DESIGN, FABRICATE & ANALYSIS OF DIELECTRIC RESONATOR

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
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for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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Department of Electrical & Electronic Engineering
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Approved:

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May 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Fatin Nor Izzati Binti Md Isa

ABSTRACT

In this study, a new material from recycle carbon based material had been introduced as a starting material in ceramic fabrication process to design a dielectric resonator antenna (DRA). In ceramic manufacturing, metal material such as copper and titanium as starting materials were difficult to be moulded and required higher production cost. Hence, the performance of a non-metal material which was carbon based material in wireless application had been investigated. This study involved implementation of ceramic fabrication process by determining the correct amount of carbon powder and binder to be pressed and appropriate sintering temperature for carbon. Next, dielectric value of carbon based ceramic would be measured and a DRA was designed in CST Microwave Studio with microstrip coupling feeding mechanism to excite the DRA. Furthermore, binder was an important material in pressing process and the wax in this study showed a good result to hold the carbon particles to form a pellet. Dielectric constant of carbon based material could be improved in the future so the size of DRA could be reduced. As conclusion, carbon based material was a good candidate to be used in DRA. For further works and improvements, the pellet could be used as a resonator in DRA circuit to determine the experimental result besides running a simulation by CST Microwave Studio. Other than that, dielectric value of carbon based material also could be improved by controlling the sintering condition and sample preparation.

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LIST OF ABBREVIATIONS

DRA	Dielectric Resonator Antenna
CST	Computer Simulation Technology
MgCO3	Magnesium Carbonate
ZnO3	Zinc Oxide
TiO2	Titanium Oxide
BaZrO3	Barium Zirconate
BST	Barium Strontium Titanate
SiCN	Silicone Carbide Nitride

CHAPTER 1

INTRODUCTION

1.1 Background of Study

A non-metal dielectric object was proven to radiate energy as the electrical resonators on 1939 by R.D Ritchmyer. However, the development of the material was implemented in the early 1960 by Okaya and Barash with further study of resonant frequency and modes [1]. Dielectric resonator antenna (DRA) is widely used in wireless communication application because of the characteristics they posses. They propose low production cost resonator which are small, easy to fabricate, very efficient in radiating purpose and greater bandwidth [2]. The objective of this project is to fabricate a pellet by using a carbon based material as a dielectric resonator. The fabrication method will be in solid state reaction to achieve a few goals which are to transform a recycle material into a dense product, to explore the potential of carbon based powder as a dielectric resonator antenna thus to implement the product in wireless communication application. The raw material assessment and product reliability will be determined by executing both physical and dielectric testing.

1.2 Problem Statement

1.2.1 Problem Identification

Conventional mixed oxide method is currently used in ceramic manufacturing by using metal powder such as calcium carbonate (CaCO3), titanium dioxide (TiO2) and copper oxide (CuO2). However, these metals are difficult to be molded and may require higher production cost and more complicated fabrication process. Thus, carbon based powder as a starting material will simplify the fabrication process. Desired pellet shape such as hemispherical, cylindrical or rectangular shapes can be easily molded and be applied in microwave devices.

1.2.2 Significance of Project

By fabricating a dielectric resonator by using carbon based material, this project is expected to enhance the exploration and research of a recycle material as a dielectric resonator. Besides, it will help to reduce the production cost in term of non expensive starting material as a new approach in dielectric resonator antenna manufacturing.

1.3 Objectives and Scope of Project

1.3.1 Main Objective

The objectives of the project are as follow:

1. To fabricate a recycle carbon based material as a pellet to design a dielectric resonator antenna.
2. To implement the solid state reaction and to verify the performance of the product by undergone dielectric testing.

1.3.2 Scope of Project

This project begins with literature review related to recent methods of fabrication in ceramic manufacturing and detailed information regarding the fabrication process of carbon based material. Next, further testing will be carried out to verify the performance of the pellet. Computer Simulation Technology (CST) software will be used to design a dielectric resonator antenna based on the product of fabrication.

1.4 Relevancy of Project

The characteristic of the recycle material in this project has been determined as a suitable starting material in the fabrication process. The non expensive recycle carbon based material will help to reduce the production cost in wireless communication application. Another than that, the high quality product will ensure the radiation reliability and also the efficiency.

1.5 Feasibility of Project

This project will be executed in two semesters consists of research, fabrication and dielectric testing of the product. The raw materials are also available for the project and the fabrication will be run at mechanical lab by the help of mechanical technicians. CST software is used to design a dielectric resonator antenna based on the fabrication product. Hence, this project will be feasible to be executed within the time frame.

CHAPTER 2

LITERATURE REVIEW

2.1 Ceramic Fabrication Process Overview

The applications of ceramics are diverse from filters for gases and liquids, thermally or acoustically insulating bulk materials, coating layers or structural products. The chemical composition and microstructure will determine the properties and functions of final product from selecting suitable starting raw materials and carry out different processing steps in the production operations [3]. In addition, there is fabrication of translucent magnesium oxide, MgO ceramics by hot-pressing which carried out either in Ar or in vacuum using nanopowder of MgO. 2-4% lithium fluoride, LiF is being used as a fugitive additive to achieve translucency where it improved the mass diffusion and densification of MgO [4].

To achieve ceramics with more complex microstructures and shapes, combination of injection molding and lost mold technique are recommended where two key points of this process are studied. The key points are solubility of plastic in various organic solvents and also binder extraction rate and strength of “green” body during de-binding. Based on the research, acrylonitrile-butadiene styrene and acetone are found to be suitable combination in the lost mold technique by using gasoline as de-binding solvent [5]. Recently, the fabrication method can be divided into two groups as follows:

i. Solid State Reaction
ii. Wet Chemical Method

2.1.1 Solid State Reaction Method

Solid state reaction method is a low cost powder production in industrial scale. The usual method is oxide-mixing technique which involves different powders that contain desired components of phase. Mechanical processes in this method are mixing and milling. With the action of heat, the powder mixture transforms to fine powders [6]. Thus, high temperature is an important key in solid state reaction not only to achieve considerable reaction rates but also to increase diffusion rates [7]. A modified solid state reaction method with addition of urea, [CO(NH2)2] also has been applied to prepare sodium potassium niobate (NKN) fine powder when a high density NKN ceramics (over 90 %) cannot be fabricated by using conventional sintering. It is found that a small amount of cobalt oxide, Co3O4 (0.03mol %) will be functioning as an effective sintering additive for potassium niobate, KNbO3 [8]. In this project, preparation of powder will be done in solid state reaction.

2.1.2 Wet Chemical Method

Sol-gel technique is recently used in ceramic manufacturing for wet chemical method. First, a raw material, metal alkoxides is mixed in alcohol. The reaction with water called hydrolysis reaction produces alcohol and very fine and very high purity powders. As precaution, the alcohol must be in suitable amount [9]. The homogeneous phases of the power obtained and additive dispersion allow better control of the composition hence easier production of thin films [10]. This technique also allow us to have variety of the sol-gel processing parameters such as annealing for crystallization temperature and addition of auxiliary chemical reagents hence the morphology and the composition of thin films can be controlled [11].

Other than that, by using the sol-gel technique with spin coating, a zine oxide (ZaO) thin film transistor (TFT) can be fabricated because this technique overcomes the disadvantage of other vacuum deposition techniques as the process requires high temperature coating and expensive equipment. The three main procedures involved are hydrolysis, condensation and polymerization [12].

2.2 Preparation and Identification

The preparation and identification which involve important steps in fabrication process usually divided into 3 sections as explained in the following sections:

2.2.1 Powder Preparation

Selection of raw materials is a starting point for ceramic fabrication sequence. For instance, silicon carbide (SiC) is one of the most important ceramic materials in form of powders, molded shapes and thin films.

It is expected to be used in a wide range of industrial applications regarding its excellent mechanical properties, high thermal and electrical conductivity and excellent oxidation resistance with high potential application as a functional ceramic [13]. Purity and particle size or shape is the necessary characteristics for raw materials [14].

Several types of material have been used previously to prepare a dielectric resonator for different applications as show in Table 1.

Table 1: Resonant frequency according to different materials

Reference Number	Materials	Applications	Resonant Frequency (GHz)
[15]	$MgCO_3$, ZnO_3, TiO_2	Microwave circuits	2.62
[16]	$BaZrO_3$	DRA	5.2-5.9
[17]	Teflon	Microwave devices with high frequency	11.6
[18]	BST, BiT	Access Points operating in WLAN IEEE 802.11 b/g and WiMAX IEEE 802.16	2.3-2.5
[19]	SiCN	Temperature and pressure sensors in high temperature turbine	12.37

2.2.2 Ceramic Fabrication

In ceramic manufacturing, powder route is one of most widely used methods to produce variety of components used in modern technology. Solid state includes a starting material in a solid phase (powder) through a sintering process. The process results in formation of a porous, shaped powder then into a dense product through firing [20].

Small powder particles of a material are bonded together during the high temperature treatment [21]. It starts from a powdery medium, forming and ends with the heat treatments. The ceramic quality and properties definitely can be modified through sintering process [22].

2.2.3 Characterization

The phases in the powder and obtained ceramics are usually characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM) and transmission electron microscopy (TEM) [23]. Other than that, Archimedes displacement principal is being used to measure the bulk density and porosity of sintered samples [24].

2.3 Micro structural and Mechanical Properties

Generally, below are the studies regarding the factors which can affect the performance of ceramic material in term of its micro structural and mechanical properties such as porosity, grain growth, bulk density and strength:

2.3.1 Effect of Powder Processing Condition

The preparation conditions of powder slurry can affect the strength of powder granules which then influence the properties of “green” compact and ceramic quality. It shows that a small amount in coarse particles in powder slurry can weaken the strength of ceramics. However, this condition does not affect the densities of ceramics. Large pores and coarse particles are found to be usually generated during powder slurry preparation, spray drying and forming of “green” compact and samples with larger coarse particles are observed to have lower strength (MPa) [22].

