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METHOD OF DETECTING SURFACE DISCONTINUITIES

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The present invention relates to a method of detecting surface discontinuities in solid bodies having generally continuous liquid impermeable surfaces, and more particularly to a method for the detection of surface flaws, cracks and the like in such bodies by the use of a colored liquid penetrant capable of wetting the surface to be inspected and containing coloring matter that is relatively unstable to ultra-violet light.

The present method includes applying to the surface to be inspected a layer of a liquid penetrant, usually although not necessarily of an oily character, that is capable of wetting the surface and that contains a dye dissolved therein which, when in extremely thin films, fades relatively rapidly upon exposure to ultra-violet light. If an excess of the penetrant is applied, the greater part of the layer of the colored penetrant so applied is removed from the surface in such manner that only a thin surface film of the colored penetrant remains thereon. Under some conditions, only a very thin film of the penetrant can be applied in the first instance, so that no removal of any excess of the penetrant is required.

The dye in the surface film left on the work piece is then faded or destroyed by exposure to ultra-violet light, but without destroying the color in any depth accumulation of the colored penetrant that has found its way into surface flaws, cracks or the like. Owing to its lack of penetrating powers, the ultra-violet light used to kill the thin film of background color does not destroy the color in accumulations of substantial depth, such as will occur in any surface flaws or cracks.

After the substantial destruction of the background color of the surface undergoing testing, the surface is inspected under ultra-violet or so-called "black light," or under any other form of fluorescigenous irradiation, or under "white light" or other suitable light capable of rendering contrastingly visible the accumulations of color at the surface flaws or cracks, if any are present. In this manner, the presence and location of surface flaws and cracks may be readily detected, using either a fluorescent or a non-fluorescent coloring material that is relatively unstable to ultra-violet light.

It has heretofore been known to test for surface discontinuities by the use of colored oily penetrants containing dyes dissolved therein. In the previous methods, however, it has been the preferred practice to use a water washable penetrant, such as an oily penetrant containing an emulsifying agent, and then to remove substantially completely the layer of penetrant from the surface undergoing inspection by the use of a water wash. Unless an emulsifying agent is used in an oily penetrant, complete removal of the colored oily penetrant from the surface by water washing is impossible, with the result that there is sufficient background fluorescence when the surface is inspected under ultra-violet light to mask indications of relatively fine surface cracks that may actually be present. However, the complete removal of the penetrant from the surface, as by a water wash or by

the use of a solvent degreaser, effects also the removal of the penetrant from particularly shallow or relatively wide surface defects, with the result that such defects are not rendered visible when the treated surface is inspected. There is also some added expense where good emulsifying agents are incorporated into the oily penetrant in sufficient amounts to render the penetrant so readily emulsifiable with water as to be easily removed from the surface by water washing.

In the case of the colored penetrant used in our present method, the surface layer of the penetrant is not removed from relatively shallow or relatively wide surface defects by the usual water washing step. Our penetrant is preferably of an oily and therefore non-water miscible character and does not contain a sufficient quantity of an emulsifying agent to render it water washable and therefore is not readily washed off during the water washing step. The result is that by our method the relatively shallow and also the relatively wide surface defects will be indicated. Also, since any given oily penetrant, if it does not contain an emulsifier, has better penetrating powers and will therefore enter finer cracks than the same penetrant containing an emulsifier, especially when the latter is used in the amount required to obtain good water washability, our method gives more sensitive indications where it is important to detect the presence of the relatively finer (tighter) cracks that cannot be detected by the use of a good water washable penetrant. Our method, by eliminating the necessity for emulsifiers or solvents to obtain a good contrasting background so as not to mask indications, may thus employ a penetrant that retains all of its natural penetrating and wetting powers.

Our method also has the advantage that it will indicate larger and shallower defects if it is desirable to obtain such indication. The extent to which various types of surface defects are rendered visible can be controlled, in accordance with our method, by varying the time required to fade or destroy the background color resulting from the residual surface film of colored penetrant remaining after most of the colored penetrant has been removed from the surface undergoing inspection. Such control of the method is made possible by changes in the technique of removing the surface layer of penetrant, in varying the time of exposure of the surface to ultra-violet light, the type and intensity of ultra-violet light source, the angle of incidence of the ultra-violet rays impinging on the surface undergoing inspection, the type of penetrant vehicle and the type and amount of dye in the penetrant, as well as varying the formula of the penetrant. In the case of rough surfaces, for instance, it is possible by destroying the background color by means of ultra-violet light to eliminate all general surface background colorations, and thus limit the indications to the detection of such surface cracks as it is desired to detect. Where good water-washable penetrants are used, however, it is not generally possible to obtain satisfactory indications of fine surface cracks in a generally rough surface, such as the rough surface of a casting.

