PREPARATION OF CHITOSAN/ NATURAL RUBBER LATEX-BASED FOAM

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Title	Preparation of Chitosan/Natural Rubber Latex-based Foam
By	Suthida Kaewkum
Field of Study	Petrochemical Engineering
Advisor	Asst. Prof. Dr. Teeraporn Suteewong

Accepted by the Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang in Partial Fulfillment of the Requirements for the Degree of Bachelor of Engineering (Petrochemical Engineering).

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Abstract

In this work, we report the preparation of light-weight biofoam from natural rubber (NR) latex compound via Dunlop process. Effect of type and concentration of foaming agent (potassium oleate and sodium bicarbonate) on density of foam were studied. Density of resulting foam decreases with increasing the amount of potassium oleate, but opposite results were found in the case of sodium bicarbonate. Hardness of foam increases with increasing amount of chitosan. DI water was added to improve the distribution of chitosan in NR latex. Foam morphology, flexural strength, water absorption and antibacterial properties of the NR-based biofoam were also investigated.

Keywords: Natural rubber latex, Natural rubber foam, Chitosan, Potassium oleate and Sodium bicarbonate

เรื่อง การเตรียมโฟมจากน้ำยางธรรมชาติและไคโตซาน
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บทคัดย่อ

งานวิจัยนี้ศึกษาการเตรียมโฟมน้ำหนักเบาจากน้ำยางธรรมชาติด้วยกระบวนการดันลอป โดยศึกษาผลของชนิดและความเข้มข้นของสารก่อโฟม (โพแทสเซียมโอเลเอตและโซเดียมไบคาร์บอเนต) ต่อความหนาแน่นของโฟม นอกจากนี้ยังศึกษาลักษณะทางสัณฐานวิทยา ความแข็ง ความแข็งแรงต่อการโค้งงอ การดูดซึมน้ำและสมบัติการต้านเชื้อจุลินทรีย์ของโฟมที่เตรียมได้ พบว่าความหนาแน่นของโฟมลดลงเมื่อเพิ่มปริมาณโพแทสเซียมโอเลเอต แต่ผลของความหนาแน่นเพิ่มขึ้นเมื่อเพิ่มปริมาณโซเดียมไบคาร์บอเนต ความแข็งของโฟมเพิ่มขึ้นเมื่อเพิ่มปริมาณของไคโตซานและโฟมที่เตรียมได้มีคุณสมบัติในการดูดซึมน้ำและต้านเชื้อจุลินทรีย์

คำสำคัญ: น้ำยางธรรมชาติ โฟมยาง ไคโตซาน โพแทสเซียมโอเลเอตและโซเดียมไบคาร์บอเนต

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Suthida Kaewkum

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CHAPTER I
INTRODUCTION

1.1 Background

Over the last decade, extending the shelf life of food has been an important issue in the retail marketplace because prolonging storage time for selling leads to cost reduction without significantly depreciating the product quality. The main reason of food spoilage is microorganism naturally found in the air, soil, water as well as animal. Production process is another source of contamination. During storage, meat or poultry release excess fluid which has negative effects in nutrition and their shelf life. This fluid allows the growth of pathogens that results in the food poisoning and diarrhea. In order to avoid this problem, the adsorbent packaging is then introduced to absorb the excess fluid and prevent its direct contact with food. Currently, the absorbent pads have been widely used in pre-cut meat found in the butchery section in supermarkets by lying between food and tray. However, the usage of absorbent pad is limited when the weight of meat high and the volume of released fluid is large because absorbent pad cannot absorb all of fluid[1].

Absorbent tray is the alternative of absorbent pad. It can absorb fluid by itself. The absorbent tray is normally made from polystyrene (PS) foam which is a non-renewable petroleum-based product. PS foam requires several years to degrade, leading to the environment concern. To reduce the environmental impact of non-biodegradable waste, the development of biodegradable absorbent tray is thus interesting. Natural rubber (NR), biodegradable material[2], is a natural polymer that is economically important in Thailand and cheaper than other synthetic biopolymer such as poly(lactic acid) (PLA)[3-4]. NR has attractive mechanical properties such as high tensile strength, elasticity, high resilience and high tear resistance[5]. Common NR products are gloves, condoms, balloon etc[6]. The NR foam has been used to produce the weight supporting materials such as mattresses, pillows, cushioning seats etc[7]. To the best of our knowledge, there is no report on NR-based adsorbent foam tray. However, to absorb fluid, as well as to remain its rigidity as absorbent tray, its hydrophobic and elasticity of NR need to be resolved[8]. In general, the water absorption ability and rigidity of NR can be improved by incorporation of hydrophilic reinforcing fillers, for example, wheat bran, lignin, soft wood and chitosan (CS)[2]. CS has been used to enhance the mechanical strength of biodegradable foam tray made from cassava starch, leading to the composite tray with similar properties to PS foam[3]. Among environmental friendly filler, CS, biodegradable and hydrophilic polysaccharide, is attractive for this purpose as it can alter chemical and physical properties as well as enhance antimicrobial properties of food packaging, leading to the longer shelf life of food[9].

