Stress Applied Patterns to the Influence of Stress Impedance Effect in Silicon/FeCuNbSiB Amorphous Powder Compound Film

Yuan Fu, Youliang Zhang, Wei Guo, Xiangping Cheng

ABSTRACT

We made use of compression-testing machine and LCR digital electric bridge to apply pressure stress and record the value of impedance which controlled by a computer throughout the whole testing process. Four stress loading methods were designed for testing, and a systematic research had been done with a scanning frequency at 1KHz for silicon/FeCuNbSiB amorphous powder compound films. It has been found that rubber matrix film is a kind of elastomer, which has some elastic deformation phenomenon such as elastic hysteresis and ratcheting. The radical reason of stress impedance (SI) effect is the internal relations between elastic deformation and impedance change. Deformation of elastic film will directly influenced the impedance, and the function of stress applied on the film will directly cause elastic deformation, thereby indirectly cause the change of impedance. Result shows, stress impedance effect is relevant to the recover process of elastic deformation. In the course of stress loading, the longer deformation recovered, the more indistinctively changed of impedance.

INTRODUCTION

Stress impedance effect is a phenomenon that the magnetoelastic object suffered exterior stress which induced deformation, and makes the object’s internal magnetization state changes. Therefore, the most directly reason of stress impedance effect is the changes of internal magnetization state. SI exist a huge difference between different materials. It is related to the magnetic property, mechanical property, magnetoelastic energy and the patterns of stress applied on the materials.

It is rare to find some research achievements on SI of rubber matrix so far. However, this kind of composite material has a better SI effect than Fe-based amorphous alloy, principally performance on the variation tendency of SI is more
remarkable. The main reason is because that the elastic modulus of this composite film is much smaller than amorphous ribbon, in other words, elastic deformation is much larger with a same pressure stress. This is exactly the reason of larger elastic deformation makes a bigger change in the state of magnetization. It is widely believed that the SI effect is caused by the stress, but rare to find a common view that SI also has some thing to do with deformation. Thus, we preliminary worked on the SI effect with deformation of this compound film.

EXPERIMENT

Preparation of Compound Film[1]

Making use of FebacCu1Nb3Si15.5B7 amorphous powder (molar ratio), which average particle size about 30μm. Matrix resin material: 107# silicone rubber and are silane ethyl mingled with the mass ratio of 9:1. The dilution resin material is acetone which takes 20% mass fraction of resin material.

![High depth of field micrograph with compound film.](image)

Resin material and amorphous powder were used with the mass ratio of 1:6, which stirred in a vacuum reaction kettle with a vacuum degree lower than 0.1 Pa. After that, poured out the mixture from agitated reactor into a matrix and shaped up into 20×20×0.3 mm composite film, which was solidified at NPT in 24 hours. 2000 times high depth of field microscopic images are shown in Fig 1.

Experimental Procedure

In order to insure the accuracy of stress applying, in experiment, a computer control system has been use to process controlling and collect figures on compression testing machine and impedance analyzer. As shown in Fig 2.

![Testing device of experiment.](image)

In Fig 2(a), the area of pressure head is 5.2 mm², and load face is rounded. The whole device can be divided into 7 parts, which are stress sensor, substrate,
compound film, pressure head, drift sensor, lever arm, and motor-driven nut. Fig. 2(b) conveyed a testing state of this film. It has two layers of copper foil each one up and down which were bonding with the process of in situ polymerization in the film. The impedance analyzer was clamp on the two sides of copper foil.

In order to reveal stress applied patterns to the SI effect and deformation, four applying schemes had been designed, which were:

Scheme one: The range of stress applying is 0-1Mpa, step of upload/offload is 0.1Mpa, pressure maintaining time of each step is 1Min. Stress applying process is upload from 0Mpa to 1Mpa, and offload from 1Mpa to 0 Mpa suspended.

