

Development of biobased microwave absorbing composites with various magnetic metals and carbons

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ABSTRACT: The preparation and characterization of a biobased electromagnetic absorbing composites derived from natural lacquer as a renewable resource with microwave-absorption fillers, including Ni–Zn ferrite and carbonyl iron (CI) as magnetic metals and soot and carbon nanotube (CNT) as carbon materials, were investigated in terms of the gel content, hardness, drying properties, and electromagnetic absorption properties. Interestingly, composites with ferrite and CI contained up to 320 and 550 wt %, respectively, of these compounds. This quite high loading capacity of the metal fillers in a natural-lacquer base could have been due to the high compatibility between the filler and the natural lacquer; this indicated that the natural lacquer worked as a binder for these metals. The morphology of the biobased composite was characterized by scanning electron microscopy. The electromagnetic absorption properties of composites were characterized in the frequency range from 0.05 and 20 GHz by the reflection loss (RL) measurement method in terms of the kind of fillers and filler loading. The natural lacquer did not affect the absorption properties of the fillers. Biobased composites showed over 99% electromagnetic absorption in the frequency range 3.0–4.0 GHz for 280 wt % ferrite and 8.9–9.7 GHz for 200 wt % CI. Conversely, 10 and 20 wt % soot exhibited good performance (RL < –20 dB) between 16.5 and 17.3 and between 8.8 and 9.2 GHz, respectively. The areas with RL values of less than –20 dB of the CNT composites were 10.4–11.0 GHz for 5 wt % and 14.6–15.2 GHz for 10 wt %. Hence, natural lacquer can be used as a binder material for electromagnetic absorption composites. © 2016 Wiley Periodicals, Inc. *J. Appl. Polym. Sci.* **2016**, *133*, 44131.

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INTRODUCTION

Recently, electromagnetic wave applications, such as electrical and electronic devices used in daily life, industry, hospitals, and the military, have earned much attention. In these fields, electromagnetic absorption materials play an important role in the realization of a comfortable environment. Electromagnetic absorption materials have normally been used as composite materials and have been prepared from dielectric or magnetic fillers and polymers. As fillers in these applications, carbonyl iron (CI),^{1–4} carbon,^{5–7} carbon nanotube (CNT),^{2,8} and magnetic compounds containing Fe, Co, and Ni^{5–10} improve the electromagnetic absorption properties. Epoxy,^{1,4,5,8,9} resins, and rubbery polymers^{11–13} as base polymer/binder materials have been used as wave-absorption materials with these fillers. Conversely, researchers normally focus their investigations on the development and improvement of novel absorption filler particles rather than on base polymer materials. Most of these materials are used with oil-based compounds. To date, there has

been no report on the use of biobased electromagnetic absorption materials.

The development of functional biobased polymer materials has received much attention because of environmental concerns in recent years.^{14–17} Natural lacquer is a natural polyphenolic compound and is well known as a traditional natural crosslinked polymer. This natural lacquer sap consists of urushiol, which contains C15 catechols with unsaturated hydrocarbons at positions 3 or 4, water, a gummy substance, a nitrogenous material, and laccase.^{18,19} Natural lacquers have a durable, beautiful surface, and therefore, they have been used in various articles and objects for protection and decoration. Natural lacquer can be cured by enzymatic and oxidative polymerization in the presence of moisture and laccase without any organic solvent.²⁰ Therefore, this natural lacquer has great potential in terms of environmentally friendly materials. In addition, natural lacquer can contain various metal compound additives, such as iron

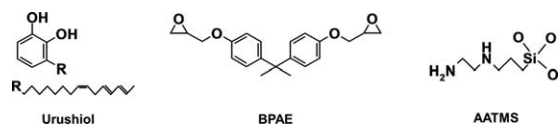


Figure 1. Chemical structures of urushiol, BPAE, and AATMS.

oxides, to stabilize the color.²¹ Traditionally, it is known that this iron oxide disperses well in natural lacquer because lacquer and iron oxide are compatible. Therefore, natural lacquer would be expected to have good compatible properties with metals and to work as a base polymer/binder for composites. Therefore, natural-lacquer-based polymer materials have been investigated according to their unique properties.^{19,22–25}

However, their crosslinking reactions (i.e., drying processes) progress slowly compared with those of other conventional organic coatings because the drying process proceeds on the basis of enzymatic and oxidative polymerization.^{24,26} This means that the drying process of natural lacquer is relatively sensitive and strongly affected by environmental conditions, such as moisture and temperature. Furthermore, it is difficult to fabricate thick resin products from natural lacquer alone because of the nature of natural lacquer. Therefore, natural lacquers can be available only for coating materials, but they are very limited for further novel applications by these issues. We have been focusing on the development of biobased functional materials derived from natural phenolic compounds (e.g., natural lacquer and cashew nut shell liquid) to determine further possible effective utilizations of natural phenols. For example,

we previously developed thick biobased composites fabricated by the chemical reactions of urushiol, epoxy, and organic silane compounds at room temperature.²³ In addition, we reported on electromagnetic absorption materials with natural lacquer in recent years.²⁷

In this study, we developed natural-lacquer-based novel materials to provide a novel possibility for their effective utilization. Herein, we investigated the preparation of biobased electromagnetic absorption materials derived from natural lacquer and various dielectric or magnetic fillers in terms of the kinds of fillers and loading on the performance.

