HOW GOOD IS YOUR INSPECTION? HOW DO YOU MEASURE UP?

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INTRODUCTION

Engineering design based on damage tolerance criteria requires assuming the presence of flaws that are not detected in production and life-cycle maintenance operations [1,2]. Structural integrity is assured during service life by material selection and design load control to accommodate flaws that cannot be, or are not detected during final inspection and acceptance. Nondestructive evaluation (NDE) is the primary basis for the assumed detection capability (no flaws present that are larger than the assumed size) and it is necessary to quantify to applied NDE detection capabilities to assure that design / structural integrity requirements are met. NDE methods involve multiple application parameters and the resultant detection capability varies with each application. For critical structures, it is necessary to quantify detection capabilities for each application and to maintain rigid process control to assure that the detection capability is constant. The smallest flaw detected is not important. The largest flaw missed is the parameter of primary concern.

HOW GOOD IS MY INSPECTION?

Although a high performance (small flaw detection) capability is assumed (and is often validated) in modern production and maintenance facilities, the requirement to quantify and demonstrate a high performance capability is relatively recent. NDE capabilities performance demonstration is not a trivial task and, unfortunately, pride in the workplace often results in overconfidence and overestimation of individual facility / operator capabilities. Good engineering practice involves comprehensive review of prior art and practices to establish a target baseline for performance with similar materials, NDE methods and process control parameters. Fortunately, much work has been done and is documented in the literature to provide target baseline capabilities in a variety of applications. A significant amount of this work has been captured and documented in a reference data book [3] thus easing the literature search task for finding baseline capabilities.

The sensitivity of NDE applications to application variables and processing parameters requires that reference data be found that most closely matches the intended

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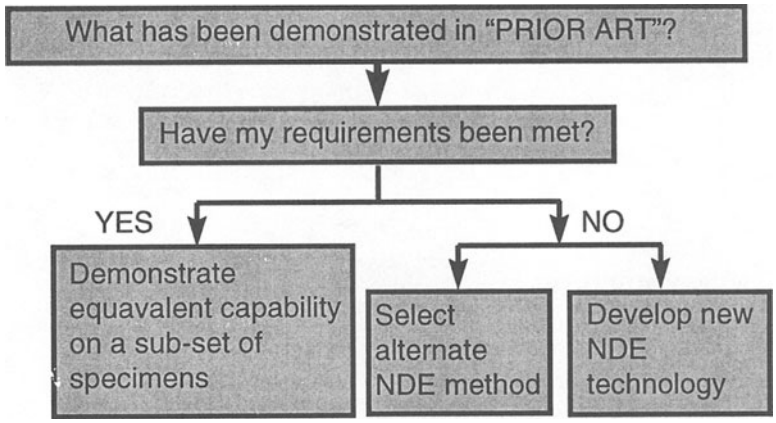

Figure 1. Recommended protocol for selecting and NDE procedure for critical, damage tolerant hardware applications.

application conditions. If a reasonable match is found, the task of demonstrating NDE procedure equivalency can be accomplished with a few representative test specimens [4]. If a match cannot be found, or, if the demonstrated capability does not meet the function use requirements for the intended application, an alternate NDE method or a full scale demonstration of the intended NDE procedure must be considered. A recommended protocol for selecting and qualifying an NDE procedure is shown schematically in Fig. 1. The user is cautioned that expectations of supernatural performance of an in-house process which greatly exceeds the reference capabilities is seldom warranted. The cost of attempting a supernatural demonstration is significant and rarely meets expectations.

PROBABILITY OF DETECTION (POD)

Since detection is dependent on multiple parameters, including materials and flaw characteristics, demonstration of capability necessarily involves processing a variety of flaws of different sizes to provide sampling and analysis that are consistent with modern statistical quality control methods. Probability of Detection (POD) is the metric that is used to quantify the capability of a nondestructive evaluation procedure for detection of cracks (or other quantifiable material anomalies). It is usually presented in the form of a curve relating the "probability of detection" as a function of increasing crack size. The engineering metric of primary interest is the threshold transition point where the curve crosses the 90% detection threshold. This point on the curve is often referenced as the 90/95 point and is used as the basis for an achievable crack detection capability for new design; for life assessment using damage tolerance procedures; and for life-cycle management based on damage tolerance and/or deterministic analysis procedures.

Nondestructive evaluation involves multiple materials, process variables and application variables and is therefor not single valued, but is described as a procedural functional variable in the same manner that materials properties are derived. The 90/95 value is the accepted convention for single valued communication of NDE procedure capabilities. The methods of sampling and data analysis are discussed elsewhere [5,6,7,8].

