MAGNETIC MEMORY TESTING OF STATIC-TENSION STEEL SAMPLE FOR LIFE EVALUATION IN COMPONENT REMANUFACTURING

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Abstract

Static tension tests of 18CrNi4A steel were done for research. In the condition of earth magnetic field, magnetic memory testing (MMT) technology was used to detect normal component of scattering magnetic field intensity-Hp(y)-of the samples. In the paper, the regularity of Hp(y) values changing with static load and position was studied. Meanwhile, the relationship between the absolute value of slope coefficient of the Hp(y) curves and static load was indicated. In addition, the interaction theory of dislocation and magnetic domain was applied to discuss the mechanism of MMT. Thus the ground experiments were studied for the application of MMT in remanufacturing life evaluation in 18CrNi4A steel.

Keywords: remanufacturing, life evaluation, static tension, magnetic memory testing(MMT)

1 Introduction

18CrNi4A steel has good mechanical properties, which is widely used to manufacture the key heavy-duty gear and shaft components in aerospace and airplane. And it has great remanufacturing value. The failed components need failure analysis and residual life prediction in order to evaluate the remanufacturing value before they are remanufactured [1]. The conventional failure analysis and life prediction methods bring damage to components, which need longer time and have high cost. However, the nondestructive testing has extensive prospects in life evaluation. But it also has a problem that the conventional nondestructive testing methods can only be used to detect existential defects [2].

In 1991, a new non-destructive testing technology named MMMT was elaborated by Russian professor Doubov[3,4]. Quick detecting defects at an early stage of their development by means of MMMT, due to magnetic memory effect on ferromagnetic materials in the process of work loads and earth magnetic field, can be used to estimate damage level and predict residual life of ferromagnetic materials before remanufacturing[5]. It has been intensively recognized by national and international academicians in the relative fields after MMMT is proposed.

Static tension test is an effective method of studying damage situation of material. In this paper, a typical ferromagnetic material was done tension test, which simulated the easiest real working situation, to explain the internal mechanism of magnetic memory effect by studying the relationship of loads and magnetic signals.

2 Experimental

The samples are made of 18CrNi4A steel, a kind of case-hardened steel, which has high tension strength and good integrated mechanical property by means of quenching and lonnealing. This material is usually applied in manufacturing critical heavy-duty gear and shaft item, also used as carburized bearing steel. Table 1 shows the chemical constitution and mechanical property of 18CrNi4A steel. Many factors, such as machining process, heat treatment condition and transport situation, intensively affect the initial magnetic signal, so all the samples were under inductive demagnetization before test in order to study the relationship of work loads and magnetic memory signals in ideal condition.

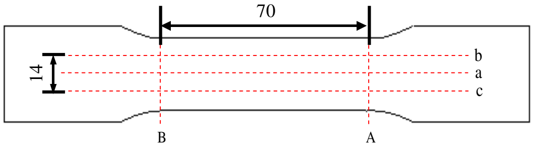

Fig.1 shape and detecting paths of Samples 18CrNi4A steel

Tension test was done by MTS810 hydraulic servo machine, whose static load error is ±0.5%. Hp(y) values were measured by EMS2003 intelligent magnetic memory/eddy current detector. The samples were on load in low speed, approximately 0.5kN/s, until preset load, lifted down and laid in north-south direction. Fig.1 provides the shape of samples and detecting paths.

C	Mn	Si	S	P	Cr	Ni
0.15~0.20	0.30~0.60	⩽0.35	⩽0.010	⩽0.015	0.80~1.10	3.75~4.25

Heat treatment	σ_b/MPa	$\sigma_{P0.2}$/MPa	δ_5/%	a_{KU}/(kJ/m^2)
810~830℃，1h，oil cooling 170~190℃，2h，air cooling	1325~1520	⩾980	⩾8	⩾600

Table 1 chemical constitution (wt.%) and mechanical property of 18CrNi4A steel

There are three paths, which interval is 7mm, on the samples, the length between A(north) and B(south) is 70mm. The probe, whose lift off is 0.5mm, is gripped on a nonferromagnetic 3D electric controled moving platform, shown in Fig.2. The interval of every detected points along paths is 0.3mm. The condition magnetic field is earth magnetic field.

