Dielectric Properties of the Hybrid Board of Polytetrafluoroethylene/ SiO_2 Nanoparticles

I.S. Tsai

Graduate Institute of Textile Engineering, Fang Chia University, Taiwan, Republic of China

Introduction

◆**Over the past ten years, the extensive growth in the wireless communications industry**

◆ **Wireless Communication System Trend**

Increasing demands :High capacity, High data rate with constraints, Portability (Low power consumption; Small form factor), Fast time-to-market

Low **dielectric Constant (*D_k*)**
Low **dielectric loss factor (*D_f*)**

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

Applications of Fluoride-based RFB

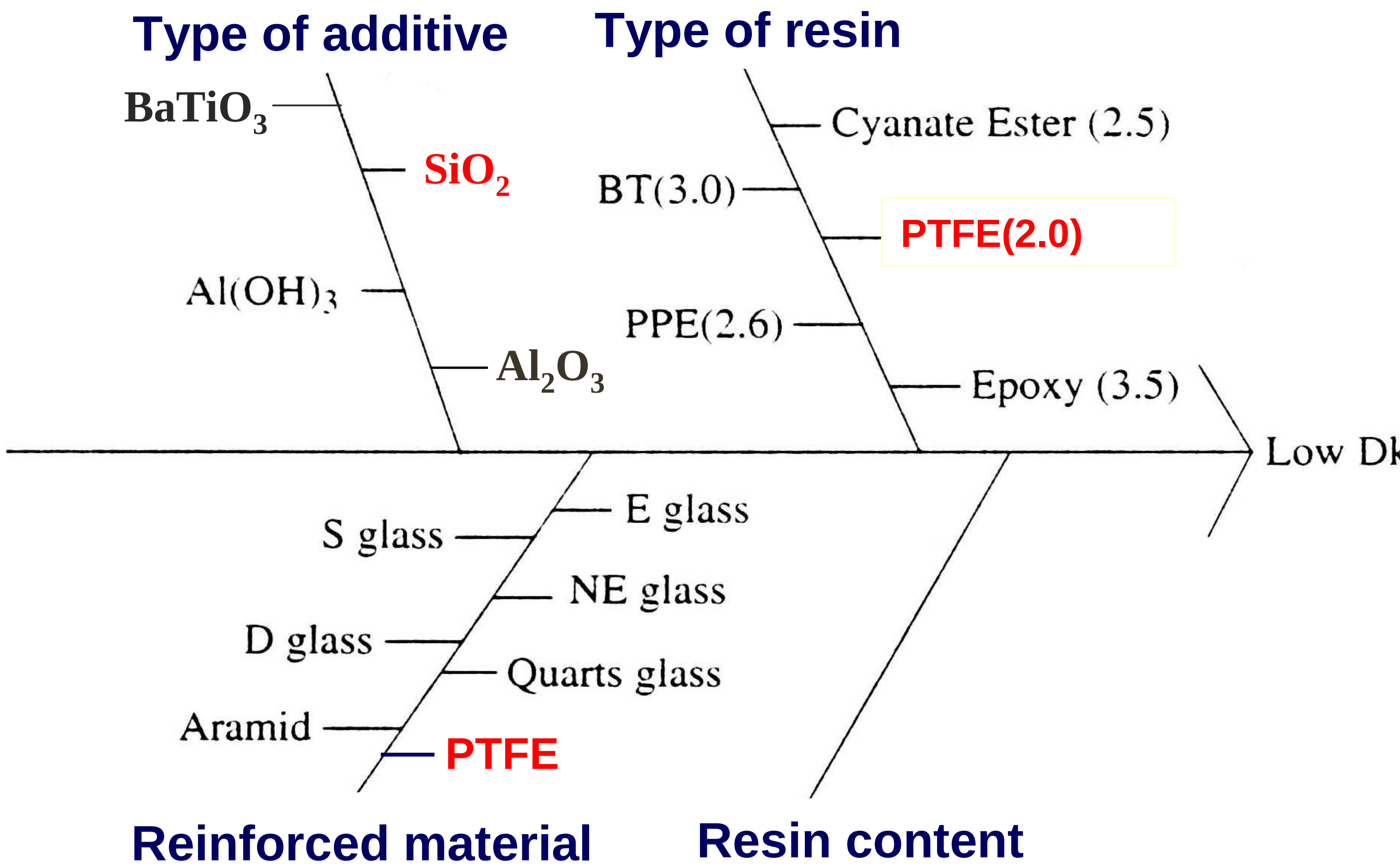
Applications	Frequency used
Cellular & Pager Telecom	1~3 GHz 13~24 GHz
Frequency Modulated Continuous Wave Radar Profiler (FMCW)	75 GHz
Direct Broadcast Satellite (DBS)	13 GHz
Low Nosic Block downconverter (LNB), LNA (Low Nosic Amplifiers) and LNC (Low block down Converter)	2~3 GHz 12~14 GHz
Global Positioning System (GPS)	1.575/1.228 GHz 2.4 GHz
Very Small Aperture Terminal (VSAT)	12~14 GHz
Digit Radio	10~38 GHz

Dielectric Constant ; Dk

The dielectric constant is the ease of polarization (indicating the size of the quantity of electricity stored) and is a standard used to evaluate its performance as an insulator.

Dielectric Loss Factor; dielectric dissipation factor D_f

The dielectric dissipation factor is the degree of electrical energy loss in an insulator and is a standard used to evaluate its performance as an insulator.



Factors affecting low dielectric constant ; D_k

The relationship between signal propagation delay time *Td* and dielectric constant D_k

$$Td = l\frac{\sqrt{D_k}}{c}$$

Td = signal propagation delay time (sec)
C = light velocity
D_k = Dielectric Constant
l = prorogation length

The relationship between dielectric constant D_k and transmission speed V

$$V = \frac{K \times C}{\sqrt{D_k}}$$

V = Transmission speed on PCB
K = constant
C = light velocity
D_k = dielectric constant of material

The relationship between signal transmission loss L and dielectric loss factor D_f

$$L = \frac{K \times \sqrt{D_K} \times D_f \times f}{C}$$

L = *signal transmission loss (dB/in)*
f = *frequency*
D_f = *dielectric loss factor*
K = *constant*
C = *light velocity(2.73 × 10⁸ m/s)*

Experimental

Materials

- **PTFE Scrim Yarn**

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

- **PTFE Fabric**

  Fabric structure: woven / warp density per inch are 46 × 40.