A further advantage to our method is that if water is used as the means for removing the excess surface layer of colored penetrant from the surface undergoing tests, before exposing the remaining surface film to ultra-violet light, the heat generated by the source that also provides ultra-violet light can be utilized to aid in the drying of such surface, thereby eliminating the need for separate heating elements or separate sources of heat, or for a separate drying step.

It is therefore an important object of this invention to provide a method for detecting surface flaws, cracks and the like, which may easily be varied under controlled conditions to give indications of various types of cracks,

or to give indications that are selective with respect to some particular type of surface crack, whether shallow or deep, wide or narrow, or long or short, depending upon what is required.

It is a further important object of this invention to provide a method for detecting surface cracks and flaws that will simultaneously indicate large, open surface defects as well as very small or fine surface defects.

It is a further object of this invention to provide a method of detecting surface discontinuities that has a wider range of applicability, both with respect to the general character of the surface to be tested, whether generally smooth or generally rough in character, and also with respect to the character of the surface defect, whether fine or coarse, shallow or deep.

Other and further important objects of this invention will become apparent from the following description and appended claims.

The penetrant to be used in our method is a liquid that has the property of wetting the surface to be tested and that has the ability to penetrate fine surface cracks and other flaws having surface openings. In general, an oily penetrant is best suited for our purposes. Since water emulsification is not necessary, the liquid vehicle used in preparing the penetrant is chosen primarily for its high penetrating ability, but should have other desirable properties, such as a relatively low vapor pressure and high flash point, and should be relatively incombustible to reduce fire hazards to a minimum and be relatively non-toxic. Satisfactory penetrant vehicles of the oily type include kerosene, mineral spirits, light fuel oils, and certain proprietary products, such as Sovaloid C, which is an alkylated aromatic petroleum compound having a minimum aromatic content of 98% of which 60% represents polyalkylated naphthalenes, such as tri-, tetramethylated naphthalenes; and partially hydrogenated terphenyl (1,4 diphenyl benzene).

Other types of penetrants that can be used, but are not preferred, are the benzenoid hydrocarbons such as benzene, toluene and xylene; ketones such as methyl ethyl ketone and isophorone; esters such as butyl acetate and amyl acetate; and acids such as acrylic acid. Since some of these penetrants are appreciably soluble in water, care must be taken if a water wash is used to remove any excess of the colored penetrant, not to use such a vigorous water wash as to remove accumulations of the colored penetrant from any surface discontinuities of the type that are to be detected.

The complete penetrant consists of the penetrating liquid vehicle and coloring matter dissolved in the vehicle. The coloring matter should be a dye which is soluble in the vehicle and which is relatively unstable to ultra-violet light. The dye may be either a fluorescent dye or a non-fluorescent dye, but in either case should be a dye that fades rather rapidly under intensive ultra-violet radiation. Examples of fluorescent dyes that are soluble in the penetrant vehicles above mentioned are 2,7-dimethyl coeroxen, perylene and celliton brilliant yellow FFA (4-amino-1, 8-naphthyl-2',4'-dimethylphenylimide.

Examples of suitable penetrant compositions are the following:

Example I

98.5% Sovaloid C (an alkylated aromatic petroleum compound)
1.5% Fluorol 5GA (2,7-dimethyl coeroxen)

The composition of this example is that of a fluorescent penetrant containing a fluorescent dye that is relatively quick fading under ultra-violet light.

Example II

99.6% partially hydrogenated terphenyl
0.4% Fluorol 5GA

The composition of this example is a slow fading fluorescent formulation, probably due to the fact that partially hydrogenated terphenyl is a better absorbent of ultra-violet light than Sovaloid C and this tends to slow down the rate of fading of the Fluorol 5GA.

Example III

50% oleic acid
47% kerosene
3% methyl-violet base

The composition of this example is a composition containing a dye that is visibly colored under white light, or ordinary sun light, and that fades under ultra-violet light.

