Dielectric Properties of the Hybrid Board of Polytetrafluoroethylene/ SiO_2 Nanoparticle

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Abstract

The dielectric properties (dielectric constant, dielectric loss factor) of the hybrid board of polytetrafluoroethylene(PTFE) emulsion/ SiO_2 nanoparticle are studied. The process parameters of board fabrication including nanoparticles add-on(1-3%), rotational speed(1200-3200 rpm)and calendering times(4, 6, 12) are altered. The impacts of these parameters on the dielectric properties of the hybrid board are studied.

Both dielectric constant and dielectric loss factor are decreased with addition of SiO_2 nanoparticles. Both dielectric constant and dielectric loss factor are decreased with increasing rotational speed and reach a maximal, in this study 3000 rpm, and then increased.

The dielectric property of hybrid board is related to the nanoparticles add-on, rotational speed of mixer, and calendering times. Among them, nanoparticles add-on plays the most important roll for acquiring low dielectric properties. However, it exits an optimal amount for add-on due to the large areas of nanoparticles.

Keyword：Polytetrafluoroethylene (PTFE), hybrid board , SiO_2 nanoparticle , dielectric constant, dielectric loss factor

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1. Introduction

The new wave about the revolution of the technology and industry is creating by the nanotechnology and the influence on the living of the human being is totally. [1, 2]

This brand new technology will not only change the way we produce stuffs but also change the characteristics of them. We can predict all the characteristics of the material we make in the middle of this century will be affected by nanotechnology. The nanotechnology and the nanocomposites have been adapted by the manufacture of plastics, electrical products, cosmetics, paint, battery, sensor, fuel battery and computer with better performance. The nanotechnology has also the applications for the medical on the delivery of medicine and the development of the new medicine. [9, 10, 11]

Organic/Inorganic Hybrid (OIH) materials are the materials that combining the characteristics derived from multiple specialties of the organic and inorganic moieties. The nanocomposites made by both nanopolymer and ceramic in this study will be great value to the applications and developments of both nanotechnology and material. Besides, the electrical, communication and traditional industry will be promoted by this project. On the other hand, hybrid board is a laminated contracture and then to be made as an important base for electronic devices. This products was based industrial products, therefore macromolecule polymer (Resin), glass fibers and purity copper laminated to combination become to composite materials[3, 4]. The Organic/Inorganic Hybrid (OIH) that is most both compound materials manufacturing process for composites board of dielectric, in which that focus on dielectric properties of composites. Among them particularly with the compound material of the fluorine is better. Electrical properties(Dielectric Constant(D_k) Dielectric Loss factor(D_f))of a wide range of dielectric materials are tabulated in table1. [5, 6, 7, 8]

Table 1 Electrical Properties of a Wide Range of Dielectric Materials are Tabulated [3]

Material	Dielectric Constant(D_k)	Dielectric loss factor (D_f)
FR4/glass	4.5	0.03
Driclad/glass	4.1	0.01
BT/Epoxy/glass	4.0	0.01
Epoxy/PPO/glass	3.9	0.01
Cyanate Ester/glass	3.5	0.01
Polyimide/glass	4.5	0.02
Ceramic fill thermoset	3.3	0.0025
EPTFE w/ thermoset	2.8	0.004
Silica fill PTFE	2.9	0.003
PTFE/glass	2.4	0.001
PTFE	2.1	0.0004

2. Experimental

2.1 Materials and Medicament of Experimental Materials

1. YMT—STYLE3101 PTFE Scrim Yarn

Table 2 shows the physical properties of a PTFE Scrim Yarn used in this work.

Table 2 PTFE Scrim Yarn of Y-Type

Type	Fineness(dtex)	Tenacity(cN/dtex)	Elongation (%)	Twist (T/m)	Shrinkage (250 ℃/30 min)
SY-1	440 (±4 %)	>2.8	7	300 S	< 2 %

Manufactured by Yeu Ming Tai Chemical industrial CO, Ltd (Taiwan).

2. PTFE Fabric

Fabric structure: Woven / Warp Density per inch are 46 × 40.

3. PTFE emulsify solution

Type 30J from Daikin(Japan): Particle Size 60~80 nm; Solid Contents: 60 %.