- **PTFE emulsify solution**

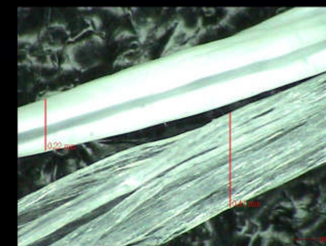
  particle size 60~80 nm; solid contents: 60 % (30J Daikin Japan).

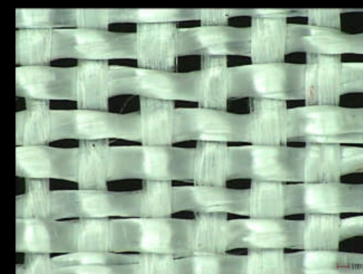
- **Silicon Dioxide**

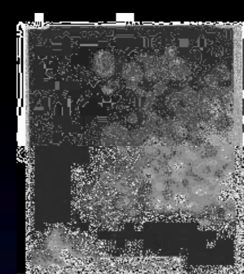
  nano silica 50 nm (U.S. Silicon)

- **Coupling Agent**

  phenyltrimethoxy silane (Dow Corning Z-6124)



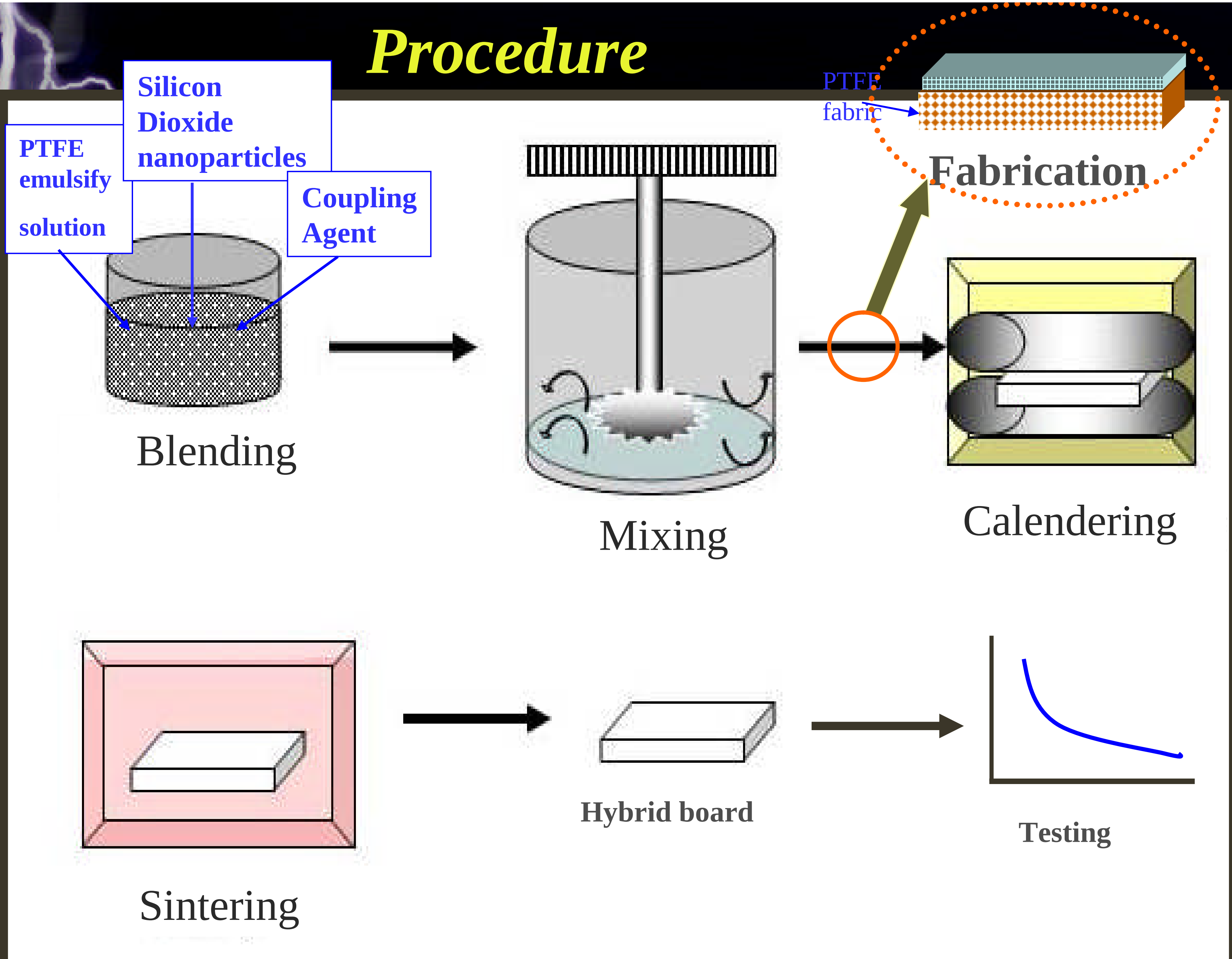




Instrumentation

- Heating sintering machine (~ 1500 ℃).
- Pressure rollers for calendaring the fabrics.
- High speed mixer (~ 3400 rpm).
- Heat drying oven (Type of OV306, Sunway scientific corporation, Taiwan).
- Viscosity Instrument (Brookfield Digital Viscometer Model DV-Π+ Version 3.0, USA).
- Network Analyzer (Type of HP 8719D, USA)
- Scanning Electron Microscope (Type of JEOL JSM-5200, Japan).