EXPERIMENTAL

Chemicals

The natural lacquer used as a renewable resource was purchased from Doityu Shoten Co., Ltd. (Osaka, Japan). Urushiol and lipid components of the lacquer were extracted from raw lacquer sap, as reported previously (Figure 1). Bisphenol A type epoxy resin (BPAE; Epoxyclear 305114) was purchased from I-Resin Co., Ltd. (Japan) and was used without further purification. An organic silane compound, *N*-(2-aminomethyl)-3-aminopropyl trimethoxysilane (AATMS), was purchased from Tokyo Chemical Industry Co., Ltd. (Japan). Ni/Zn-type ferrite and CI as magnetic metal fillers were purchased from Toda Kogyo Corp. (Japan) and BASF Japan, Ltd. (Japan), respectively. Amorphous soot and single-walled CNT as carbon materials were purchased from Minowa Shikkou (Japan) and Showa Denko K.K. (Japan), respectively. All materials were used without further purification.

Table I. Molecular Weight Properties of the Biobased Composites

Entry	Additive content (wt %)		Content ratio (%) ^a			Molecular weight		
	AATMS	BPAE	Monomer	Oligomer	Polymer	M_n	M_w	M_w/M_n
1	0	0	49.1	45.7	5.2	510	2140	4.2
2	5	5	49.5	44.9	5.6	320	2350	7.4
3	5	10	52.3	41.7	6.0	290	2370	8.3
4	5	15	52.1	41.5	6.4	310	2440	7.8
5	5	20	55.7	39.1	5.2	270	2170	8.0
6	10	5	41.1	44.0	14.9	710	4740	6.7
7	10	10	37.8	44.7	17.5	510	5320	10.4
8	10	15	41.8	43.0	15.2	470	4810	10.3
9	10	20	43.1	41.7	15.2	480	5060	10.7
10	15	5	26.0	50.5	23.5	790	6980	8.8
11	15	10	29.0	47.2	23.8	760	7380	9.8
12	15	15	31.4	45.4	23.3	660	7130	10.8
13	15	20	31.4	43.4	22.2	610	6780	11.1
14	20	5	20.3	48.3	31.4	1320	10,400	7.8
15	20	10	19.9	50.8	29.2	1120	9790	8.8
16	20	15	20.1	50.5	29.4	1140	9320	8.2
17	20	20	24.4	48.4	27.2	1070	7560	7.1

M_n , number-average molecular weight; M_w , weight-average molecular weight.

^aOligomer: Dimer \leq Molecular weight < 10,000 g/mol. Polymer: Molecular weight \geq 10,000 g/mol.

Table II. Drying Properties and Hardnesses of the Biobased Composites

Entry	Additive content (wt %)		Drying properties (h)			Hardness ^a					
	AATMS	BPAE	DF	TF	HD	1 day	3 days	5 days	7 days	15 days	30 days
1	0	0	18.5	23.1	24<	TF	HD	HD	HD	6B	—
2	5	5	0.9	1.7	3.8	4B	4B	3B	HB	3H	8H
3	5	10	0.5	1.5	3.9	5B	4B	3B	HB	3H	8H
4	5	15	0.9	1.7	6.8	6B	4B	3B	2B	H	4H
5	5	20	1.2	1.9	8.9	HD	5B	4B	3B	H	4H
6	10	5	1.4	2.5	18.2	5B	2B	2B	B	2H	4H
7	10	10	2.0	3.5	18.4	6B	4B	3B	2B	H	H
8	10	15	4.6	8.9	23.2	HD	6B	5B	3B	H	H
9	10	20	5.3	8.0	23.4	HD	HD	6B	4B	HB	H
10	15	5	3.5	8.1	24<	TF	HD	HD	HD	HD	5B
11	15	10	3.9	9.2	24<	TF	HD	HD	HD	6B	5B
12	15	15	2.9	6.6	24<	TF	HD	HD	6B	5B	3B
13	15	20	5.0	10.6	23.2	HD	HD	HD	6B	3B	HB
14	20	5	2.7	7.3	24<	TF	HD	HD	HD	HD	5B
15	20	10	2.7	4.0	16.3	HD	HD	HD	HD	HD	4B
16	20	15	1.5	3.8	23.4	HD	HD	HD	HD	5B	3B
17	20	20	0.9	4.6	13.1	HD	6B	6B	6B	4B	3B

DF, dust-free dry (based on JIS-K-5400); HD, hardened dry (based on JIS-K-5400); TF, touch-free dry (based on JIS-K-5400).

