17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

Study on the Penetration Theory of Flaw

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Abstract

In the field of commercial manufacture, the permeation flaw detection is always used to inspect the surface quality of production. In conventional permeation flaw detection, the fluorescence or none fluorescence penetrant infiltrate the surface of the work and the developed image is used for flaw detection. The infiltration capacity of penetrant is very important to permeation flaw detection. If the flaw of the work isn't infiltrated by the penetrant adequately, the permeation flaw detection will not work well. In this paper, the penetration theory of flaw is analyzed. The influential factors of infiltration capacity are discussed. The expression of the infiltration rate of capillary liquid column and the expression of the penetrant climb of flaw model are deducted. We have observed that, besides the physical property of material, the infiltration capacity of penetrant has a relationship with the atmosphere, the depth, width, spatial location of the flaw and whether the flaw is breakthrough. The conclusions of this paper are beneficial to improve the sensitivity of the permeation flaw detection.

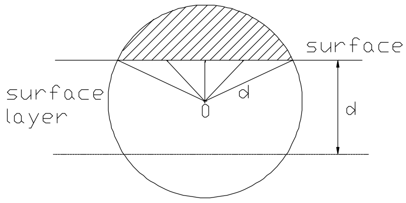
Keywords: Permeation flaw detection; Flaw model; Penetrant analyzing; Influential factor

In order to control the production quality during commercial manufacture, the penetration theory of flaw, which can result the elimination of components with exterior penetration according to the technology demands, is usually been used to verify the quality of their surface. As far as it goes, the general methods accomplish detection via adopting a kind of penetrant with fluorescence or non-fluorescence to penetrate superficial defect and then display them. Whether the permeation flaw detection is successful mainly rest with infiltration capacity in the disfigurement that is the most important key in this process. If the penetrant is not able to soak work piece, then the inner flaws can not be saturated enough, these means of the permeation flaw detection is meaningless.

1 Factors that influence penetrant penetrate flaws

1.1The influence of penetrant

By the molecule reciprocity standpoint, liquid superficial molecular density is less than those inner. As figure 1, given o is centre of ball and radius r, all the molecules inside sphere appeal to one at the point o, but because shadow has no gravitation outside liquid surface, the distance between liquid superficial molecules must be more than ro of balance position, the attraction whose potential energy among molecule trends lessened spontaneously is main interactive power and assumes surface tension which result in self-contractive direction on surface. Surface tension, which is the liquid superficial physics property as well as one of facts affecting the infiltration capability, rest with surface tension coefficient α. When liquid contacts solid, there will be a flat of thin appendicle layer whose physics property is different from those of single-phase liquid or solid for as much as the molecule in appendicle layer are attracted by inner ones of liquid and solid at the same time. Furthermore, if reciprocity among the molecule in appendicle layer exclusive from each other in the mass, the appendicle layer has patulous trend and then liquid is able to soak the face of solid. On condition that osculatory angle θ denotes interphase physics property, then θ is also one of facts affecting the infiltration capability. So $\alpha\cos\theta$ is the main fact on total.



picture1 interactio namong moecule in liquid surface layer

1.2 Influence of flaw types、flaw position、penetrant glutinosity η、air pressure and so on

The penetration theory of flaw is based on capillary elements in which the diameter of capillary decides directly these phenomena. Generally speaking, firstly capillary phenomena is more evident with the thinner diameter of capillary; secondly friction inside liquid is increscent when penetrant glutinosity η becomes bigger; thirdly air pressure around also make influence of height of liquid column. Flaw type and form of actual work piece are complex, such as interstice、finestra、veins、layer and so on, which result in the obvious different shape with ideal capillary. The space position of flaw such as perpendicularity、level、incline、hatch also have a certain influence.

1.3 Influence of pollution degree on the surface, that is, other mantle and flaw jam.

For example, infiltration capacity of flaw might be impacted by smeary jam fatigue flaw in the inner of service work piece, quencher medium jam of quencher piece, cautery jam of crack among crystals.