Figure 1 shows the SEM images of alumina ceramic having 75~90miu m coarse particles.

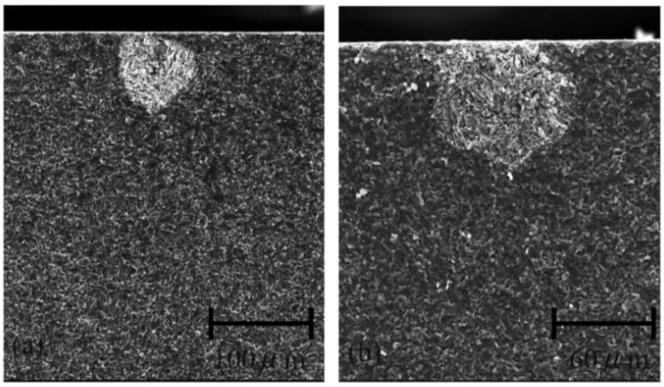


Figure 1: SEM images of alumina particles with 75~90miu m coarse particles
a) 370 MPa b) 406 MPa

2.3.2 Effect of Pre Sintered Powder

Pre sintering will eliminate certain amounts of impurities after the milling process by heated up the dried powder to the high temperature [25]. The flexural strength can be increased and the porosity is decreased if the powder had undergone pre sintering process. It is because the pores between aggregates and agglomerates are eliminated. The speedy gain growth also makes the body to have greater surface area [3].

Porous alumina shows that it has better micro structural features of ceramic body when the powder undergone pre sintering process for 2 hours by having less pores and more particles with bigger size as shown in Figure 2. The reduction in porosity as well as the increment of pre sintering temperature is believed to improve the strength and hardness of porous alumina [3].

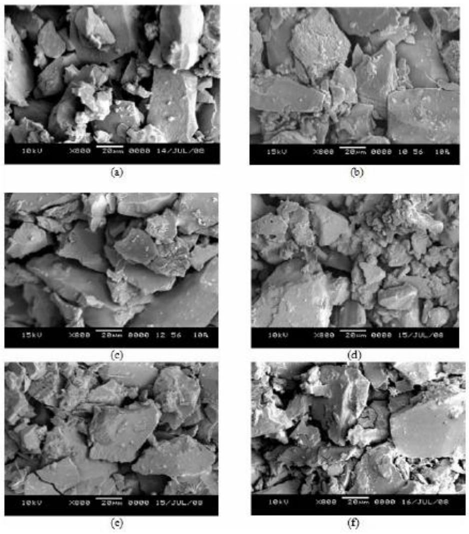


Figure 2: a) SEM images of single sintered porous alumina. Micrograph of porous alumina which undergone pre sintering at b) 1100•C c) 1300•C d) 1300•C e) 1400•C f) 1500•C

In a different study of yttria-stabilized zirconia (YSZ) powder, YSZ powder has been pre sintered at 200•C for 120 hours. The produced electrolyte proved to be dense and impermeable and if the hold time is reduced to 20 hours, the produced electrolyte found to be porous. However, an ideal electrolyte can be obtained by increasing the pre sintering temperature to 600•C for 20 hours. Without undergone pre sintering process, the electrolyte has been investigated to be highly porous which lead to a drop in open circuit voltage [26]. Figure 3 shows the SEM images of electrolyte surface with different pre sintering condition.

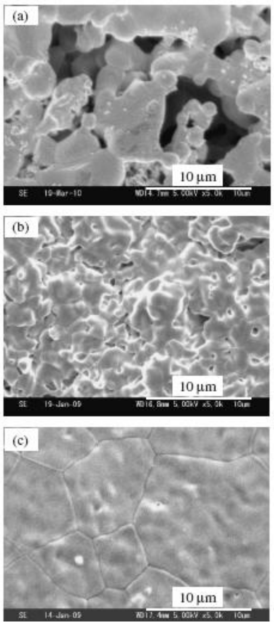


Figure 3: SEM images of electrolyte surface a) without pre sintering b) pre sintered at 200•C for 20 h c) pre sintered at 200•C for 120 h

2.3.3 Effect of Sintering Temperature

In solid state, sintering will bond together the small powder particles of a material by solid state diffusion to provide strength and to eliminate the porosity [27]. It involves physical changes in the compacts such as grain total volume and physical properties such as relative density [28].

Benzodiazepine (BNZ) ceramics reveal that its microstructure is closed to final stage sintering process at 1050•C for 2 hours where maximum density can be obtained. However, the ceramics have relative low density when sintered below 950•C as well as at 1000•C also for 2 hours. It proves that the sintering temperature must be below the melting point of the powder because the BNZ ceramic is partially melted down at 1100•C by considering phase purity and ceramic density. Besides, the grain sizes and grain boundaries increased if the sintering temperature increased [29]. Figure 4 shows the SEM images of BNZ ceramic with different sintering temperature:

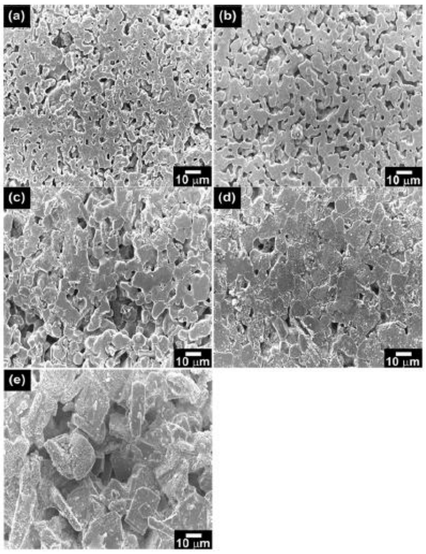


Figure 4: SEM images of BNZ ceramic which sintered at a) 900•C b) 950•C c) 1000•C d) 1050•C e) 1100•C

Another research regarding the effect of sintering temperature is Rice Husk Ash (RHA) ceramics. At 1100•C, the grain of the particle is not totally developed but at 1200•C and above, the crystalline increased thus proved the surface condition and crystal phase in ceramic changed due to the increment of sintering temperature. In other words, porosity decreased as sintering temperature increased. The hold time of sintering is 2 hours [30]. Figure 5 shows the surface morphology of RHA ceramic.

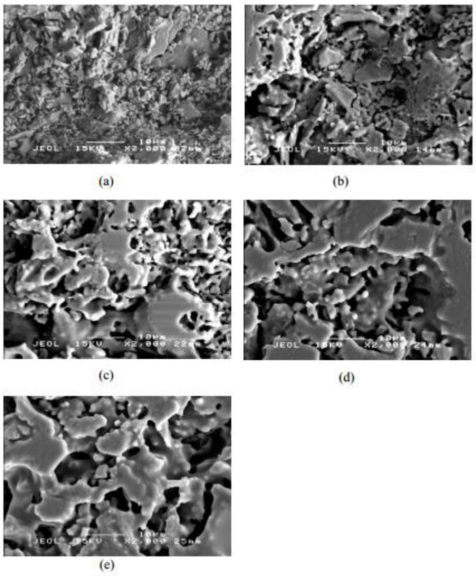


Figure 5: SEM images of RHA ceramic which sintered at a) 1000•C
b) 1100•C c) 1200•C d) 1300•C e) 1400•C

2.3.4 Effect of Binder Type

Based on past study, the effect of different type and content of binders for both dried and sintered ceramic Raschig rings has been investigated. The dried rings were sintered in an electrical high temperature furnace within a temperature range (25C-1270•C) for the hold time from 1 hour to 2 hours. Defect dimensions and distribution of pores in ceramic are proven to influence the mechanical performance of sintered ceramics Raschig rings. Addition of 0.5wt % polyvinyl alcohol enhances the mechanical reliability of sintered ceramic while 0.75 wt% carboxymethyl cellulose (CMC) can improve the compressive strength. 1.75 wt% Arabic gum also shows high value of strength. However, by observation fracture surface of Raschig ring prepared by has larger defects if compared with 0.75 wt% CMC [31]. Figure 6 shows the SEM images of defect fracture surface that affected by different type of binder.

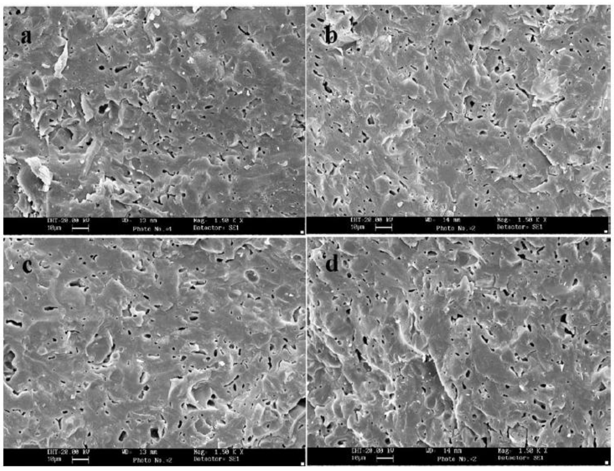


Figure 6: SEM images of fracture surface a) without binder b) 1 % PVA c) 0.75 % CMC d) 1.75 % AG

In different study, a lead zirconate titanate (PZT) precurso sol is being used as a binder for PZT powders and it is compared to samples which prepared by using PVA, conventional binder. Based on the study after sintering condition at 1150•C for 4 hours, pellet with 7 wt% PZT has obtained with 95 % theoretically density which greater than pellet with polyvinyl acetate (PVA) which has obtained only 78% theoretically density [32].