4. Silicon Dioxide

U.S. Silicon Nano Silica 50 nm

5. Coupling Agent

Phenyltrimethoxy Silane Dow Corning Z-6124

6. Heat Setting

The tempertures vary from 35 ℃,100 ℃, 200 ℃, 250 ℃ to 300 ℃, respectively.

Procedure

The process parameters of board fabrication including powder add-on(1-3%), rotational speed(1200-3200 rpm), temperature(30-345 ℃), stage of sintering and cooling(1-16) and calendering times(1-12) are altered. The impacts of these parameters on the dielectric properties of the hybrid board are studied.

The experimental proceeded as follows, as showed in Figure 1: 60% solid content PTFE emulsion was blended and mixed with SiO_2 nanoparticle and coupling agent in a blender. During the mixing, the fabrications of PTFE were formed and impacted by the rotational speed of the blender. After mixing, the viscosity of mixed solution was increased and became to a gel (semi-solid) state. The gel was proceeded with molding and calendaring in order to release bubble and increase surface uniformity. Then, the gel was solidified by sintering and cooling to hybrid board. The temperature and stage of sintering and cooling plays an important roll for the solidification of hybrid board.

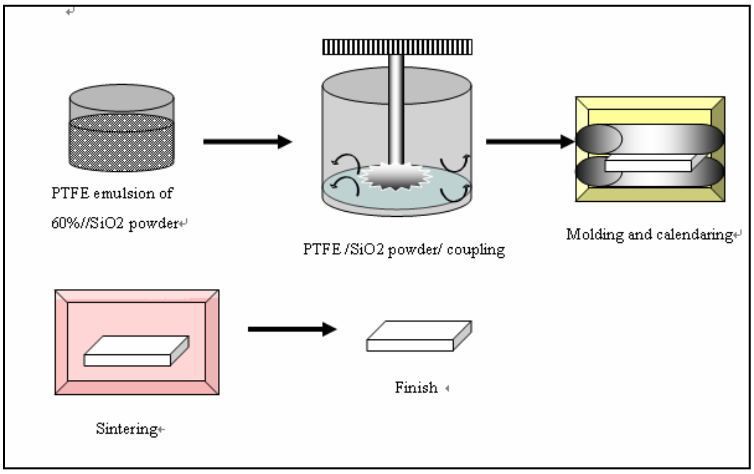


Figure1 Experimental procedure.

A dielectric property of hybrid board is closely related to the sintering conditions including temperature and time in stage of sintering and cooling. In the previous experimental, we had found an optimal sintering condition for acquiring better dielectric properties. In this study, all the experiments were carried out in the identical sintering condition, as showed in Figure 2.

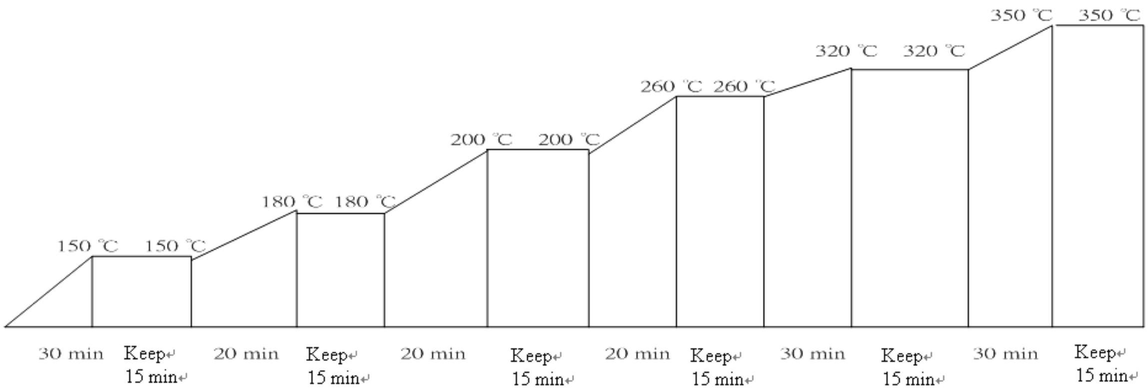


Figure 2 sintering condition

Instrumentation

A heating sintering machine up to 1500 ℃ was built. A pair of pressure rollers was built for calendaring the fabrics. A high speed mixer up to the rotational speed of 3400 rpm was built. A heat drying oven (Type of OV306, Sunway scientific corporation, Taiwan) was used. A Viscosity Instrument (Brookfield Digital Viscometer Model DV-Π+ Version 3.0, USA) was used for the testing solution viscosity, A set of Network Analyzer (Type of HP 8719D, USA) was used for detecting dielectric properties. A Scanning Electron Microscope (Type of JEOL JSM-5200, Japan) was used for the surface observations.