2 The characteristic analysis of penetrant

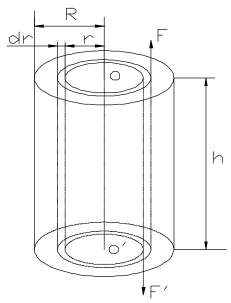
Material performance of penetrant is usually toke both by the static infiltration capacity $S_{pp} = \alpha\cos\theta$ and the dynamic infiltration capacity $K_{pp} = \frac{\alpha\cos\theta}{\eta}$.

2.1 The physical meaning of static infiltration capacity

S_{pp} is a physics measurement to weigh the infiltration capacity of flaw, which is explained by the height of ideal capillary penetrant. Taking no account of friction inside liquid, the above formula illuminate the infiltration capacity of flaw becomes stronger with S_{pp} ($\theta \le 5^o$) bigger, corresponding radius of capillary is smaller, the height to overcome ascending liquid is higher.

2.2 The physical meaning of dynamic infiltration capacity

Dynamic infiltration capacity also can betoken by infiltration rate, which reflects the physical meaning of needful time to achieve homeostasis. Obviously ascending movement of liquid inside capillary is a complex process. On the beginning, the weight of liquid tend to zero because capillary does not form liquid, here both friction inside liquid $F = -2\pi r h \eta (\frac{dv}{dr})$ and append pressure on bend $F = 2\pi r\alpha \cos\theta$. Generally speaking, friction is resistance of ascending liquid, append pressure is power contrary, both preserve invariability in the ascending process. With the development of liquid, its height increases that is meaning its pressure increases, the rate of ascending liquid becomes slow and friction changes along with rate. Therefore strictly speaking, in the whole ascending process, liquid moves on irregular velocity, as result in complex solution to get the penetrative rate. But if we don't consider liquid density, that is, except liquid gravity and its pressure $p = \rho g h$, the rate can be obtained easily. From now on, we deduce the formula of penetrant velocity V by hydrodynamics.



Picture2 fore analysis of the liquid column

Just as figure 2, the length of liquid column is L after time interval Δt . We shear liquid column into lots of thin cylinder layers whose depth is dr and both sides stand power that shows by sign F、F′ for each one. Hereinto, the direction of F is the same that of V, but the direction of F' is reverse.

Friction in hydrodynamics is $F = -2\pi r L \eta (\frac{dv}{dr})$

After difference, we get $dF = -2\pi L \eta d(r\frac{dv}{dr})$

Pressure difference is $dF = F - F^{'} \neq 0$

Side pressure difference is $(P - P^{'})2\pi r dr = dF$

Therefore $(P - P^{'})2\pi r dr = -2\pi L \eta d(r\frac{dv}{dr})$

Integral twice according to boundary condition, we obtain $V = \frac{(P - P')(R^2 - r^2)}{4L\eta}$ (1)

Because circumfluence is $dQ = V 2\pi r dr$

After T, the ascending height L is equal to h, all the liquid flux is

$$Q = \int_0^R dQ = \int_0^R \frac{(P-P')}{4L\eta}(R^2 - r^2)2\pi r dr = \frac{\pi(P-P')R^4}{8\eta h} \quad (2)$$

The difference of liquid pressure is caused by append pressure on bend

$$P - P' = \frac{2\pi R\alpha\cos\theta}{\pi R^2} = \frac{2\alpha\cos\theta}{R} \quad (3)$$

From (2) and (3), we can obtain the infiltration rate $V = \frac{Q}{\pi R^2}$

$$V = \frac{\pi \frac{2\alpha\cos\theta}{R} R^4}{8\eta h} \cdot \frac{1}{\pi R^2} = \frac{R\alpha\cos\theta}{4h\eta} \quad (4)$$

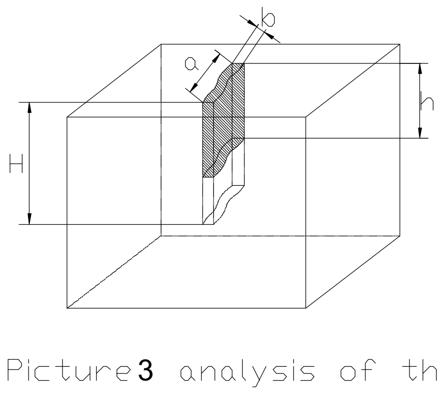
Formula (4) makes out that the infiltration rate of penetrant is correlative with not only dynamic infiltration capacity $\frac{\alpha\cos\theta}{\eta}$, but also radius of capillary and height of liquid column.