^aThe pencil hardness was as follows: HD << 6B < B < HB < F < H << 9H.

Film and Composite Preparation

The composite film was prepared with a 76- μm applicator (Yoshimitsu Seiki, Tokyo, Japan) at $23 \pm 1^\circ\text{C}$ to investigate the optimum proportions of natural lacquer, BPAE, and AATMS. The film was stored in the dark at 25°C and 50% relative humidity to evaluate the drying and hardness properties. For thick composite preparations, mixtures of natural lacquer, BPAE, organosilicon compounds, and microwave-absorption fillers were poured into a fluororesin tube (*o.d.* = 16 mm, *i.d.* = 14 mm) at $23 \pm 1^\circ\text{C}$. The filler loadings of the composites were up to 320 wt % for ferrite, from 550 wt % for CI, 20 wt % for soot, and 10 wt % for CNTs. After 3 days, the formed thick composite was removed from the tube.

Characterization

The molecular weight of the composite was determined at 40°C by aqueous phase gel permeation chromatography (TSK gel column α -3000, α -4000 and α -M, Tosoh Co., Ltd., Tokyo, Japan) with dimethylformamide as an eluent with 0.01 mol of LiBr on a high-performance liquid chromatography system with an RI-8012 refractive-index detector with polystyrene standards. The drying of the epoxy coatings at $23 \pm 1^\circ\text{C}$ can be divided into three stages: dust-free dry, touch-free dry, and hardened dry. Each stage was measured with an automatic drying time recorder (RC autorecorder of paint drying time, TaiYu Co., Ltd., Osaka, Japan) at $23 \pm 1^\circ\text{C}$ and 50% relative humidity. Pencil hardness is based on the current national standard GB/T6739-1996. H and B indicate the hardness and softness, respectively, of tested coatings, and higher numbers express the relative hardness or softness of the tested coatings. F and HB

indicate medium hardness. However, F is a slightly harder coating than HB. In this study, pencil lead hardness was determined with a C-221 pencil hardness tester (Yoshimitsu Seiki, Tokyo, Japan) at $23 \pm 1^\circ\text{C}$. The gel contents of the natural lacquer and biobased composites were determined by immersion in acetone at $23 \pm 1^\circ\text{C}$ for 24 h. After immersion, the nonsoluble parts

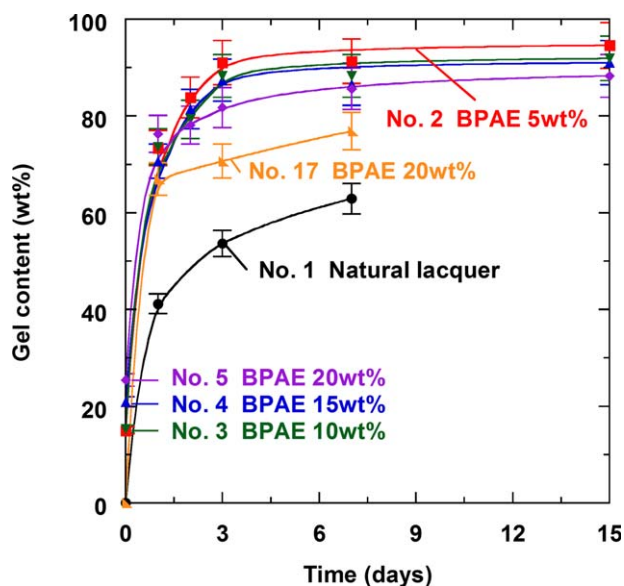


Figure 2. Gel contents of natural-lacquer-based and biobased composites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

