EIGHTH WORLD CONFERENCE ON NONDESTRUCTIVE TESTING
HUITIEME CONFERENCE MONDIALE SUR LES ESSAIS NON DESTRUCTIFS

5C 14

A RED DYE PENETRANT METHOD FOR INSPECTING NUCLEAR POWER STATION COMPONENTS

CONTROLE DES PIECES DE CENTRALES NUCLEARES PAR RESSUAGE A PENETRANT ROUGE

BRITTAIN P.I. — IVER BUCKS

BRENT CHEMICALS INTERNATIONAL LIMITED — ENGLAND

SUMMARY: A method suitable for inspecting large components, such as nuclear boiler shells, utilising red dye penetrant and a powder developer applied electrostatically, is described.

RESUME : Une methode appropriée pour le contrôle de pièces de grandes dimensions, telles que coquilles d'échangeurs nucleares, mettant en oeuvre un penetrant coloré et un révélateur sec appliqués par procédé électrostatique.

I. INTRODUCTION

The dye penetrant inspection process for the detection of surface-opening flaws, especially in metal objects, is both simple in operation and widely-used in practice. In manufacturing industries such as metallurgical production, heavy and light engineering, including aerospace and automotive, fabrication and construction, as well as in the servicing and overhaul of engineering equipment, dye penetrant methods are rightly regarded as one of the accepted standard inspection techniques.

I.1 The Red Dye Method

Red dye penetrant testing is widely regarded as a 'traditional' or 'classical' method, having altered little in practice over the past few decades. The sensitivity of available products has increased somewhat, and the importance of freedom from toxic, reactive, corrosive or ash-forming constituents is now widely recognised. (1) In essence, however, the process has remained essentially unchanged, comprising the following established steps:-

I.1.1 Thoroughly clean the component and defects

I.1.2 Apply red penetrant and allow penetration time

I.1.3 Wash off using a suitable solvent, or water, or a combination of water and an emulsifier

Alternatively:

I.1.4 Dry the component

I.1.5 Spray with solvent-based developer

Or:

I.1.4a Immerse the component in a water-based developer

I.1.5a Drain and dry

I.1.6 Allow time for any indications to develop

I.1.7 Inspect

The sensitivity of the red dye process for small defects is generally not as high as fluorescent penetrant processes, although certain critical solvent-vapour removal processes can give good performance under closely controlled conditions. However, the method is relatively cheap, robust and simple, factors which commend its use in all but the most critical applications.

II. INSPECTION OF LARGE COMPONENTS

Large components present a special problem. Sheer bulk and weight render transportation difficult. The size of the several tanks necessary to process large components means costly equipment covering a relatively larger floor area. The cost of the high volume of penetrant fluid necessary to fill each tank is considerable.

Such factors indicate that, if possible, inspection of unwieldy equipment should be carried out in the production shop, the cleaning, penetrant, remover and developer fluids being applied by brushing or spraying methods. Brushing is inconvenient and often wasteful. Spray application is an obvious choice, except that overspray and solvent evaporation mean that special booths or extracted areas must be used if inconvenience or possibly danger to shop personnel is to be avoided. This overspray problem can be practically eliminated by the use of electrostatic spray equipment.

II.1 Electrostatic Application

The principles of electrostatic, liquid and powder spray guns are well known. Briefly the liquid droplets or powder particles on leaving the gun are electrostatically charged, usually negatively, to a potential which may be of the order of 50 - 100 kV. These charged droplets or particles will be attracted to the earthed component being coated and, if the velocity is suitably adjusted, none of them will escape across the electric field, thus eliminating overspray and dust problems.

Commercially available electrostatic spray equipment is now highly reliable and completely safe to use, (2) and equipment of this kind has been successful in use for at least five years for the application of fluorescent penetrant inspection fluids. Such fluorescent systems are most frequently used in conjunction with a powder developer, when a minimal, almost imperceptible coating is usually applied. It has been stated that the use of a fluorescent penetrant and powder developer, both electrostatically applied, results in a higher sensitivity compared with that resulting if the identical products are applied in a conventional manner. (3) The reason for this is not clear, but it may be connected with the generally much greater uniformity of coverage readily achieved by the electrostatic method, coupled with the tendency for the field to concentrate at sharp edges.

