes conflicting each other (e.g. removability/sensitivity) [1]. Although liquid penetrant is an easy method to apply, over 40 factors have been identified that can affect the performance of a penetrant inspection [2]. These factors include variables influenced by (a) the formulation of the materials, (b) the inspection methods and techniques, (c) the process control procedures, (d) human factors, and (e) the sample and flaw characteristics.

In fact, different product families (penetrant, remover/emulsifier, developer] are being used, adapted to parts and structures requirements to optimize results. For that, different penetrant systems (penetrant-emulsifier/remover combination or penetrant only for water washable system) were developed by manufacturers and qualified as a system in accordance with the requirements of the aerospace material specification SAE AMS 2644 (former MIL-I-25135). Moreover, a qualified commercial list of products under AMS 2644 appears in QPL-AMS-2644, according to their type, method, and sensitivity level. Listing of materials on the QPL (=Qualified Product List) does not guarantee that subsequent products of the same formulation will be acceptable; it merely indicates that the original raw materials, formulation and compounding practice can result in an acceptable product. However, many factors and conditions involved in manufacturing of the penetrant systems may affect their performance.

Magnetic Particle Inspection is used to detect open to surface or slightly subsurface (up to 6mm depth) discontinuities in ferromagnetic materials only. Magnetic particle examination consists of magnetizing the area to be examined, applying suitably prepared magnetic particles in a appropriate vehicle while the area is magnetized, and subsequently interpreting and evaluating any resulting particle accumulations. Since the particles used are smaller, wet method techniques are generally used to locate smaller discontinuities than the dry method [3]. Material specification AMS 2641 is applied to the MPI Vehicle (oil-based), whereas SAE AMS 3040, 3041, 3042, 3043, 3044, 3045, 3046, are applicable to different magnetic particles.

Because contrast is invariably higher with fluorescent materials, these are invariably utilized in both process examinations for aerospace applications. Thus, throughout the paper the Penetrant Testing (PT) method will be referred as FPI (Fluorescent Penetrant Inspection) and the wet method used in Magnetic Particle Testing (MT) will be also referred as MPI (Magnetic Particle Inspection).

For both methods, evaluation and qualification of systems, the control of incoming materials, the in-process control, the qualification of the inspectors and the applicable inspection standards are primordial to achieve the best results.

In the present paper, the qualification of penetrant and magnetic particle systems was performed comparatively. The testing process described in international specifications was followed providing the best detectability of defects in standard specimens. Optimum values of the main characteristics of the processes involved were predefined.

2 FPI Penetrant Systems Qualification

In order to maintain the integrity of a penetrant process, the process as a whole and the individual components of the system are regularly checked to ensure that they meet the required standards. Thus, the in-use penetrant system overall performance is being daily checked using the same standardized test panels, according to ASTM E 1417. The comparison is made using photographs of initial (previously) obtained indications using the master panels and unused material (an example is given in Figure 1). When the performance of the in-use materials falls below the performance of the unused materials, the in-use materials are further checked prior to conducting any penetrant examinations on real parts. The same procedure was used in order to qualify fresh penetrant systems, comprising penetrant, emulsifier (if used) and developer. The qualification was performed by processing standardized test panels with known defects (PSM type) at the appropriate processing parameters. These standardized panels are made of stainless steel that are chrome plated on one half and surfaced finished on the other half to produce the desired roughness (for rinsability/removability check). The chrome plated section is impacted from the back side to produce a starburst set of cracks. There are five impacted areas to produce range of crack sizes (Figure 1).

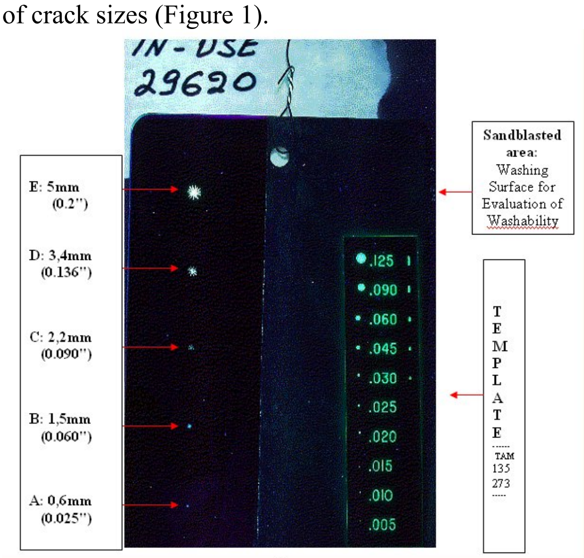


Figure 1 Initial system capability test of a calibrated test panel PSM-5 upon receipt. Penetrant Type I (fluorescent), Method D, sensitivity Level 4 (ultra-high), form a (dry developer)