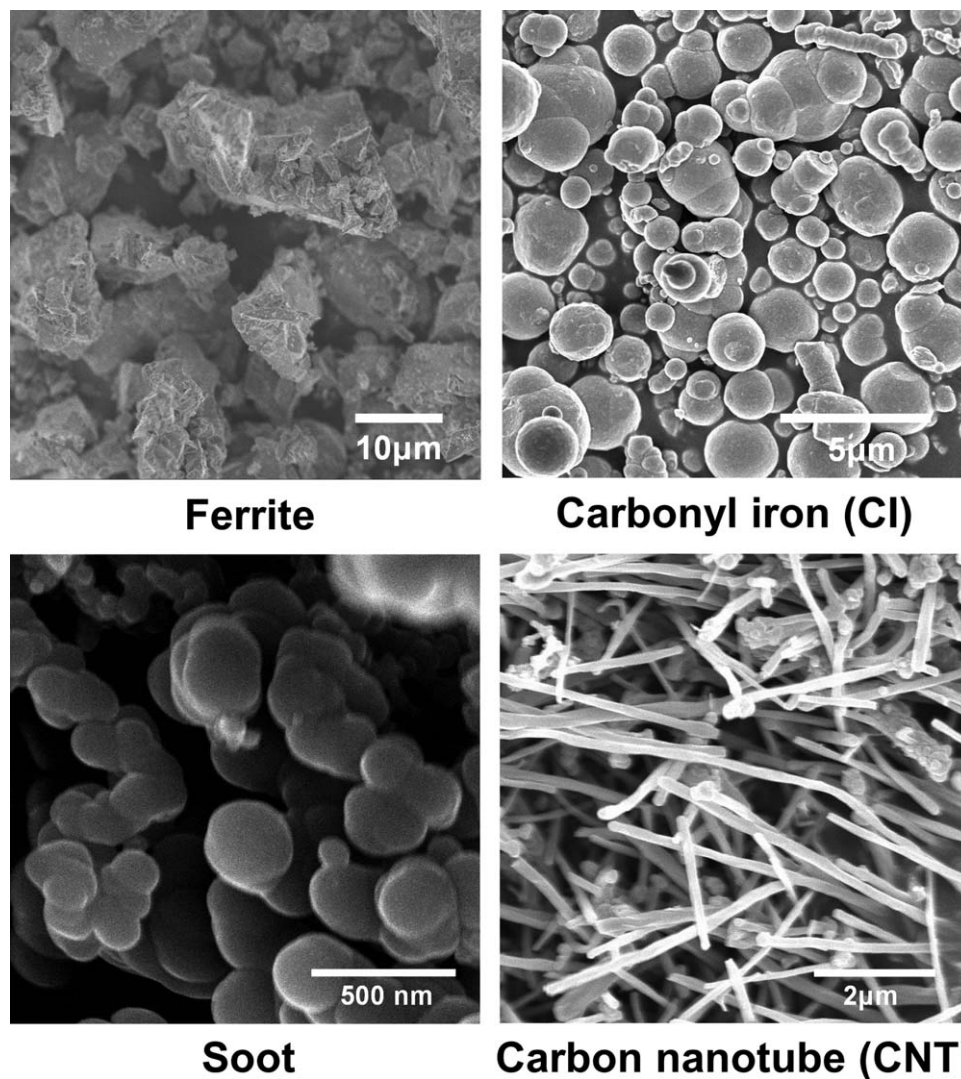


Figure 3. SEM images of the electromagnetic absorption fillers.

were dried well and weighed. The gel content was calculated by the following equation:

$$\text{Gel content (\%)} = \frac{w_t}{w_0} \times 100 \quad (1)$$

where w_1 and w_0 are the weight of the insoluble fraction and the original weight of the completely dried sample, respectively. Scanning electron microscopy (SEM) of cross sections of the biobased composites was performed with a high-resolution field emission scanning electron microscope (S5200, JEOL, Ltd., Tokyo, Japan). The microwave-absorption properties of the samples were measured by the reflection loss (RL) measurement method and a vector network analyzer (Agilent 8722ES) with a short-backed cylindrical waveguide sample holder, whose dimensions included a 3.0 mm inner diameter, a 7.0 mm outer diameter, and a 5.0 mm thickness. The complex permeability and complex permittivity were extracted in the frequency range of 0.05–20 GHz from the S-parameter transmission data as the electromagnetic absorption parameters with the Nicolson–Ross method.^{27,28} The RL curves were calculated with the following equations⁹:

$$Z_{in} = Z_0 \left(\frac{\mu_r}{\epsilon_r} \right)^{0.5} \tanh \left[\left(j \frac{2\pi f d}{c} \right) (\mu_r \epsilon_r)^{0.5} \right] \quad (2)$$

$$\text{RL} = 20 \log \left| \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \right| \quad (3)$$

where μ_r and ϵ_r are the relative permeability and permittivity, respectively; f is the frequency of the electromagnetic wave; d is the thickness of the sample; c is the velocity of light; Z_0 is the impedance of air; and Z_{in} is the input impedance of the sample.