This work aims to fabricate the new biodegradable absorbent foam trays from NR foam using chitosan as active filler via Dunlop process. Potassium oleate and Sodium bicarbonate are used as the foaming agent. The water absorption, hardness and antimicrobial properties of obtained multifunctional foam trays will be studied by water absorption test, compressive strength test and total plate count method, respectively

1.2 Objective

To fabricate and characterize the biodegradable absorbent foam tray from natural rubber blended with chitosan

1.3 Scopes of Work

1.3.1 Study the effect of foaming agents on foam properties

1.3.2 Study the mass effect of amount of chitosan on the hardness, antimicrobial activity and water absorption of NR foam tray

1.3.3 Study the water absorption, mechanical properties and antimicrobial of NR foam tray

1.4 Expected Outputs

1.4.1 Environmental friendly adsorbent foam tray made from NR latex

1.4.2 Increase the quantity and value of NR usage

CHAPTER II
LITERATURE REVIEW

2.1 Food Packaging Materials

The demand of packaging has grown in fresh food industry. Petroleum-based polymer has been widely used for food packaging because of its mechanical properties, thermal conductivity, lightweight and low cost. Common petroleum-based polymers are used for food packaging such as polyethylene terephthalate (PET), polypropylene (PP), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC) and polystyrene (PS). Expanded polystyrene (EPS) is one of packaging material, made from expanded beads using pentane as a blowing agent. Because of its low density and rigidity, EPS is used for several applications such as trays, plates and food boxes[10-11].

2.2 Bio-based Packaging

Among environmental concerns, Bio-based packaging has been introduced to replace petroleum-derive packaging due to its biodegradable and eco-friendly. These alternatives should also have the following properties, durability, gas permeability, heat resistance, impact resistance and flexibility. Biomaterials that have been reported as components in food packaging are starch, polylactic acid (PLA), natural rubber (NR) and chitosan (CS) etc[12]. Recently, foam trays prepared from cassava starch have been used to package fresh cut fruits. Starch is a cheap and natural material, and non-toxic. However, its water resistance and strength are poor, strength and flexibility of starch-based foam were improved by the addition of kraft fiber and chitosan. The resulting foam showed higher density, tensile strength and elongation. It was found that cassava starch-base foam, consisting of 30% kraft fiber and 4% chitosan, had properties similar to polystyrene foam[3]. In addition, water resistance of the starch foam was improved by blending with NR latex resulting in higher density and flexibility[2, 13]. However, varying of moisture conditions effect in starch foam behavior, it is flexibility and low strength at high moisture levels, but brittle at low moisture levels[13].

In the last few years, polylactic acid (PLA) have been used as a hinged tray[12]. It is derived from renewable sources such as corn, sugarcane and beetroot and produced via fermentation of starch and condensation of lactic acid. There are reports that compared the effects of two different polymers i.e., polyethylene terephthalate (PET) and PLA, in fabrication of hinged trays, on quality of fresh-cut and cooked spinach, economic product in Italy. The samples were stored at 4°C for 16 days. Testing were water activity, color evaluation, quantitative analysis of pigments, total polyphenols, and microbiological analyses. The maximum storage of fresh-cut or cooked spinach in both polymeric is six days. PLA tray can maintain spinach flavor longer than PET tray. Because of its biodegradability and composability, PLA packaging was then selected instead PET. However, the drawbacks of PLA package are the formation of condensed water on the internal surface and the cost of PLA need to be resolved[12, 14].

2.3 Natural Rubber (NR) Latex

NR, cis-1,4-polyisoprene, is one of interesting natural polymer. NR latex is a colloidal system consist of 35% rubber particles, 0.6% phospholipids, 0.5% proteins and 0.09% non-rubber. NR is a source of microbial growth because its nutritious substances such as proteins and carbohydrate. Ammonia in then added to preserve the latex. Properties of NR film are high elongation, high tensile strength and flexibility[15].

Besides thin film products, NR foam is commonly found as. The hardness of NR foam can be improved by reinforcing fillers. Authors prepared NR latex foam via Dunlop method using rice husk powder (RHP) as fillers. Incorporation of RHP in NR foam increased the hardness and density of composite foam, but decreased tensile strength and elongation at break. Addition of RHP into NR latex foam exhibit foam rigidity[7]. Kenaf powder was also reported as filler for NR latex foam. The composite foam has lower tensile strength, compressive strength and elongation at break of composite foam decrease while density and elasticity increase[16].

Recently, semi-rigid foam from NR has been developed using calcium silicate ($CaSiO_3$) as a filler. The $CaSiO_3$ can be prepared from silicon dioxide (SiO_2) and calcium carbonate ($CaCO_3$). The composite foam was fabricated by sulphur-curing process using potassium oleate as the foaming agent. Addition of $CaSiO_3$ into NR increased physical, mechanical and thermal properties of composite foam[6].

Dunlop method is widely used to prepare NR foam, e.g. pillows, cushions and mattresses[17]. This method involves the beating of air into compounded latex using foaming agent. Potassium oleate is commonly used as a foaming agent in Dunlop method because of its fast and controllable frothing rate[10]. Others foaming agents are sodium bicarbonate ($NaHCO_3$) and N,N'-dinitrosopentamethylenetetramine (DNPT, $C_5H_{10}N_6O_2$). Normally, foaming agent used to generate gases within polymer, causes the cellular structure when temperature increases and its thermal decomposition occurs. Gases generated from $NaHCO_3$ and DNPT are carbon dioxide (CO_2) and nitrogen gas (N_2), respectively. Temperature and time of foam production are important parameters that affect different foam properties. There is a report on the effect of $NaHCO_3$ and DNPT on properties of NR foam vulcanized at 396 K using $CaCO_3$ as a filler. The composite foam involving $NaHCO_3$ has higher bulk density, relative foam density, crosslink density and compression set than DNPT based product. $CaCO_3$ improved both mechanical properties and thermal resistance of the composite foams[18].

2.4 Chitosan

CS is a polysaccharide and is derived from deacetylation of chitin found in shells of crustaceans such as crabs and shrimp. CS is dissolved in acidic solution. CS is attractive filler for NR foam because of its water absorption and antimicrobial properties[19]. Moreover, CS has been used as deodorizer in NR[13]. Water absorption of chitosan-NR composite has been reported. Sample were prepared by blending NR and CS. The amount of water absorbed increased with the amount of CS. While the antimicrobial activity of chitosan depends on its molecular weight (MW) and degree of acetylation (DA)[20].