For the present study two water washable penetrant systems of the same sensitivity, Level 3 (high) (SYSTEM 2: Method A), as well as one lipophilic post-emulsified penetrant system (SYSTEM 3: Method B) and one hydrophilic post-emulsified penetrant system (SYSTEM 4: Method D) were compared. Standard test procedure per ASTM E 1417 was applied. Non-aqueous wet developer is used (form d), which is generally recognized as the most sensitive when properly applied [1]. Conditions of the test are given in Table 1.

Table 1 Test Parameters

Dwell time minimum: 10min. @ 30 ºC
Water temperature 28°C
Water pressure: 40 psi (275 kPa)
Drying @ 65 ºC
Examination under UV light, min 1200 $\mu W/cm^2$ @ 30 cm

Evidence of proper PT system performance can be assessed when the minimum number of indications in the test panel is visible under black light inspection for the specific sensitivity level of penetrant being used. It has to be noted that each indication shall be measured to assure that its longest dimension under UV illumination meets the requirements shown in Table 2. It was verified that the size of the indications shall be within ± 20% of the size measured from the master panel.

Table 2 PSM panels artificial discontinuities min size

Artificial Discontinuity	Minimum Diameter Size (mm)
A	No size limit
B	1.1
C	1.9
D	3.2
E	4.6

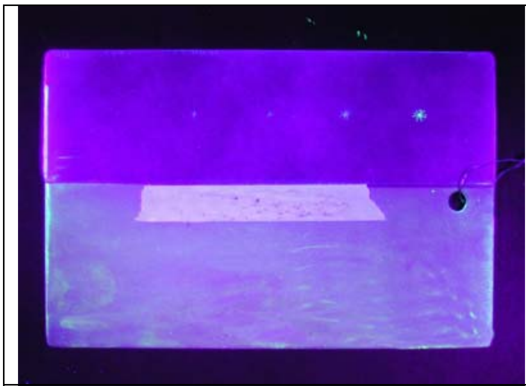
For the overall working PSM panels at HAI the minimum number of crack centers for each sensitivity level shall be as in the Table 3 below per an internal HAI Process Specification, which comprises customers control testing requirements.

The results are presented in the Figures 2-4.

Table 3 Min detectable number of cracks per FPI Method - Level (sensitivity)

System	Method - Level	Minimum number of crack centers
1	A-2	4
2	A-3	4
3	B-3	4
4	D-3	4

5	D-4	5



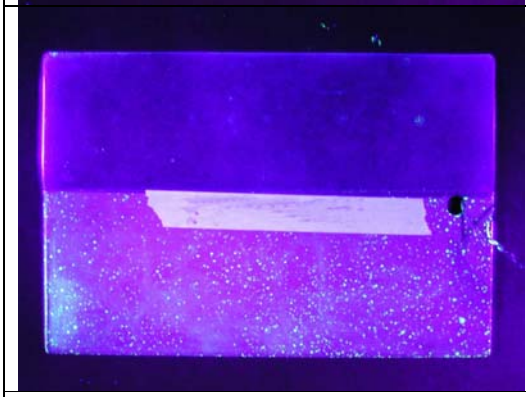


Figure 2 Results on PSM panel for water washable systems 2 (Method A, Level 3, form d)

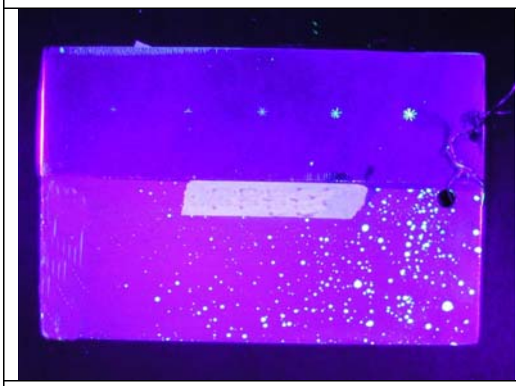


Figure 3 Results on PSM panel for hydrophilic postemulsifiable penetrant + remover; system 4: Method D, Level 3, form d