RESULTS AND DISCUSSION

The molecular weight properties of biobased composites prepared with various proportions of BPAE and AATMS are summarized in Table I. The base natural lacquer showed the lowest polymer concentration and molecular weight. As the AATMS organic silane concentration increased, the polymer concentration and molecular weight tended to increase; this indicated that an effective sol–gel reaction between organic silane and urushiol had occurred. On the other hand, a high BPAE concentration decreased the polymer concentration; this indicated

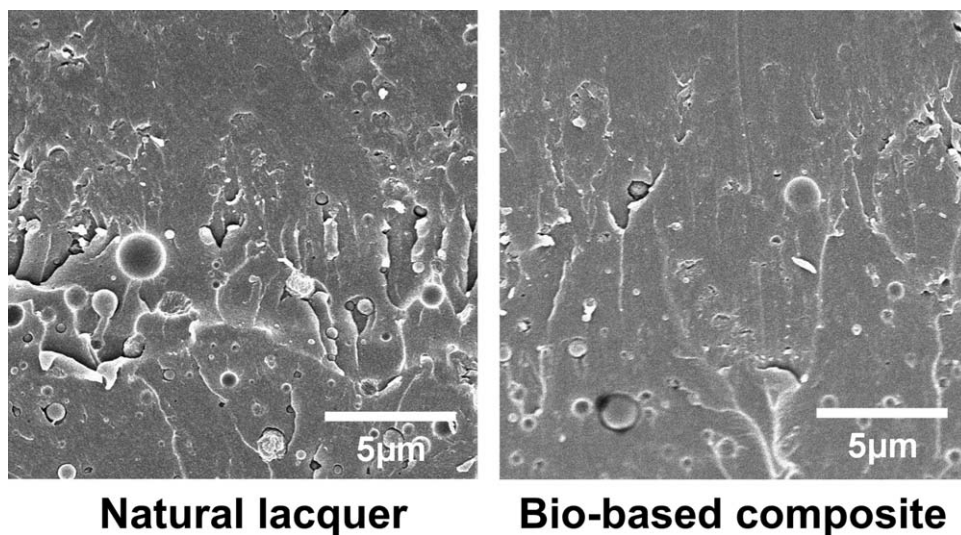


Figure 4. Cross-sectional SEM images of the natural-lacquer-based and biobased composites without a filler.

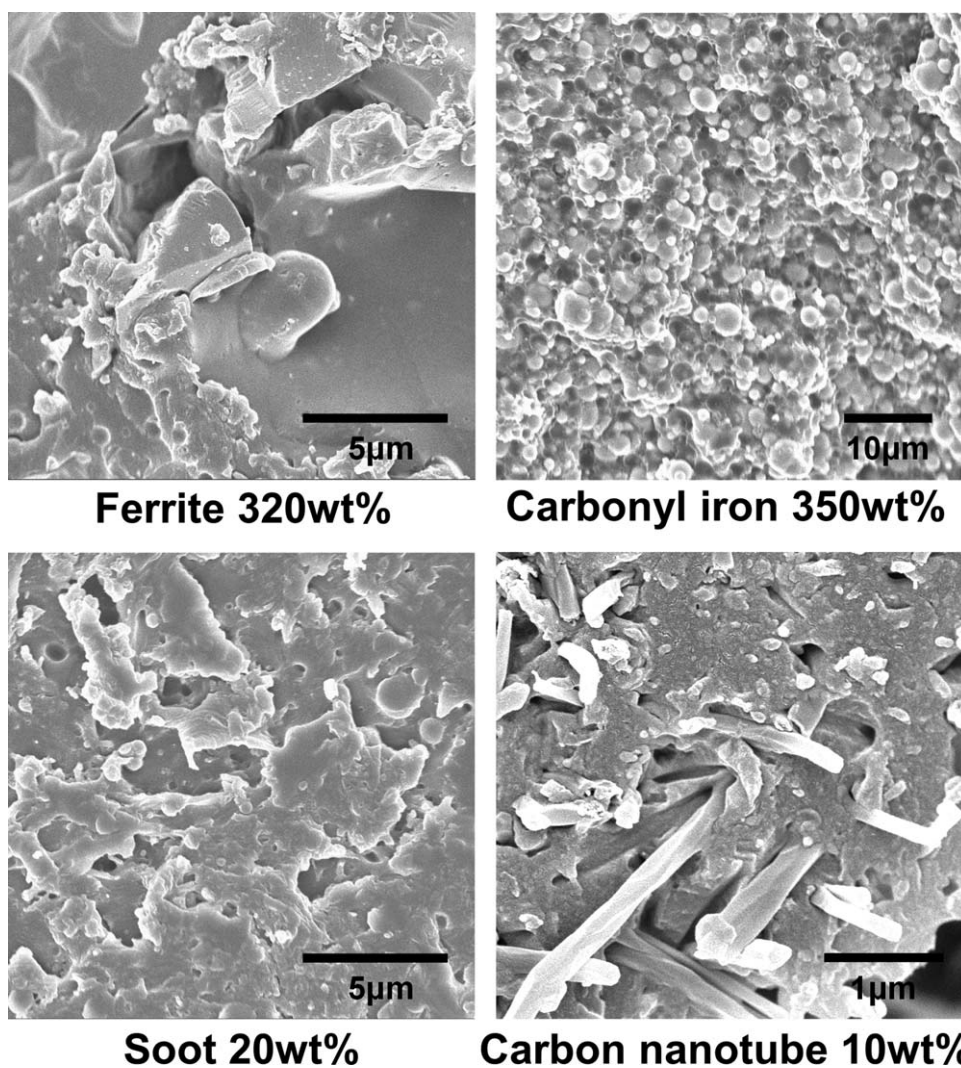


Figure 5. Cross-sectional SEM images of the bio-based composites with various fillers.

