Transactions of the Materials Research Society of Japan 29 [2] 453-456 (2004)

Electric and Mechanical Properties of Carbon Coils

T. Hashishin, H. Iwanaga, S. Motojima[1], Y. Hishikawa[2]

Dept. of Mater. Sci. and Eng., Fac. of Eng., Nagasaki Univ., Nagasaki 852-8521 Japan

Fax: 81-95-819-2648, e-mail: hasisin@net.nagasaki-u.ac.jp, iwanagah@net.nagasaki-u.ac.jp,

[1]Dept. of Appl. Chem., Fac. of Eng., Gifu Univ., Gifu 501-1193 Japan,

Fax: 81-58-293-5012, e-mail: motojima@apchem.gifu-u.ac.jp,

[2]CMC TD Co., Ltd., Kagamihara, Gifu 509-0108 Japan,

Fax: 81-58-379-0688, e-mail: cmctd3@bronze.ocn.ne.jp

The electric and mechanical properties of carbon coils were investigated. The electric property of mono coil was evaluated as the relation between electric resistance and elongation or temperature. An increase in the electric resistance of 250 to 500 kΩ was firstly confirmed as a step-by-step variation of the elongation ratio from 0.15 to 0.9, based on the pitch interval of the coils. The electric resistance was increased with elevated elongation of the coil. The behavior of electric resistance at ranging from 50 to 120℃ varied between 615 and 580 kΩ and similar to that of a semiconductor. The absorbent properties of electromagnetic wave were measured in the frequency zone from 50 MHz to 13.51 GHz. The absorbent level of carbon coils tended to be greater than that of other carbon materials. The increases in the length and the content of carbon coils would relate to chirality of them.

Keywords: Carbon coils, Electric resistance, Elongation, Electromagnetic wave absorption

1. INTRODUCTION

Carbon microcoils with a double helix structure (referred to as "carbon coils" hereafter) were prepared by the catalytic pyrolysis of acetylene containing a small amount of sulfur or phosphorus impurity at 750-800℃.[1-9] Each carbon coil works as an electromagnetic coil element when subjected to a fluctuating electric or magnetic field by irradiation of electromagnetic waves. As a result, a current induced by an electromotive force flows in the coil according to the Lentz law and Joule heat is generated. Thus, the electromagnetic wave drastically attenuates; linear polarization, circular polarization (right-handed, left-handed), reflection and scattering of the electromagnetic waves occur due to the high conductivity of the coils. Moreover, the dispersing coils in the matrix will be able to efficiently absorb the electromagnetic wave even if an electromagnetic wave was applied from any direction, because the coils are oriented in all directions in the matrix. It is considered that an effective wavelength range covers the GHz region, because the diameter of the carbon coils synthesized until now is on the μm order and the length is on the mm order. Therefore, the useful application of carbon coils can be expected as a novel lightweight, electromagnetic wave absorbing material with a high absorbing power for the electromagnetic wave over a wide range in the GHz region from all directions.

In this study, the electric property of mono coil was evaluated as the relation between elongation and specific resistance or temperature and the resistance. A carbon coil-silicone resin composite material was produced, and the effects of the length and content of the carbon coil on the electromagnetic wave absorption properties were investigated.

2. EXPERIMENTAL

2.1. Electric property of carbon coils

Carbon coils have morphology as shown in Fig.1. In order to measure the electric resistance of carbon coils, they were set on the electrode using glue and Ag paste in Fig.2. Herein, the carbon coils cut off at the location of "C". The residual coils were observed by SEM in order to confirm the rotation number and diameter of carbon coils. After Ag paste setting on the electrode was dried at 120℃ for 4 h using drier, the electrode was introduced into the electric furnace and the electric resistance of carbon coils was measured at each temperature 50 to 120℃. The electric resistance of carbon coils elongated by manipulation was measured using test apparatus as shown in Fig. 3.

