PENETRANT TESTING AND YEAR 2060

By Patrick DUBOSC [(*)] and Pierre CHEMIN [(**)]

I- INTRODUCTION

The death of a major NDT method is heralded! In fact since a famous paper in an American technical journal in 1970, the death of Penetrant Testing is postponed year after year, but it is still a going concern.

Penetrant Testing is by large the most widely used NDT method, and many are the NDT suppliers of other methods ready to step onto this turf! Even ready to replace it with Ultrasonic Testing (UT) or Eddy Current Testing (ET). Nevertheless PT is still valid, valiant, invaluable and irreplaceable.

All the NDT methods have their own niche; none can replace any other one they use.

True some industries have seen along the years a dramatic decrease of the volumes of penetrant testing materials they use.

Just as an example: many years ago car manufacturers' subcontractors had to check all their parts, even the non-critical ones, in a time when sampling was uncommon.

Imagine now that the prime did use again PT to check the same parts! That was the way of life! Double-check: a beloved time for penetrant materials suppliers! This time has gone!

PT, that's true, does not seem an "attractive" method for some people and is even labelled as a "minor method" by more and more people.

Penetrant Testing puts many people off:

- Using chemicals which may soil or stain hands, clothes, and further may be bad-smelling.
- Penetrant, solvent, developer used in bad conditions.
- Processing in dirty and badly- maintained installations.

Well PT gives a bad impression to many. So easier, more pleasant, more comfortable to use an electronic equipment as in UT or ET!

And yet everything cannot be done through electronics.

Is PT an NDT method for the future? Oh yes!

- Every day new manual, half automatic or fully automatic PT lines are commissioned.

- Every day new users perform a PT inspection for the first time.

2- THE PRODUCTS

Performances of the penetrant testing materials currently available are at the level required by all the major industries including nuclear and aerospace ones.

Nevertheless we may assume materials will change in the future.

The main points are hygiene, safety and environment improvement concerns.

Chemistry engineers have faced a lot of challenges along the years. Here are some examples:

- Substitution of 1,1,1-trichloroethane.
- Substitution of chlorofluorohydrocarbons.
- Substitution of glycol ethers.
- Reduction of the volatile organic compounds (VOC).
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2.1- ENDOCRINE DISRUPTING SUBSTANCES

At the very beginning of the 21st century the endocrine disrupting substances (EDS) have been another source for concerns: the main target is the nonylphenol ethoxylates (NPE) [(1) (2)] family and, in fact, the larger alkylphenol ethoxylates family. APE, the acronym for this family is a source of smile for our English-speaking friends.

The European Union has prevented use of NPE in detergents (except when cleaning liquids are recycled or burned) as they are toxic; using them "may have an immediate or long-term harmful effect on the environment or on biodiversity". This means that detergents or any chemical containing these substances even at high concentrations may be used as far as they or their effluents be either recycled or burnt... This was misunderstood by users of large quantities of such chemicals when hastily reading the Directive.

NPE were used in many water-washable (WW) penetrants as well as in hydrophilic emulsifiers formulas. A large European manufacturer of aircraft engines required that "no product entering our plants shall contain APEs". All the plants had a four-month time-span to comply.

On PT lines, if they meet regulations requirements, liquid effluents are either treated and recycled or collected and burnt. As for the penetrant or used emulsifiers tanks the products are given for a -high! - fee to registered companies able to dispose of the chemicals as per local regulations.

Keep in mind that the Directive allows up to 0.1% of APE in untreated waste water (which is well above the real figure measured in waste water coming from rinsing and washing stations when taking into account the concentration of APE in penetrants and emulsifiers and the dilution

due to the large volume of water used to remove the excess of penetrant: removing one litre of a Level 2 WW penetrant may require between 400 and 1000 litres of water while a Level 4 post-emulsifiable [PE] penetrant may require up to 4000 litres!).

Nowadays in Europe most of the WW penetrants and the hydrophilic emulsifiers are free from these chemicals.

In the USA, well, in fact NPE sales are increasing. For our PT business the situation depends on manufacturers; some still have formulation comprising NPE or APE while others anticipate what could be a ban within a decade.

2.2- STUDY ANALYSIS

PT as a whole will need thorough adjustments to meet the current and future requirements without impairing the method's performances; it will still be a major NDT method in 2060, we are confident!

3- WASTE WATER TREATMENT

We anticipate few changes in this area:

- Waste water from PT shall be treated as a separate waste from any other waste water. Waste water from PT may be recycled if it is adequately treated. If the recycled water contains even small amounts of surface-active agents (surfactants) and if it is used to wash off/rinse parts, there is a major risk that the penetrant be too much emulsified, hence a dramatic effect on the process sensitivity. Quite often a waste water treatment installation for PT effluents and the PT line are quite close together and are considered as an entity.