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

In order to achieve the main objective of this project, brief researches about the topic need to be done by focusing on the selected papers. It is crucial to uphold the reliability of information and to ensure the credibility of this project.

Besides, several sources such as internet research, books and journals are used to perform fundamental studies and also the literature reviews. It will enhance the understanding about both chemical and mechanical requirements of each step taken in the fabrication process thus guarantee the feasibility of this project.

The pellet which is the final product of fabrication will be used for the antenna design. Hence, dielectric testing of pellet will be carried out to analyze the dielectric properties of material. A testing in a DRA design can be done by doing simulation using the CST Microwave Studio.

3.2 Flow Chart

Below flow chart in Figure 7 explains the methodology to execute this project. There are several processes involved during ceramic fabrication process such as implementation of solid state reaction method. Next process will be dielectric testing. Once the dielectric constant has been identified, a testing in DRA can be done using CST Microwave Studio.

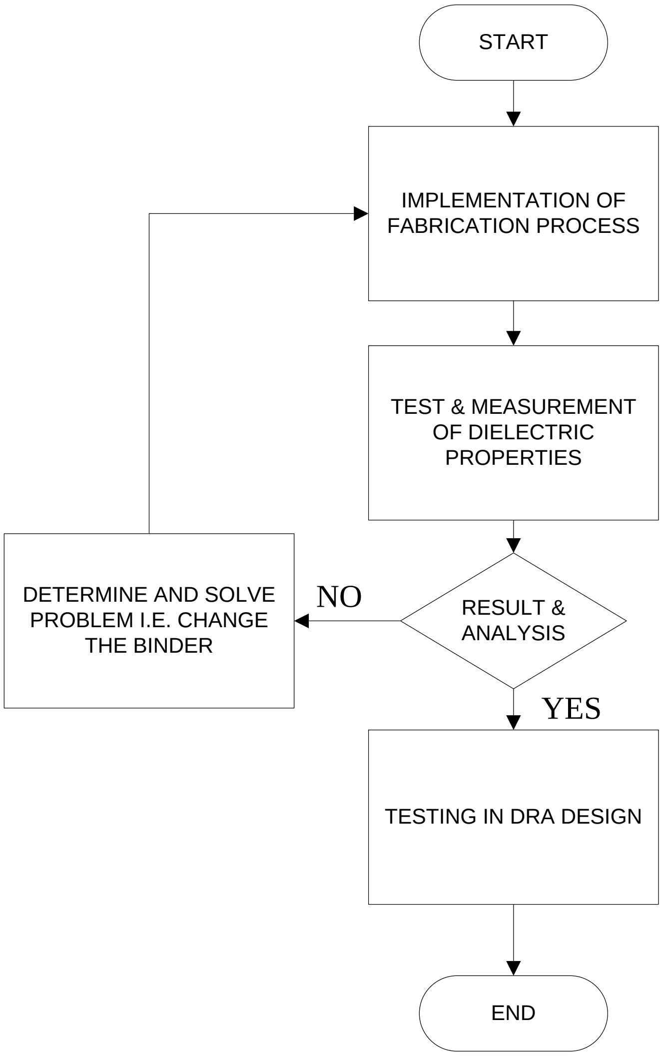


Figure 7: Flow chart of project flow

3.2.1 Implementation of Ceramic Fabrication Process

Figure 8 shows the steps taken to fabricate a pellet which include sample preparation till the final sintering. The correct ratio of carbon to wax will be experimented during pressing process to identify most compressive pellet hence it will be sintered at respective temperature to improve the strength and dielectric constant.

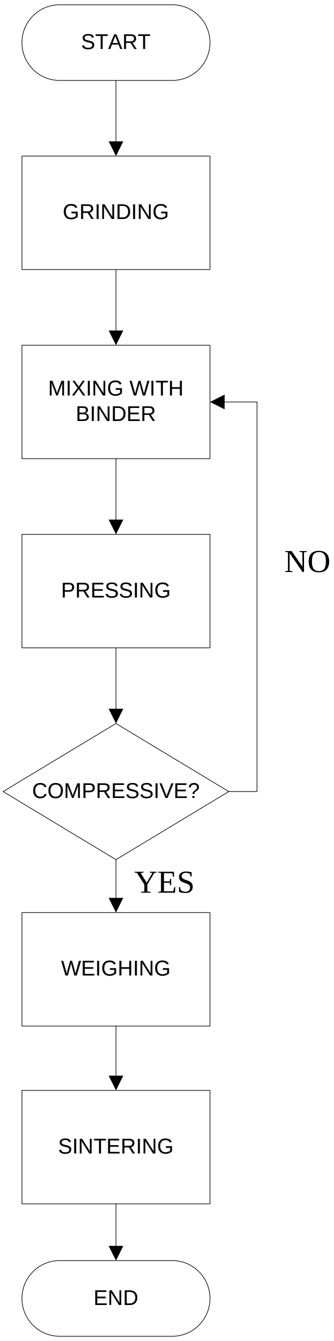


Figure 8: Flow chart of ceramic fabrication process

3.2.2 Test and Measurement of Dielectric Properties

Testing can be divided into physical properties such as density, porosity and hardness and dielectric properties. Below testings will be implemented for raw material assessment and quality control as well as fit for purpose.

In dielectric media, permittivity and loss tangent is the crucial material properties for propagation of electromagnetic. Phase velocity adjustment will be used to ensure a low loss case when the permittivity controls the propagation of energy. Dielectric loss measures how much electrical energy that dielectric material can absorb which subjected to an alternating electric field [33]. Permittivity is defined by a complex quantity by Equation 1.

$$\varepsilon_r = \varepsilon_{r'} - \varepsilon_{r''} \qquad (1)$$

And Equation 2 shows that the dielectric loss is given by the loss tangent which is the ratio of the imaginary to the real part of the permittivity.

$$\tan d = {}^{\varepsilon_{r''}}/_{\varepsilon_{r'}} \qquad (2)$$

where $\varepsilon_{r'}$ is the real or measured part and $\varepsilon_{r''}$is the imaginary part.

3.2.3 Test in Dielectric Resonator Antenna (DRA) Design

Return loss is the measurement of the ability of the transmission line to deliver the power to an antenna. Higher power ratio is desired which indicate the better efficiency between the line and antenna [34]. The expression will be in dB as defined in Equation 3.

$$RL = 10log_{10}\frac{(P_{in})}{P_{ref}} \qquad (3)$$

where P_{in} is power incident on the antenna-under-test (AUT) and P_{ref} is power reflected back to the source.

Far field measurement as expressed in Equation 4 is undergone to identify how far the transmitting antenna and the receiving antenna should be separated to obtain a reasonable far field gain and radiation patterns [35].

$$R \geq \frac{2D^2}{operating\,wavelenght} \quad (4)$$

where R is range length and D is aperture diameter of the antenna under test.

3.3 Project Duration

In order to have effective monitoring of this project, a Gantt chart consists of one year duration has been developed. See Appendix A.

3.4 Tools Required

The fabrication processes and testing will be conducted in mechanical and electrical and electronic lab with the help of mechanical and electronic technologists. In addition, the CST Microwave Studio is used to design and simulate the DRA.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Results

Different ratios of wax and carbon powder and pressing condition has been sampled and investigated to determine which “green” compact shows most sturdy and compressive condition. “Green” compact is a pellet before a sintering process. A selected “green” compact from the samples then will be sintered under respective sintering profile. Below is the whole fabrication process:

4.1.1 Mold Cleaning

A cylindrical mold as shown in Figure 9 and Figure 10 is being used for experimental work and it will be cleaned up to ensure the absence of impurities on the surfaces of mold. Besides, a clean mold serves better pressing process that influences the formation of “green” compact.

Figure 10: Top view of mold (D=40 mm)

Figure 9: Side view of mold (D=40 mm)

4.1.2 Grinding

The objective of grinding is to reduce the powder to its primary particle size and to increase the surface area of powder. Hence, smaller particle size will ease the powder pressing process. Three tablespoon of carbon powder has been grinded for 3 minutes. Figure 11 shows the grinding machine that being used in this project and the example of carbon powder before and after grinding process shown in Figure 12 and Figure 13.

Figure 11: Grinding Machine

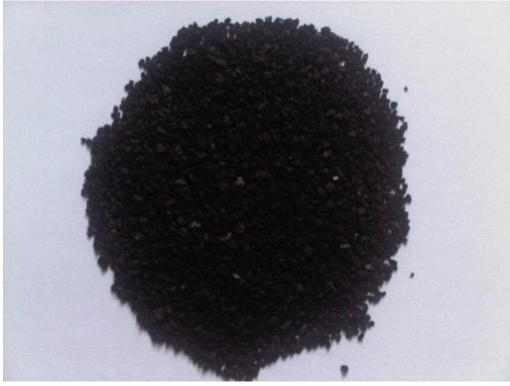


Figure 12: Carbon powder before grinding

Figure 13: Carbon Powder after grinding

4.1.3 Mixing With Binder

A binder called wax as shown in Figure 15 is being used to bind the carbon powder particles during powder pressing process. A correct ratio of wax and carbon powder will produce a sturdy and compressive “green” compact. The mixture of wax and carbon powder as shown in Figure 14 has to be well blended in the mold before pressed with the pressing tool in next process.

Figure 15: “Wax” binder

Figure 14: Mixture of carbon and wax

4.1.4 Pressing

The mixture of wax and carbon powder will be pressed to shape the powder into formed part known as a “green” compact by using a pressing tool as shown in Figure 16 with maximum pressure available, 10,000 psi (700 Bar). The pressure from the pressing tool will start to be applied when the mold already reach the top of the pressing tool and will continuously applied until desired pressure. The mold will be released after certain holding time. Figure 17 shows how to place the mold onto the pressing tool.