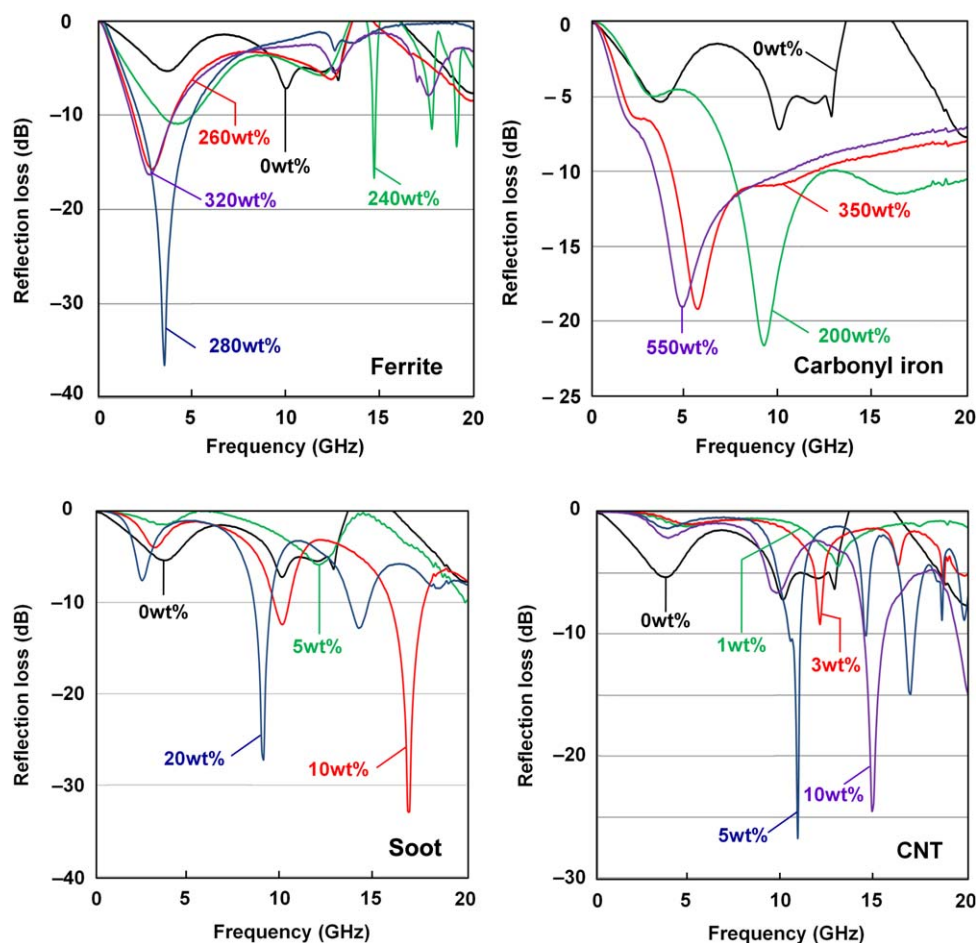


Figure 6. Frequency characteristics of RL for biobased composites with magnetic metal and carbon fillers. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

that excess BPAE inhibited the sol-gel reaction. On the basis of these results, the polymer concentration and molecular weight were more strongly affected by the organic silane concentration than by that of BPAE. The drying and hardness properties of the biobased composites are summarized in Table II. The base natural lacquer required a longer time to dry than the other composites. The addition of BPAE and silane compound to the natural lacquer significantly improved the drying properties because of the sol-gel and crosslinking reaction among these compounds. On the basis of the drying time, composites with 5 wt % AATMS dried more rapidly than the other composites. As expected from the molecular weight properties of the composites, a high concentration of BPAE seemed to improve the drying rate, but there was no obvious trend in the hardness.

Figure 2 presents the gel contents of the natural lacquer and biobased composites. As expected from the drying and hardness properties of the composites, the gel contents of all of the composites were higher than that of the natural lacquer; this indicated that the composites prepared from AATMS and BPAE had a higher crosslinking density than the natural lacquer. In addition, the BPAE concentration with the same amount of 5 wt % AATMS (Entries 2-5) increased with decreasing gel content. On the basis of these results,

the best conditions for the preparation of composites with the AATMS organic silane compound and BPAE with natural lacquer were estimated to be 5 wt % AATMS and 5 wt % BPAE (Entry 2); this was also smallest amount of additives tested. Therefore, the preparation of the electromagnetic absorption composite was based on the addition of 5 wt % AATMS and 5 wt % BPAE.