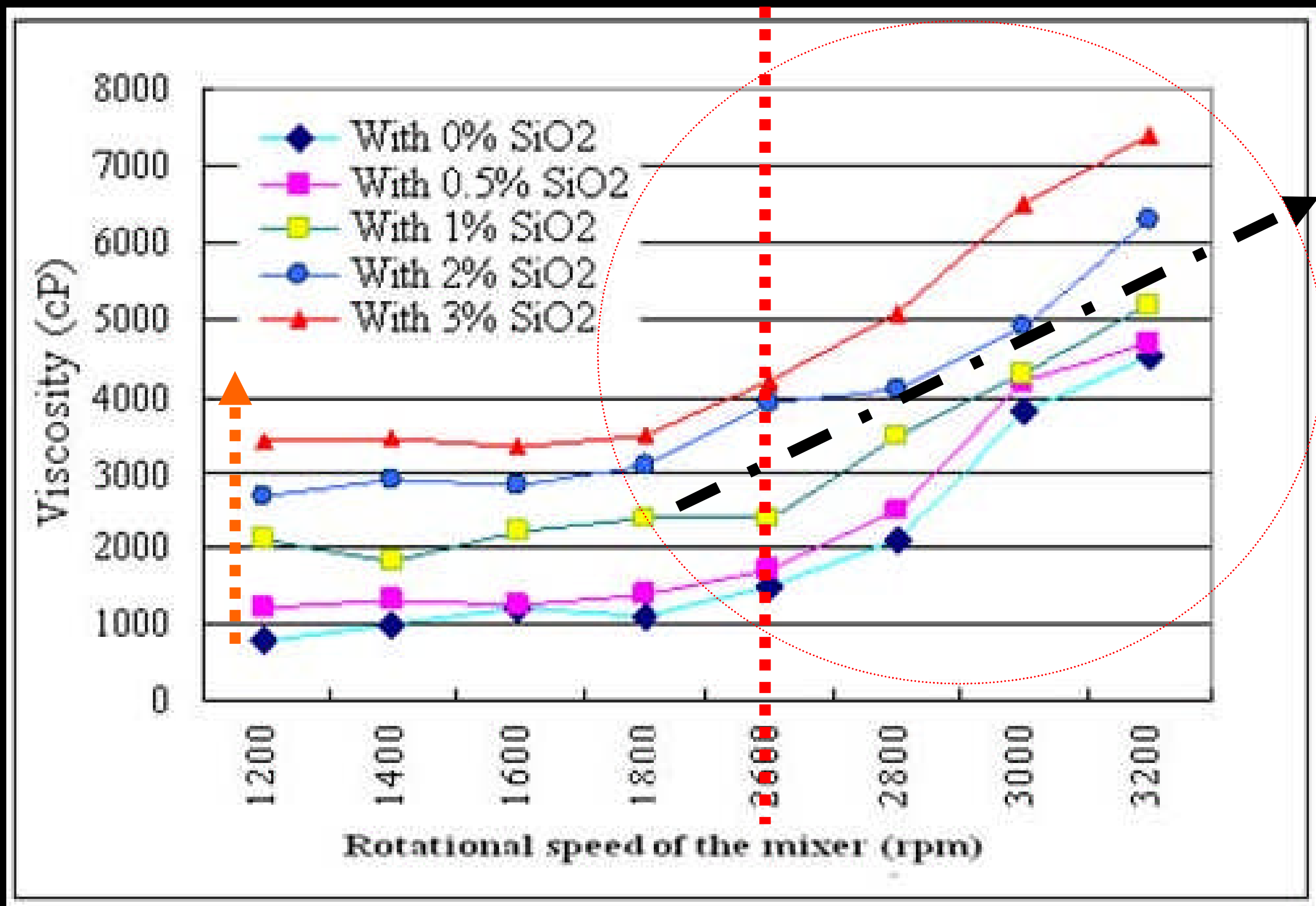
Procedure



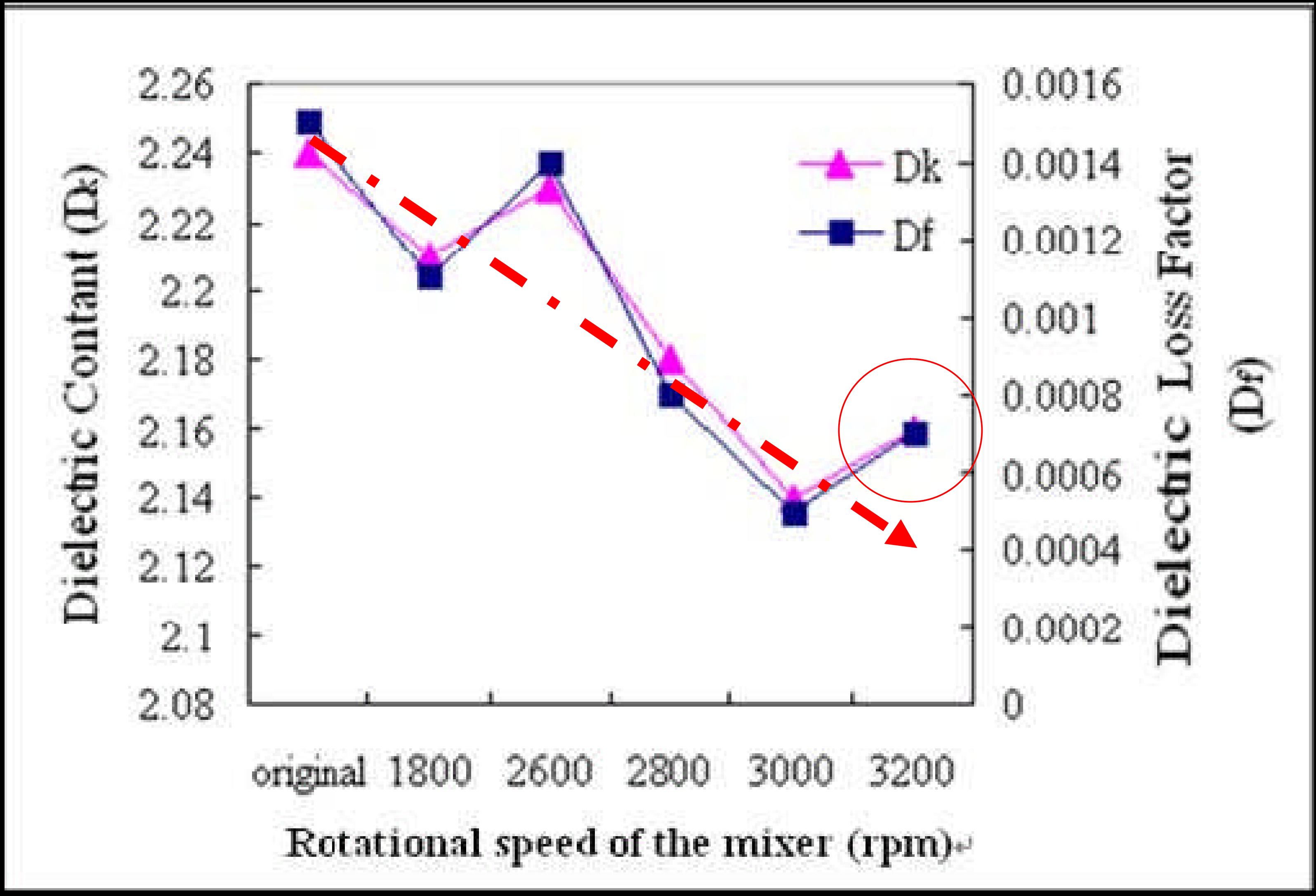
PTFE emulsify solution
Silicon Dioxide nanoparticles
Coupling Agent
Blending
Mixing
PTFE fabric
Fabrication
Calendering
Sintering
Hybrid board
Testing