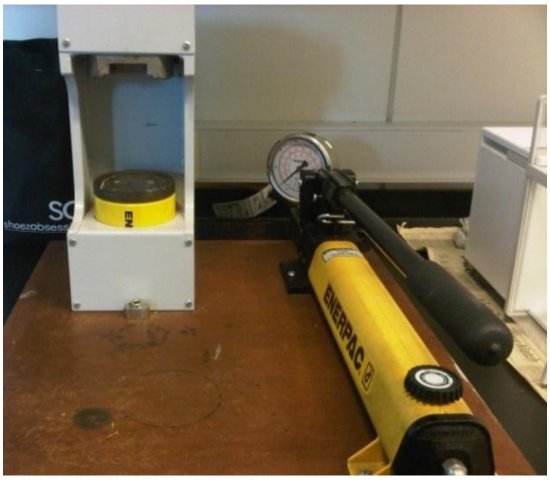


Figure 16: Pressing tool

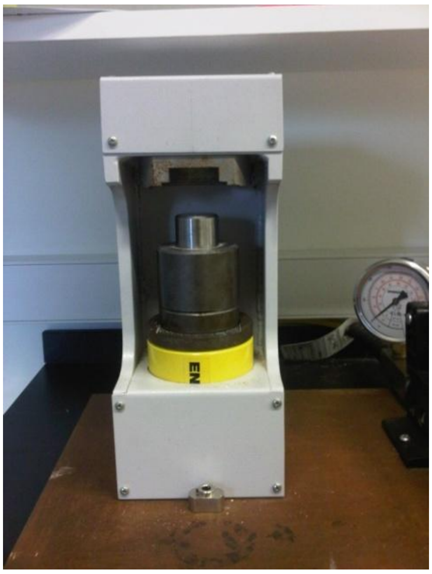


Figure 17: Pressing tool with mold

4.1.5 Weighing

After being pressed into “green” compact, it will be weigh on a weight scale to determine the weight of pellet as shown in Figure 17 with balance maximum weight of 200 gram.

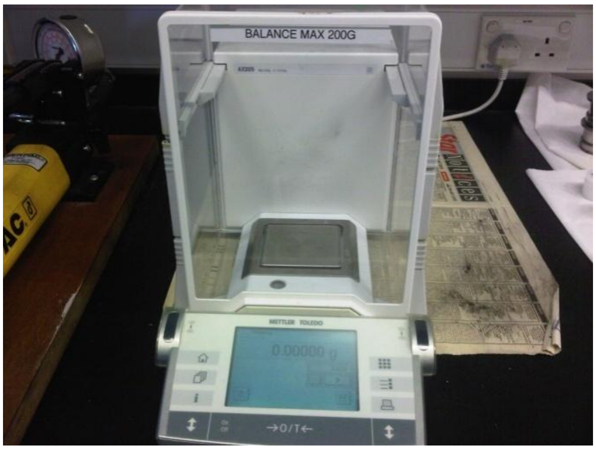


Figure 18: Weight Scale

4.1.6 Sintering

Sintering is a process to transform a powdered material into a solid mass by a heat treatment. It is important to enhance the strength and conductivity and also to reduce the porosity of pellet. The process is done in a sintering furnace without any gas as shown in Figure 19 and material safety data sheet for activated carbon is referred to prevent any dangerous circumstances. See Appendix B and Appendix C. Table 2 shows the temperature profile by controlling the heating and cooling rate and also the holding temperature.

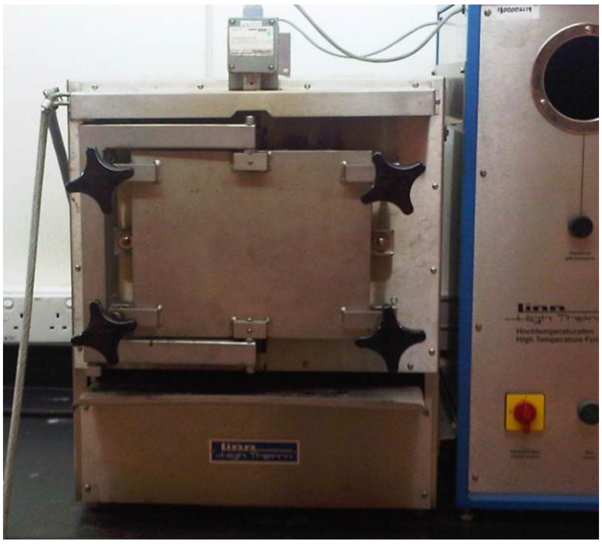


Figure 19: Sintering furnace

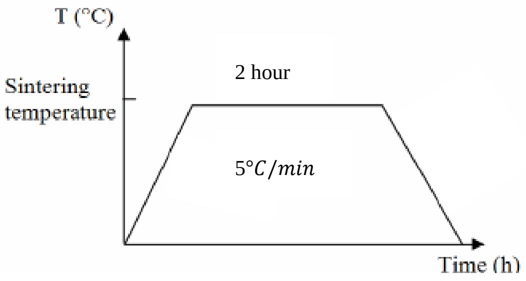
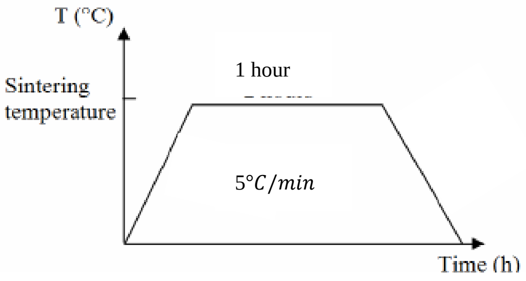
Process	**Temperature Profile**	**Condition**
1		Heating & Cooling Rate: $5°C/min$ Holding Temperature & Time: 350C for 2 hours
2		Heating & Cooling Rate: $5°C/min$ Holding Temperature & Time: 150C for 1 hour

Figure 20: Temperature profile of sintering process

4.2 Experimental Result of “Green” Compacts (Pellet)

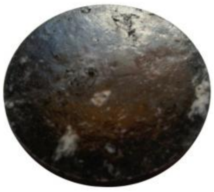
Table 2 shows the results of “green” compact from different ratio of wax and carbon and pressing condition. The average thickness of sample is within 4-5 mm according to the amount of carbon and wax.

Table 2: Samples from different ratio of carbon to wax and pressing condition

Sample	**Carbon : Wax Ratio**	**Pressing Condition (pressure/hold time)**	**Weight (g)**
1	4 : 7	100 kN for 120 s	6.48
2	2 : 9	50 kN for 60 s and increase to 100 kN for 60 s	6.20
3	2 : 9	50 kN for 75 s and increase to 100 kN for 45 s	6.23
4	1 : 6	100 kN for 120 s	5.91
5	1 : 6	100 kN for 180 s	5.67

Table 3 includes the “green” compact samples from Table 2 respectively. A 50 cent coin is used to compare the size of pellet.

Table 3: “Green” compact samples

Sample	Surface	Front View	Side View
1			
2			
3			
4			
5			

4.3 Experimental Result of Ceramic

Ceramic is a pellet after a sintering process. A dielectric testing has been done to check the dielectric constant after sintering process to determine the dielectric constant. However, the minimum thickness of ceramic in dielectric testing must be 20 mm and above. A new pellet is fabricated as referred from the experimental result of carbon to wax ratio but using a smaller mold of 20 mm diameter as shown in Figure 20. Next process is dielectric testing by using dielectric probe in electrical & electronic department. The result shows the dielectric constant of pellet in Figure 21 and 22 is 7.

Figure 21: Side view of mold (D= 20 mm)

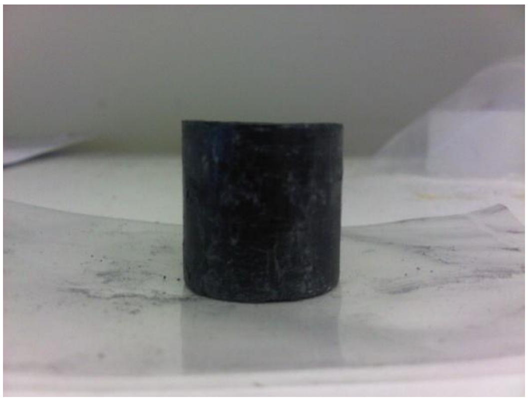


Figure 23: Top view of pellet

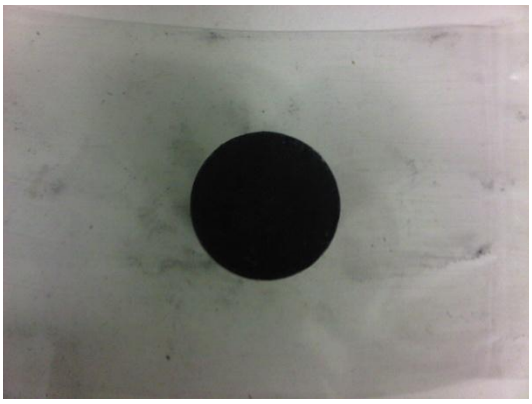


Figure 22: Side view of pellet

4.4 Simulation Result of the Antenna

The carbon based material has been developed and tested as an antenna. One type of antenna has been simulated in CST Microwave Studio which is microstrip.

