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ANALYSIS OF TENSILE TESTING OF A SOFT FERROMAGNETIC ELASTIC STRIP CONTAINING A CENTRAL CRACK UNDER A MAGNETCI FIELD

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Summary The effect of magnetic fields on the fracture mechanics parameters is discussed by analyzing the plane problems of a soft ferromagnetic strip with a central crack under a uniform magnetic field. Tensile tests are also conducted on center-cracked soft magnetic plate with strain gage technique, and the numerical predictions are compared with the test results.

INTRODUCTION

With the increasing applications of ferromagnetic materials as fusion reactors, MHD devices, magnetically levitated vehicles, etc., the theme of magneto-elastic interactions has been addressed in the recent past. If a ferromagnetic material is used in a magnetic field, the combination of mechanical and magnetic forces could produce elevated stresses and strains. The ferromagnetic materials may be degraded in such a stress level. The strength of the ferromagnetic materials is also weakened by the presence of defects such as voids and cracks. It is therefore important to understand the degradation phenomena of the ferromagnetic materials. The fracture behavior of the ferromagnetic materials is thus of much recent interest. The influence of the magnetic field on the singular stress distributions near the crack tip in an infinite body was shown [1,2] based on a linear theory for the soft ferromagnetic elastic materials of multidomain structure [3]. Considered in [4] is the problem of determining the stress intensity factors in an infinitely long strip of a soft ferromagnetic elastic material with a crack parallel to the edges of the strip.

This paper applies a linear theory for the ferromagnetic elastic materials of multidomain structure [3] to the problem of determining the distribution of stress in a cracked soft ferromagnetic strip permeated by a uniform magnetostatic field normal to the crack surface. The plane problems are considered for the infinitely long strip containing a central crack normal to the edges of the strip. Tensile tests are also conducted on soft magnetic plate with a central crack to obtain the values of the fracture mechanics parameters, and the numerical results are compared with the experimental values.

ANALYSIS

Consider a soft ferromagnetic isotropic linear elastic strip of width 2h which contains a central crack of length 2a aligned with its plane normal to the free edges as shown in Fig. 1. A rectangular Cartesian coordinate system (x,y,z) is attached to be the center of the crack for reference purposes. The x-axis is directed along the line of the crack and y-axis along the direction of the perpendicular bisector of the crack. The edges of the soft ferromagnetic elastic strip are therefore the lines with equations $x=\pm h$, while the crack occupies the segment $-a < x < a$, y=0. We consider a uniform normal stress, $\sigma_{yy}=\sigma_0$, applied with a uniform magnetic field of magnetic induction $B_{0y}=B_0$. Only the first quadrant with appropriate boundary conditions needs to be analyzed owing to symmetry.

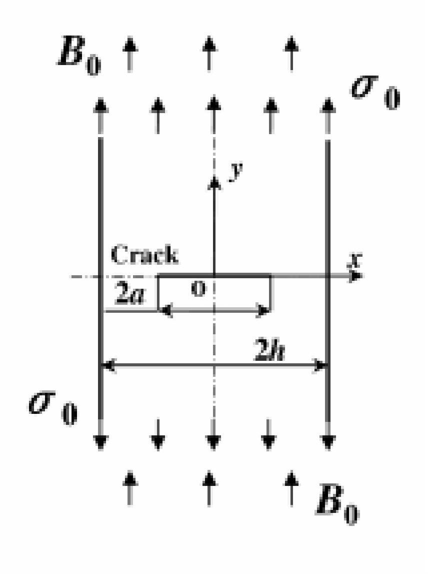

Fig. 1 A central crack in a soft ferromagnetic elastic strip

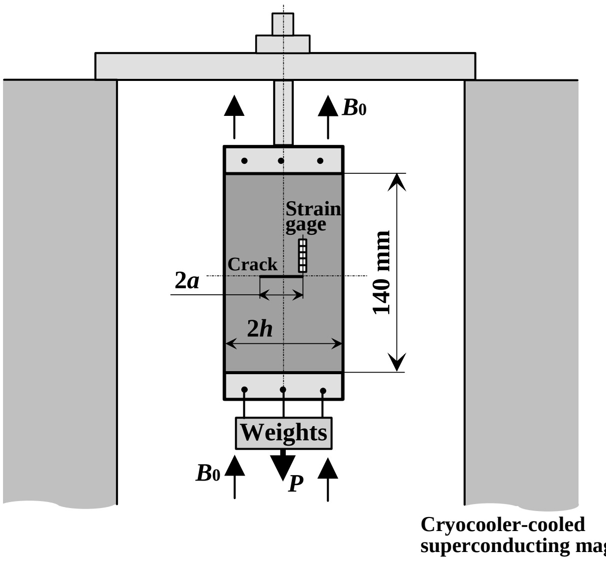

Fig. 2 Testing set-up

The method of solution involves the use of Fourier transforms to reduce the mixed boundary value problem to two simultaneous dual integral equations. The solution is then given in terms of a single Fredholm integral equation of the second kind.