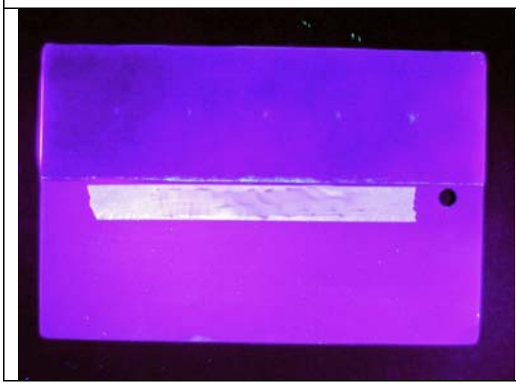


Figure 4 Results on PSM panel for lipophilic postemulsifiable penetrant + emulsifier; system 3: Method B, Level 3, form d

After each use, all penetrant and developer residues are cleaned by ultrasounds and the panels are stored submerged in protected dry envelope to minimize degradation. In addition, each test panel is annually sent off to the supplier for thorough cleaning, crack measurement and calibration.

3 Magnetic Particle Testing Materials Qualification

Two magnetic particles systems (Wet Method-Fluorescent, magnetic particles in suspension) were compared in wet horizontal magnetic particle equipment in which the suspension is retained in a reservoir and re-circulated for continuous use. One system is suspended in water and the other in light petroleum, and they are both fluorescent ready-to-use at a given concentration and both are applied to the test surface by pouring. When water is used as a suspension for magnetic particles it shall be conditioned suitable to provide for proper wetting, particle dispersion and corrosion protection. Both wet particles meet the requirements of AMS 3045 (Magnetic Particles, Fluorescent, Wet Method, Oil Vehicle, ready-to-use).

Proper wetting is determined by water break test. Operating temperature was 28^0C. The viscosity of the liquid vehicles used is kept below 5cSt (5 mm^2/s) to obtain optimum results. The particles concentration in the test bath was measured to be 0.15 ml.

The comparison and the performance tests were carried out using a Ketos Ring, as described in ASTM E1444 (Figure 5) and the following methodology: The conductor is placed with a diameter between 25 and 31 mm and a length longer than 40 cm through the center of the ring. The Ketos ring is placed on the length of the conductor. Magnetization is applied to the ring circularly by passing the current specified in Table 3 through the conductor. The wet suspension is poured to the ring using the continuous method. Examination is followed within 1 min after current application (examination of fluorescent baths was conducted under a black light of not less than 1200 $\mu w/cm^2$). The numbers of hole indications shall meet or exceed these specified in Table 4.

Results are given in Figure 6.

Table 4 Required Indications When Using the KETOS Ring Specimen of Figure 5

Particles Used	Central Conductor FWDC Amperage	Minimum Number Holes
Wet suspension, Fluorescent	1400 2500 3400	3 5 6