4.4.1 Microstrip Antenna

The simulation of microstrip antenna is conducted with CST Microwave Studio. Based on the Equation 5, radius to height, $\frac{a}{h}$ ratio of DRA is 5.67 (radius, a=14.17 mm and height, h=2.5 mm). A layer of aluminum is patched on the DRA with its thickness of the aluminum was 0.1 mm. Table 5 shows the following details of feeder and ground plane.

$$f_r = \frac{6.324}{\sqrt{\varepsilon_r + 2}}\left\{0.27 + 0.36\frac{a}{2h} + 0.02\left(\frac{a}{2h}\right)^2\right\} \qquad (5)$$

Table 4: Dimension of feeder and ground plane

	Width (mm)	**Length (mm)**	**Thickness (mm)**
Feeder	1.9	50	-
Ground Plane	50	60	1

The ground plane is Rogers RO4003 (dielectric constant=1 at 2.45 GHz) material at the front surface and copper material for the bottom. Thus, dielectric tolerance and loss can be ignored. DRA is placed approximately at 32mm from the bottom and the rectangular slot (width=4 mm, length=13 mm) and circle slot (radius=4.5 mm) are both at the back of the antenna.

The rectangular slot was placed at 22 mm from the top and the circle was placed at 22mm from the bottom of the ground plane. Figure 23 shows the graph of return loss from the simulation in CST. It shows return loss is -11.04848 dB at frequency 2.45 GHz. Besides, Figure 24 and Figure 25 show directivity (6.256 dBi) and gain (5.279 dBi) from simulation result respectively.

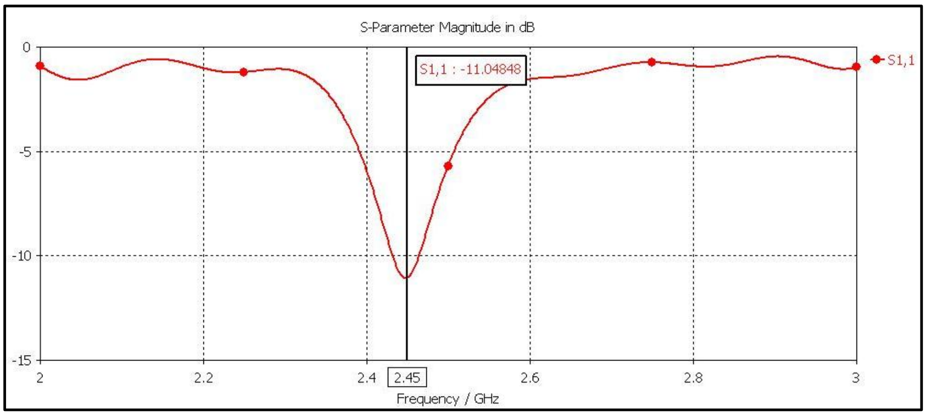
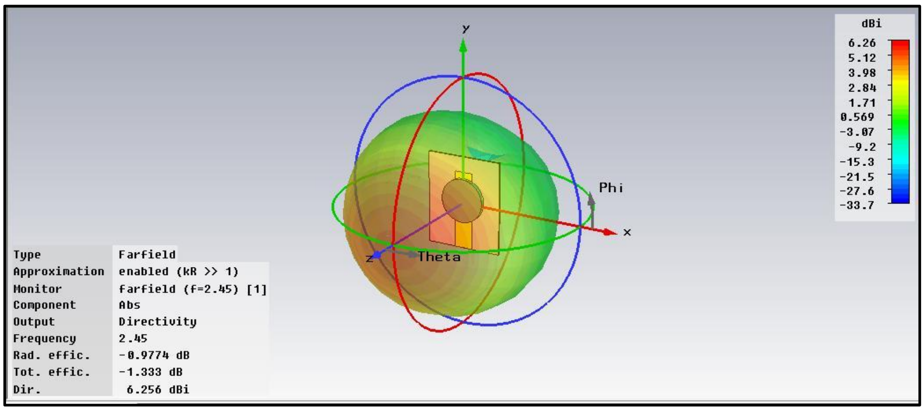
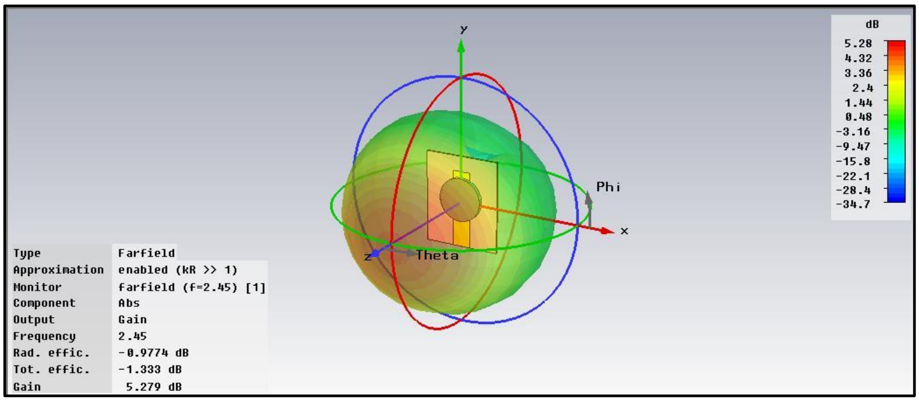


Figure 24: Return Loss



```
Type           Farfield
Approximation  enabled (kR >> 1)
Monitor        farfield (f=2.45) [1]
Component      Abs
Output         Directivity
Frequency      2.45
Rad. effic.    -0.9774 dB
Tot. effic.    -1.333 dB
Dir.            6.256 dBi
```

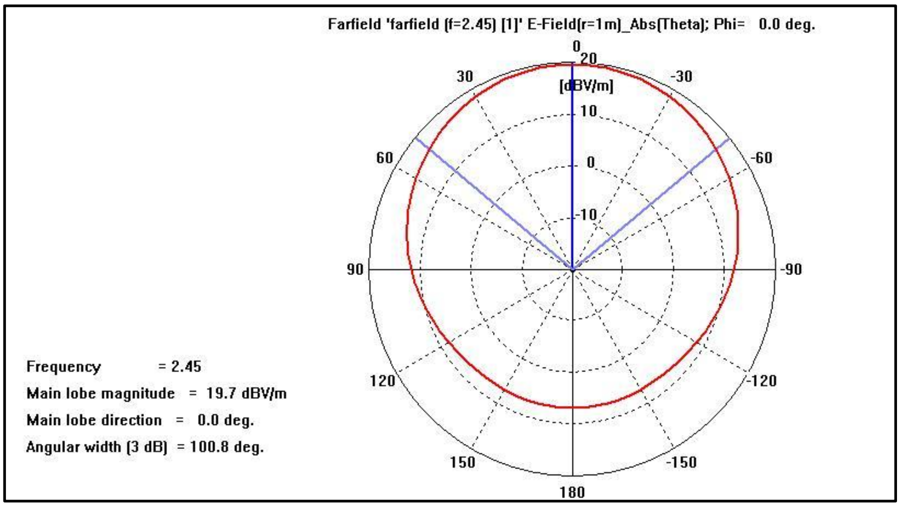
Figure 25: Directivity



```
Type           Farfield
Approximation  enabled (kR >> 1)
Monitor        farfield (f=2.45) [1]
Component      Abs
Output         Gain
Frequency      2.45
Rad. effic.    -0.9774 dB
Tot. effic.    -1.333 dB
Gain            5.279 dB
```

Figure 26: Gain

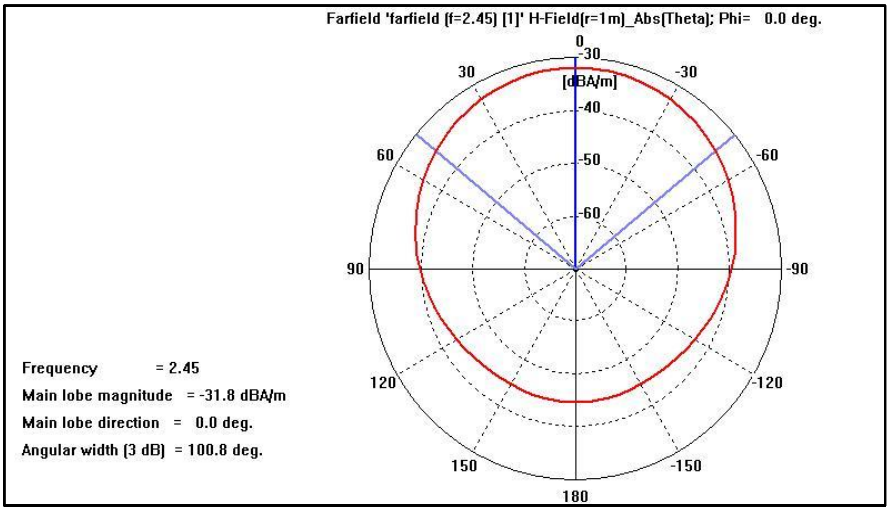
In addition, 2-dimensional radiation pattern of E filed and H field in Figure 26 and Figure 27 respectively show that -3 dB beamwidth is 100.8º in all direction and has been identified as omnidirectional.



Farfield 'farfield (f=2.45) [1]' E-Field(r=1m)_Abs(Theta); Phi= 0.0 deg.

Frequency = 2.45
Main lobe magnitude = 19.7 dBV/m
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 100.8 deg.

Figure 27: E-field radiation pattern



Farfield 'farfield (f=2.45) [1]' H-Field(r=1m)_Abs(Theta); Phi= 0.0 deg.

Frequency = 2.45
Main lobe magnitude = -31.8 dBA/m
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 100.8 deg.

Figure 28: H-field radiation pattern

4.5 Discussion

The experimental results of “green” compacts (pellet) and ceramic have been discussed where the focus point during the formation of “green” compact is investigation of carbon to wax ratio for most compressive pellet. In ceramic, the result of dielectric testing is observed.