CHAPTER III
RESEARCH METHODOLOGY

This work aims to fabricate and to characterize the biodegradable absorbent foam trays made from NR latex using chitosan as active filler via Dunlop process. Effect of foaming agents, i.e., potassium oleate and sodium bicarbonate on properties of composite foam will be studied. The density, hardness, flexural strength, water absorption and antimicrobial properties of biocomposite foam are systematically investigated.

3.1 Chemicals

1) Sulphur Prevulcazied Natural Rubber Latex (SPNRL)
2) Chitosan food grade (MW: 890 kDa and particle size 75 μm)
3) 20% Potassium Oleate (commercial grade)
4) 10% Sodium bicarbonate (food grade)
5) 12.5% Sodium silicofluoride (commercial grade)
6) Deionized water

3.2 Equipment and Apparatus

1) Beaker
2) Pipette and micropipettes
3) Temperature-controlled magnetic stirrer
4) Magnetic bar
5) Stands and clamps
6) Spatulas
7) Para film
8) Paperclips
9) Petri dish
10) Vial
11) Scales
12) Oven
13) Hand mixer
14) Aluminum tray

3.3 Procedure

3.3.1 Preparation of Natural Rubber/Chitosan Foam (NCF)

1) SPNRL was passed through a sieve and store in glass bottle.
2) Determine total solid content (TSC) and dry rubber content (DRC)
3) Potassium oleate and chitosan powder were added into the SPNRL beaker. The mixture was beaten for 4.5 minutes using hand mixer level

2 from 6 before adding sodium silicofluoride (SSF) into the compound. Then the mixture was further beaten for 30 second.

4) The compounds were casted into the mold and then heated in a hot air oven at 100°C for 2 h.
5) The NCFs were removed from the mold and washed with water.
6) The NCF samples were dried in a hot air oven at 80°C until the foams were completely dried.
7) Changing potassium oleate to sodium bicarbonate and following above step.

3.3.2 Preparation of Natural Rubber/Chitosan Foam (NCF) with DI Water

1) SPNRL and DI water were mixed and stirred at 450 rpm for 5 minutes.
2) Potassium oleate and chitosan powder were added into the SPNRL beaker. The mixture was beaten for 4.5 minutes using hand mixer level 2 from 6 before adding SSF into the compound. Then the mixture was further beaten for 30 second.
3) The compounds were casted into the mold and then heated in a hot air oven at 100°C for 2 h.
4) The NCFs were removed from the mold and washed with water.
5) The NCF samples were dried in a hot air oven at 80°C until the foams were completely dried.
6) Changing potassium oleate to sodium bicarbonate and following above step.

Table 1. Formula of Natural Rubber Foams

Samples name	SPNRL (phr)	Chitosan (phr)	SSF (phr)	Potassium oleate (phr)	Sodium bicarbonate (phr)	DI water (%)
NRF-1.5P	100	-	2	1.5	-	-
NRF-3.0P	100	-	2	3.0	-	-
NRF-10.0P	100	-	2	10.0	-	-
NRF-1.5S	100	-	2	-	1.5	-
NRF-3.0S	100	-	2	-	3.0	-
NRF-10.0S	100	-	2	-	10.0	-
NRF-3.0P-10CS	100	10	2	3.0	-	-
NRF-3.0P-20CS	100	20	2	3.0	-	-
NRF-3.0P-30CS	100	30	2	3.0	-	-
NRF-1.5S-10CS	100	10	2	-	1.5	-
NR-1.5S-20CS	100	20	2	-	1.5	-
NR-1.5S-30CS	100	30	2	-	1.5	-
NRF-3.0P-20CS-10DI	100	20	2	3.0		10
NRF-3.0P-20CS-20DI	100	20	2	3.0		20
NRF-3.0P-20CS-30DI	100	20	2	3.0		30
NRF-1.5S-20CS-10DI	100	20	2		1.5	10
NR-1.5S-20CS-10DI	100	20	2		1.5	20
NR-1.5S-30CS-10DI	100	20	2		1.5	30

pphr is part per hundred of rubber.
NRF is natural rubber foam.
P is potassium oleate.
S is sodium bicarbonate.
Number is amount of loading.

3.4 Characterization

3.4.1 Total Solid Content (TSC)

The TSC of SPNRL is obtained by drying of NR latex sample, the result is the sum of dry rubber content and solid nonrubber content such as protein. It was determined according to ASTM D1076-15 using the following equation:

$$\%TSC = \frac{W}{W_t} \times 100$$

W is the weight of dry SPNRL (g) after drying at 70 °C.

W_t is the weight of SPNRL (g).

3.4.2 Dry Rubber Content (DRC)

The DRC of SPNRL is the percentage by weight of dry rubber, which is coagulated by 2% acetic acid. It was determined according to ASTM D1076-15 using the following equation:

$$\%DSC = \frac{\text{mass of dry coagulum}}{\text{mass of sample}}$$

3.4.3 Water Absorption Test

The known-weight samples are immersed in deionized water at room temperature. Record the weight of samples at different time intervals until the weight is constant. Percent change in mass calculated as follows:

$$W_g = \frac{\left[W_e - W_0\right]}{W_e} \times 100$$

W_g is the weight gained.

W_e is the equilibrium weight.

W_0 is the oven weight samples.

3.4.4 Foam Density

Density of the composite foam is determined according to ASTM D297 using Densimeter Model MD 200S (ALFA Mirage Co.,LTD Japan). The samples used in this test is regular shape with dimensions of 2.0 cm in wide and 2 cm in length.

3.4.5 Hardness

The hardness of chitosan incorporated NR foam samples were measured using Durometer type OO (ASTM 2240). This method is suitable for soft materials that are easy to distort by a soft touch of finger.

3.4.6 Flexural Strength

The flexural strength of chitosan incorporated NR foam samples were measured using a three-point flexural test.