2.2. EM wave absorption property of carbon coils

A composite material of the carbon coil as shown in Fig. 1 and the silicone resin was used as the electromagnetic wave absorption material. The carbon coils were first homogeneously dispersed in the silicone by agitation and deforming. A cylindrical sample with a 7mm outer diameter and 3mm inside diameter was then produced by heat curing for 2 hours at 110～120℃ in a metal mold. The electromagnetic wave absorption properties were evaluated by the S parameter method using the network analyzer within the 50MHz～13.51GHz frequency range. The sample was cut to a thickness of which the absorption properties were most effectively recognized in the preliminary experiment. In order to compare the absorption properties of the carbon coils with those of other carbonaceous materials, two absorbers which respectively contain the same amount of carbon fibers and graphite powder in the silicone were produced. carbon coils whose length was 90～150 μm, 150～300 μm and 500～1000 μm, and whose weight was 0.01～0.05g were used to examine the effect of the length and content of the carbon coils on the absorption properties. When investigating the effect of heat-treatment on the absorption properties, the as-grown carbon coils, which were heat treated at 2000～3000℃ in Ar atmosphere for 1hr, were added to the silicone.

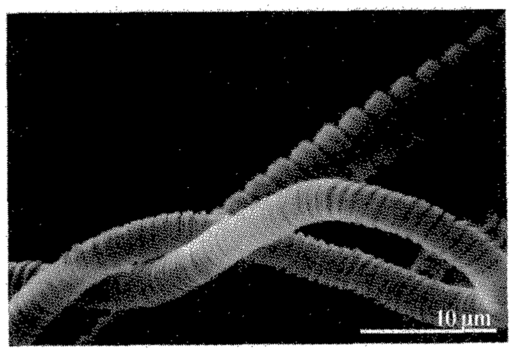

Fig. 1 SEM photograph of carbon coils.

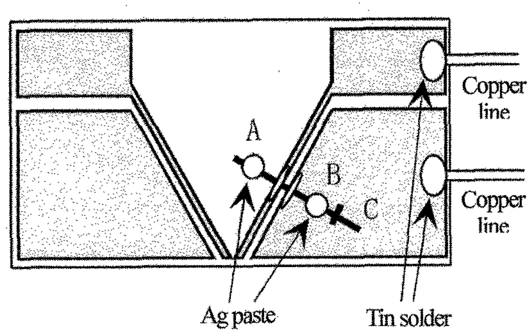

Fig. 2 Schematic illustration of electrode on which carbon coils set.

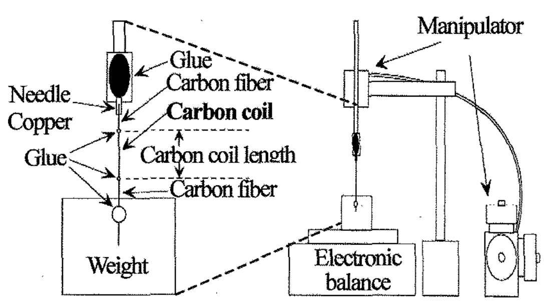

Fig. 3 Simultaneous measurement apparatus of elongation and electric resistance of carbon coils.

3. RESULTS AND DISCUSSION

3.1. Electric property of carbon coils

Figure 4 shows the relation between electric resistance and elongation or temperature in the electric property of carbon coils. The electric resistance of carbon coils increased remarkably with rising elongation ranging from 0.175 to 0.3. The increase of electric resistance corresponds to broaden space between each pitch of carbon coils covered with the exceed carbon generated by the pyrolysis of exceed carbon. each pitch of carbon coils. In the meantime, electric resistance of carbon coils decreased gradually with elevated temperature at 50 to 120℃. This tendency indicates carbon coils have the property as a semiconductor.

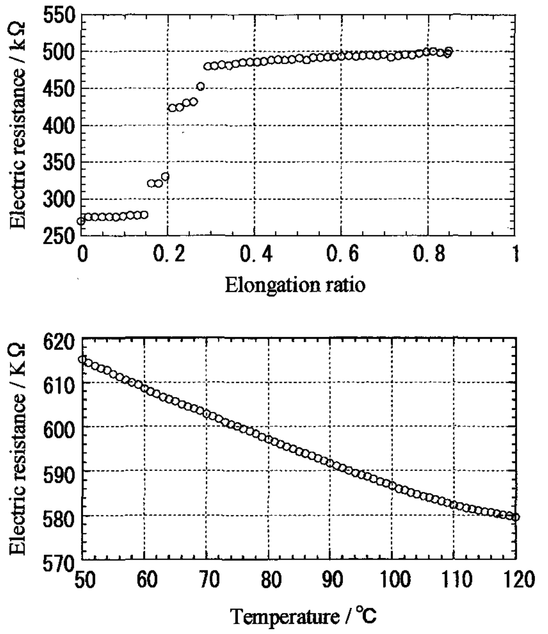

Fig. 4 Simultaneous measurement apparatus of elongation and electric resistance of carbon coils.