The stress intensity factor k_{h1} is obtained as

$$k_{h1} = \lim_{x \to a^+} \{2\pi(x-a)\}^{1/2} \{t_{yy}(x,0) + t^M{}_{yy}(x,0)\}$$

where $t_{yy}(x,y)$ and $t^M{}_{yy}(x,y)$ are the components of magnetic and Maxwell stress tensors .

EXPERIMENTAL PROCEDURE

Tensile tests were conducted on nickel-iron soft magnetic materials with center-cracked plate specimen geometry in the 100 mm diameter bore of a 10 T (T: Tesla) cryocooler-cooled superconducting magnet at room temperature (Fig. 2). Three soft magnetic materials (TMC-V: Young's modulus E=182 GPa, Poisson's ratio ν=0.146, specific magnetic permeability μ_r=27900; TMH-B: E=203 GPa, ν=0.279, μ_r=10690; TMB: E=146 GPa, ν=0.228, μ_r=9030) developed by NEC/Tokin Co. Ltd. were selected. The specimens are 140 mm length and 1 mm thickness. The crack length was varied (2a= 10, 15, 20 mm) while keeping the specimen width fixed at 2h=40 mm. Initial through-the-thickness notches were machined using electro-discharge machining. The specimens were fatigue precracked and then annealed to obtain the optimum magnetic properties. A simple strain gage method is very suitable to determine the magnetic stress intensity factor [5]. A five element strip gage (KFG-1-120-D19-16N10C2 from Kyowa Electronic Instruments Co., Ltd., Japan) was installed along the 90-deg line and the center point of the element closest to the crack tip was 2 mm. The strain sensors have an active length of 1 mm.

Tensile load and a magnetic field were simultaneous applied to center-cracked plate specimens. A superconducting magnet was used to create a static uniform magnetic field of magnetic induction B_0 normal to the crack surface. The specimens were loaded by P=29.4 N load that consisted of weights. For each specimen size five tests were performed. The strains were recorded as a function of magnetic field.

RESULTS AND DISCUSSION

Fig. 3 provides the normalized stress intensity factor $k_{h1}/\sigma_0 a^{1/2}$ as a function of h/a for ν=0.25, μ_r=10000 and the normalized magnetic field $b_c=(B_0^2/\mu_0\mu)^{1/2}$ = 0, 0.0032, 0.0047 (magnetic permeability of the vacuum $\mu_0=4\pi\times10^{-7}$N/A^2, shear modulus $\mu=E/2(1+\nu)$) obtained from the theoretical analysis. The dashed curve obtained for b_c=0 coincides with the purely elastic case. The normalized stress intensity factor tends to infinity as $h/a \to 1$, and decreases slowly as h/a increases and tends to the result of the infinite solid as $h/a \to \infty$. Applying the magnetic field increases the stress intensity factor. The calculated stress intensity factors $k_{h1}/\sigma_0 a^{1/2}$ of TMC-V, TMH-B and TMB for h/a=2 under various values of $b_c \times 10^2$ are compared with the measured data in Fig. 4. The agreement between the two is good. A larger value of b_c tends to increase the stress intensity factor depending on the material.

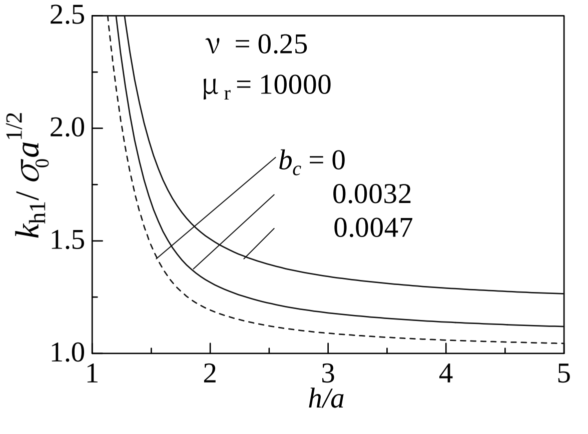

Fig.3 Stress intensity factor vs strip-width to crack-length ratio

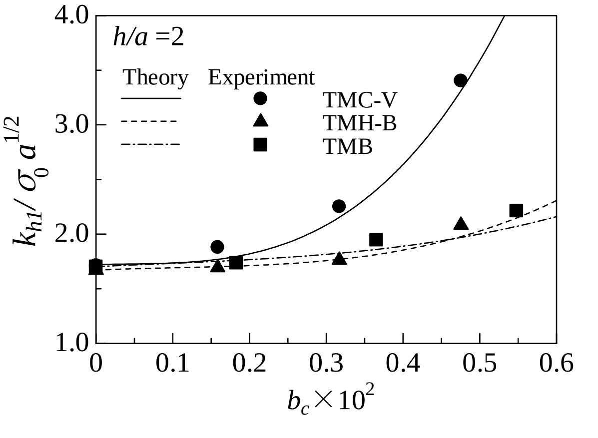

Fig.4 Stress intensity factor vs magnetic field

References

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