Thermal pulse video thermography nondestructive testing of the defects in carbon steel*

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Abstract: Carbon steel is widely used in many fields. It is of great importance to study the behavior of carbon steel in nondestructive testing. To investigate the behavior of carbon steel in thermal pulse video thermography nondestructive testing, two standard carbon steel test-pieces are made. The sizes and depths of defects in two standard carbon steel test-pieces are studied by thermal pulse video thermography. The results show that for the purpose of minimizing errors of size measurements the testing time should be chosen at about 0.3 s after the thermal heat flux applied to the specimen with defects of smaller depths (l<1.8 mm) and it is more difficult to measure the size of shallower defect than that of deeper defects. For the defects with diameters larger than 6 mm, the depth measurement errors are usually small if the thermograms are in high contrast. If defect diameters are smaller than 6 mm, the depth measurement errors are usually more than 10%. To determine the depth of the defect it should be performed shortly after the thermal flux applied to the test-piece to avoid the blurring of the thermal images due to heat diffusion.

Key words: Carbon steel; Thermography; Nondestructive testing

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碳钢中缺陷的脉冲红外热成像无损探伤*

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摘要: 由于碳钢材料在许多领域有着非常广泛的应用, 所以研究碳钢的无损探伤规律具有很重要的现实意义。为探究碳钢在脉冲红外热成像无损探伤中的规律, 特设计 A、B 两种标准试件, 利用脉冲红外热成像技术对两种标准碳钢试件中缺陷的大小和深度进行了定量化研究。研究结果表明, 测量近表(l<1.8 mm)小缺陷的大小时, 应选择在热脉冲作用后约 0.3 s 进行, 此时测量误差比较小, 并且对深度小的缺陷进行大小的测量要比深度较大的缺陷困难。对于深度较大的缺陷, 只要红外热图像清晰, 测

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量误差都比较小。测量缺陷深度时，当缺陷直径大于 6 mm 时，测量误差比较小。当缺陷直径小于 6 mm 时，误差比较大，甚至无法探测到缺陷。由于热扩散，测量缺陷的深度应选择在热脉冲作用后的短时间内进行，以保证红外热图像的清晰度，减小测量误差。

关键词：碳钢； 红外热成像； 无损探伤

0 Introduction

Since pulse-video thermography (PVT) originally developed at Harwell,PVT has been developed as one of the powerful noncontact NDT techniques by many researchers[1~7],and it made us possible to detect flaws and defects with high resolution.

Carbon steel is widely used in many fields,so it is of great importance to study the defect testing of it.In this paper two standard test-pieces are made of carbon steel,and artificial defects in the test-pieces are quantitatively studied using thermal pulse video thermography.Testing results are presented and analyzed.

1 Standard test-pieces

In order to investigate defect testing in carbon steel test-pieces,we designed two types of standard test-pieces, namely test-piece A and B,with flat-bottom defects as shown in Fig.1 and Fig.2. The defects in test-piece A are of the same diameter (10 mm) but at different depths.In test-piece B,however,the defects are at the same depth (1.1 mm) but with different diameters.

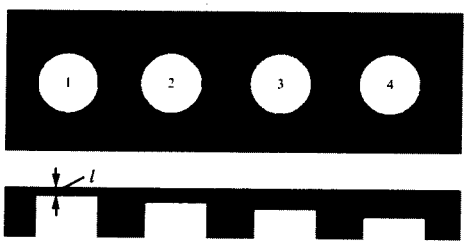

Fig.1 Specimen A

(1: l=0.8 mm; 2: l=1.1 mm; 3: l=1.3 mm; 4: l=1.8 mm)

2 Experimental results and analysis

According to the methods of measuring the sizes and depths of defects using PVT [8],the following experimental results can be obtained.

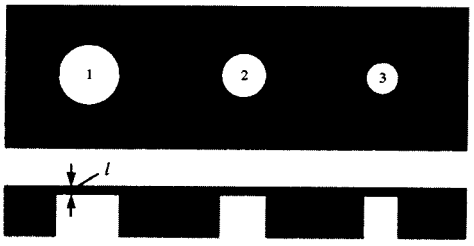

Fig.2 Specimen B

(1: D=10 mm; 2: D=8 mm; 3: D=6 mm)