3.2. EM wave absorption property of carbon coils

Figure 5 shows the electromagnetic wave absorption properties of the carbon coils and other carbonaceous materials. The absorption of the sample in which carbon was more fibrous than the powder-like one is higher, and the absorption of the sample with the coil-like carbon is higher than that of the linear carbon. This must be due to the chiral structure of the coil. Unlike the achiral material, the electromagnetic wave causes remarkable reflection and absorption, circular polarization (left-handed, right-handed), when an electromagnetic wave is irradiated in the chiral material. For example, it was suggested by Varadan et al. that a conductive polymer with a chiral structure showed electromagnetic wave absorption.[10] The effects of the length of the carbon coils on the absorption properties are shown in Fig. 6. The absorption is strengthened when the coil is lengthened. The wavelength of the electromagnetic wave is 30cm at 1GHz and 3cm at 10GHz. The diameter of the coil is 1～10 μ m, the coil pitch is 0-1 μ m, and the length of the coil is 90～1000 μ m. These sizes are on the same order as the wavelength (0.8～1000 μ m) of the infrared ray region. However, the results show that the carbon coil with the μ m order absorbs the electromagnetic wave whose wavelength is somewhat greater than the wavelength of the infrared region, as shown in Fig. 5. The interaction between the shape and size of the electroconductive microcoils and electromagnetic waves has not been well clarified. However, it

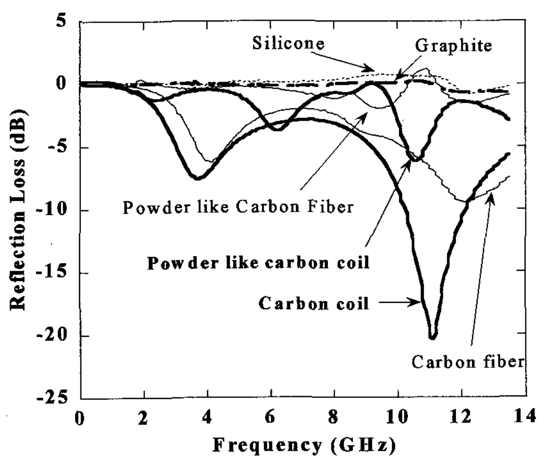

Fig. 5 Reflection loss in each carbon material.

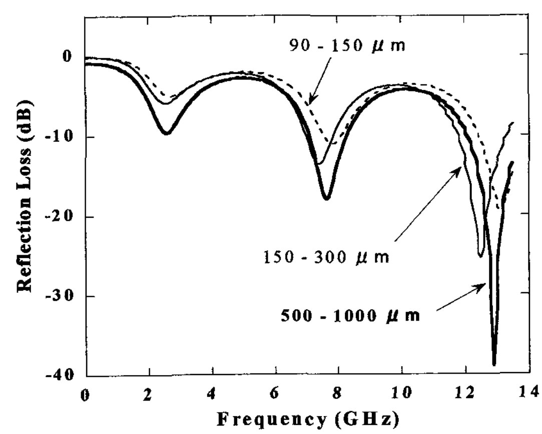

Fig. 6 Effect of the length of carbon coils on reflection loss.

appears that the material should have a chiral structure with a chiral parameter as large as possible, so that the material may efficiently absorb the electromagnetic waves. For example, the coil whose ratio of coil diameter (d) to coil pitch (p), d/p=0.48, has the highest electromagnetic wave absorption properties.[11] The absorption of the electromagnetic wave increases roughly in proportion to the carbon coil content in the matrix (Fig. 7).