3.4.7 Antibacterial Activity

The antibacterial activity of the composite foam was investigated using Agar Diffusion method.

CHAPTER IV
RESULTS AND DISCUSSION

The aim of this work is to study the preparation of biodegradable absorbent foam from NR latex. Potassium oleate and sodium bicarbonate were used as a foaming agent for studying the morphology and density of foam. The lowest density of each type of foaming agent were selected to the hardness improvement step. Chitosan used as a reinforcing filler to improve the hardness and flexural of light-weight foam. DI water was used to improve the distribution, compatibility of chitosan and NR latex and mechanical properties (hardness and flexural strength) of NR foam. Hardness and flexural strength of foam were studied by hardness testing (type OO) and three-point bending flexural testing, respectively. The water absorption and antibacterial activity were investigated.

4.1 Effect Foaming Agent on Foam Density

This study is to investigate the effect of foaming agent, i.e., potassium oleate and sodium bicarbonate, and their concentration on density and morphology of rubber foam. Foam samples were prepared using potassium oleate or sodium bicarbonate as foaming agent without chitosan.

4.1.2 Potassium oleate

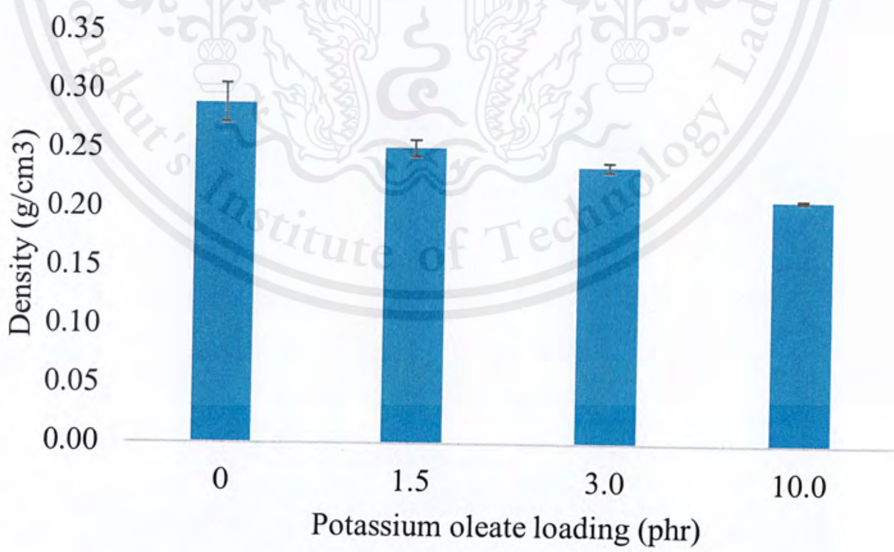


Figure 1. Effect of potassium oleate on the density of foams

As shown in Figure 1, density of rubber foam containing 1.5, 3.0 and 10.0 phr potassium oleate are 0.289, 0.251, 0.235 and 0.208 g/cm^3, respectively. Comparing with control sample (no foaming agent), density of these composite foam decreased with increasing concentration of potassium oleate because potassium oleate is air stabilizer that prevents the collapse of air bubble generated during beating step. Thus, void size of potassium oleate foam tend to increase as shown in Figure 2. Potassium oleate, an anionic surfactant, can reduce the surface tension at the air-liquid interface during beat step. These stable voids can move across the latex surface freely and coalescence by collisions to the bigger foam[21]. Therefore, increasing concentration of potassium oleate leading to lower density. Although the sample using 10 phr potassium oleate has lowest density, its pore size is not uniform as shown in Figure 2., which lower the foam strength. This is because high surfactant content, it can introduce the air into the latex surface rapidly affecting coalescence and shape of bubber. Therefore, 3.0 phr potassium oleate was selected to the next step.

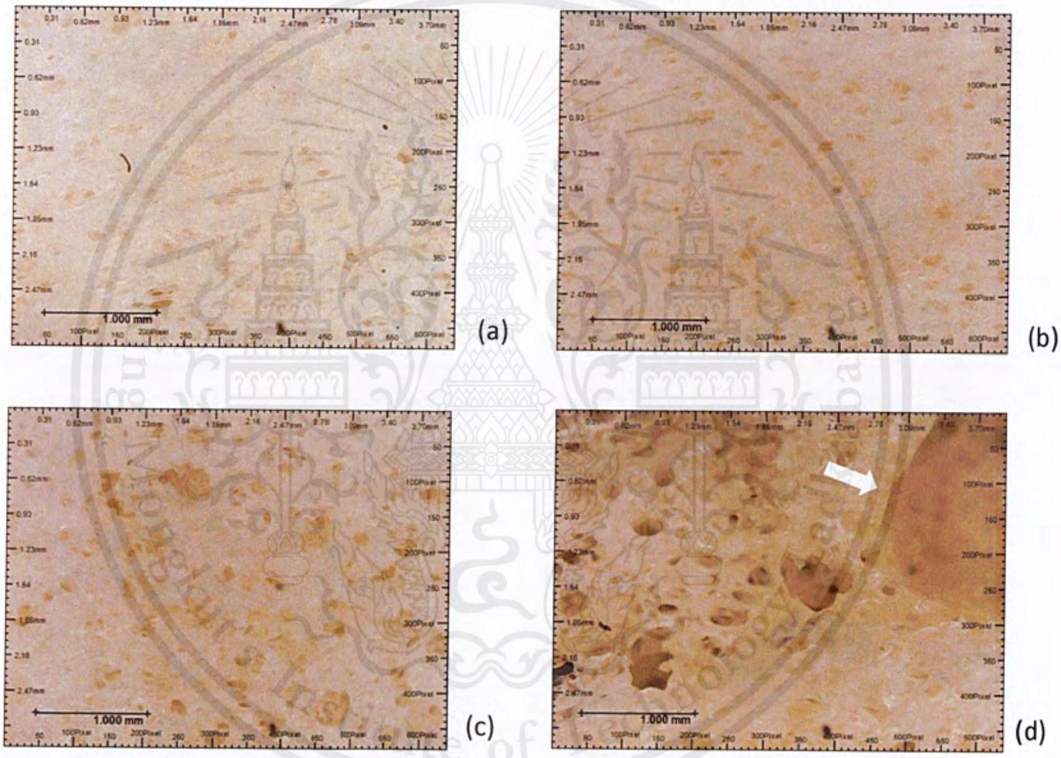


Figure 2. Cross-sectioned optical images of rubber foam (a) without potassium oleate and with (b) 1.5 (c) 3.0 (d) 10 phr potassium oleate