Fig.2 nonferromagnetic 3D electric controlled moving platform

3 Experimental results and analysis

3.1 Magnetic memory signals before cracking

In experiment, there exist the same variation rules, just different in values, in the results of Hp(y) values along three paths. Therefore, just the relationship of Hp(y) values and work loads in path (a) is shown in Fig3.

The yield point load of 18CrNi4A steel is 200kN and the cracking point load is 220kN in load-displacement curve. The dash lines in Fig.3 are the curves after yielding. All the curves are approximately linear, crossing at the point of 35mm, with only one zero value in each curve. It is known that the sample is magnetized along the stress axial line influenced by condition magnetic field and work loads[6]. The process of magnetizing is regarded as a uniform magnetization, so the sample is like a ferromagnet, whose characteristic of magnetic field is same with the results in Fig.3.

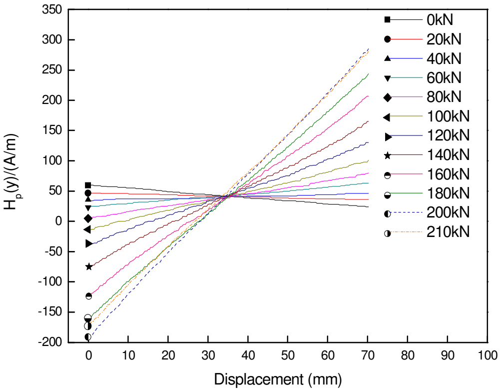

Fig.3 Hp(y) values－displacement curves on different loads in path (a) before cracking

Fig.3 shows that there exists an obvious regularity between slope of curves and work loads. The relation between the absolute value |k| of slope and work loads F, shown in Fig.4, is fitted by the equation of y=bx+a. The testing values of slope coefficient are minus, related to testing direction, so their absolute values |k| are used for easy analysis.

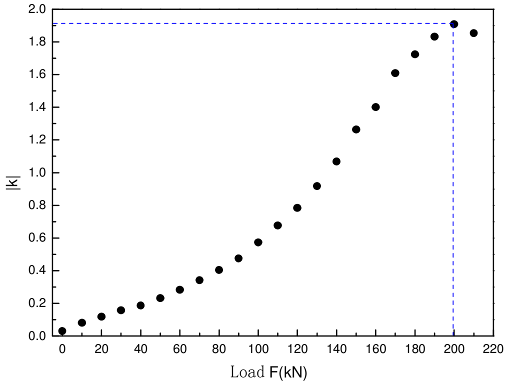

Fig.4 tensile loads-|k| curve for 18CrNi4A steel

3.1.1 Magnetic memory signals in the elastic range

In the elastic range of stress, |k| increase continually with the rise of work loads. k| changes a little at the beginning, but it changes a lot subsequently. There is the maximum of |k|, which is 1.91, on the yield point load, shown in Fig.4.

According to the present research[7], there is the following equation when ferromagnetics are in weak magnetic field and unilateralism load:

$$\mu = \mu_T (1 + bH / \mu_T)[a_0 + a_1 |\sigma|^m \exp(n|\sigma|)] \quad (1)$$

where μ_T is initial magnetic permeability related with T; T is temperature; b is constant related with material construction property; a_0， a_1， m， n are coefficients depending on direction of load and stress value. The equation shows that the relation between magnetic permeability and stress is nonlinear. Therefore, the permeability changes rapidly and ferromagnetics are liable to magnetize when stress goes up, agreed with the change of |k| in elastic stage.

3.1.2 Magnetic memory signals in the plastic range

Fig.4 shows that there is the maximum of |k| on the yield point. However, |k| decreases with the rise of work loads in the plastic range. Inelastic deforming, damaging and the effect of micro defects to the domain in the plastic range are rarely involved in magnetic physics. The situation of weak magnetic signals in plastic range can only be qualitatively explained. At present, the explanation, the anchoring effect of dislocation to domain leads to the change of magnetic signals, is widely accepted.

According to metal physics[8], ferromagnetics can be magnetized by themselves under earth magnetic field when they are in tensile load. Meanwhile, there are many dislocations in the material in the plastic stage. The dislocations become the main reason for blocking of domain wall motion and magnetic moment rotation.