Scheme two: The range of stress applying is 0-1Mpa. Stress applying process is uploaded with the downward displacement of pressure head at the speed of 0.01mm/min while the stress up to 1Mpa, and pressure maintaining 30s. After that, stress offloaded with the pressure head upward displacement at the speed of 0.01mm/min from 1Mpa to 0Mpa suspended.

Scheme three: The range of stress applying is 0-1Mpa. Pressure head upload/offload with the speed of 0.01mm/min downward/upward. Before the stress up to 1Mpa, upload and offload are alternately proceeds with steps of 0.2Mpa and 0.1 Mpa separately. After 1Mpa, offload and upload are also alternately proceed with steps of 0.2Mpa and 0.1 Mpa separately, while stress offloaded to 0Mpa suspended.

Scheme four: The range of stress applying is 0-1Mpa. Stress applying process is uploaded with the downward displacement of pressure head at the speed of 0.1mm/min, while the stress up to 1Mpa, and pressure maintaining 60s. After that, stress offloaded with the pressure head upward displacement at the speed of 0.1mm/min from 1Mpa to 0.01Mpa, and pressure maintaining 60s as one cycle. Run four cycles suspended.

RESULTS AND DISCUSSION

Figure 3. Stress-time, impedance-time and stress-deformation curves of scheme one.

Fig.3 conveys curves of Stress-time, Impedance-time 3(a), and Stress-deformation 3(b) in scheme one. It can be distinctly appeared the tendency of stress applying pattern and variation trend of impedance in Fig 3(a). Stress upload and offload is stepped and axisymmetric. However the change of impedance is not the case, in the prime of stress applying, the impedance presents a stepped increase. When stress up to 0.7Mpa that the value of impedance do not increase any
more, and after the stress offload below 0.4Mpa, impedance present a decline. Fig 3(b) displays a situation of stress-deformation in scheme one, and the final deformation is 0.01mm. The curve of stress-deformation in scheme one is not very stable, this because in the stress applying process, pressure maintaining takes a large percentage of time. In the state of pressure maintaining, stress applying is not very precise and exist in some tiny irregular fluctuate. In fig 3(a), we can distinctly perceive that these irregular fluctuates make the state of deformation appears chaotic change.

Figure 4. Stress-time, impedance-time and stress-deformation curves of scheme two.

Fig4 are the curves of scheme two, in which can be perceived that the process of stress applying is continuous and not many time of pressure maintaining. Thus, impedance in scheme two changes with stress is more obviously. But it’s worth noting that, when the time of pressure maintaining at 1Mpa, impedance do not present stable. This because this compound film exist in elastic aftereffect, videlicet, when the stress is tending towards stability, the deformation of film has not be as stable as stress which makes the impedance also unstable. So it can be think that the SI effect is more apply to the deformation that stress leads than apply to the stress. In addition, when the stress is offloaded to 0.2Mpa, impedance appears another peak value. In Fig4(b), the stress-deformation curve present a zigzag change, only have a small disturbance in pressure maintaining at 1Mpa. The final deformation is 0.048mm.

Figure 5. Stress-time, impedance-time and stress-deformation curves of scheme three.
Fig5 are the curves of scheme three, we can perceive in 5(a) that the impedance changes with stress is very obviously, since the effect of elastic aftereffect makes the impedance has not return to initial value when suspended. This phenomenon in the four schemes all exist more or less, but the interval between two curves in Fig 5(b) is narrower than that in Fig4(b). It is because elastic aftereffect in scheme three is weaker than that in scheme two. The radical reason is the form of stress applying in scheme three, that upload and offload alternately proceed in stress applying decreased elastic aftereffect and made SI effect obviously. The final deformation in scheme 3 is 0.01mm

![Figure 5](image-url)

Figure 6. Stress-time, impedance-time and stress-deformation curves of scheme four.