3. Experimental results

3.1 Impact of rotational speed and add-on percentage of $Si0_2$ nanoparticles on dielectric properties of hybrid board

The study of viscosity alteration by adding different percentage $Si0_2$ nanoparticles under different rotation speed is showed in Figure 3. Clearly, the viscosity is increased from 800 to 7400 cP by adding more percentage $Si0_2$ nanoparticles and increasing the rotation speed of the mixer. The viscosity above the rotational speed of 2600 rpm appears a significant increment because that on one hand the fibril formation increased tremendously, on the other hand the water evaporated rapidly when in higher rotational speed.

Figure 4 and Figure 5 shows the SEM photographs of the hybrid boards in the magnification of 8000X and 20000X. The surface on the boards appears some fibril structures that are caused by the stirring during the solidification under sintering. As we know, molding type PTFE has the special feature that a band-like crystalline is formed under high rotational speed and results in a fibril when the water and surfactant is vanished.

Figure 6 shows the impact of rotational speed of the mixer on dielectric constant(D_k) and dielectric loss factor(D_f) of hybrid board. Both D_k and D_f are decreased with increasing the rotational speed due to a tremendous increment of pore cells in nanoscale. Therefore, a hybrid board with porous structure in nanoscale is one of the method to decrease both D_k and $D_{f..}$ It is proved that controlling the porous formation of material is more important than controlling the nanoparticles [12,13]. The rotational speed appears a maximal value for lower D_k and D_f when it above 3000 rpm. It is caused by a thermal dissipation problem in high rotational speed.

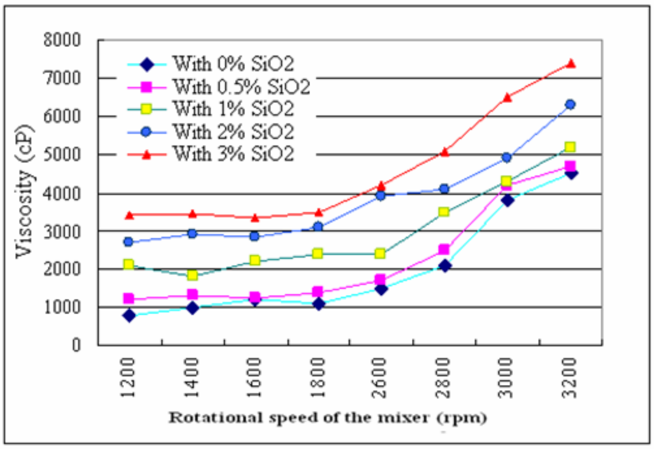


Figure 3 Viscosity alteration by adding different percentage $Si0_2$ nanoparticles under different rotation speed

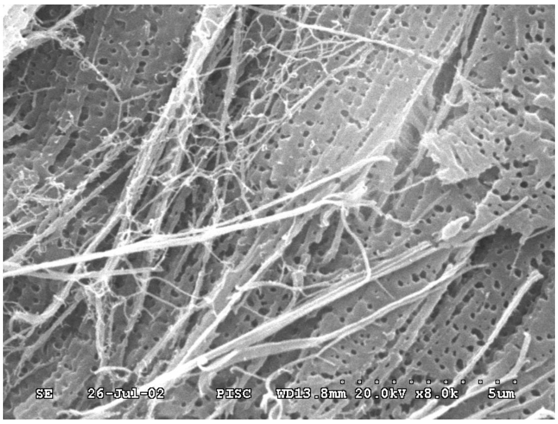


Figure 4 SEM photograph of fibrils on the surface of the hybrid board, magnification × 8000.