Because domain wall is bigger than dislocation, there are many dislocations interacted with domain wall forming pile-up of dislocation. There exists anchoring effect for domain wall because of non-uniform distribution of dislocations in the side of domain wall, leading to the rise of coercive force and decrease of magnetic susceptibility and intensity, the effect of self-magnetizing is weakened. Thus the results in the plastic range in this paper can be well explained.

3.1.3 Discussion about magnetic memory testing of stress distribution in ferromagnetic component

According to the previous reports[9,10], there is definite relation between stress and magnetic signal, correlated variables are very important. Fig.4 shows that the stress is related with |k|. The degree of correlation should be characterized by related coefficients r:

$$r = \frac{\sum_{i=1}^{n} x_i \bullet y_i - n\overline{x}\,\overline{y}}{[(\sum_{i=1}^{n} x_i^2 - n\overline{x}^2)(\sum_{i=1}^{n} y_i^2 - n\overline{y}^2)]^{1/2}} \qquad (2)$$

where x is stress σ; y is the absolute value |k| of slope. By the results in fig.4, r equals 0.974, approaching to 1, showing that |k| is intensively related with σ.

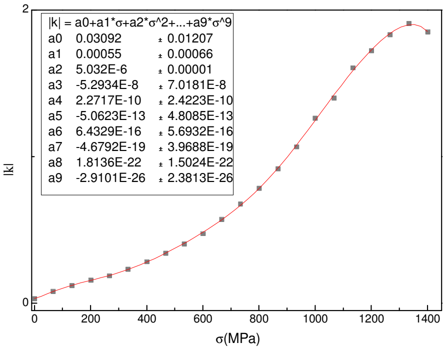

Fig.5 related curve of |k| and σ

The relation between |k| and σ is simulated by the polynomial, showing in fig.5. Through the related curve, the tensile stress working on the 18CrNi4A steel samples can be calculated by |k| tested by metal magnetic memory method. This method is not only fit for 18CrNi4A steel, but also it suits for other ferromagnetics. In most situations, the practical components are rarely under uniaxial stress, but the intensity of some equipments, such as pressure vessel and boiler furnace, is designed according to the static intensity. Therefore, it is easy for metal magnetic memory test to detect whether there is something wrong with equipment, then correlated with other nondestructive methods to estimate.

3.2 Magnetic memory signal analysis after cracking

Fig.6 is the picture of tensile failure in the sample. When the load was 220kN, the sample broke in the angle of 45, where there was necking phenomenon.

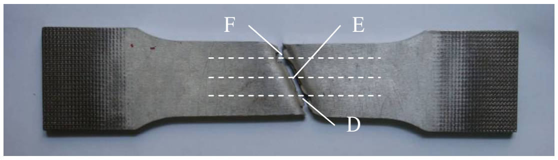

Fig.6 tensile failure of 18CrNi4A steel

The failure sample was detected in the method of MMMT in the same paths in Fig.1. The results are shown in Fig.7. The Hp(y) values intensively change and the |k| values suddenly increase near the fracture, with only one zero value in each path. The points (D, E and F) are the breaking points corresponding with the zero value.

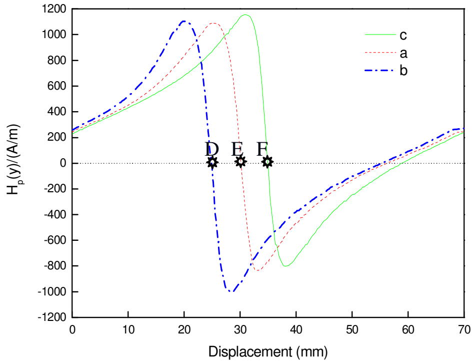

Fig.7 Hp(y) values-displacement curves in different paths after cracking

Known from ferromagnetics, if there are defects, cutting the magnetic lines, in the surface of ferromagnetic items. Some magnetic flux may escape from one side of defects, then they jump into the other side, generating magnetic polarization in the sides of defects and yielding leakage field intensity Hp. Driving magnetic field is the earth magnetic field in MMMT, so Hp is very low, needing highly sensitive magneto sensor to detect. The normal component of leakage field intensity Hp(y) is provided in the following formula[11]:

$$H_p(y) = \frac{\rho_{ms}}{4\pi\mu_0} \bullet \ln\frac{[(x+b)^2+(y+h)^2][(x-b)^2+y^2]}{[(x+b)^2+y^2][(x-b)^2+(y+h)^2]} \qquad (3)$$

where ρ_{ms} is magnetic charge density; μ_0 is vacuum permeability; h is depth of cracking; b is width of cracking.