Based on Table 3, different samples are pressed to form “green” compact in cylindrical shaped of 40 mm diameter. Maximum pressure that has been applied in this experiment is 100Kn and the maximum hold time before the mold is released is 180 seconds. However, according to Table 4, Sample 1 shows worst fracture surface for both sides compared to other samples.

Next samples, Sample 2 and Sample 3 show improvement by reducing the amount of carbon and increase the amount of wax. The pressing conditions as shown in Table 3 have been applied. However, only upper side of “green” compact for both samples (faced the punch) shows even surface and lower side of “green” compact from Sample 2 shows worse fracture surface than Sample 3 because of its lesser holding time at 50 kN.

As shown by Sample 4 and Sample 5 respectively, Sample 4 shows less even surface for both sides (upper and lower) of “green” compact if compared to Sample 5 under same ratio of wax and carbon powder but at different hold time at pressing. If the mixture is not well-blended before the pressing process, it will produce a surface with white-colored mark as shown by Sample 5.

The thickness and weight of samples are varied based on the ratio of wax and carbon powder. However, they might be not accurate as the ratio of wax and carbon powder is inconsistently measured by spatula as shown in Figure 14 and Figure 15.

A new pellet of 20mm diameter is formed based on the experimental result of “green” compact and sintered based on Table 2 to fulfill the requirement of dielectric testing on pellet. The pellet has been pressed at 75 kN but with longer pressing time if compared to the pellet of 40 mm diameter which is approximately 10 minutes. However, at 350•C the pellet was burned into powder form which indicates the sintering temperature is too high and not suitable. Second process is at 150•C and with similar holding time and heating and cooling rate. The results shows that sintering temperature at 150•C is appropriate for carbon based pellet to transform into solid mass as the strength of pellet is improved after sintering process.

On the other hand, return loss result from simulation of DRA by CST Microwave Studio is low. It is less than -10 dB thus the efficiency between the line and antenna is considered as high. In addition, the DRA is omnidirectional based on the radiation pattern which means the antenna radiates power uniformly in all directions in one plane.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Dielectric resonator antenna (DRA) plays an important role in wireless communication application because of the characteristics they posses such as low production cost and easy to fabricate. DRA in cylindrical shape also has greater design flexibility in determining the parameters such as dielectric constant and permittivity.

Besides, a carbon based material from recycle items such as rice husk and wood has been used in this project as starting powder which will be transformed into a dense product by various steps of ceramic fabrication.

In this project, “green” compact sample with greater amount of wax than carbon powder (1:6) relatively considered as good result which has more even surface in sturdy and compressive condition. It proves that carbon powder is a suitable starting powder and wax as a suitable binder to bind the carbon particles in this project. In addition, dielectric constant shows appropriate result to be obtained in DRA design for wireless application.

5.2 Recommendation

Based on the results obtained, the affects of maximum applied pressure as well as the hold time need to be investigated if the “green” compact shows any improvement. In addition, if the thickness of pellet increased, the pressing time also has to be increased to ensure the pellet is compressive and not crack when removing it from the mold.

Other than that, pre sintering process for carbon powder can be implemented before the mixing process as it will reduce the porosity of powder thus enhance the strength of final product. Moreover, greater conductivity of pellet can be achieved by ceramic surface condition improvement.

Besides, the simulation result of DRA by using CST Microwave Studio can be compared with a further work by constructing a DRA circuit based on the pellet. Hence, resonant frequency can be identified by using a network analyzer. Other ceramic characterization such as Scanning Electron Microscopy (SME) and X-Ray Diffraction (XRD) could be done in ceramic phase to identify its crystal structure and electrical conductivity respectively.

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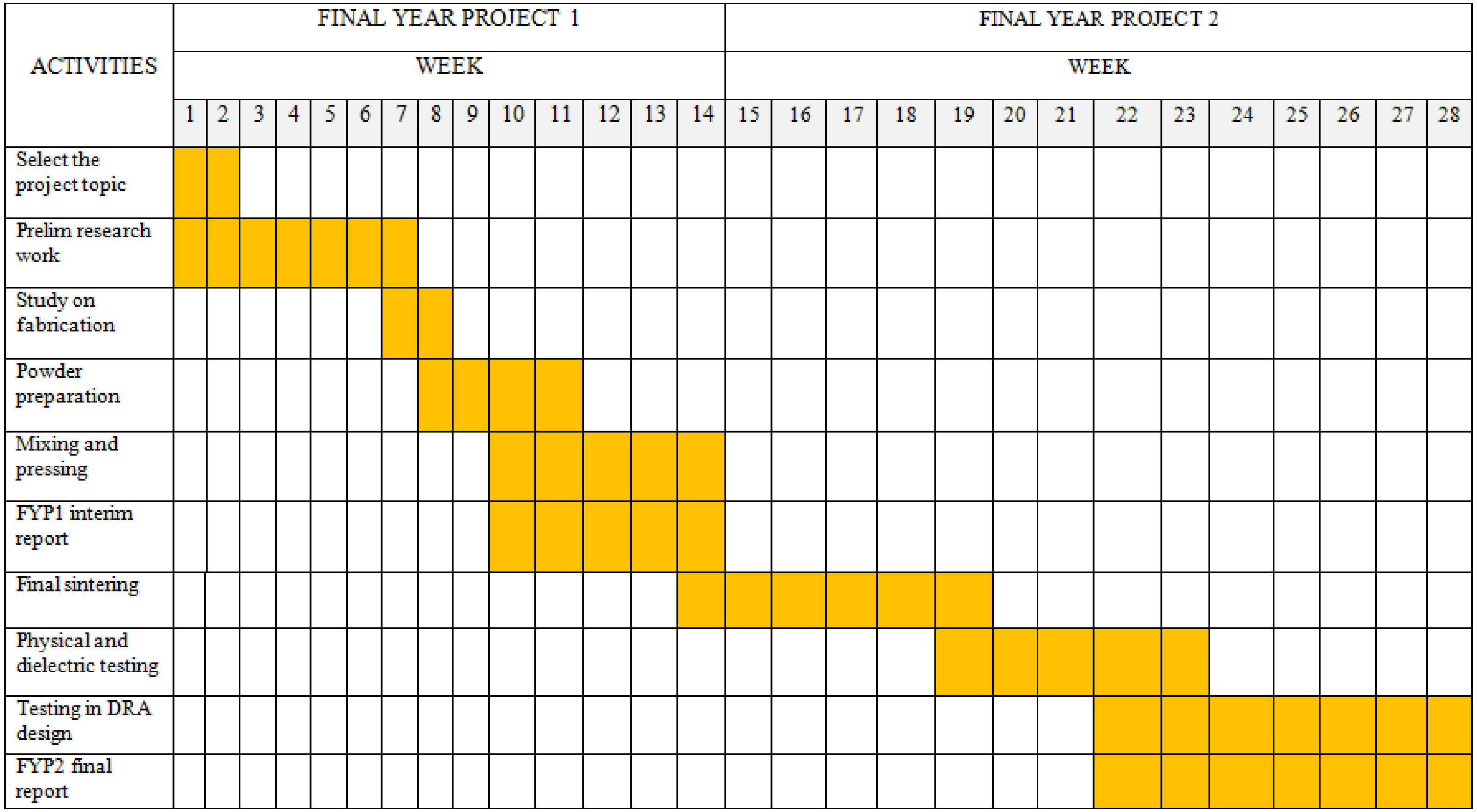
APPENDIX A

GANTT CHART



ACTIVITIES	FINAL YEAR PROJECT 1														FINAL YEAR PROJECT 2													
	WEEK														WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Select the project topic	■	■																										
Prelim research work	■	■	■	■	■	■	■																					
Study on fabrication							■	■																				
Powder preparation								■	■	■	■																	
Mixing and pressing										■	■	■	■	■														
FYP1 interim report										■	■	■	■	■														
Final sintering														■	■	■	■	■	■									
Physical and dielectric testing																			■	■	■	■	■					
Testing in DRA design																						■	■	■	■	■	■	■
FYP2 final report																						■	■	■	■	■	■	■

APPENDIX B

MATERIAL SAFETY DATA SHEET

Norit **Activated Carbon**

leading in purification

MATERIAL SAFETY DATA SHEET

NFPA HAZARD SYMBOL*

Norit MSDS No. 117
Revision Date: September 29, 2010
Revision No. 06

4-Extreme
3-High
2-Moderate
1-Slight
0-Insignificant
*-See Section 16 for Special Hazards

Norit Activated Carbons

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Norit Americas Inc. **3200 West University Avenue** **Marshall, TX 75670**

Emergency Telephone Numbers:

CHEM•TEL Inc. (800) 255-3924 (24 hour) Sales Office (800) 641-9245 Pryor Plant (918) 825-5570

Names used on product labels:

NORIT GAC (Included all grades produced from Bituminous/Subbituminous Coal)
NORIT PAC (Included all grades produced from Bituminous/Subbituminous Coal)
NORIT VAPURE (Included all grades produced from Bituminous/Subbituminous Coal)

NORIT® is a registered trademark of Norit Americas Inc. This MSDS also covers all the experimental products from the same starting materials.

Chemical Name	•	Activated Carbon
Product Use	•	Liquid and vapor applications (purification, decolorization, separation, and deodorization)

2. COMPOSITION / INFORMATION ON INGREDIENTS

IDENTITY	CAS NO.	%
Activated Carbon	7440-44-0	100

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW:

Odorless black granules or powder. **Activated carbon (especially when wet) can deplete oxygen from air in enclosed spaces, and dangerously low levels of oxygen may result.** When workers enter a vessel containing activated carbon, follow procedures for potentially low oxygen. Workers should also take appropriate precautions when dealing with spent (used) activated carbons which may exhibit properties of adsorbed materials.