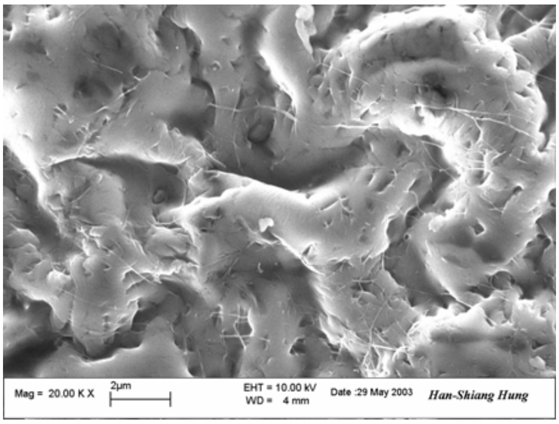


Figure 5 SEM photograph of fibrils on the surface of the hybrid board, in magnification of 20000.

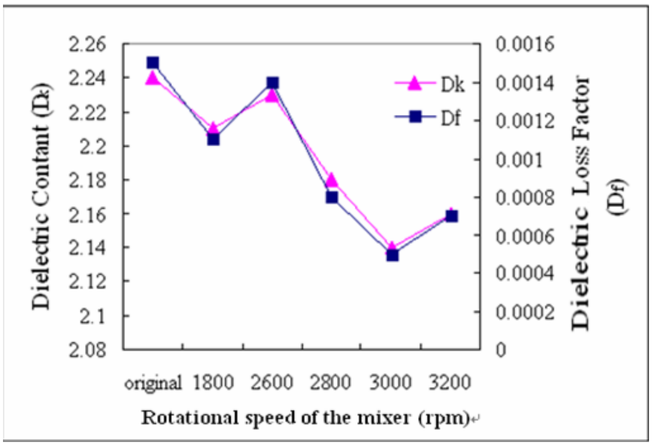
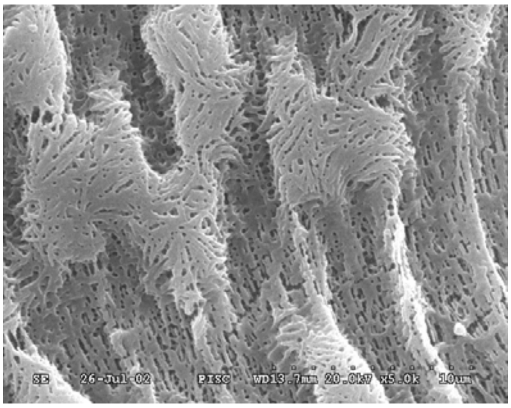


Figure 6 The impact of rotational speed of the mixer on dielectric constant(D_k) and dielectric loss factor(D_f) of hybrid board.

3.2 SEM of hybrid boards with different calendaring times

Figure 7 shows the SEM photographs of hybrid boards with different calendering times in magnification of 5000. Clearly, the surfaces of hybrid board are smooth and micro pores to fix up and the compact structures consist of many fibrils and linkage with each other. However, the space between layer to layer is not identical when compares the calendering times of twelve (Figure 7c) to that of four (Figure 7a). The calendering times has less effect on both D_k and D_f (the figure is omitted). Calendering times is related to the strength and hardness of the board (we don't discuss them in this conference).



a) Four calendering times

(b) Six calendering times

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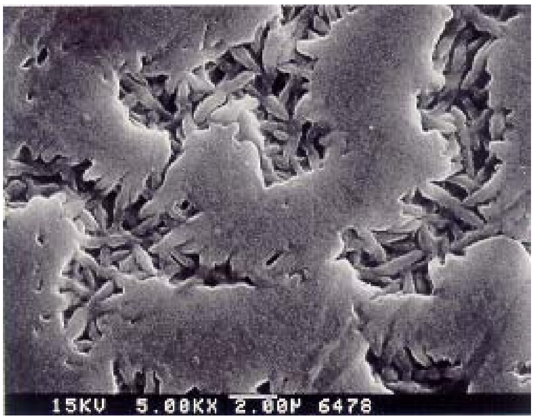