Known from the formula, Hp(y) change sign symbol, with the zero values, in the defects. Therefore, the accurate position of defects can be detected by means of MMMT.

3.3 Applications in Remanufacturing

Fig.8 shows a gear shaft used for some time. Metal magnetic memory method was used to detect the gear shaft along the paths, shown in Fig.8. Testing results are presented in Fig.9.

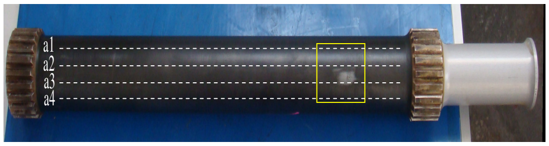

Fig.8 gear shaft and testing paths

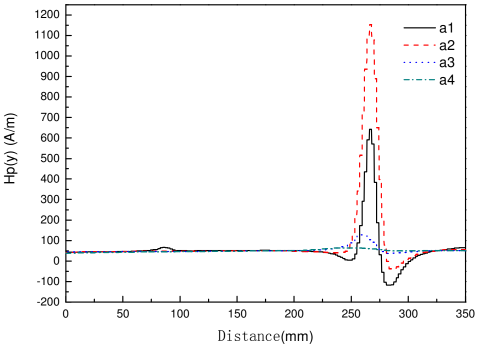

Fig.9 magnetic signals of the gear shaft

There are abnormal signal peaks near the driving gear showing that there exists stress concentration, then the ultrasonic testing was used, cracking was not found.

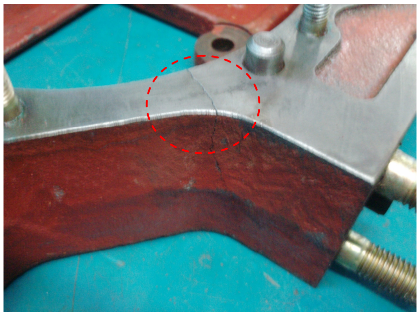

Fig.10 cracking of gearbox casing

Fig.10 shows a gearbox casing where there is a 33mm deep cracking, approximately resulted by intensive impact. Metal magnetic memory method was used to detect the cracking, shown in Fig.11.

The result shows that magnetic signals near the cracking intensively changed, then correlated with other nondestructive methods to quantitatively detect.

As a new nondestructive method, magnetic memory method is not perfect. There are some problems to solve, such as quantitative testing, sensitivity and resolution. The experiments result that metal magnetic memory method can detect stress concentration area and the position of surface micro cracking. But it can not quantitatively test defects, must be correlated with other nondestructive methods, such as ultrasonic, eddy current and X-ray testing.

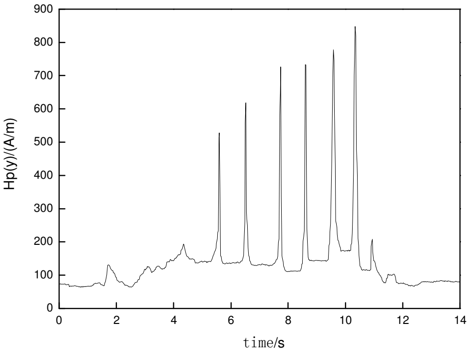

Fig.11 magnetic signals of the cracking in gearbox casing

4 Conclusion

(1) All the Hp(y) values-displacement testing curves before cracking are approximately linear, with only one zero value in each curve. In the elastic range of stress, |k| value increases continually with the rise of work loads. In the plastic range, |k| value decrease with the rise of work loads, meanwhile, there is the maximum of |k| on the yield point load.

(2) The curve of |k| and σ is described in the mathematical statistics method, therefore, the stress distribution station can be tested by magnetic memory method.

(3) After tensile failure, the Hp(y) values intensively change and the |k| values suddenly increase near the fracture. The breaking points correspond with the zero values. Magnetic memory testing can be used to detect the micro-defects in the 18CrNi4A steel samples.

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