Experimental results

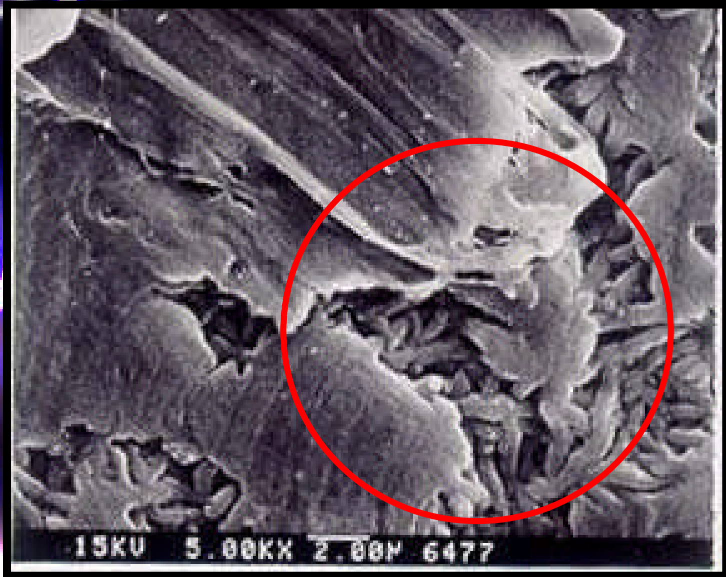
Impact of rotational speed and add-on percentage of SiO_2 nanoparticles on viscosity of hybrid board



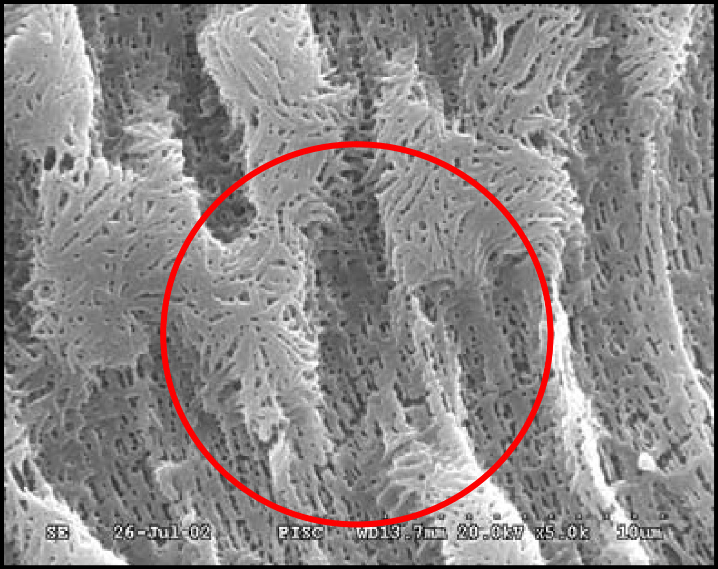
Impact of rotational speed of the mixer on dielectric constant (D_k) and dielectric loss factor (D_f) of hybrid board.