4.1.2 Sodium bicarbonate

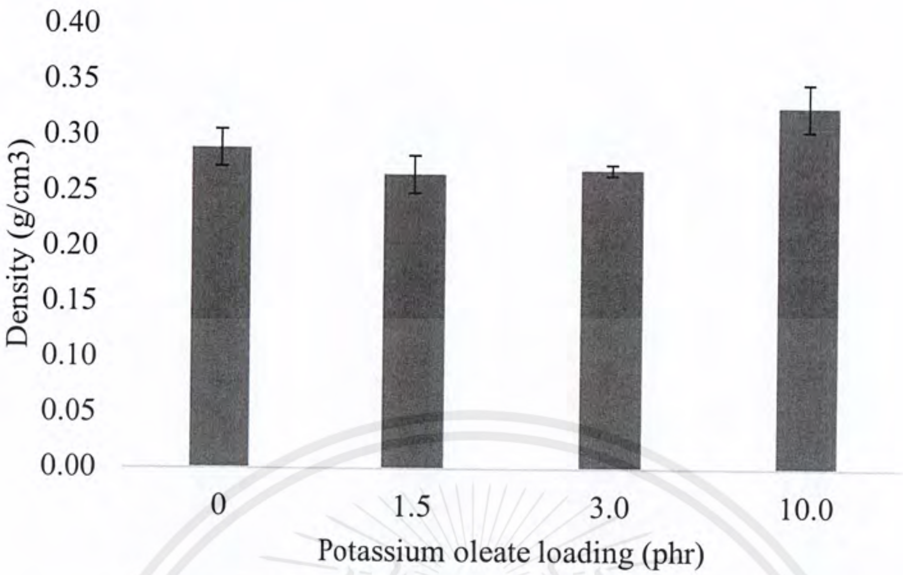


Figure 3. Effect of potassium oleate on the density of foams

As shown in Figure 3, foam density with controlled sample (no sodium bicarbonate), 1.5, 3.0 and 10 phr sodium bicarbonate are 0.289, 0.266, 0.270 and 0.326, respectively. Density of foam using 1.5 and 3.0 phr sodium bicarbonate decrease when compared with controlled sample. This basic foaming agent shortens the growth time of foam because its alkalinity can accelerate the cure rate of NR[22], limiting the diffusion of gas from the bulk/inner part through the foam surface, allowing the carbon dioxide from thermal decomposition of sodium bicarbonate expand its size[23]. It can be seen that foaming mechanism of sodium bicarbonate and potassium oleate is different. Sodium carbonate does not stabilize air bubbles introduced during mixing NR latex, but it releases carbon dioxide gas during thermal decomposition in during step, resulting in open-cell structure[18]. This reason can explain the pore size of rubber as shown in Figure 4., pore size of these foam insignificantly increases with increasing concentration of sodium bicarbonate.

Comparison of 1.5, 3.0 and 10.0 phr sodium bicarbonate, foam density tends to increase with increasing concentration of sodium bicarbonate. This is because exceed amount of sodium bicarbonate leading to incomplete reaction, presenting of remaining sodium bicarbonate or generation of sodium carbonate from the thermal decomposition of sodium bicarbonate. Therefore, increasing amount of sodium bicarbonate leading to higher foam density. From the results, 1.5 phr sodium bicarbonate is selected to next step because it is the lowest density.