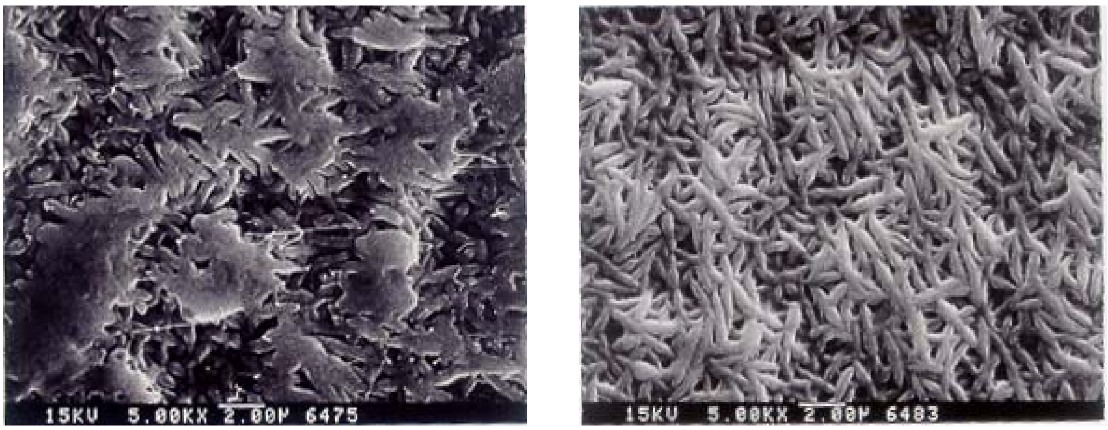
(c) Twelve calendering times

Figure 7. SEM photographs of hybrid boards with different calendering times in magnification of 5000.

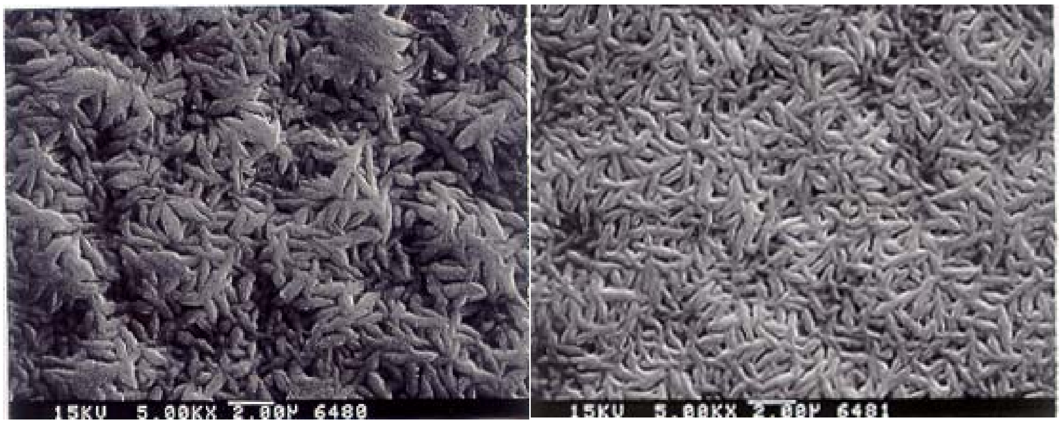
3.3 Impact of add-on percentage of $Si0_2$ nanoparticle on dielectric properties

SEM photographs of different add-on percentage $Si0_2$ nanoparticles in magnification of 5000 are showed in Figure 8, where (a),(b),(c),(d) represent add-on percentage of 0.5, 1, 2 and 3, respectively. The shape of the lamellae with $Si0_2$ nanoparticles is not like any shapes reported for bulk PTFE materials. Instead, the lamella with $Si0_2$ nanoparticles possesses a star-like shape when compares to strip and band shapes of conventional PTFE materials . Abundant concave or micro-cracks can be observed on the surface of the board even in an uniform smooth layer independent of add-on percentage.

The fibrils in star-like shape structure, that $Si0_2$ nanoparticles are wrapped by PTFE, appear a smaller dimension along with particle recruitment increased..



(a) Add-on 0.5% SiO_2 nanoparticle (b) Add-on 1% SiO_2 nanoparticle



(c) Add-on 2% SiO_2 nanoparticle (d) Add-on 3% SiO_2 nanoparticle

Figure 8 SEM photographs of different add-on percentage $Si0_2$ nanoparticles in magnification of 5000.