SEM photos of hybrid boards with different calendering times

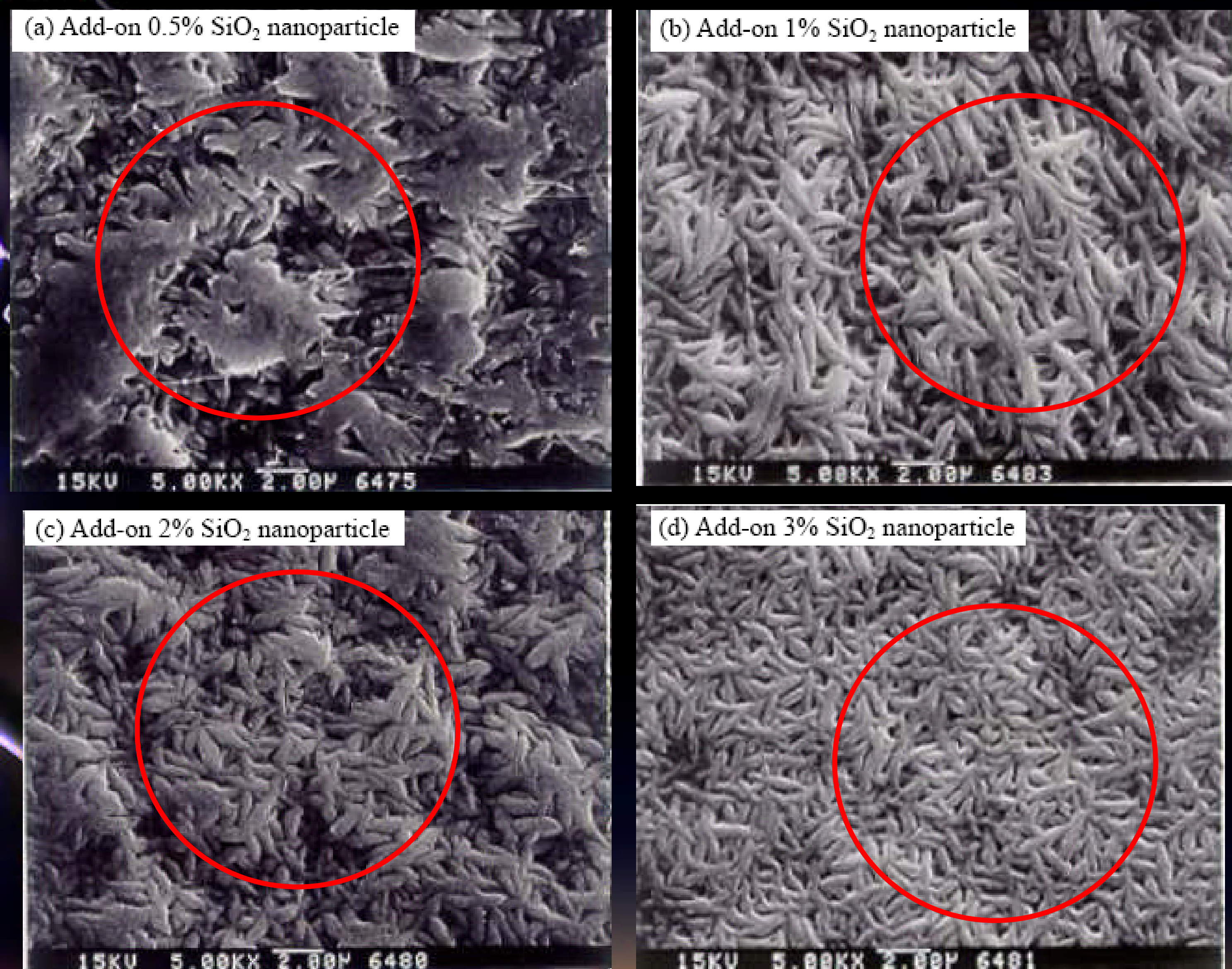


(a) Four calendering times

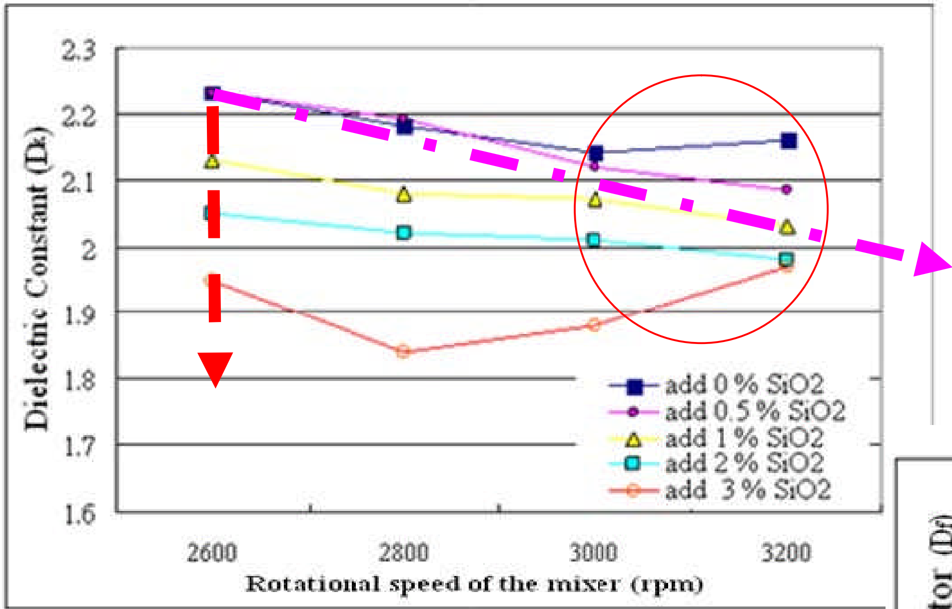


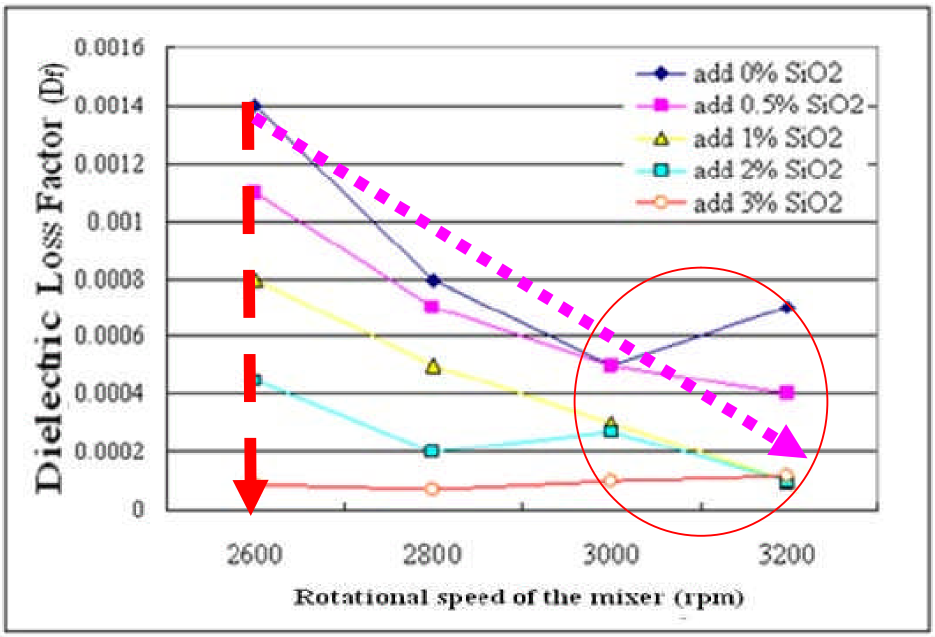
(b) Six calendering times

(c) Twelve calendering times


(a) Add-on 0.5% SiO_2 nanoparticle
15KV 5.00KX 2.00µ 6475
(b) Add-on 1% SiO_2 nanoparticle
15KV 5.00KX 2.00µ 6483
(c) Add-on 2% SiO_2 nanoparticle
15KV 5.00KX 2.00µ 6480
(d) Add-on 3% SiO_2 nanoparticle
15KV 5.00KX 2.00µ 6481

Impact of rotational speed of the spindle on dielectric properties





Conclusion

The dielectric property of hybrid board is related to the nanoparticles add-on, rotational speed of spindle, 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 surface area of nanoparticles.

In Addition

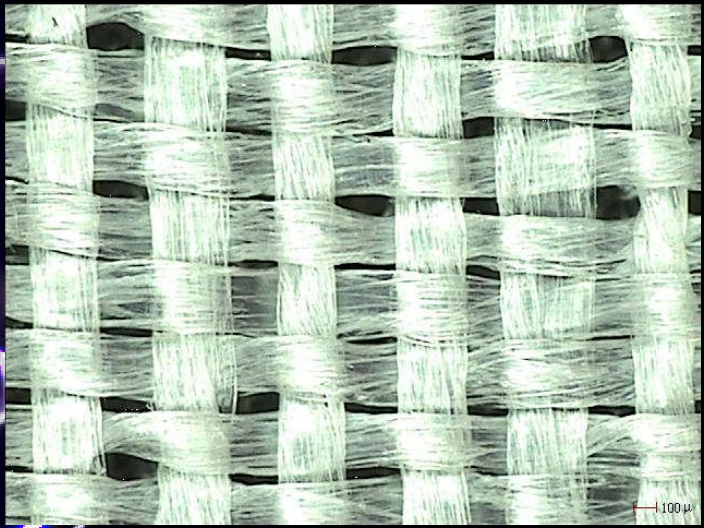
- Add-on of SiO_2 nanoparticles decrease coefficient of thermal expansion of PTFE hybrid board.
- Instead of PTFE, for conventional electric-epoxy resin, Add-on of SiO_2 Nanoparticles also decrease the dielectric properties, conductivity and coefficient of thermal expansion of epoxy hybrid board.
- Comparison of add-on Al_2O_3 Nanoparticles and SiO_2 nanoparticles for PTFE hybrid board, add-on Al_2O_3 Nanoparticles shows a poor dielectric properties, but a better thermal property (less thermal expansion).
- Add-on of $BaTiO_3$ nanoparticles shows a similar dielectric properties to SiO_2 nanoparticles of PTFE hybrid board.
- The smaller the particle size is, the less is the Add-on amount.
- A new approach to improve the **thermal expansion** during sintering is undertaken.