In carrying out the method of our invention, the colored liquid penetrant is first applied to the surface undergoing test, by any of the usual procedures, such as by a dip, by spraying or by brushing the liquid penetrant onto the surface in such way and in such manner as to form a continuous layer thereover of the penetrant. Alternatively, procedures may be used that apply a very thin layer of film of the liquid penetrant, as by means of a fog or mist, or by means of wiping the penetrant onto the surface, or if a volatile constituent is included in the liquid penetrant composition, by evaporation of such volatile constituent. If the initial film is thin enough, the subsequent step of removing the excess of the liquid penetrant by washing with water may be eliminated, for instance, if the penetrant is applied to the test surface by wiping with a rag, or the like, the liquid penetrant, while entering any surface flaws that may be present, is spread in such a thin film over the surface generally that the color content thereof can be easily and quickly destroyed by irradiation with ultra-violet light. This eliminates the necessity of any separate step of removing the penetrant from the test surface before inspection.

Where the layer of the liquid penetrant produced on the surface to be examined is relatively heavy, a major portion of the penetrant is removed by any suitable means, as by wiping, by hosing with water, or by means of a water spray, to leave on the surface a thin, but uniformly continuous film of the liquid penetrant. It is generally preferred to dry this film before exposing the surface to ultra-violet light for the purpose of destroying or killing the background coloration. Drying may be accomplished by a blast of air, or by placing in a circulating air drier, or a solvent or vapor degreaser removal method may be used if the operator is interested in relatively tight, or fine, surface defects only.

In the next step, the dry, or substantially dry surface, containing the residual film of colored penetrant, is exposed to ultra-violet light. Drying may be simultaneously accomplished by the use of a blast of hot or cold air, or by placing the article in an oven while exposed to ultra-violet light, or in a circulating air drier, or by the use of a separate infra-red light, or by the use of an ultra-violet light source that includes infra-red. The surface undergoing testing should be uniformly exposed to ultra-violet light for even exposure of the surface film, but the beams of ultra-violet light should preferably be at an angle other than normal to the surface in order not to strike directly into the colored penetrant that may be present in any surface cracks or flaws. This however, is not so essential in the case of relatively deep surface cracks or flaws, since then a greater depth of dye is present in the defect than in the thin surface film of the colored penetrant, and the film is therefore faded more rapidly than is the dye in the surface defect. This is

probably due to the absorptive action on the ultra-violet light of the liquid vehicle in the penetrant, whereby the thin film left on the general surface undergoing test is more rapidly faded than the greater depth accumulations of the colored penetrant in surface defects.

Excellent sources of short wave ultra-violet include sun lamps, germicidal type bulbs and carbon arcs. Near ultra-violet light such as black lights also are effective in destroying background coloration but much more slowly than short wave ultra-violet lights. The term "ultra-violet" is intended to include wave lengths of around 2000 to about 4000 Angstrom units, and wave lengths of around 2500 Angstrom units or less are considered short wave ultra-violet light.

The time required to effect fading of a quick fading fluorescent penerant, such as that of the composition given in Example I, will ordinarily be about 10 seconds, but longer exposure to ultra-violet light may be required in the case of the compositions of penetrant given in the other examples.

After the general background coloration on the surface undergoing test has been substantially destroyed, or faded, the surface is then inspected under ultra-violet light, white light, or other suitable light source. Preferably, a developer is applied to the surface being tested before such inspection. A suitable developer may be used, either in dry powder form or in the form of a liquid suspension of finely divided particles. French talc is an example of a suitable developer, but other finely powdered materials having a capillary action and preferably white in color may be used.

Where a suspension is employed, a dispersion of talc or the like in denatured alcohol has been found to be suitable. After the liquid suspension has been applied to the surface undergoing test, the alcohol is allowed to evaporate and the dry powder, by capillary action, then causes the colored liquid penetrant to be drawn out of any surface cracks or flaws to color the developer in and above such crack or flaw. The alcohol prior to evaporation may also act as a solvent for the penetrant or dye to aid in bringing it back out of the flaw. The use of a white developer enhances the contrast between the color that is brought out in this manner, when viewed either under ultra-violet light or under white light. Where a non-fluorescent dye is used in the penetrant, inspection is carried out under white light.