- Activated carbon filters are a good way of treating water. In fact, even when other treatment means are used the last step is an activated carbon filter. There are now a lot of replaceable filters which ease maintenance.

Coalescence filters may be used on post-emulsifiable (PE) penetrants lines to put apart water and non-emulsified penetrants coming from the pre-wash step, previous to the hydrophilic emulsifier’s application.

OTHER METHODS

Mechanical vapour compression (MVC) requires huge investments for small quantities of clean water per day.

Biological process (bacteria "eat" the organic molecules and produce mainly water and carbon dioxide) require to enrich the pollutants with phosphorus (as phosphoric acid), nitrogen and compressed air (to bring oxygen to the tank).

These two methods need to be used as planned. By experience we know that, due to the low daily volume of clean water given by these installations when compared with their size and their sophistication, users are prone to use the units beyond their capability...and, as a consequence, there is a dramatic lowering of the quality of the "clean water".

Furthermore a biological unit shall run 24/24, 7/7: no week-ends, no holidays (vacations, for our American friends).

Many other industrial methods are inefficient and have been given up: ozone, ferric perchloride or even hydrogen peroxide as oxidants; PTFE disks with baffles to use the tiny difference of density between water and non emulsified chemicals; electrolysis has even been tested on waste water from PT lines... when penetrants materials give no ion in water!

Membranes, be they for ultrafiltration, nanofiltration or reverse osmosis are not the right way, economically and technically speaking.

Keep in mind that the process which, as if by magic, comprises a dirty water tank, a clean water tank and in the middle a "black box" that no one checks or maintain and that produces no refuse does not exist! Except for the biological method (which nevertheless produces refuse as "activated sludge" which cannot be thrown away as domestic refuse), a waste water treatment installation **condenses** the pollutants....Sooner or later this "concentrate" shall be disposed of!

4- INDICATIONS VIEWING

Automation in PT deals only with parts processing. Inspection is always carried out by a human being.

Almost all the "black box" systems have failed when trying to replace the human eyes (the sensors) connected to the human brain (the signal processor).

In the 2000 decade an American company introduced a system comprising a video camera, a manually adjustable lens and a suitable software.

A French Maintenance, Repair and Overhaul (MRO) company carried out industrial tests. Results were good except that no handling equipment allowed for a quick, reliable handling while minimising the "blind surfaces". It was seen more as a laboratory equipment than an industrial one.

A suitable handling equipment, whatever the viewing system, should allow for:

- Taking every part after the development time has elapsed.

- Showing the automatic viewer sensor all the surfaces to be checked (this is very difficult when surfaces are complicated).

- Classifying the parts according to the results of inspection.

An improvement would be that such a system be able to check very different parts without any recalibration: MRO lines inspect so many kinds of parts!

We have been told this system is supplied to foundries, to car industry manufacturers, to railways industry. As far as we know it is not yet included in completely automatic FPI lines; it may be used primarily as a "filter" previous to human inspection: parts without any indication would go directly to the "accepted" line while those with any kind of indication would go to the inspection booth and be seen by a human inspector. We have no information about its would-be use in aerospace industry.

We are dubious about any automatic viewing, at least for the following reasons:

- What about the wipe-off (rebleed) technique?

- How to discern between acceptable indications and indications probably due to a discontinuity? A very tiny indication may be a large discontinuity the top of which has been almost closed by a mechanical action. A human inspector could then use a fine sandpaper just to reopen the discontinuity.

- How to "feel" that an area with a background a bit stronger than usual on a casting is in fact an area of non-acceptable porosities?

5- HOW TO MAKE PENETRANTS FLUORESCE

The real breakthrough came with diodes able first to give 385 nm, then 370 nm, then 365 nm radiation. Nevertheless these diodes did not give high UV-A irradiance. But once again R and D by manufacturers was successful, and powerful 365/370 nm sources became available.

But then another concern was talked of on a wide scale: UV-A radiation dangers for skin and eyes. Though this has been known for decades (both of us sent warnings some 25 years ago), it suddenly appeared as if the major concern for inspectors safety in PT lines!

Penetrant manufacturers, helped by diodes manufacturers, soon understood that there was an escape way: try 405 nm, then 450 nm diodes i.e. diodes emitting in the violet or blue (respectively) range of the visible spectrum. The fluorescent dyes used in penetrants respond fairly well to these wavelengths. But at least three drawbacks are facing this solution:

- No standard allows for using any source other than 365 nm ones to excite fluorescence of penetrants.

- Violet or blue visible lights...are visible! And they are detrimental to the ability of the

inspectors' eyes to detect tiny green or yellow-green indications.

- The fluorescence brightness is lower than with 365 nm. For decades penetrants formula were optimised for 365 nm, and it is understandable that these formula do not have the best response to 450 nm (which seems to be the future standard).