Meanwhile, when the as-grown carbon coils were heated at 3000℃ in a CO+CO_2 atmosphere for 6 h, the graphitization were developed, but the morphology of the coils was maintained.[12] The absorption of the carbon coils heat-treated at 2500℃and 3000℃ was higher than that of the coils heat-treated at 2000℃, as shown in Fig. 8. The development of the (002) plane at 2500℃and 3000℃was greater than that of the as-grown carbon coils in the XRD patterns, and the specific

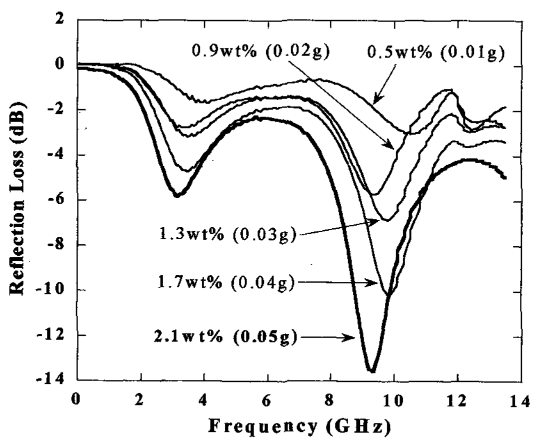

Fig. 7 Effect of the content of carbon coils on reflection loss.

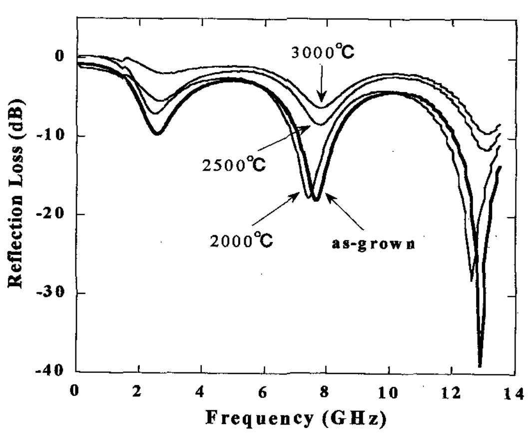

Fig. 8 Effect of heat treatment of carbon coils on reflection loss.

resistance of the carbon coils heat-treated at 3000℃; 2.0×10^{-6} Ω·m, was lower than that of the as-grown carbon coils of 2.0×10^{-4} Ω·m. Therefore, as the graphitization (crystallization) of the carbon coils progressed, the electrical resistance of the coils decreased thus leading to a lower absorption. This result is consistent with the lower absorption property of the graphite observed in Fig. 5.

4.CONCLUSIONS

The electric and mechanical properties of carbon coils were investigated. An increase in the electric resistance of 250 to 500 kΩ was firstly confirmed as a step-by-step variation of the elongation ratio from 0.15 to 0.9, based on the pitch interval of the coils. The absorbent properties of electromagnetic wave were measured in the frequency zone from 50 MHz to 13.51 GHz. The absorbent level of carbon coils tended to be greater than that of other carbon materials. The increases in the length and the content of carbon coils would relate to chirality of them.

REFERENCES

[1] S. Motojima, M. Kawaguchi, K. Nozaki and H. Iwanaga, Appl. Phys. Lett. **56**, 321 (1990).
[2] S. Motojima, M. Hirata and H. Iwanaga, J. Chem. Vapor Deposition **3**, 87 (1994).
[3] S. Motojima, Y. Itoh, S. Asakura and H. Iwanaga, J. Mater. Sci. **30**, 5049 (1995).
[4] S. Motojima, S. Asakura, M. Hirata and H. Iwanaga, Mater. Sci. Eng. **34**, L9 (1995).
[5] S. Motojima, S. Asakura, T. Kasemura, S. Takeuchi and H. Iwanaga, Carbon **34**, 289 (1996).
[6] S. Motojima, T. Hamamoto, N. Ueshima, Y. Kojima, and H. Iwanaga, Electrochem. Soc. Proc. **97-25**, 433 (1997).
[7] S. Motojima, Y. Kojima, T. Hamamoto, N. Ueshima and H. Iwanaga, Electrochem. Soc. Proc. **97-39**, 595 (1997).
[8] S. Motojima, X. Chen, T. Kuzuya, W-I. Hwang, M. Fujii and H. Iwanaga, J. Phys. IV (France) **9**, Pr8-445 (1999).
[9] X. Chen and S. Motojima. J. Mater. Sci. **34**, 3581 (1999).
[10] V. K. Varadan and V. V. Varadan, USP 4948922 (1990).
[11] V. K. Varadan, The proceedings of 1st Carbon Micro Coil Workshop (1997).
[12] X. Chen, W-I. Hwang, S. Shimada, M. Fujii, H. Iwanaga and S. Motojima, J. Mater. Res. **15**, 808-814 (2000).

(Received October 11, 2003, Accepted December 15, 2003)