Generally, the moldability of a composite material is liable to be reduced with increasing filler concentration because the excess filler could become aggregated, and this increased the rigidity of the composite. However, we successfully prepared biobased composites containing up to 320 wt % ferrite and 550 wt % CI in magnetic metal systems, respectively. In addition, these magnetic metal particles were dispersed uniformly in a natural lacquer-based composite because of their smooth surfaces and sphericity. This result indicates that the natural lacquer had great compatibility with the metal fillers and worked as a binder of the fillers. Traditionally, natural lacquer has been used with pigments such as Bengal red (iron oxide), iron powder, and coal to change the color of materials.²¹ This compatibility with fillers is known as one of the properties of natural lacquer. Therefore, we hypothesized that a natural-lacquer-based composite could contain high concentrations of fillers.

Table III. Electromagnetic Absorption Properties of the Biobased Composites with Various Magnetic Metals

Filler	Filler loading (wt %)	Thickness (mm)	Minimum RL			Reference
			Frequency (GHz)	RL (dB)	RL < -20 dB (GHz)	
Ferrite	280	5.0	3.5	-37	3.0-4.0	This study
CI	200	5.0	9.3	-22	8.9-9.7	This study
CI	75	1.7	8.8	-29	8.4-9.3	1
Ni-coated CI	75	1.7	10.2	-30	9.5-10.8	1
CI	35 (vol %)	1.5	14.1	-23	13.3-14.9	2
CNT/CI	2.2/35 (vol %)	1.5	11.2	-34	10.5-11.9	2
CNT/CI	2.2/35 (vol %)	1.8	9.2	-31	8.5-9.8	2
CNT/CI	4.4/35 (vol %)	3.0	4.0	-42	3.6-4.4	2
CI	30	1.5	11.0	-22	10.0-12.0	3
CI	30	2.0	7.8	-33	7.0-8.6	3
CI	50	2.0	9.0	-33	8.5-9.5	4
CI	50	4.0	1.0	-23	0.8-1.2	4
Dendrite-Fe	70	1.5	7.8	-33	7.0-8.6	5
Dendrite-Fe	70	2.3	11.0	-24.5	10.0-11.0	5
Fe ₃ C/carbon	70	3.2	4.4	-32	4.1-4.7	5
Fe ₃ C/carbon	70	6.5	2.0	-25	1.8-2.2	5
Fe ₃ C/carbon	70	13.5	0.85	-24	0.8-0.9	5
Fe/Y ₂ O ₃	80	3.0-5.0	2.6	-36	2.0-3.5	8
FeCo/Y ₂ O ₃	80	2.8-7.0	3.2	-55	1.9-5.4	8
FeCo/Y ₂ O ₃	80	3.1-7.2	3.1	-37	2.1-5.0	8
FeCo/Y ₂ O ₃	80	2.0-7.4	3.9	-45	2.2-9.7	8
FeCo/C	30	1.7-3.0	10.8	-48.2	5.7-11.5	9
CoFe	15	2.1-2.3	14.8	-23	11.8-15.2	10

Figure 3 presents the SEM images of the fillers used as electromagnetic absorption particles. The sizes of the spherical ferrite crystals and CI particles were estimated to be 10–30 and 1–3 μm , respectively. The soot particles were spherical with a

size around 0.5–1.0 μm , whereas single-walled CNTs were 0.5 μm in diameter. Figure 4 presents the cross-sectional SEM images of natural-lacquer-based and biobased composites without fillers. SEM images showed that spheres around 0.5–2.0 μm

Table IV. Electromagnetic Absorption Properties of the Biobased Composites with Carbon Materials

Filler	Filler loading (wt %)	Thickness (mm)	Minimum RL			Reference
			Frequency (GHz)	RL (dB)	RL < -20 dB (GHz)	
Soot	10	5.0	16.9	-33	16.5-17.3	This study
Soot	20	5.0	9.0	-28	8.8-9.2	This study
CNT	5	5.0	10.7	-27	10.4-11.0	This study
CNT	10	5.0	14.9	-25	14.6-15.2	This study
CNT/CI	2.2/35 (vol %)	1.5	11.2	-34	10.5-11.9	2
CNT/CI	2.2/35 (vol %)	1.8	9.2	-31	8.5-9.8	2
CNT/CI	4.4/35 (vol %)	3.0	4.0	-42	3.6-4.4	2
Fe ₃ C/carbon	70	3.2	4.4	-32	4.1-4.7	5
Fe ₃ C/carbon	70	6.5	2.0	-25	1.8-2.2	5
Fe ₃ C/carbon	70	13.5	0.85	-24	0.8-0.9	5
CNTs	5	1.0	11.3	-23.5	10.8-11.8	6
Fe-CNT	10	1.0	13.2	-32	12.6-13.8	6
FeCo/C	30	1.7-3.0	10.8	-48.2	5.7-11.5	9

were dispersed in both natural lacquer and composites. Natural lacquer sap contains various compounds, including urushiol, water, a gummy substance, a nitrogenous material, and lac-case.^{18,19} These microsize spheres are compatible with the water–oil emulsion structure. In addition, the appearance of silica, which is a byproduct of the condensation reaction between AATMS and urushiol, was not observed in the composite; this indicated that the composite did not undergo considerable phase separation after the sol–gel reaction.