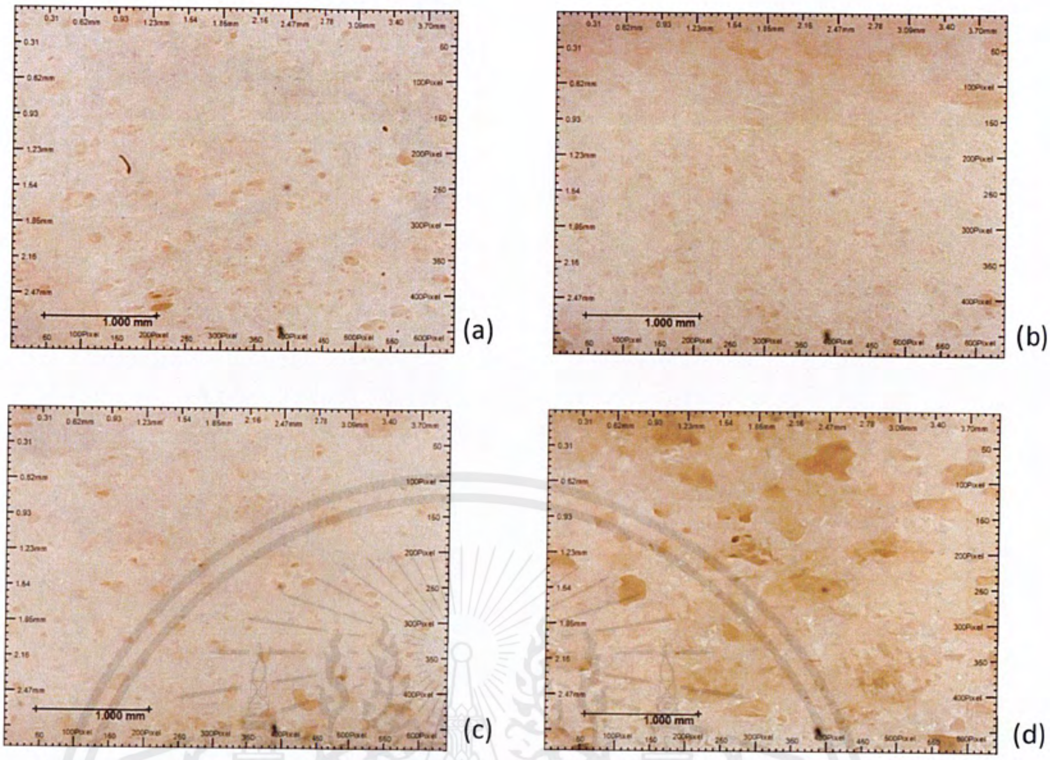


Figure 4. Cross-sectioned optical images of rubber foam (a) without sodium bicarbonate and with (b) 1.5 (c) 3.0 (d) 10 phr sodium bicarbonate bicarbonate

4.2 Effect of Chitosan on Hardness of Foam

This study is to investigate the effect of chitosan on hardness of rubber foam. Foam samples were prepared using 3.0 phr potassium oleate or 1.5 phr sodium bicarbonate as foaming agent with various amount of chitosan.

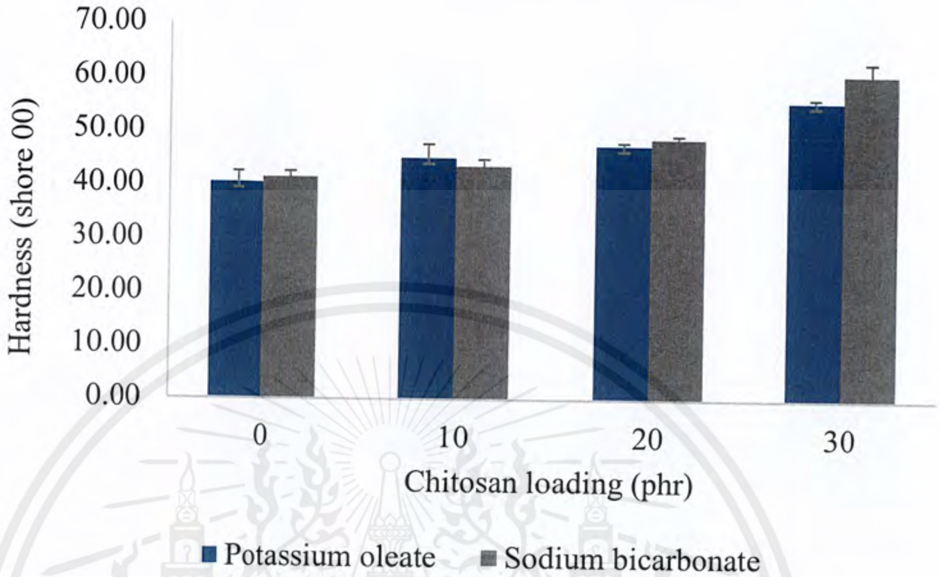


Figure 5. Effect of amount of chitosan on the hardness of foams using potassium oleate (blue) and sodium bicarbonate (gray) as foaming agent

In this study, chitosan particle was reduced to micrometer level in size because the smaller particle diameter, the better distribution efficiency become. Figure 5. shown the effect of chitosan loading on the foam hardness. Hardness of NR foam increased with increasing amount of chitosan because the polymer of high molecular weight such as chitosan, it can get entangled with NR chain at the interfacial region[24]. The hardness value of controlled sample (without chitosan) using potassium oleate and sodium bicarbonate as a foaming agent are 40 and 41, respectively. The value of hardness for chitosan incorporated NR (NR-CS) foam at 10, 20 and 30 phr are 45, 47 and 55 for potassium oleate as a foaming agent and 43, 48 and 60 for sodium bicarbonate as a foaming agent, respectively. The hardness of NR-CS foam using sodium bicarbonate trends to increase the hardness more than NR-CS foam using potassium oleate, due to remaining of sodium bicarbonate in incomplete reaction.

In this study, although rubber foam containing 30 phr chitosan and using sodium bicarbonate has highest hardness, it coagulates during mixing step because when reinforcing agent is exceeded, higher viscosity presented, and aggregation occur. It coagulates during mixing step[25] as shown in Figure 6. Therefore, 20 phr chitosan using both type of foaming agent was selected to the next step.


(a)


(b)

Figure 6. Images of NR foam with 30 phr using sodium carbonate as a foaming agent (a) before heated and (b) after heated

4.3 Effect of DI water on flexural strength of foam

This study is to investigate the effect of DI water on flexural strength of rubber foam. Foam samples were prepared using 20 phr chitosan and 3.0 phr potassium oleate or 1.5 phr sodium bicarbonate as foaming agent with various amount DI water.