The actual flaw measurement is narrow (i.e. R is small), cannot but the infiltration rate is low and the needed time is enough long to take balance stabile status within touch, this phenomena inosculate theory formula. So it can reflect the height of ascending liquid column in a unit time that dynamic infiltration capacity is decided by the infiltration rate.

3 Flaw infiltration capacity analysis of work piece

Flaw type and flaw form of actual work piece are complex. Their size generally manifests wide top and narrow base but not the ideal capillary. Take the normal interstice for example, there are transfixion interstice and non- transfixion interstice. Usually non- transfixion interstice easily close in gas. If so, pressurized air pressure increase with addition of infiltration capacity, then these will influence infiltration capacity inside flaw. From now on, we deduce the formula of penetrant height by the model theory of flaw.

Just as figure 3, set flaw belongs to non- transfixion interstice toward top along vertical line. Its length is a, its width is b, its height is H. After a period of time, the airproofed gas get balance, the height of infiltration capacity turn into h.



Picture3 analysis of the crack model

To analyze force suffered by filtered liquid, there are atmospheric pressure P_0 ab、 append pressure on bend $2(a+b)\alpha\cos\theta$ and airproofed atmospheric pressure P_1ab

Given temperature and mass of inner gas retain constant, we can obtain according to energetic law

$$P_0abH = P_1(H-h)ab \qquad (1)$$

$$\text{i.e.} \quad P_1 = \frac{P_0H}{(H-h)}$$

If liquid density is not considered, penetrate stop, and liquid stand balance along vertical line. We can get

$$P_0ab + 2(a+b)\alpha\cos\theta = P_1ab$$

Coordinate above equation, we get $h = \dfrac{2H(a+b)\alpha\cos\theta}{2(a+b)\alpha\cos\theta + P_0ab}$ (2)

i.e.

$$h = \frac{H}{1+\dfrac{P_0ab}{2(a+b)\alpha\cos\theta}}$$

If a>>b，then b/a→0, so $h = \dfrac{H}{1+\dfrac{P_0b}{2\alpha\cos\theta}}$ (3)

Formula (3) makes out that the infiltration height of penetrant h is correlative with the depth of flaw H and the width b while outside atmospheric pressure P_0 maintain invariability and static infiltration capacity $\alpha\cos\theta$ is ascertained. In common, we can also deduce the height of semi-through capillary $h = \dfrac{H}{1+\dfrac{P_0r}{2\alpha\cos\theta}}$. Why the formula of semi-through capillary is different from that of through capillary lies on semi-through capillary close in gas to obtain h throughout the balance of air pressure and tensility, while through capillary get h throughout the balance of tensility and gravity itself.

4Conclusion

The above analyzes theoretically those main facts to influence infiltration capacity of flaw and realizes the formula of the infiltration rate of capillary and the height of infiltration capacity. Till now, we have observed that, besides the physical property of material, the infiltration capacity of penetrant has a relationship with the atmosphere, the depth, the width, the spatial location of the flaw and whether the flaw is breakthrough. For the same material, thinner flaw, longer time. Formula (3) that is different from through capillary is the penetration theory of semi-through capillary. Therefore, we should firstly know the approximate type of checked works in order to ensure to select manner and time, then to heat the work piece to depress gas density inside flaw.

These methods included cooling inner gas and trembling properly the work piece is beneficial to filter. In a word, to improve the sensitivity of the permeation flaw detection demands increase penetrant inside flaw as to the best of one's abilities.

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