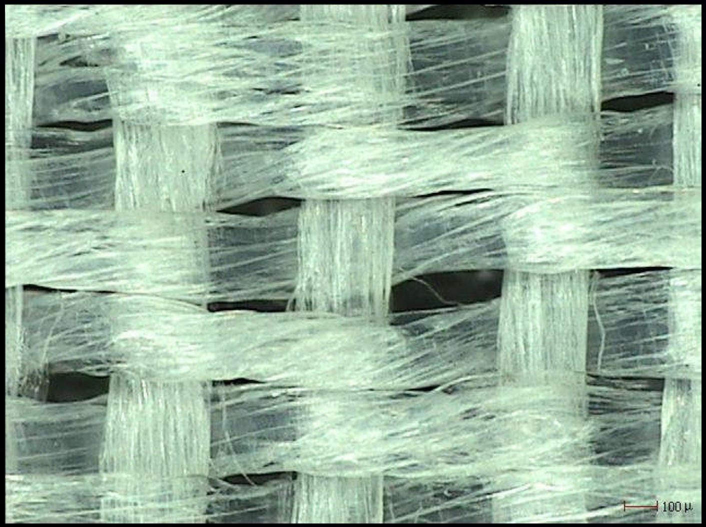

Thanks so much for your
attention!

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 %

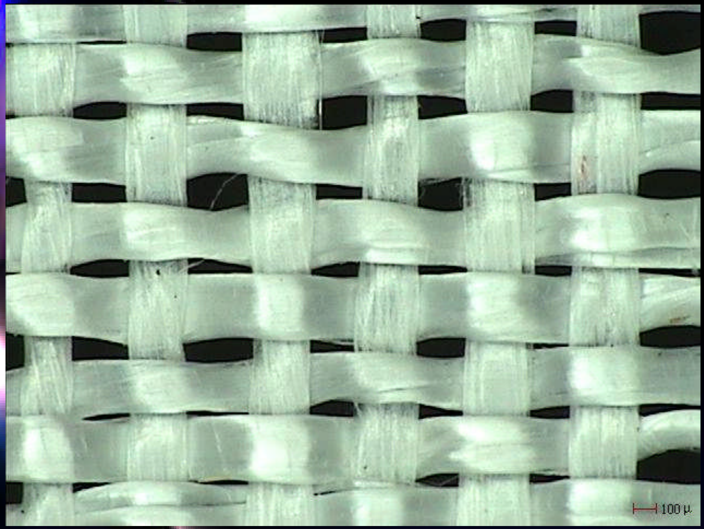
SEM photo of PTFE scrim yarns

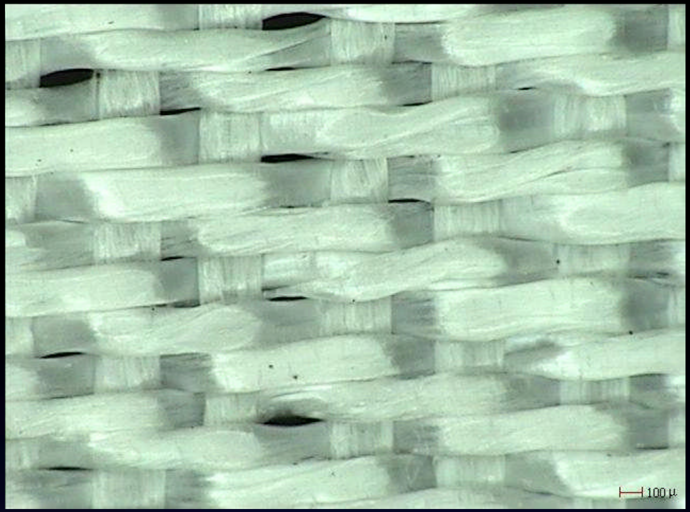




Plain fabric of type B

2/1 twill fabric of type B





Plain fabric of type Y

2/1 twill fabric of type Y

SEM photos of PTFE woven fabrics

Experimental parameters

- Amount of PTFE emulsify solution kept constant.
- Amount of coupling agent kept constant.
- Particle size is identical.
- Nanoparticles add-on: 1 – 3 %

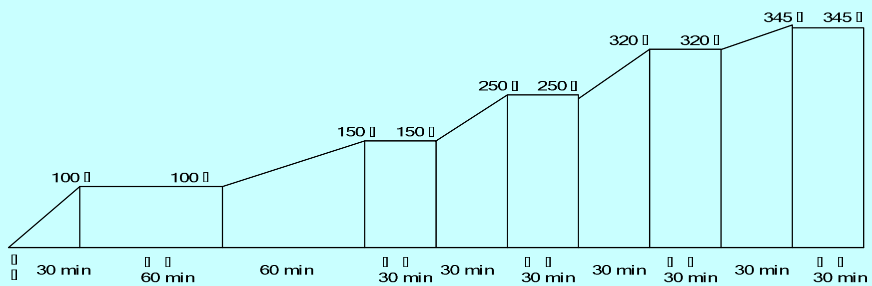
Experimental parameters

- Volume of mixer kept constant.
- Type of the spindle is identical.
- Rotational speed of spindle: 1200 – 3000 rpm

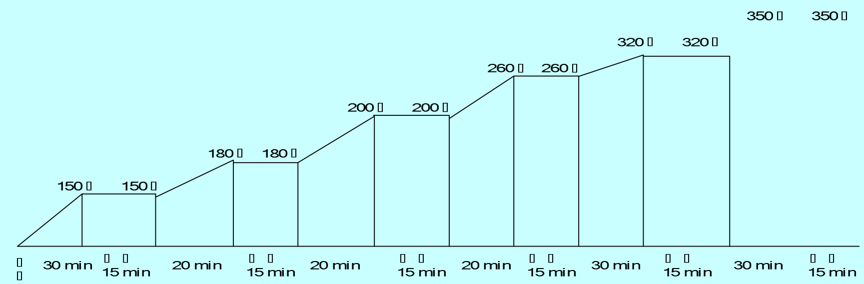
Experimental parameters

- Pressure of the calender kept constant.
- Type of the calender is identical.
- Calendering times: 4, 6, 12