II.2 The Developer Question

The developer system required for a red dye penetrant differs in one important respect from developers used in fluorescent penetrant systems. Because the red dye system requires irradiation by visible light the developer must provide a relatively opaque white background so that optimum contrast between the background and any indication results. Such a background is most usually obtained by the use of a solvent supported white powder system. For ease and consistency of application, the solvent must be relatively volatile. This means in practice that the developer is either inflammable or toxic. In either case, it will not be acceptable for spraying in the open shop unless stringent precautions are enforced.

Clearly there is a strong case for a solventless, ie. dry powder, developer. Could such a system be made to work in practice?

II.3 Experimental

Initial development work was carried out using aluminium alloy specimens approximately 50 x 100 x 8 mm thick, containing a concentric system of thermal shock cracks produced by locally heating with an air/towns-gas flame and quenching in water. (4) (5) The specimens were cleaned between tests by degreasing in trichlorethylene vapour followed by ultrasonic cleaning in a methylene chloride/ acetone mixture.

Where more accurate comparisons of ultimate sensitivity were required, stress cracked chromium-plated specimens were used, having a plating thickness of approximately 60 u. The preparation and use of this type of testpiece has been described. (5)

The penetrant used throughout was a high-contrast medium rinsing red dye type, having a viscosity of 5.0 cS at 38 °C and a flash point above 93 °C (Cleveland open cup).

Application to these testpieces was by dipping, followed by 10 mn contact time, air-water spray rinsing and drying at 80 °C in an air circulating oven. The testpieces were allowed to cool and were then coated electrostatically with powder developer using a negative electrostatic charge of 100 kV, a circular section nozzle, a nozzle-workpiece distance of 20 cm and a powder flow rate of approximately 500 g/h.

It was soon evident that conventional powders suitable for use with fluorescent penetrant systems were unsatisfactory, contrast and sensitivity being extremely poor. Certain materials such as titanium dioxide based compositions, although readily providing a good opaque background, reduced the brilliancy of the indications which appeared duller and brownish compared with more optimum formulations, the overall effect again being a loss of contrast and sensitivity.

Admixture with a variety of recognised or possible developer powders did not effect any substantial improvement. Eventually a powder mixture was found which appeared to give the necessary sensitivity when applied electrostatically, and a number of trials on testpieces and on larger components confirmed that the contrast and sensitivity achieved using this powder developer under prescribed conditions, was comparable with that obtained using a similar procedure but with a solvent-based spray applied developer.

Repeated large scale trials were carried out with this modified powder developer using established electrostatic powder equipment satisfactorily. However, when the same powder developer formulation was used in a simpler and more portable electrostatic gun and generator, some difficulties were experienced with non-uniformity of powder flow, particularly surging on starting up. Further modifications had therefore to be made to improve the flow characteristics of the powder. With this last modification made, it was considered that the system was ready for full-scale trialling.

II.4 Full-Scale Trials

Trials were arranged at two European companies manufacturing heavy pressurised vessels for nuclear power stations. In both cases the components were cylindrical stainless steel tubes, approximately 2.5 m diameter x 10 m long x 7 cm thick. The components were treated in the open shop lying horizontally on supporting rubber rollers which enabled the tube to be rotated about its own axis. Suitable earthing arrangements were made.

In both cases the tubes were reasonably clean, and local dry brushing was all that was necessary to remove dust and grit. Had heavier contamination been present, a number of alternative precleaning arrangements, described below, could have been used.

Coating with red dye penetrant using the electrostatic technique took approximately 12 mn and used less than 2 l of penetrant. Overspray was practically eliminated and caused no inconvenience to the operators. The electrostatic attraction was equally effective when spraying the inside of the component, which involved the operator walking backwards through the tube, progressively covering the inside surface, whilst a second operator assisted by pulling the cables along as required. The operation is clearly very suitable for automation, if required.

After a contact time of 10 mn the excess penetrant was removed by spraying with water from a hosepipe, working from the top towards the bottom of the component on both the inside and outside surfaces. This part of the operation took approximately 20 mn. The removal of excess water was assisted by air blowing and in one case by mopping with clean dry cloths. In the second case, cold water rinsing was followed by hot water applied from a hot water spray unit, so as to reduce the drying time.

Finally, the dry components were coated electrostatically with powder, using a similar progressive technique to that described for the red dye penetrant application. The powder flow rate was appreciably higher than that normally used for fluorescent penetrant development, so that the surfaces were uniformly covered with a fairly dense white coating. Very little free floating powder remained in the atmosphere, in marked contrast to the normal non-electrostatic powder dusting procedure. A development time of 20 mn was allowed. The indications obtained were crisp and bleed-through of background dye was minimal.