How to counteract?

It is not so difficult...if changing standards on such an "entrenched" data is easy!!! By experience we know that years, many years, may be needed before such an important change is accepted. And during an "interim period" while both would be acceptable, auditors and auditees will have a ...funny time!!! But say this is only "policy", and not really a technical point.

The visible light that should not be visible: this is very easy. Inspectors shall wear suitable filtered goggles, as seen in the CSI/NCIS TV series!! (respectively: Criminal *S*cene Investigation and Navy *C*riminal *S*cene Investigation*)*.

The fluorescent brightness drop is in fact the most important problem. Tests have shown that using the current fluorescent penetrants may lead to fluorescent brightness in the 60 to 80% when compared with the figure under 365 nm.

In-use penetrants, when monthly tested for fluorescence brightness, shall have more than 80, and sometimes more than 90% of the fluorescence brightness they had when new. That means in many cases, just by using a 450 nm source, the fluorescence brightness for an unused penetrant will be lower than acceptable for the same in-use penetrant!

The only way is for penetrants manufacturers to redesign formulas, to have them tested and approved by the USAF (at least for the aerospace industry). And we are sure that, if the formula is optimised for use under 450 nm, it will then not be optimised for use under 365nm! That means it will be forbidden to mix "365" and "450" penetrants; that the PT lines shall be devoted either to 365 inspection or to 450 nm inspection, shall have the suitable penetrants AND the suitable sources, goggles, viewing conditions, irradiance meters, suitable radiometers either for UV-A radiation or for 450 nm radiation, suitable luxmeters, etc! A nightmare for auditees, a source of major non-compliance reports(NCR) issued by auditors, a source of additional revenue for auditing companies which will have to send again auditors to check that NCRs have been dealt with!

The new dyes/brighteners shall be chosen among non-harmful, non cancer-inducing chemicals. Not that easy for chemistry engineers!

And the question arises for fluorescent magnetic particles! If the 450 nm sources become the standard (which is likely) these particles will also need a formula adjustment. An additional problem for manufacturers, as the fluorescent dye (almost all the manufacturers use the same one nowadays) is different from any fluorescent dye used in PT!

6- HOW TO APPLY PENETRANT MATERIALS

Materials may be very good, if improperly used, the process results are likely to be bad.

Many improvements are necessary to improve current performance.

As a first step the surface preparation shall remove EVERYTHING which is not the basic metal without impairing its mechanical performances nor its fatigue strength. Mechanical processes of surface preparation are generally to be followed by chemical preparation. For instance vibrodescaling had been seen as the right answer for turbine blades descaling until proof was given that some defects had not been detected due to metal smearing from this mechanical process.

Easy to understand that surface preparation is more easily achieved in workshop than on-site.

Penetrant application is generally the easiest step in the entire penetrant testing process.

Applying an emulsifier requires some precautions to be taken [(3)].

Dry powder application is by far the step where numerous improvements should be enforced. [(4)] [(5)] [(6)] [(7)].

Design of the handling equipment shall be such that the "contact surface" between parts and the equipment be minimised. Further no surface of any part shall be hidden from products application.

Optimising and enforcing control parameters, PT lines maintenance, checking in-use materials quality/performances are on the same level as quality assurance audits and inspectors training to improve overall performance and reliability.

7- THE SAE-AMS 2644 SPECIFICATION

At the end of 2007 US Air Force WRIGHT PATTERSON Research Laboratory asked every manufacturer to give an updated list of the products then qualified, still manufactured and that the manufacturer would like to see in the next QPL annexed to the SAE-AMS 2644 specification. The products no longer manufactured would be deleted.

Further the laboratory gave every manufacturer the new procedure due for service on Jan 1st, 2008. For instance manufacturers would have to endorse all the costs incurred for qualification.

To begin with the applicant fills in and signs a questionnaire for AFRL/RXSA department and supplies it with a 16-chapter Materials and Safety Data Sheet (MSDS).

Then AFRL/RXSA checks the documents and accepts or not that the applicant goes on with the qualification process. If not explanations are given.

Laboratories of five penetrant materials manufacturer as well as an independent laboratory are qualified to carry out some tests.

Another independent laboratory is the only one approved to carry out tests for sensitivity of penetrants, washability of Type 1 (fluorescent) penetrants and bioresistance of water soluble and developers in suspension in water.

All these laboratories are based in the USA.

Results from the qualified laboratories and data supplied by the applicant are compiled to have the product listed - or not - in the QPL. The applicant gets an official advice.

OUR COMMENTS

Europe as well as the rest of the world are happy that the USA stays with the QPL.