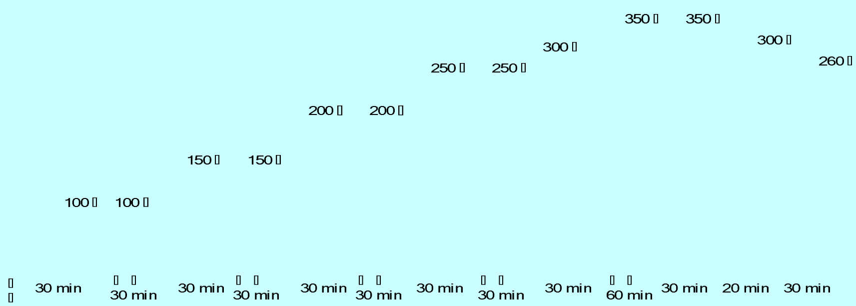
Sintering conditions



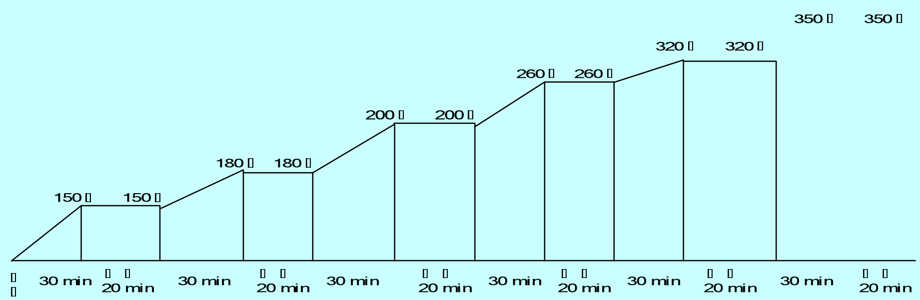
(a)



(b)

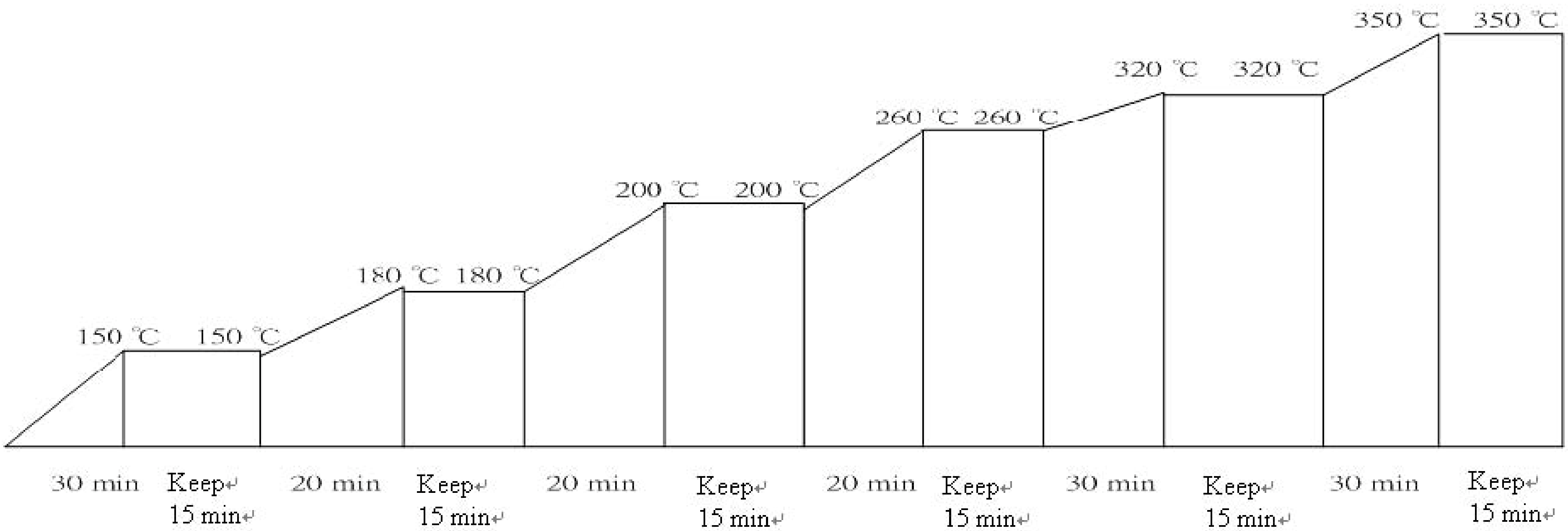


(c)



(d)

sintering condition



High rotational speed of spindle

- Fibril formation increased tremendously
- Water evaporated rapidly
- Increment of pore cells in nano-scale
- Thermal dissipation problem