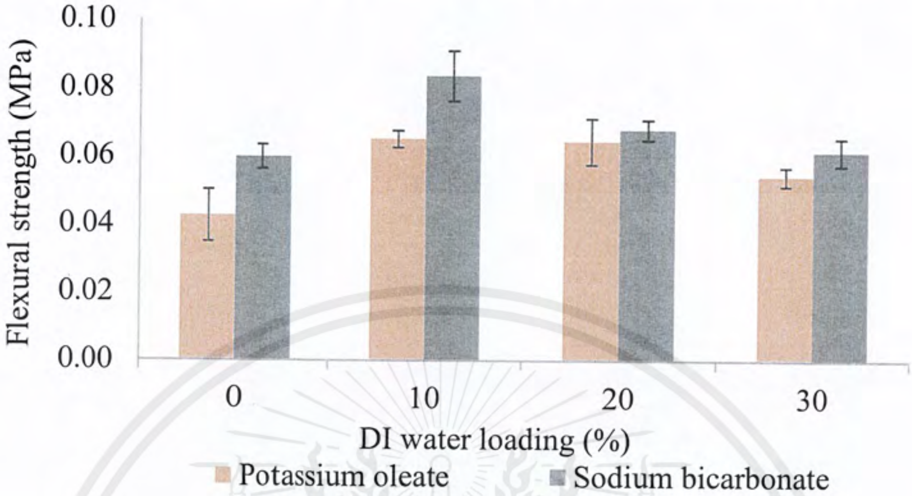


Figure 7. Flexural of foams with vary amount of DI water

As shown in Figure 7, addition of DI water tends to increase flexural strength of composite foam, but when compared with 10, 20 and 30% DI water, the flexural strength of composite foam tends to decrease. From the results, addition of 10% DI water of both type of foaming agent are highest flexural strength. Focus on the sample using 10% DI water of both type o foaming agent, it can be seen that, sample using potassium oleate has cracking appearance as shown in Figure 8 because it non uniform curing. Therefore, the composite foam sample using sodium bicarbonate with 10% DI water is the best sample of this study.

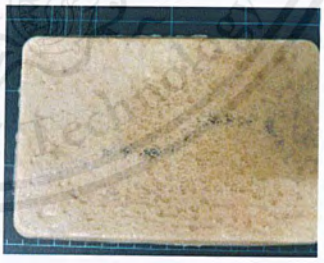

(a)

(b)

Figure 8. Images of foam with 20 phr chitosan and 10% DI water using 3.0 phr potassium oleate as a forming agent: (a) top (b) bottom


(a)

(b)

Figure 9. Images of foam with 20 phr chitosan and 10% DI water using 1.5 phr sodium bicarbonate as a forming agent: (a) top (b) bottom

4.4 Effect of Chitosan and DI Water on Density of Foam

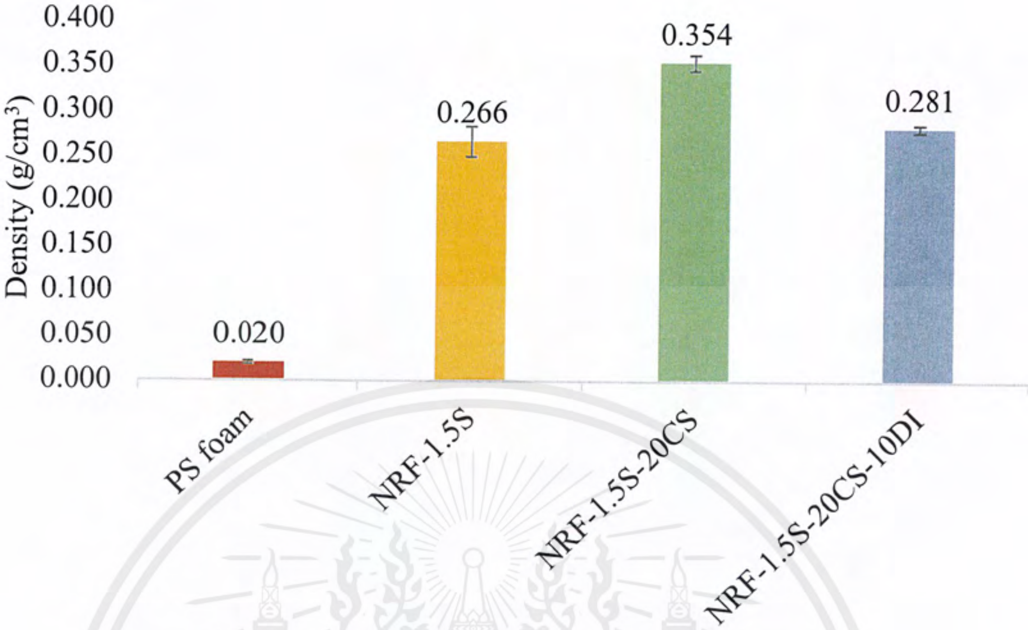
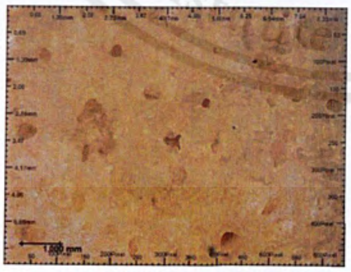


Figure 10. Density of foams at best condition

As shown in figure 10, foam density using sodium bicarbonate at the best condition of each step compared with polystyrene foam, it can be seen that when added chitosan into rubber foam, density of foam increase because density of chitosan (0.3 g/cm3) more than rubber foam (0.266 g/cm^3). Addition of DI water result in density of foam decrease because the void size of foam increases[26] as shown in Figure 11. Therefore, the rubber foam with 20 phr chitosan and 10% DI water using 1.5 phr sodium bicarbonate is the best condition of this work.


(a)

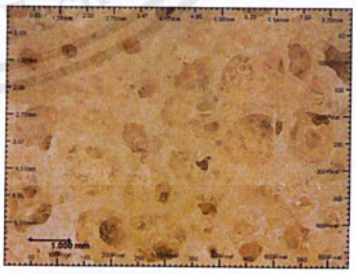

(b)

Figure 11. Images of foam using 20 phr chitosan using sodium bicarbonate as a forming agent (a) without DI water (b) with 10% DI water

4.5 Water Absorption and Antibacterial Activity

According to the objective is to fabrication the absorbent foam tray, therefore the water absorption and antibacterial activity was investigated. The foam sample with 20 phr chitosan and 10% DI water using 1.5 phr sodium bicarbonate was used in this study.