Our method thus serves to detect cracks or other flaws having surface openings by rendering such cracks or flaws visible, either under ultra-violet light or under white light, depending upon whether fluorescent coloring materials are used or non-fluorescent materials are employed. The presence, location and extent of the surface defects are made visible to the unaided eye, where such surface defects might not otherwise be detectable by unaided visual inspection.

As previously explained, since water emulsification is not necessary, the penetrating liquid used in our method is chosen primarily for its high degree of penetrating ability. It is, however, feasible to incorporate small amounts of an emusifying agent, such as to 1% by volume, if water is to be used to remove excess surface penetrant, since by so doing it is somewhat easier to obtain more uniform and thinner residual films of the colored penetrant that will fade more rapidly under the action of ultra-violet light. Also, fading rates can be controlled or varied by adding small amounts, say, from a trace to 0.1% by weight of other substances to the colored penetrant, such as Cinnamalazine, or Sudan Yellow GGA, which appear to increase the absorptive action of the penetrant toward ultra-violet light, and therefore retards the fading of the dye used. Cinnamalazine has the formula:

—CH=CH—CH=N—N=CH—CH=CH—

likewise, other types of liquid vehicles, such as a No. 2 fuel oil, may be employed to decrease the life of the dye under ultra-violet light by decreasing the filtering or absorptive action of the penetrant vehicle.

As a specific example of our method, the following is given:

Example IV

An 18–8 type stainless steel was tested for surface flaws. It was first dipped in a colored liquid penetrant of the following composition:

99.6% partially hydrogenated terphenyl
0.4% Fluorol 5GA

Immediately after being dipped, the article was withdrawn from the penetrant and water washed with a heavy spray of water, the spray nozzle being held 12 inches from the test piece and the water washing being continued for 30 seconds on each side. Thereafter the test piece was dried in an air blast and exposed to ultra-violet light in a Weather-O-Meter of the Twin arc type such as that designated as DL–TS, manufactured by Atlas Electric Devices Co., which has a rating based upon its ability to decompose 9.440 mg. of oxalic acid per sq. cm. in one hour. After 80 seconds exposure in this device, the background fluorescence had been effectively faded or otherwise destroyed and the test piece was inspected under black light.

If, in place of the penetrant composition above given in this example other compositions were used, different periods of time varying between 10 and 120 seconds might be required for destruction of the background fluorescence, as, for instance, is shown in the following table:

Composition	Time Required, seconds
98.5% Sovaloid C 1.5% Fluorol 5GA	10
99.6% liquid vehicle 80% by volume terphenyl 20% by volume #2 fuel oil 0.4% Fluorol 5GA	40
99.5% Santicizer #8 0.5% Fluorol 5GA	120
99.5% Santicizer E–15 0.5% Fluorol 5GA	50
99.5% Santicizer #141 0.5% Fluorol 5GA	30

Santicizer #8 is said to be a mixture of N-ethyl ortho- and para-N-toluene sulfonamides; Santicizer E–15, ethyl, phthalyl ethyl glycollate; and Santicizer #141, an alkyl-aryl phosphate.

In any of the foregoing formulas, the percentage of dye may be varied from a minimum of about 0.25% by weight up to saturation, but in general, any percentage over about 1.5% by weight is uneconomical because of cost and also because of the length of time required to fade or destroy all objectionable background color. By the term "background" color, is meant the general or over-all coloration of the test surface, as distinguished from the color of any accumulations of the colored penetrant at surface discontinuities.

While it is not generally desirable to incorporate an emulsifying agent in the liquid penetrant, it is feasible to use an external emulsifying agent to facilitate removal of the excess of penetrant. For instance, after dipping the test piece in a non-water miscible liquid penetrant of the oily type, such as kerosene, mineral spirits, light fuel oils, Sovaloid C or a partially hydrogenated terphenyl, the excess of penetrant can be removed by bringing the test piece into more or less static contact with a viscous emulsifying agent, such as Twitchell's reagent, without agitation or any scrubbing action, so as to emulsify only the surface film of penetrant, and then water washing, followed by drying, the application of a dry or wet developer and finally inspecting the test surface. By avoiding substantial mixing of the viscous emulsifying agent and the penetrant, removal of the penetrant from surface flaws by the subsequent water washing step is also avoided.

It will be understood that modifications and variations may be effected without departing from the scope of the novel concepts of the present invention.