As a matter of fact the aircraft manufacturers require that PT products be listed in the QPL-SAE-AMS 2644; sometimes they issue their own QPL which displays only some of the AMS QPL products!

The only independent laboratory, in charge of qualification tests (except for sensitivity, washing of Type 1 penetrants and bioresistance of water-based developers) is renowned. For the last three decades manufacturers of chemicals used for surface cleaning (such as: aircraft cleaning, paint removers, etc.) shall have their products tested by this laboratory after the applicable military specifications (MIL specs); if approved the products are then listed in the relevant annex of the MIL spec provided that such QPL exists since most MIL specs have no QPL. These tests costs are also paid by the manufacturers.

Not a bad idea that an independent laboratory be in charge of all the sensitivity and removability tests of Type 1 penetrants. Sensitivity tests have always been carried out on specific series of test blocks (turbine blades with stress-corrosion induced cracks on the leading edge) that only the Wright Patterson laboratory was able to manufacture. We may guess that the reference blocks and their manufacturing process have been transferred to this laboratory.

The penetrants manufacturers have quite often faced troubles getting their penetrants approved for the sensitivity level they targeted. It seems it is one of the reasons for the Level 1/2. It occurred several times that a manufacturer hoped to gain the Level 3 qualification for a WW penetrant, but failed and got only the Level 2. There were even harsher disappointments.

Would it be possible that the ISO 3452-2 standard goes farther to better match the AMS 2644 specification?

At least one European laboratory should be able to carry out qualification tests (as far it has all the suitable equipments and competent people) as per the ISO 3452-2 standard using the Type 1 reference blocks described in ISO 3452-3 for the sensitivity test. Contrary to the SAE-AMS 2644 specification process it is then conceivable to "quantify" the data as Jean VAERMAN [8] [9], from

SNECMA, did several decades ago.

What was the process thought by Jean VAERMAN? The four Type 1 panels are processed on a small fully automatic PT line in the laboratory. Then the panels are photographed under specific and reproducible conditions. When the film is processed indications are visible on the negative film itself as parallel lines. The films are scanned by a sensor in a direction perpendicular to the indications at several distances from the edge of the panels. Seven scans results are averaged. Some cracks may appear as dotted lines and preliminary tests led to this figure of seven scans to get reproducible results. Then the ratio of the number of detected flaws and the number of known flaws is calculated for each panel. Finally the four ratios are averaged, leading to the sensitivity level of the penetrant: Level 2, 3 or 4. This process should be adapted using now digital still cameras.

Both the ISO 3452-2 and the SAE-AMS 2644 use marketed degreasers, penetrants, emulsifiers and developers as references. This could be questionable if one imagines a reference product shows a light drift in performance along the years. But no independent laboratory is able to design equivalent products. So better to use widely accepted, high quality, reliable commercial products from different suppliers (all American, as a matter of fact!!).

Another questionable point is that the defects of the ISO 3452-3 Type 1 panels are artificial. Such cracks cannot be compared to real defects. Nevertheless the SAE-AMS 2644 reference parts display also "artificial defects", though closer to real ones. Another point "against" real defects is that it is very difficult to manufacture reproducible parts.

A last questionable point: would a penetrant qualified, say, as a Level 3 when using cracks induced by stress-corrosion still be a Level 3 if another type of crack had been used for qualification? Every day penetrants qualified on stress-corrosion induced cracks are used to find cracks due to manufacturing/processing of parts.

Nobody says it is not right. But nobody can suggest a better way to qualify products!

This point is debatable for the future.

8- CONCLUSION

Hygiene, Safety and Environment concerns and regulations will lead to forbidding chemicals or to restrain their use.

Therefore penetrant materials manufacturers will have to redesign numerous products deleting use of chemicals which proved very useful and efficient for decades...but which will be considered as unacceptable.

Very likely UV-A will be replaced by 450 nm light for fluorescent inspection.

The ISO 3452-2 standard and the SAE-AMS 2644 specification should come closer to each other. The American specification is aerospace-applications oriented while the ISO standard is more

general. Using a modified "VAERMAN's method" for sensitivity qualification would be recommended.

Inspectors and users training as well as Quality Assurance audits will be irreplaceable for this method reliability.

NEVERTHELESS THE UTMOST IMPORTANCE shall be given to the "new generation" of engineers, users, inspectors, auditors. Penetrant Testing will be a reliable method for many decades if, and only if:

- The basics of the method are fulfilled: as we have written on our website in an Editorial [10] dated June 2009:

"Manufacturing a yoghourt takes as long a time as it did a century ago.
Manufacturing good bread takes as long a time as it took several centuries ago.
Performing a good PT inspection requires as long a time as it did 40 or 50 years ago, even if penetrants sensitivity is by far much higher, even if viewing conditions are far better".

In this paper we explain why. Please spare some minutes to have a look at it.

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