II.5 Precleaning

The two boiler components processed were relatively clean and free from oil. Had a precleaning been necessary, one of several large-surface application techniques could have been used, ie:

II.5.1 Sprayed or foamed-on "brushless" detergent

II.5.2 Foamed-on standard detergent assisted locally by brushing

II.5.3 High pressure hot water washing using an alkali or emulsion additive

II.5.4 Sprayed on heavy duty alkali cleaner followed by high pressure hot water washing using an alkali or emulsion additive

These operations must, of course, be followed by rinsing and drying. The use of a final hot water rinse will considerably assist the rate of drying, particularly in cold weather.

II.6 Advantages of the method

The advantages of the system described stem from the following main considerations:-

II.6.1 The operation is in-situ, and by application, rather than by immersion. Thus the component need not be moved, as would be necessary if treatment were by successive immersion in a series of tanks. Processing is possible in the open shop with a minimum use of ground space.

II.6.2 The quantity of chemicals used is small, comparable with normal "drag-out" volumes. Since fresh chemicals are used for each component, there is no possibility of contamination in deterioration having taken place with the resulting loss in efficiency of the process. Equally, the physical volume of high flash point but nevertheless combustible penetrant material stored in the area is a matter of kilogrammes rather than tonnes.

II.6.3 Volatile solvents, which are usually either toxic or inflammable, or both, are not used. The electrostatic process minimises aerial contamination by droplets and powder dust. Thus any inconvenience and hazards to operators and plant are of an extremely low and therefore acceptable order.

II.6.4 The complete absence of halogenated solvents means that low total halogen analyses can be guaranteed, with figures of below 30 p.p.m. for example, being possible on production batches of penetrant. Thus the requirements of the A.S.M.E. Boiler and Pressure Vessel Code Section V (1974 Edition) Article 6 Paragraph T630 are readily met. (1000 p.p.m. max. on a relatively non-volatile material). This will ensure that any potential stress corrosion problems are in no way aggravated by the use of the penetrant. In fact, town's water is possibly the most suspect of the fluids coming into contact with the workpiece, and there may be a case for using mixed-bed deionised water for final washing operations.

II.6.5 In contrast to conventional red dye systems, the residual developer film is readily removable by simple washing or wiping.

II.7 Local Reworking

When local defects are indicated in thick sections, remedial operations must ensure removal of all suspect or cracked metal. This must be verified by local penetrant inspection before repair welding can be undertaken; aerosol processes have been widely used for this purpose. Unfortunately many aerosol red dye penetrant systems embody chloro-fluorinated hydrocarbon propellants and solvent developer formulations are frequently based on 1:1:1 trichloroethane or other less tolerable chlorinated hydrocarbon solvents.

These propellant gases, although volatile, after expulsion evaporate from the useful part of the aerosol concentrate in an asymptotic fashion, so that traces of propellant may be detected in the penetrant several days after spraying from the aerosol can. It is also possible that traces of volatile chlorine containing solvents may become trapped in subsequently closed circuits where hydrolysis is liable to occur, with the consequent danger of internal corrosion. It is therefore prudent that aerosol kits used for local inspection operations should embody butane, carbon dioxide or nitrogen propellants, and that any solvents used for cleaning, penetrant removal or developer formulations should be of hydrocarbon or oxy-hydrocarbon variety. If such solvents are used, the increased inflammability risk must be recognised.

An alternative solventless system is available. Thixotropic compositions in the form of a pourable gel are available. These have the advantage of remaining where they are applied and do not flow away onto adjacent surfaces. Excess penetrant is removed by wiping with lint-free tissues and final clean-up is achieved by means of a thixotropic lipophilic emulsifier. In development, a powder system may be applied electrostatically, or a non-halogenated aerosol type solvent developer can be used.

REFERENCES

(1) British Patent Specification No. 839,640. Improvements in or relating to testing agents for use in detecting flaws in articles or components.

(2) LEVER R.C., Design parameters for electrostatic power supplies. Industrial Finishing and Surface Coatings. (Dec. 1974)

(3) RUDA E., The use of electrostatic spraying equipment in production crack detection with fluorescent penetrants, Symposium: Advanced systems for surface treatment, cleaning and non-destructive testing in the aerospace industry. Ascot, England, (Sept. 1973)

(4) U.S. Government Military Specification MIL-1-25135C, clause 4.5.14.1.

(5) FLEMING D.J., Test pieces for supervisory checks on penetrant flaw detection processes. British Ministry of Aviation, Lab. report No. N.D.T./ 13/66.