We claim as our invention:

1. The method of testing articles for surface discontinuities, which comprises applying to the surface of an article to be tested a nonwater miscible liquid penetrant containing coloring matter which is susceptible to fading upon exposure to high intensity short-wave ultra-violet light, forming a continuous layer of said penetrant over said surface, removing from said surface all but a residual adherent film of said colored penetrant, destroying the background color in said film by exposing said film to high intensity short wave ultra-violet light, terminating said exposure short of the time required to destroy the color of any penetrant lodged in a surface discontinuity, and finally inspecting said surface under a source of fluorescigenous irradiation of lesser intensity and of longer wave length that renders contrastingly visible the presence of any colored penetrant in a surface discontinuty.

2. The method of testing articles for surface discontinuities, which comprises applying to the surface of an article to be tested a non-water miscible liquid penetrant containing coloring matter which is susceptible to fading upon extended exposure to high intensity short-wave ultra-violet light, forming a continuous layer of said penetrant over said surface, removing from said surface all but a residual adherent film of said colored penetrant, destroying the background color in said film by spacing said film to high intensity short wave ultra-violet light, terminating said exposure short of the time required to destroy the color of any penetrant lodged in a surface discontinuity, and finally inspecting said surface under a source of ultra-violet light of less ultra-violet intensity and longer wave length than employed in the original exposure.

3. The method of testing articles for surface discontinuities which comprises applying to the surface of an article to be tested a non-water miscible liquid penetrant containing an emulsifying agent and containing coloring matter which is susceptible to fading upon extended exposure to high intensity short wave ultra-violet light, washing off excess liquid from said surface while leaving a thin residual film of said penetrant thereon, substantially drying said surface, irradiating said surface with high intensity short wave ultra-violet light for a time sufficient to destroy substantially the color of the film in portions of the surface free from surface discontinuities but not sufficient to destroy completely the color of the penetrant lodged in a surface discontinuity, and inspecting said surface under ultra-violet light of lesser intensity and longer wave length to observe the presence and location of any accumulation of color in surface discontinuities.

4. The method of testing articles for surface discontinuities which comprises applying to the surface of an article to be tested a non-water miscible liquid penetrant containing an emulsifying agent and containing coloring matter which is susceptible to fading upon extended exposure to high intensity short wave ultra-violet light, washing off excess liquid from said surface while leaving a thin residual film of said penetrant thereon, substantially drying said surface, irradiating said surface with high intensity short wave ultra-violet light for a time sufficient to destroy substantially the color of the film in portions of the surface free from surface discontinuities but not sufficient to destroy completely the color of the penetrant lodged in a surface discontinuity, applying a developer to said surface to accentuate the contrast between any accumulation of color in a surface discontinuity and in said surface generally, and inspecting said surface under ultra-violet light of lesser intensity and longer wave length to observe the presence and location of any accumulation of color in surface discontinuities.

5. The method of testing articles for surface discontinuities which comprises applying to the surface to be tested a continuous layer of a colored oily non-water miscible penetrant capable of wetting said surface and containing coloring matter that fades upon extended exposure to high intensity short wave ultra-violet light, removing from said surface all of said layer except a residual film and any of said penetrant that has penetrated into a surface flaw, irradiating said surface with high intensity short wave ultra-violet light until said surface absorbs a quantum of ultra-violet energy sufficient to materially fade the color of the portions of said film on parts of said surface which do not have surface discontinuities thereby rendering said portions contrastingly visible from the portions of said penetrant which have penetrated into a surface discontinuity when inspected by ultra-violet light, and thereafter irradiating said surface with ultra-violet light at a lower energy level than the first irradiation to render contrastingly visible the presence of surface discontinuities.

6. The method of testing articles for surface discontinuities which comprises applying to the surface to be tested a continuous layer of a non-water miscible liquid penetrant containing fluorescent coloring matter which is susceptible to fading upon extended exposure to high intensity short wave ultra-violet light, forming a thin layer of said penetrant on said surface, removing from said surface all of said layer except a residual film and any of said penetrant that has penetrated into surface flaw, irradiating said surface with ultra-violet light until said surface film absorbs a quantum of ultra-violet energy sufficient to materially fade the color of those portions of said film on parts of said surface which do not have surface flaws thereby rendering said portions contrastingly visible from the portions of said penetrant which have penetrated into a surface flaw when inspected by ultra-violet light, and thereafter irradiating said surface with ultra-violet light at a lower energy level than the first irradiation to render contrastingly visible the presence of surface discontinuities.

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