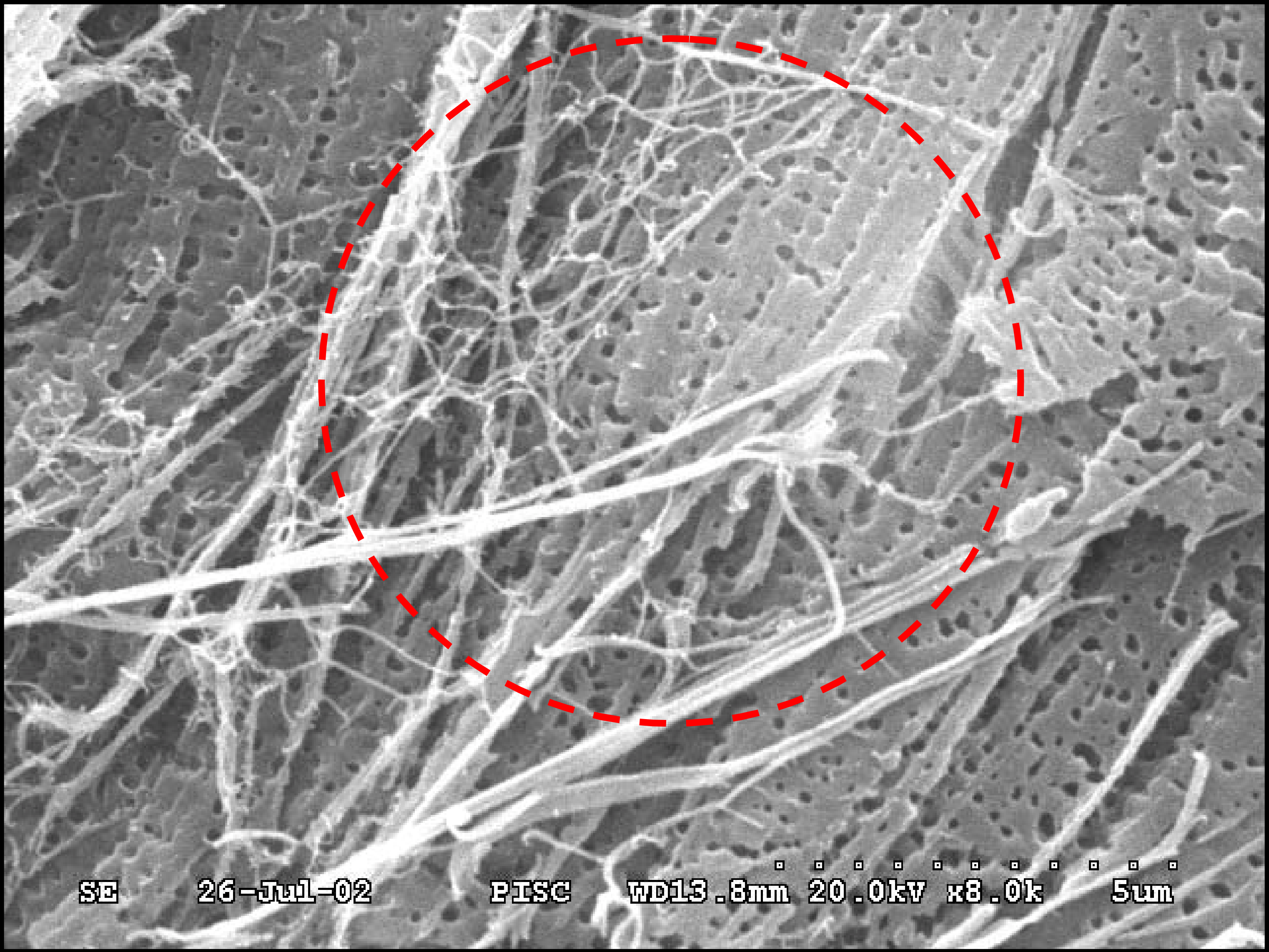


Figure 4 SEM photograph of fibrils on the surface of the hybrid board, magnification × 8000.

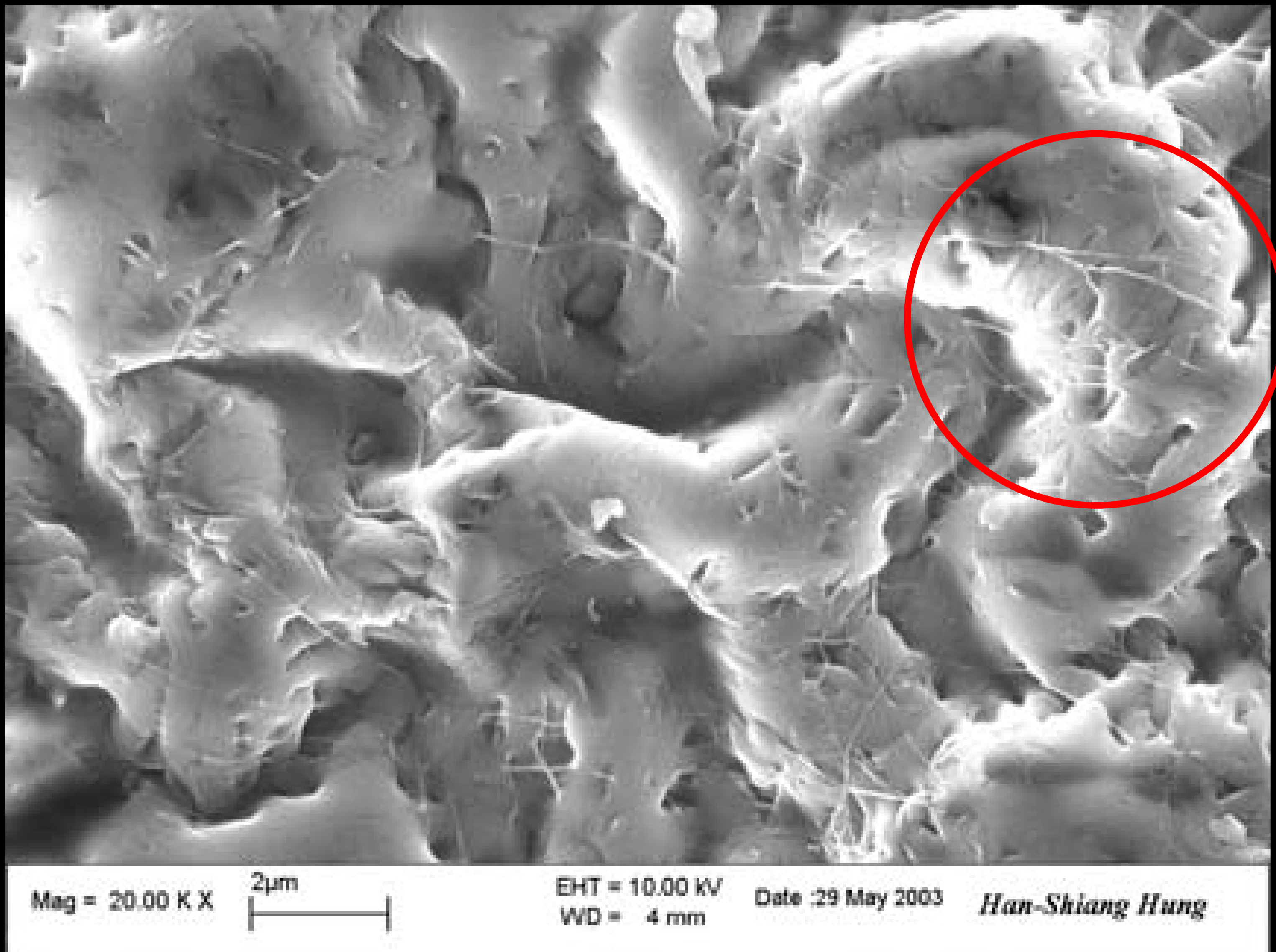


Figure 5 SEM photograph of fibrils on the surface of the hybrid board, in magnification of 20000.

Impact of Calendering Times

- Less effect on both D_k and D_f.
- Related to strength and hardness of the board.

High add-on percentage of SiO_2 nanoparticles

- More star-like shape structure.
- Abundant concave or micro-cracks is formed.
- Decrease thermal expansion
- Large surface area.
- Lead to coagulation and to form a bulky block.