ARTICLE IN PRESS

Measurement xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Managing the uncertainty of conformity assessment in environmental testing by machine learning

Giulio D'Emilia*, David Di Gasbarro, Antonella Gaspari, Emanuela Natale

University of L'Aquila, Department of Industrial and Information Engineering and of Economics, v. G. Gronchi, 18-67100 L'Aquila, Italy

ARTICLE INFO

Keywords:
Environmental testing
Vibration
Fatigue
Probability distribution
Uncertainty
Thermal testing
Neural networks
Machine learning
Solder joint

ABSTRACT

A machine learning approach is described, with reference to the conformity assessment of pin solder joints for electronic devices after tests based on cyclic thermal stresses. Metrological concepts, in particular expanded uncertainty, confidence level and conformity assessment, are used to reinterpret expert judgements, with the aim of transferring as much as possible the expert judgement know-how into a semi-automated evaluation process of X-ray images. This also allows us to reduce to an acceptable level the percentage of errors of the method, with respect to the identification of faulted specimens. A tailored procedure is set, which is able to reach a satisfactory level of correct acknowledgment of the status of pieces, giving also indication of cases where the level of confidence is unsatisfactory. The obtained results show that in this way the occurrence of mistakes strongly decreases. The paper also analyses the effect of algorithms and of the most relevant data processing settings on the ambiguity percentage.

1. Introduction

Environmental testing plays a fundamental role in the reliability assessment of many engineering fields, like mechanical, electronic and material engineering.

Many issues are of interest, depending on a very large number of aspects, mainly referring to the aim of testing, to the typology and to the complexity of the items to be tested and to the quantities to be taken into account. In fact, a very huge amount of literature has been developed [1–3] and also many standards exist [4,5], in the technical and military field.

Even though a comprehensive analysis is impossible to do from a practical point of view, some general considerations arise. As a general rule, environmental testing is expected to demonstrate the adequacy of specimens to resist to specified loads (depending on cases, static/dynamic load, temperature/humidity/vibration as the quantity of interest and so on) without unacceptable degradation of its functional and/or structural integrity, when subjected to the specified test requirements. Different experimental approaches are available, which depend on the specific application. Test requirements are set in order to represent real loads and the accumulated stress effects, so that the resulting mechanical/electrical/thermal weaknesses and degradation in the specified performance can be identified.

This information, in conjunction with the relevant specification, makes possible to assess if the specimens could be accepted or refused.

Another approach, that is very studied too, is to carry on environmental testing, in particular taking into account vibration solicitations, to support models and procedures, aiming to evaluate the mechanical fatigue effects; often the results of this study could be useful for estimation of Residual Fatigue Life (RFL).

As an example, in [6] a methodology is proposed, to define residual fatigue life of simple mechanical components. It describes a very integrated approach, including experimental analysis, theoretical mechanical models and probabilistic considerations.

If the given approaches are compared, at first glance it seems that a complete and coherent probabilistic point of view is considered only when it is strictly needed, according, for instance, to reliability and prognostic considerations. In fact, most of the results connected to environmental testing are in terms of pass/no pass, according to predefined thresholds.

Anyway, many aspects are described in terms of Probability Density Function (PDF) of parameters in the vibration environmental testing on the whole: as example, we can consider the statistical behaviour of the random driving signal, [7,8] (also taking into account the actions to optimize the dynamic behaviour of the driving/actuating devices: e.g. clipping, [9], phase management, [10,11], mixing of different type of solicitations [2]); furthermore, the real output PDF is difficult to predict, even though the input PDF is known, due to the system effects (which are often not linear).

If the possibility of carrying on accelerated (ALT) or highly

* Corresponding author.
E-mail address: giulio.demilia@univaq.it (G. D'Emilia).

https://doi.org/10.1016/j.measurement.2017.12.034
Received 6 October 2017; Received in revised form 20 December 2017; Accepted 21 December 2017
0263-2241/

accelerated (HALT) tests is considered, the above problems are emphasized [12]. Recently, many methods have been proposed for modelling and describing ALT scenarios and data, that are discussed in literature [13,14]. Topics of general interest are analyzed, regarding probability relationships between different levels of stress connected to ALT with imprecise statistical model [13]. In other cases [14], reliability models for complex phenomena connected to thermal cyclic fatigue are built, with reference to specific and tailored statistic models. Attention is paid to discuss uncertainty involved into the proposed models [13,14].

Therefore, the need of defining the problems, including their probabilistic information is fundamental and affects the capability of validating the information deriving from data and which will be the basis for decision making.

In other terms, this scenario will affect the quality of information deriving from probabilistic characteristics of measurements, i.e. their uncertainty and its propagation throughout the process to the final decision, including the confidence level of actions.

Environmental testing requires merging data of different type, of different meaning and quality in a way that the uncertainty propagation remain under control; this goal is not so easy to achieve, due to the lack of a consolidated approach, able to manage uncertainty throughout the whole process of such a kind [15].