POTENTIAL HEALTH EFFECTS:

Medical conditions aggravated by exposure: None documented

Routes of Exposure:

Eyes:	•	Not corrosive, but like most particulate materials, may cause mild physical irritation.
Skin:	•	Not corrosive and not a primary skin irritant. Mild irritation is possible due to abrasive action of dust.
Ingestion:	•	No known deleterious effects.
Inhalation:	•	Possible mild irritation of respiratory tract due to drying and abrasive actions of dust.
Chronic Effects:	•	IARC: Not listed • NTP: Not listed • OSHA: Not regulated

For additional information, see Section 16.

4. FIRST AID MEASURES

Skin:	•	Wash material off the skin with soap and water. Seek medical attention if irritation occurs.
Eyes:	•	Flush with copious amounts of water. Seek medical attention if irritation occurs.
Ingestion:	•	Give one or two glasses of water to drink. Seek medical attention if gastrointestinal symptoms develop.
Inhalation:	•	Remove to fresh air. Seek medical attention if cough or respiratory symptoms develop.

---

* Reprinted with permission from NFPA 704, Identification of the Fire Hazards of Materials, Copyright ©1992, National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association, on the referenced subject which is represented only by the standard in its entirety.

Page 2 of 4
Norit MSDS No. 117
Revision Date: September 29, 2010
Revision No. 06

Norit
leading in purification

5. FIRE FIGHTING MEASURES

Flashpoint	• Not Applicable.
Non-flammable	• 16CFR1500.44.
Not Self Heating	• UN Manual of Tests and Criteria, Test N.3.
Flammability Limits in Air	• LFL and UFL Not Applicable.

GENERAL HAZARD:
Activated carbon is difficult to ignite and tends to burn slowly (smolder) without producing smoke or flame. Toxic gases will form upon combustion.

FIRE FIGHTING INSTRUCTIONS:
If possible to do safely, move smoldering activated carbon to a non-hazardous area, preferably out of doors. Extinguish fire using water fog, fine water spray, carbon dioxide or foam. Avoid stirring up dust clouds.

FIRE FIGHTING EQUIPMENT:
Fire fighting personnel should wear full protective equipment, including self-contained breathing apparatus (SCBA) for all inside fires and large outdoor fires.

HAZARDOUS COMBUSTION PRODUCTS:
Combustion products may include smoke and oxides of carbon (for example, carbon monoxide). Materials allowed to smolder for long periods in enclosed spaces, may produce amounts of carbon monoxide which reach the lower explosive limit (carbon monoxide LEL = 12.5% in air). Under certain conditions, any airborne dust may be an explosion hazard. Used activated carbon may produce additional combustion products.

6. ACCIDENTAL RELEASE MEASURES

IF A SPILL OR LEAK OCCURS:
Clean up spills in a manner that does not disperse dust into the air. Handle in accordance with good industrial hygiene and safety practices. These practices include avoiding unnecessary exposure, and removal of material from eyes, skin, and clothing.

DISPOSAL METHOD:
Spent granular activated carbon may be recyclable. Dispose of virgin (unused) carbon (waste or spillage) in a facility permitted for non-hazardous wastes. Spent (used) carbon should be disposed of in accordance with applicable laws.

CONTAINER DISPOSAL:
Do not reuse empty bags. Dispose of in facility permitted for non-hazardous wastes.

7. HANDLING AND STORAGE

Storage Temperature:	• Ambient
Storage Pressure:	• Atmospheric
Handling:	• Follow good handling and housekeeping practices to minimize spills, generation of airborne dusts, and accumulation of dusts on exposed surfaces. • Use with adequate exhaust ventilation to draw dust away from workers' breathing zones. • Prevent or minimize exposures to dusts by using appropriate personal protection equipment. • Wash exposed skin areas thoroughly with soap and water after handling.
Storage:	• Store product in a closed dry container. Maintain good housekeeping. Store away from strong oxidizers such as ozone, liquid oxygen, chlorine, permanganate, etc.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Engineering Controls:
- Use local exhaust ventilation to control emissions near the source. Ventilation systems should be sized and configured to prevent exceedence of recommended or regulated exposure limits (for example, OSHA PELs).

Eye Protection:
- Safety glasses with side shields are recommended for any type of handling. Where eye contact or dusty conditions may be likely, dust tight goggles are recommended. Have eye flushing equipment available.

Skin Protection:
- Avoid contact with the skin. Wear appropriate dust resistant clothing. Wash contaminated clothing and clean protective equipment before reuse. Wash skin thoroughly after handling.

Respiratory Protection:
- Use NIOSH/MSHA approved respiratory protection equipment appropriate to the material and/or its concentration where airborne exposure is likely. If exposures cannot be kept to a minimum with engineering controls, consult respirator manufacturer to determine appropriate type equipment for a given application. Observe respirator use limitations specified by NIOSH/MSHA or the manufacturer.

Airborne Exposure Guidelines:

Recommended Exposure Limits 8-hr TWA	Activated Carbon
Total Dust	10 mg/m^{3*}
Respirable Fraction	3 mg/m^{3*}

*OSHA and ACGIH have not established specific exposure limits for this material. The recommended exposure limits for these activated carbon products are base on the Threshold Limit Values adopted by ACGIH for Particulates (Insoluble) Not Otherwise Classified. The OSHA PEL for Nuisance Dust is 15 mg/m^3 (5 mg/m^3 respirable fraction).

9. PHYSICAL AND CHEMICAL PROPERTIES

Boiling Point, C:	• NA	Freezing Point, C:	• NA
Bulk Density - Granular Grades	• 28-34 lbs/ft^3	% Volatiles	• NA
Bulk Density - Powder Grades	• 15-35 lbs/ft^3	Solubility in Water	• Insoluble
Vapor Pressure	• NA	Appearance and Odor	• Black granules or powder with no odor
Vapor Density	• NA		
Evaporation Rate	• NA		

NA - Not applicable

10. STABILITY AND REACTIVITY DATA

Stability:
- This product is stable under the specified conditions of storage, shipment and use.

Incompatibility:
- Contact with strong oxidizers such as ozone, liquid oxygen, chlorine, permanganate, etc. may result in rapid combustion. Avoid contact with strong acids.

Hazardous Decomposition Products:
- Oxides of Carbon

Hazardous Polymerization:
- Does not occur.

11. TOXICOLOGICAL INFORMATION

This material is non-toxic in its original state. Used activated carbon may exhibit characteristics of the adsorbed material.

12. ECOLOGICAL INFORMATION

This material, in its original state, is not harmful to the environment. Used activated carbon may exhibit characteristics of the adsorbed material.

13. DISPOSAL CONSIDERATIONS

Activated carbon, in its original state, is not a hazardous material or hazardous waste. Follow applicable governmental regulations for waste disposal.

Used activated carbon may become classified as a hazardous waste depending upon the application. Follow applicable regulations for disposal.

Recycling (reactivation) may be a viable alternative to disposal. Contact Norit Americas Inc. for information.

14. TRANSPORT INFORMATION

DOT (Department of Transportation)

Proper Shipping Name:	•	Activated carbon (Not DOT Regulated).
Hazard Class:	•	Not applicable.
UN/NA Number:	•	Not applicable.
Packing Group:	•	Not applicable.
Freight Classification:	•	STCC Code - #2899643 NMFC #040560

15. REGULATORY INFORMATION

FEDERAL REGULATIONS:

OSHA Hazard Communication Standard, 29CFR1910.1200:	•	See "Particulates not otherwise regulated," in Table Z-1, of 29CFR1910.1000, "Limits For Air Contaminates".
CERCLA/SUPERFUND, 40CFR117, 302:	•	Notification of spills of this material is not required.
SARA/SUPERFUND:	• • •	Amendments and Reauthorization Act of 1986 (Title III), Sections 302, and 313:. SECTION 302 - EXTREMELY HAZARDOUS SUBSTANCES (40CFR355): This product is not listed as an extremely hazardous substance. SECTION 313 - LIST OF TOXIC CHEMICALS: This product is not listed.
Toxic Substances Control Act, 40CFR710:	•	Activated carbon is on the inventory list.
Resource Conservation and Recovery Act:	•	This product, in its original state, does not meet the criteria of hazardous waste.

STATE REGULATIONS:

California Occupational Safety and Health:	•	Not listed.
Massachusetts Substance List:	•	Not listed.
New Jersey Right-to-Know:	•	Not listed.
Pennsylvania Right-to-Know:	•	Not listed.

16. OTHER INFORMATION

Activated carbon can be safely stored in any normal storage area, but away from sources of direct heat.

WARNING: Activated carbon (especially when wet) can deplete oxygen from the air, and dangerously low levels of oxygen may result. When workers enter a vessel containing activated carbon, procedures for potentially low oxygen areas should be followed.