Figure 5 presents the SEM images of the biobased composites with various fillers. All fillers were dispersed well in the composites without interfacial defects; this suggested that the biobased composite had a high compatibility with all of the fillers. A high loading of fillers in polymer materials and a lack of interaction between them sometimes causes filler aggregation and interfacial defects between the polymer and filler phases.^{29,30} In this study, the ferrite and CI fillers were quite well dispersed in the binder of the composite at a very high loading (e.g., 320–350 wt %), as shown in Figure 5. The carbon composites were also dispersed well, but some CNTs aggregated into large bundles in the composites because of the high aggregation properties of the CNT. Therefore, we found that the natural lacquer prevented some critical problems in the composites (e.g., large aggregations and interfacial defects) due to magnetic metals and carbon materials on the basis of their excellent compatibility.

Figure 6 presents the frequency characteristics of RL for biobased composites with magnetic metals and carbon fillers, respectively. Summaries of the electromagnetic absorption properties of various materials with magnetic metals and carbons are listed in Tables III and IV, respectively. When an electromagnetic wave absorber has an RL below -20 dB, which corresponds to over 99.00% of the microwave-absorption properties, the material can be used as an absorption material in this application. The base natural lacquer showed weak absorption peaks (< -10 dB) at 4.0 and 10.5 GHz. For magnetic metals, the minimum RL was observed at 3.5 GHz for 280 wt % ferrite (RL < -20 : 3.0–4.0 GHz), and at 9.3 GHz for 200 wt % CI (RL < -20 : 8.9–9.7 GHz). The minimum RL of the CI composites shifted from 9.3 to a lower frequency of 5.0 GHz with increasing filler loading. As shown in Table III, the CI composites had a wide absorption band between 1.0 and 14.1 GHz (RL < -20 dB), depending on the thickness and loading.^{1–4} The Fe-containing composites showed the effective absorption of RL < -20 dB at 0.9–14.8 GHz.^{5–10} Conversely, the absorption peaks for carbon composites were sharper than those for metal composites. For biobased composites containing soot, the minimum RL was obtained around 16.9 GHz (RL < -20 : 16.5–17.3 GHz) for 10 wt % and 9.0 GHz (RL < -20 : 8.8–9.2 GHz) for 20 wt %. The minimum RL of the soot composites shifted to a higher frequency area with increased loading. This might have been because soot loading increased the dielectric polarization and attenuated electromagnetic waves by multi-scatter and reflection. Therefore, the electromagnetic wave of the soot composites was attenuated by eddy current loss. On the other hand, the CNT-based composites showed a minimum RL value at 10.7 GHz (RL < -20 : 10.4–11.0 GHz) for 5 wt % and 14.9 GHz (RL < -20 : 14.6–15.2 GHz) for 10 wt %. This absorption

properties of CNT is normally based on dielectric loss rather than on magnetic loss. Therefore, we found that the natural lacquer retained the absorption properties of the fillers in the composites and could be highly loaded with fillers; this indicated that it could be used as a binder material for not only electromagnetic absorbers but also the other composites without a reduction of the absorption properties.

CONCLUSIONS

We investigated the development of biobased electromagnetic absorption materials from natural lacquer and various dielectric/magnetic fillers, including ferrite, CI, soot, and CNT. The composition of the natural-lacquer-based composite was optimized by the gel concentration, composite hardness, and drying properties. We found that this biobased composite could contain quite high concentrations of magnetic metals because of the high compatibility of the metals and natural lacquer. SEM images of the biobased composites showed well-dispersed fillers with the natural lacquer as a binder. Magnetic metal-based composites exhibited over 99% electromagnetic absorption (RL < -20 dB) in the frequency range of 3.0–4.0 GHz for 280 wt % ferrite and 8.9–9.7 GHz for 200 wt % CI, whereas the carbon-based materials showed a frequency range of 16.5–17.3 GHz for 10 wt % soot, 8.8–9.2 GHz for 20 wt % soot, 10.4–11.0 GHz for 5 wt % CNT, and 14.6–15.2 GHz for 10 wt % CNT. In addition, natural lacquer did not affect the absorption properties of the fillers. Therefore, natural lacquer can serve as an effective binder for electromagnetic absorption composites without loss of the absorption properties.

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