Figure 6 are the curves of scheme four and the only periodic stress applying pattern. In fig 6(a), we can divide the stress applying time into four cycles which are 0-275s, 276-554s, 555-820s and 821-1097s. The values of impedance also present a periodic change, but the tendency of impedance is not similar as stress. Each cycle appears two peak values in impedance, which is similar to scheme two. It can be compared with scheme two. Scheme two can be regarded as one cycle of scheme four. The only different is the speed of stress applying in scheme two is much slower than one cycle of scheme four. Since the similar stress applying pattern makes the changes of impedance in scheme two and four also resemble. In scheme two, the impedance appears two conjoined twin peaks and in each cycle of scheme four, the impedance also appears two individual peaks. The peak values appear in the same time points in scheme two and scheme four. In each one, the first peak appears while stress up to the point of 1Mpa and the second peak appears while the stress offload to the point of 0.2Mpa. However, the reason of the second peak has nothing to do with elastic deformation, but have some thing to do with piezomagnetic effect of compound film. Sudden offloading makes the state of magnetization of amorphous powder in the compound film changes from compression magnetization to free magnetization. The swift change of magnetization state of amorphous powder will induce the impedance appears an instantaneous mutation, which is proportional to the speed of stress offloading.

Fig 6(b) displays the situation of stress-deformation in four cycles. It appears a distinct ratchet effect. Ratchet effect is a plastic deformation circular and cumulative phenomenon that induced by a cyclic loading of non-symmetric stress. Ratcheting strain $\xi_r$ can be expressed as follows$^{[2]}$.

$$\xi_r = \frac{1}{2} (\xi_{\text{max}} + \xi_{\text{min}})$$

(1)
Where, $\xi_{\text{max}}$ and $\xi_{\text{min}}$ represent the maximal deformation and minimal deformation in each cycle of stress respectively. Meanwhile, the increment value of ratcheting strain in each cyclic process can be defined as ratchet strain rate write as $\frac{d\xi}{dN}$. N represents recycle times. In addition, Cycle viscoplastic body ratchet effect constitutive master equation can be written as [2]:

$$
\begin{aligned}
\xi &= \xi^{vp} + \xi^e \\
\dot{\xi}^e &= D^{-1} : \sigma \\
\dot{\xi}^{vp} &= \sqrt{\frac{3}{2K}} \frac{s-a}{\|s-a\|} \\
F_y &= \sqrt{1.5(s-a)/(s-a)-Q}
\end{aligned}
$$

(2)

$\xi$, $\xi^{vp}$, $\xi^e$ and $\dot{\xi}^{vp}$ represent total strain, viscoplastic strain, elastic strain and viscoplastic strain rate second order tensor; $D$ is elasticity tensor; $s$ and $\alpha$ represent deviatoric stress and back stress tensor; $K$ and $n$ is reaction rate and relevance material constant; $Q$ is resistance to deformation of isotropy; $< >$ is Macauley operator, which means: when $x < 0$, $<x> = 0$; when $x > 0$, $<x> = x$; $F_y$ is Von-Mises yield function.

Meanwhile, ratchet effect plays a great part in the influence of impedance. The generation of ratchet effect is combined action between viscoplastic strain and elastic aftereffect in elastic strain. The relationship between impedance and strain can be characterized as follows [3]:

$$
Z \propto \frac{E(\sigma)(\xi - \xi^e)}{(1 - \xi^{vp})(1 - \xi^e)}
$$

(3)

Where, $E(\sigma)$ represent the elastic modulus of film with stress $\sigma$.

**CONCLUSION**

By means of applying four kinds of stress upon silicon/FeCuNbSiB amorphous powder compound film, we have revealed that the impedance not only related to the value of stress but also have something to do with the forms of stress applying process. In experiment, we regard that the radical reason of SI effect is because the elastic deformation which induced by stress. Among scheme one to four, the maximal stress are the same of 1 Mpa, but different patterns of stress applying make the film lead different elastic deformation, which directly influenced the value of impedance.

**REFERENCES**