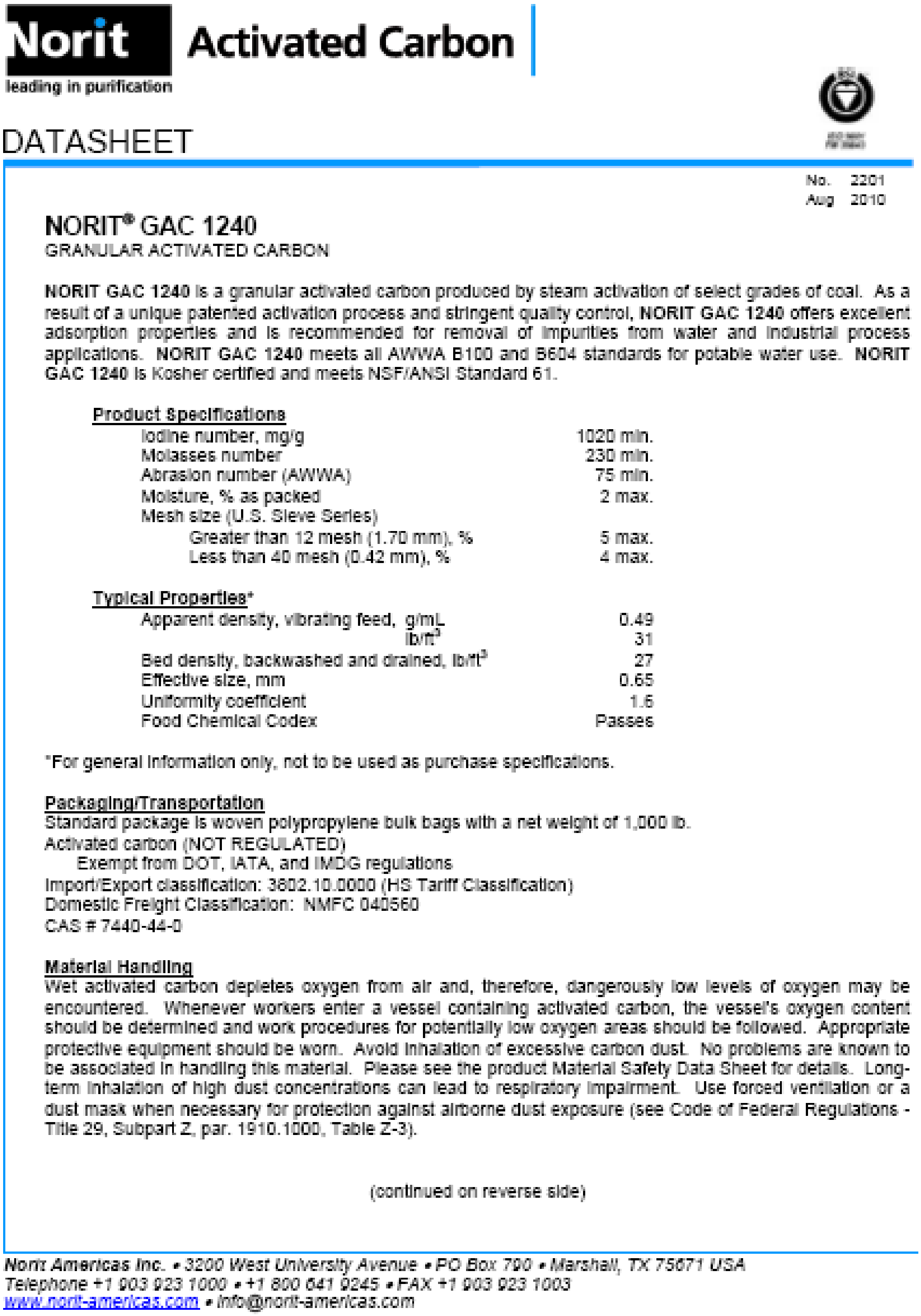
Activated carbons are not listed as potential carcinogens by any agency. Because Norit Americas adheres to a very conservative position regarding all health and safety matters, we recommend and follow a practice of requiring respiratory protection whenever there is any evidence of airborne dust.

REVISION SUMMARY:
REV 06: Revsion date change
REV 05: New format
REV 04: Added the VAPURE products

The information herein is given in good faith but no warranty, expressed or implied, is made.

APPENDIX C

TECHNICAL DATA SHEET



Norit leading in purification

Activated Carbon

DATASHEET

No. 2201
Aug 2010

NORIT® GAC 1240

GRANULAR ACTIVATED CARBON

NORIT GAC 1240 is a granular activated carbon produced by steam activation of select grades of coal. As a result of a unique patented activation process and stringent quality control, **NORIT GAC 1240** offers excellent adsorption properties and is recommended for removal of impurities from water and industrial process applications. **NORIT GAC 1240** meets all AWWA B100 and B604 standards for potable water use. **NORIT GAC 1240** is Kosher certified and meets NSF/ANSI Standard 61.

Product Specifications

Iodine number, mg/g	1020 min.
Molasses number	230 min.
Abrasion number (AWWA)	75 min.
Moisture, % as packed	2 max.
Mesh size (U.S. Sieve Series)	
Greater than 12 mesh (1.70 mm), %	5 max.
Less than 40 mesh (0.42 mm), %	4 max.

Typical Properties*

Apparent density, vibrating feed, g/mL	0.49
lb/ft^3	31
Bed density, backwashed and drained, lb/ft^3	27
Effective size, mm	0.65
Uniformity coefficient	1.6
Food Chemical Codex	Passes

*For general information only, not to be used as purchase specifications.

Packaging/Transportation

Standard package is woven polypropylene bulk bags with a net weight of 1,000 lb.
Activated carbon (NOT REGULATED)
Exempt from DOT, IATA, and IMDG regulations
Import/Export classification: 3802.10.0000 (HS Tariff Classification)
Domestic Freight Classification: NMFC 040560
CAS # 7440-44-0

Material Handling

Wet activated carbon depletes oxygen from air and, therefore, dangerously low levels of oxygen may be encountered. Whenever workers enter a vessel containing activated carbon, the vessel's oxygen content should be determined and work procedures for potentially low oxygen areas should be followed. Appropriate protective equipment should be worn. Avoid inhalation of excessive carbon dust. No problems are known to be associated in handling this material. Please see the product Material Safety Data Sheet for details. Long-term inhalation of high dust concentrations can lead to respiratory impairment. Use forced ventilation or a dust mask when necessary for protection against airborne dust exposure (see Code of Federal Regulations - Title 29, Subpart Z, par. 1910.1000, Table Z-3).

(continued on reverse side)

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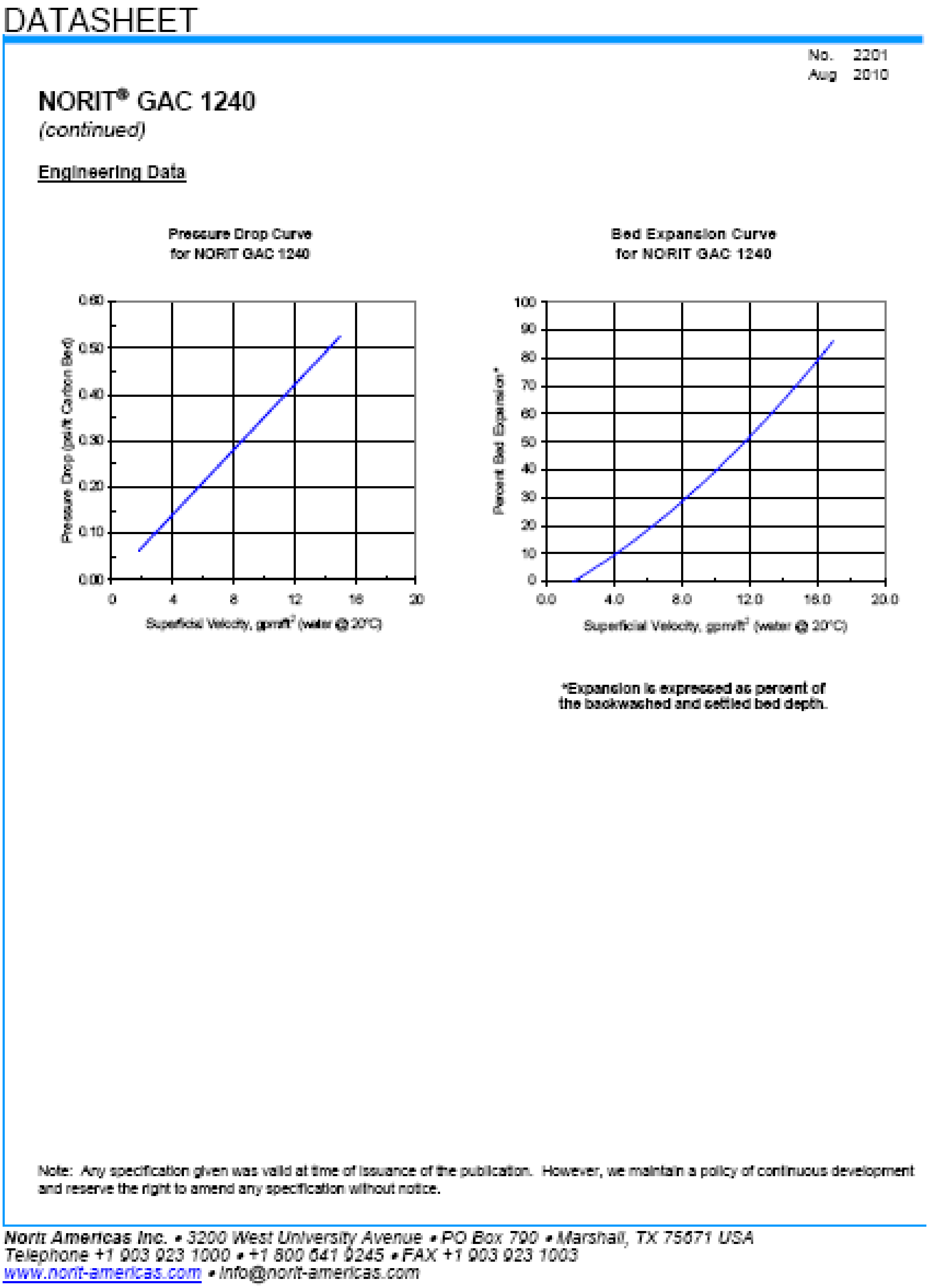

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NORIT® GAC 1240

(continued)

Engineering Data

Pressure Drop Curve
for NORIT GAC 1240

Bed Expansion Curve
for NORIT GAC 1240

*Expansion is expressed as percent of the backwashed and settled bed depth.

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