Figure 9 and Figure 10 demonstrates the impact of rotational speed of the mixer on the dielectric properties of hybrid boards. As it stated in Figure 6, the dielectric properties is decreased with increasing rotational speed. For the add-on percentage of SiO_2 nanoparticle, the dielectric property is negative proportional to the amount of add-on. Obviously, the amount of add-on SiO_2 nanoparticle has its limitation in cooperation with rotational speed, in this study 2%. Due to a large surface areas, a higher content of SiO_2 nanoparticle leads to coagulation to form a bulky block.

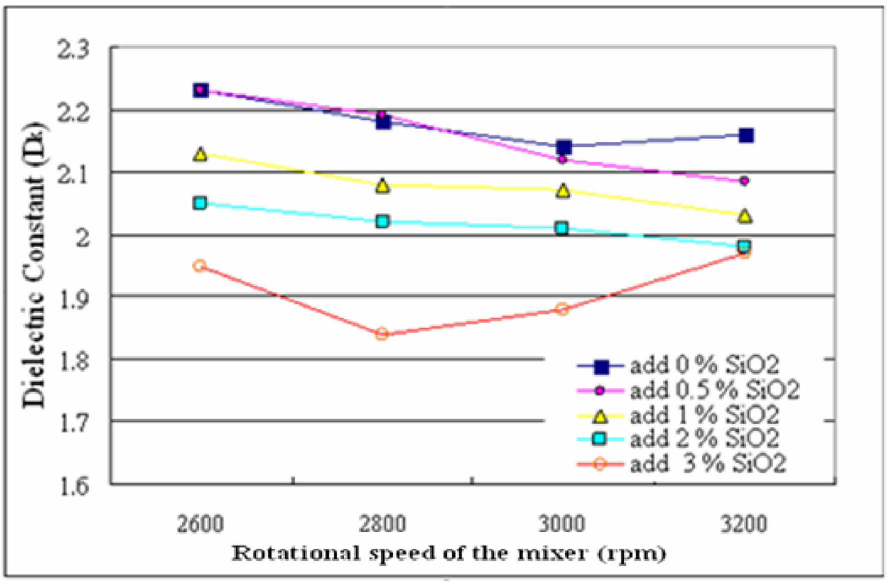


Figure 9 Impact of rotational speed of the mixer on the dielectric constant (D_k) of hybrid boards.

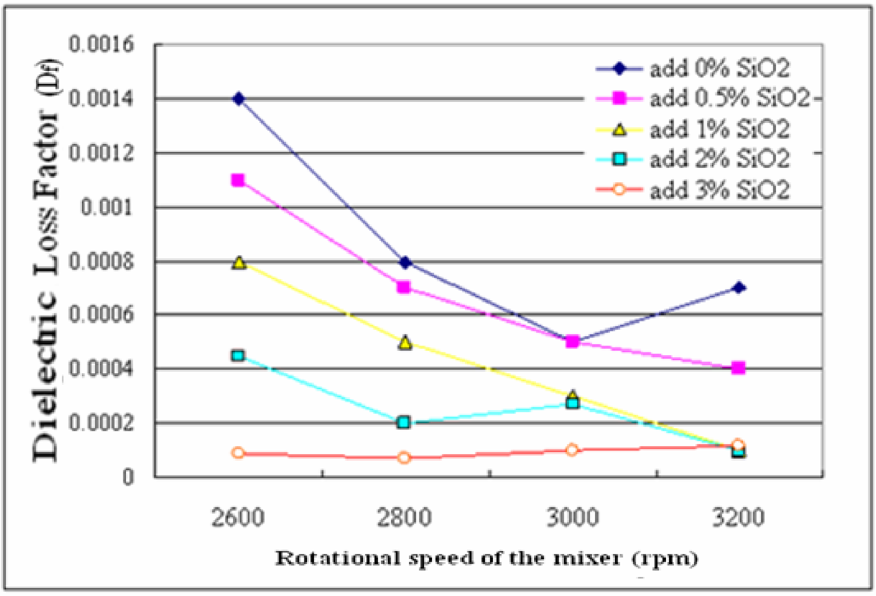


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Figure 10 Impact of rotational speed of the mixer on the loss factor (D_f) of hybrid boards.

Conclusions

The dielectric property of hybrid board is related to the nanoparticles add-on, rotational speed of mixer, and calendering times. Among them, nanoparticles add-on plays the most important roll for acquiring low dielectric property. However, it exits an optimal amount for add-on due to the large areas of nanoparticles.

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