POD data are specific to specific NDE procedures and applications and rigid conformance to the material, flaw type, "calibration method", NDE procedure and conditions of application are imposed in use of data and/or generation of data. It is therefor necessary to identify and included materials and NDE processing / measurement parameters for each data set used and to assure that the application and NDE process parameters are consistent with the data used / generated and that those parameters will be held constant for the intended application. / life-cycle. It is important to noted that good design practices using POD data includes application of a design margin to accommodate expected variances in application.

POD DATA AND USE

The development and evolution of the POD metric has resulted in a much better understanding of NDE procedures applications and sensitivity of individual procedures to changes in materials, application and processing parameters. It is important to recognize that POD is a measure of end-to-end NDE process capabilities and results should be expected to vary with slight changes in processing parameters [9,10]. For example, Fig. 2 shows the relative effects of etching and proof testing on fluorescent penetrant when applied to aluminum alloy specimens. FIGURE 3 shows the corresponding effects for fluorescent penetrant inspection when applied to titanium alloy panels.

HOW DO I MEASURE UP?

The available reference data on NDE capabilities performance is substantial and has increased with requirements imposed by increasing use of damage tolerance as a basis for assuring initial and continuing structural integrity of engineering components, assemblies and systems in critical applications. Such data provides a valuable reference for establishing, comparing and improving detection capabilities in individual applications. Some references [11] now contain raw data for additional aid in integrating the products of prior art with newly developed data. New and more general NDE models are now being developed to provide further aid to new applications. It is important to recognize that both

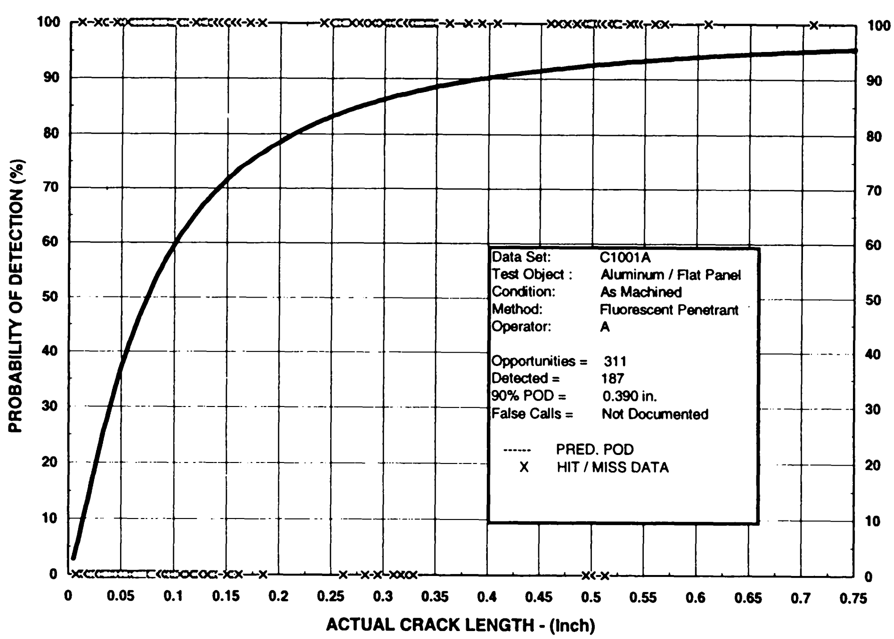

Figure 2a. Relative performance capabilities of fluorescent penetrant inspection on aluminum alloy panels - as machined.