2.1 Measurements of defect sizes

Fig.3 shows the independence of the size measurements of defects with the same diameter on detection time. It can be seen in Fig.3 that with the decrease of defect diameter D the measurements of the defect sizes change slowly with testing time t. When the defect diameter is 6 mm, the fitting line is nearly horizontal. Moreover,with the decrease of defect diameter, the measurements of the sizes of the defects are more accurate. However,if the diameter of the defect is smaller than 8 mm,the thermogram has a low contrast,and last very shortly.This makes the quantitative analysis of the defect much more difficult.What interests us is the fact that though larger defect has high-contrast thermograms,the measurements of the defect sizes changes shap-

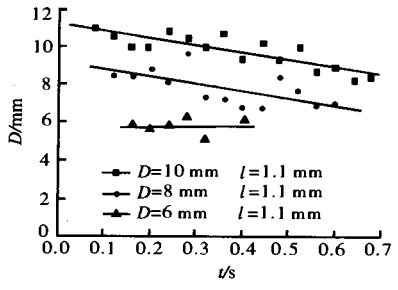

Fig.3 Dependence of defect diameter D on time t for specimen B

ly with testing time t.Fig.3 reveals that size measurement errors grow bigger with time going. This may be due to the increase of the lateral thermal diffusivity. So only when testing is performed at appropriate time the errors would be bigger.For carbon steel specimen,the testing should be performed at about 0.3 s after the thermal heat flux applied to the specimen.

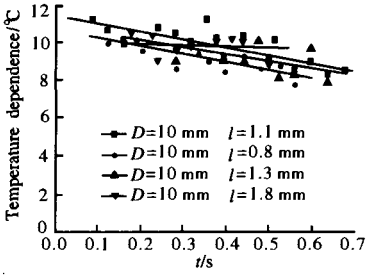

Fig.4 Dependence of defect diameter D on time t for specimen A

Fig.4 shows the dependence of the size measurements of the defects in specimen B on testing time t.It can be found in Fig.4 that the size (diameter) measurements change slowly with the increase of defect depth l. When the defect is at the depth of 1.8 mm,the fitting line is nearly parallel to time axis.In this case,the size measurement errors are very small.With the decrease of the depth of defect,the measurement errors due to the testing time increase apparently.An interesting thing is that it is more difficult to accurately measure the depths of shallower defects than that of deeper ones.It may be due to the fact that thermal energy collects in a smaller volume for shallower defects after thermal heat flux applied to the specimen.It makes the temperature above the defect increase rapidly and causes higher temperature gradient around the boundary of the defect.So thermal diffusivity increases around the boundary and area of temperature abnormality in the thermogram shrinks rapidly with time.If the testing time is not chosen appropriately, the measurement errors are usually big.

2.2 Measurements of defect depths

Fig.5 shows the dependence of temperature difference above the defect on time.It can be easily found in Fig.5 that temperature difference ΔT grows rapidly after thermal flux applied to specimen and reaches a maximum at t_{max}.Thereafter,ΔT slowly goes down.From Fig. 5 we can read the peak time t_{max} of each defect.For carbon steel, its special heat is 465.0 J/kg·K ,the thermal conductivity is 49.8 W/mK and the density is 7840 kg/m^3 .According to previous method of measuring defect depth we can easily obtain the depth of each defect.Tab. 1 shows the testing results and errors.

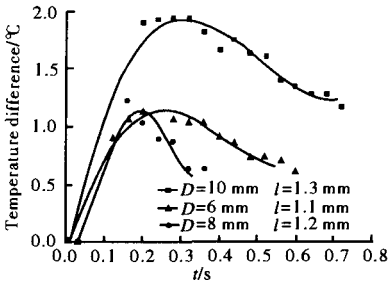

Fig.5 Dependence of temperature difference on time

Table 1 shows that depth measurement errors go up with the increases of defect sizes.For the defect with the diameter of 6 mm the error is up to 10%.

Tab.1 Measurements of defect depths

Defect	Actual depth / mm	Testing depth / mm	Error
D=10 mm, l=1.3 mm	1.3	1.38	6%
D=8 mm, l=1.2 mm	1.2	1.28	7%
D=6 mm, l=1.1 mm	1.1	1.21	10%

3 Conclusion

(1) For the defects at depths smaller than 1.8 mm, in order to minimize size measurement errors testing time should be chosen at about 0.3 s.However,for defects at depths more than 1.8 mm,measurement results are usually accurate if thermograms are in high contrast.

(2) Because of the influence of thermal diffusivity, depth measurements should be performed shortly after the thermal heat flux applied to specimen.

(3) In measuring the depths of defects, if defect diameter is larger than 6 mm, measurement error is usually small. Otherwise, measurement error is big and even the defect can not be detected.

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(上接第 441 页)

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