Furthermore, in many cases the evaluation of test results is devoted to some expert judgement. The way of integrating this contribution into probabilistic approaches has been already applied with reference to cyclic thermal ALT, with the aim to make probabilistic models more reliable [16]; anyway, it appears difficult to completely represent such a personal contribution into objective models, taking into account long-term personal experience and know-how. In fact, failure and/or degradation, deriving from thermal failure, cause stresses difficult to model, due to their entity (much higher than vibration), causing the materials to work in the plastic deformation range, and due to the material interaction, which is difficult to accurately describe, even though advanced FEM models are set up [17].

Many attempts are available, trying to merge the judgement of expert to artificial intelligence solutions, in order to improve the possibility of fusing information coming from different sources in different contexts and with different aims. In [18], an industrial model validation assessment is realized by merging quantitative metrics and qualitative judgements of experts of the matter, to make possible semi-automate model validation process, able to incorporate even more data of different type. The authors in [19,20] aim at reducing the need of the expert contribution to enterprise or clinical practices with machine learning methods. Different levels of expertize judgements are combined in [21] by learning methods, in order to make more safe the information extraction from clinical reports. All these contributions are of interest in understanding the possibility of using machine learning in the processing of data of environmental testing, even though an approach presenting some more general interest is necessary.

Finally, using metrological concepts and approach, like uncertainty budget, level of confidence, expanded uncertainty and conformity assessment, has already been demonstrated to be an useful method to face some specific aspects in environmental testing, in particular probability issues. In fact, as a preliminary set of examples, the use of these concepts allowed to face in an improved way both vibration testing and pass/no pass decision modalities for mechanical components [22] and cyclic thermal fatigue, concerning the possibility of correlating tests carried out at different intensity levels [13].

In this paper, a methodology is presented, aiming to achieve some of the above contributions of machine learning and of metrological concepts to data processing of environmental testing, with reference to the degradation assessment of pins solder joints, subjected to ALT cyclic thermal stresses.

The expert judgement, of on/off type and based on the examination of X-ray images, is analyzed by machine learning techniques, in order to define a new examination technique, trying to:

- latch the “expert” expertise,
- define a level of confidence of the judgement of both expert and automated method,
- set a level of ambiguity of results, in case the confidence of a sure judgment is not enough.

Section 2 describes the methodology and emphasizes the way the different concepts are merged. In particular, the machine learning approach is described, tailored for this application with reference to the data processing settings. In Section 3 the results are presented with reference to a real case of industrial interest, where the analysis of images of pins solder joints is the basis for the evaluation of their degradation due to ALT thermal tests. The possible improvement in reducing the error percentage in automated method is analyzed and physically motivated.

Conclusions and future work end the paper.

2. Methodology

A “global” methodology aiming at realizing a rigorous, complete and integrated approach for the uncertainty management in environmental testing of every type is, of course, very difficult to realize and it is out of the scope of this paper.

A methodology is presented in the following, based on some machine learning techniques and aiming at showing, in a preliminary manner, how some results of an environmental test could be re-interpreted and enriched, by means of some metrological considerations.

The scenario, among many possible cases, refers to the degradation assessment of pins solder joints, subjected to ALT cyclic thermal stresses. The available data are 200 X-ray digital pictures of the pins after thermal cycles and corresponding expert on/off judgements (Fig. 1). Usually in the industrial applications the data are processed, in

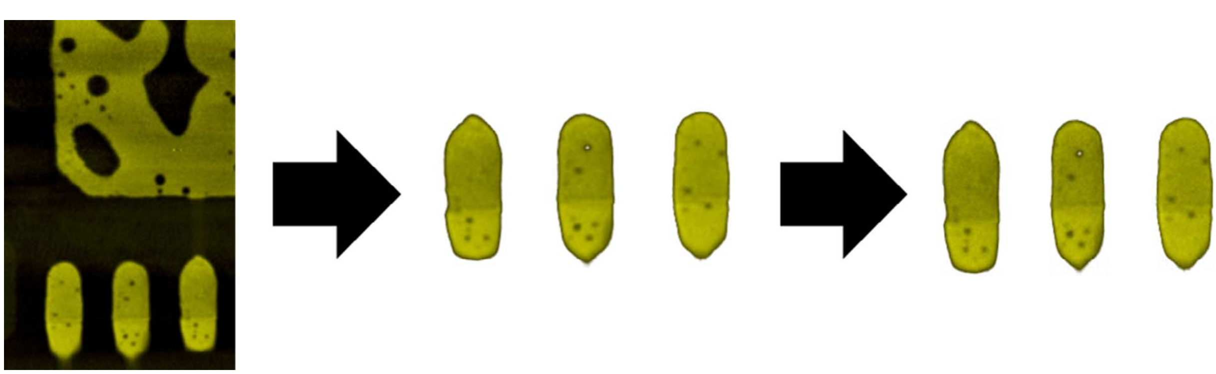

Fig. 1. A particular of original image. After 3 pins are extracted. After the noise has been added.