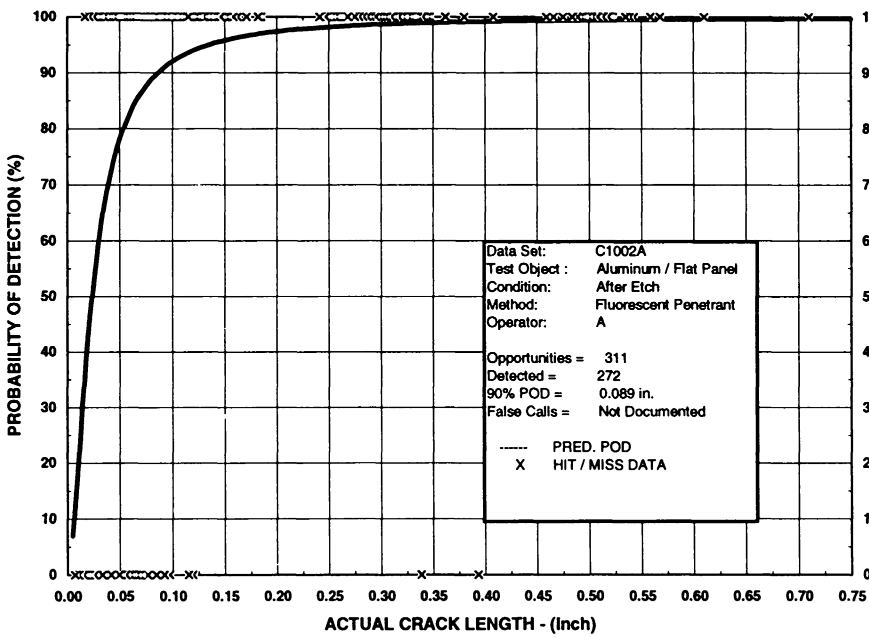

Figure 2b. Relative performance capabilities of fluorescent penetrant inspection on aluminum alloy panels - after etch.

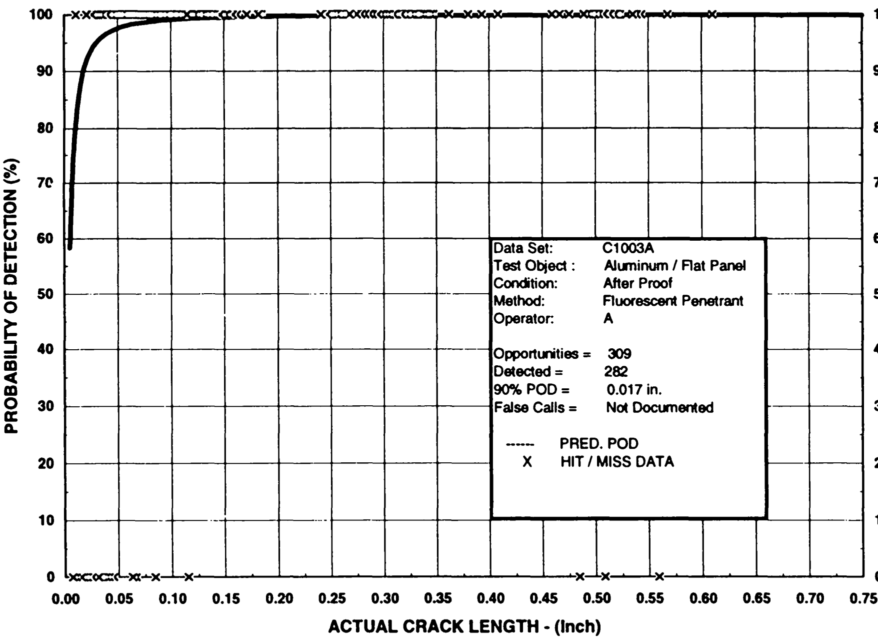

Figure 2c. Relative performance capabilities of fluorescent penetrant inspection on aluminum alloy panels - after etch and proof loading.

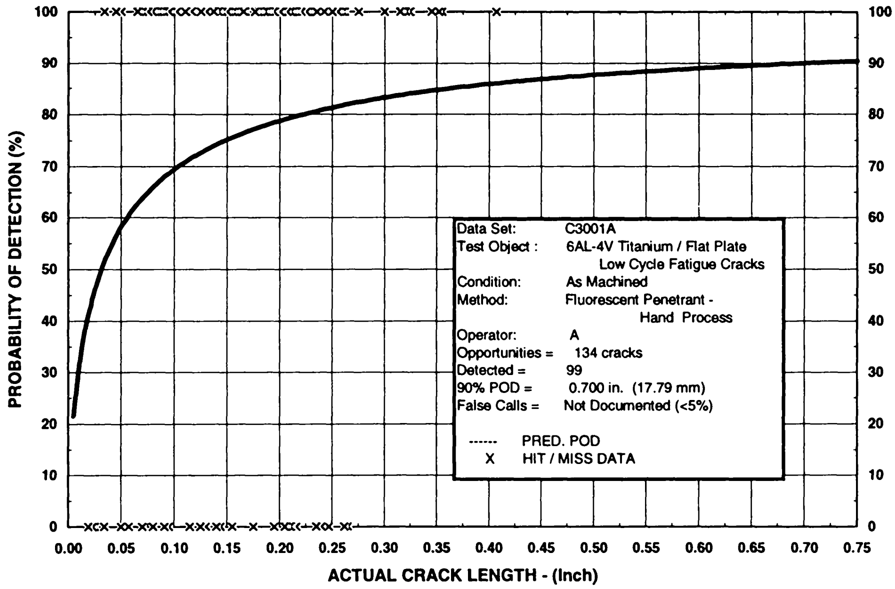

Figure 3a. Relative performance capabilities of fluorescent penetrant inspection on titanium alloy panels - as machined.