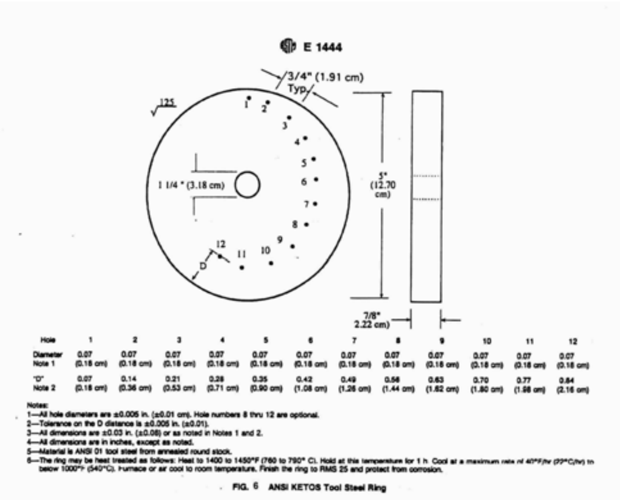


Figure 5 Manufacturing details of a Ketos Ring per ASTM E 1444

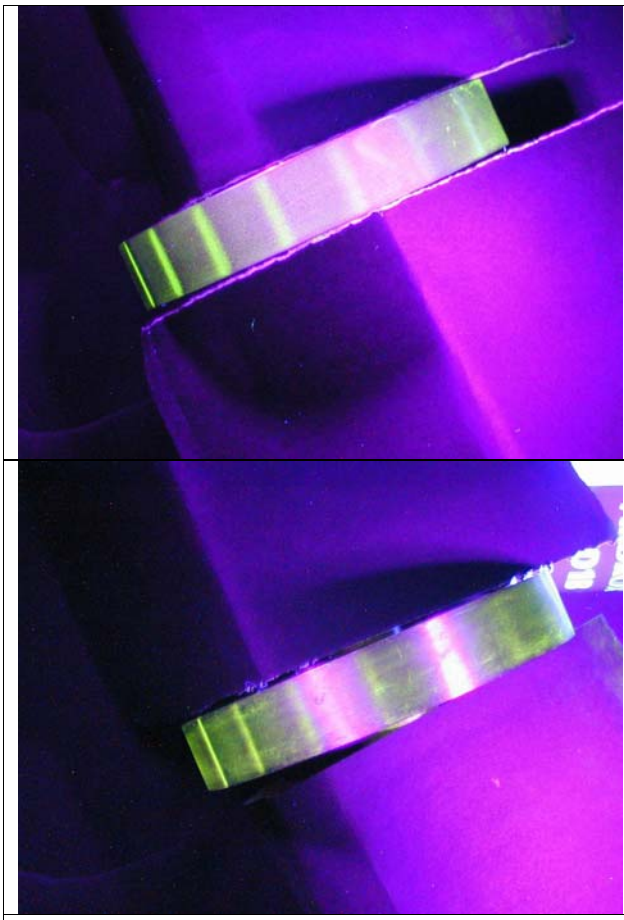


Figure 6 MPI comparative results for two different MP systems

4 Discussion of results

The selection of a liquid penetrant system is not a straightforward task. Many factors must be considered when selecting the penetrant materials [penetrant, remover/emulsifier and developer] for a particular application.

As described in section 2, two FPI commercial products of the same Method A (water washable) were comparatively investigated using the standard PSM panels. As shown in Figure 2, the performance of the first one is slightly better that the second, by clearly revealing the 5 defects, whereas the indications of the second one are blurred. It has to be also mentioned that under the same process parameters the washablility (penetrant removability) of the later was inferior (penetrant residues in the lower part (rough part) of the panel).

Another consideration in the selection of a penetrant system is whether water washable, postemulsifiable or solvent removable penetrants will be used. Postemulsifiable systems are designed to reduce the possibility of over washing, which is one of the factors known to reduce sensitivity. Solvent removable penetrants, when properly used, can have the highest sensitivity, but are usually not practical for large-area inspection or high-volume production. In Figures 3 & 4 the results of a hydrophilic penetrant/remover system and a lipophilic penetrant/emulsifier were given respectively. Considering the Figures 2, 3 & 4 the higher sensitivity of the postemulsifiable hydrophilic penetrant can be concluded.

Figure 6 depicts the results of two different MPI systems under the same parameters using the Ketos ring; only in the first one (oil based vehicle) the maximum number of holes can be seen.

The influence of various process parameters upon detectability of defects in penetrant testing has been investigated by both researchers and product manufacturers [2] [4] [5] [6]. An earlier method, referred to as “Two Fold Congruency test”, has been developed by Pratt & Whitney to screen penetrants for sensitivity and reproducibility [7]. This test, performed on controlled parts in the laboratory, statistically evaluates indications found by each penetrant against a standard. Vision systems and computed algorithms were used to quantify the results of penetrant testing along with operating parameters [8] [9]. The developed methodology (software+equipment) allows a quantitative evaluation of defect indications by its optical and geometrical characteristics correlated to the physical undergoing processes. These methods and equipment could be a possible solution to assess the quality of a new product family used in PT or MT inspection.

5 Conclusions

Increased knowledge of surface chemistry, new chemical compounds and improved methods of formulation have resulted in the development of mainly penetrant systems, and to a lesser content magnetic particle systems, with increased sensitivity and flaw detection capabilities. Although quality assurance provisions are required from material manufacturers, as described in the current industrial specifications SAE AMS 2644 and EN ISO 3452-2 for FPI, as well as in the applicable SAE AMS for MPI, these materials cannot always assure the sensitivity, reproducibility or washablity required for the inspection. Even certificates of conformance issued by the manufacturer confirming the compliance to the as mentioned requirements are not sufficient. Thus, prior to using or specifying a new product family for FPI or MPI, the materials should be thoroughly tested to assure adequate washablity, sensitivity and reproducibility for penetrant systems and sensitivity and reproducibility for magnetic particle/vehicle system.

6 References

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