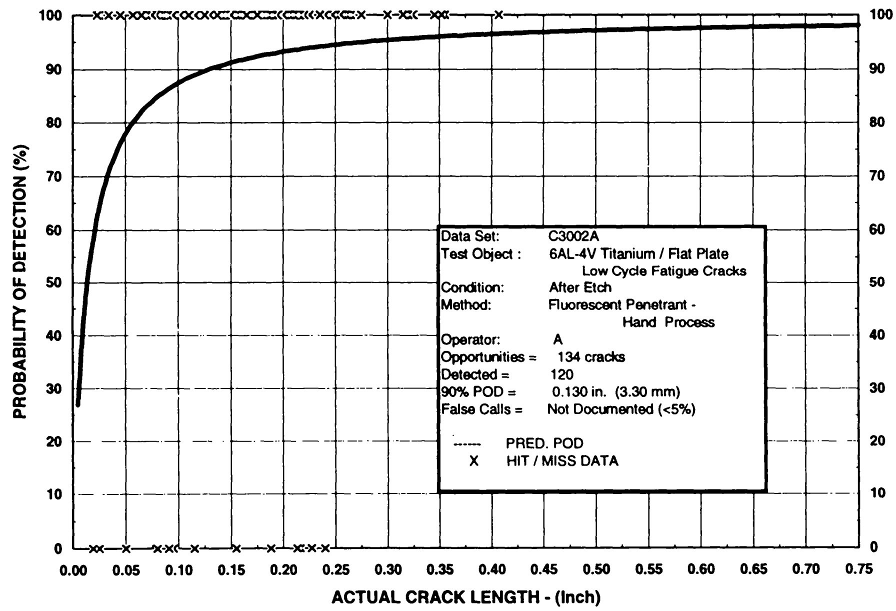

Figure 3b. Relative performance capabilities of fluorescent penetrant inspection on titanium alloy panels - after etch.

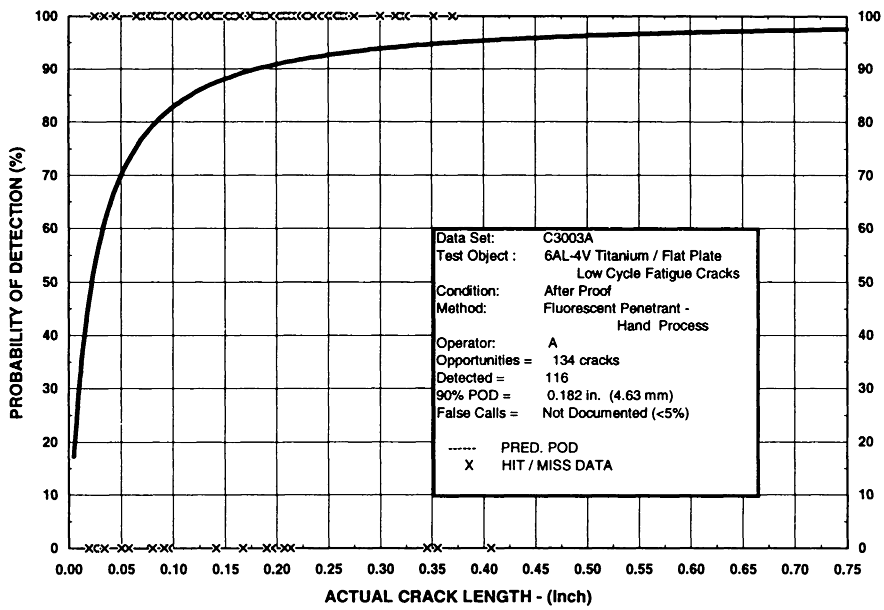

Figure 3c. Relative performance capabilities of fluorescent penetrant inspection on titanium alloy panels - after etch and proof loading.

the reference data and predictive data from the emerging models must be validated for each specific application to assure that the boundary condition for the data and models are specifically applicable.

SUMMARY

A "no flaws" acceptance criteria was always unrealistic and is now a relic of past practice. Pride and confidence in NDE capabilities in the workplace is a natural and admirable quality. In many cases, such confidence has not been tested or validated due to the state of the art of the technology and the blind confidence that "performing to a specification, code or standard assures success at all levels." Engineering data, analysis tools and consulting services are now available to quantify the level of performance capabilities and damage tolerance in requirements in design and life-cycle maintenance demand such quantification. Fortunately, others have walked this path before and the protocol and references cited in this paper are intended to provide an introduction and starting point for NDE procedure quantification for in-house operations. The process of demonstrating capabilities most often results in a new awareness of critical parameters in NDE procedures and resultant improvements in overall NDE capabilities.

How do you measure up? It is relatively simple to convince those who want to believe that you can walk on water. It is far more difficult to demonstrate that capability.

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