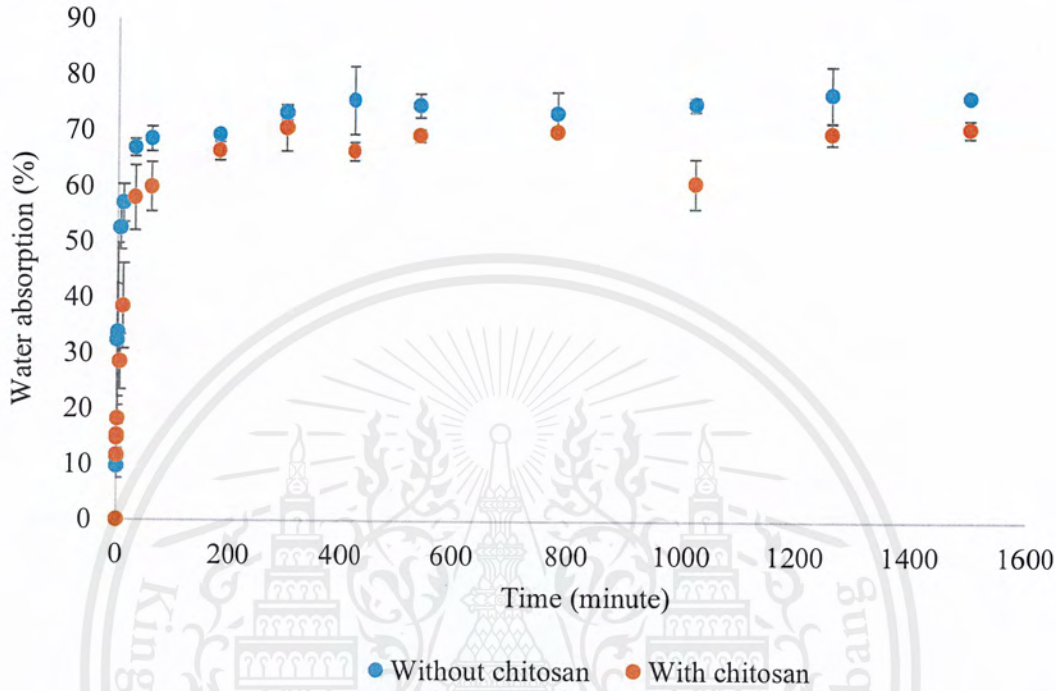


Figure 12. Water absorption of foams at 20 phr chitosan with 10% DI water using 1.5 phr sodium bicarbonate as a foaming agent

As shown in Figure 12, the water absorption of composite foam increases with time, but it is less than pure NR foam. Normally, Natural rubber is hydrophobic, its water absorbability can be neglected[15]. Therefore, water absorbability of NR foam relates to the porosity of foam.

Table 2. Antibacterial activity of each type bacteria

S. aureus	M. luteus	P. aeruginosa	E. coli
Active	Active	inactive	inactive

As shown in table 2, the composite foam has an antibacterial activity with gram positive bacteria (S. aureus and M. luteus).

CHAPTER V
CONCLUSION

5.1 Conclusion

In this study, light-weight biofoam from natural rubber latex and chitosan were prepared using potassium oleate or sodium bicarbonate as a foaming agent. Density of foam decreases with increasing concentration of potassium oleate. Increasing concentration of sodium bicarbonate tends to increase foam density. The lowest density of foam using potassium oleate or sodium bicarbonate were selected to the hardness improvement step that is 3.0 phr potassium oleate and 1.5 phr sodium bicarbonate. Hardness of foam increases with increasing amount of chitosan in both type of foaming agent. Addition of 10% DI water can increase flexural strength of composite foam. NR foam incorporated with 20 phr chitosan and 10% DI water using 1.5 phr sodium bicarbonate as a foaming agent is the best condition of this study. The composite foam has water absorption and antibacterial activity.

5.2 Suggestions

1) Should study effect of gelling agent (SSF) on morphology of foam
2) Should study effect of mixer level on morphology and mechanical properties of foam

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APPENDIX A

EXPERIMENTAL DATA

A.1 Effect of Foaming Agent on Foam Density

Table A.1.1 Density of foam using potassium oleate as foaming agent

20% potassium oleate	Samples name	Density	Average
0	NRF-P	0.287	0.2893±0.0166
		0.274	
		0.307	
1.5	NRF-1.5P	0.245	0.2513±0.0071
		0.25	
		0.259	
3.0 phr	NRF-3.0P	0.232	0.2357±0.0040
		0.235	
		0.24	
10.0 phr	NRF-10.0P	0.207	0.208±0.0010
		0.209	
		0.208	

Table A.1.2 Density of foam using sodium bicarbonate as foaming agent

10% sodium bicarbonate (phr)	Samples name	Density	Average
0	NRF-S	0.287	0.289±0.0166
		0.274	
		0.307	
1.5	NRF-1.5S	0.285	0.266±0.0168
		0.26	
		0.253	
3	NRF-3.0S	0.265	0.270±0.0050
		0.269	
		0.275	
10	NRF-10.0S	0.339	0.326±0.0211
		0.338	
		0.302	

A.2 Effect of Chitosan on Hardness of Foam

Table A.2.1 Hardness of foam using potassium oleate

Chitosan loading (phr)	Samples name	Average
0	NRF-3.0P	40.33±2.1
10	NRF-3.0P-10CS	45.00±2.6
20	NRF-3.0P-20CS	47.33±0.6
30	NRF-3.0P-20CS	55.67±0.6

Table A.2.1 Hardness of foam using sodium bicarbonate

Chitosan loading (phr)	Samples name	Average
0	NRF-3.0P	41.33±1.2
10	NRF-3.0P-10CS	43.50±1.3
20	NRF-3.0P-20CS	48.67±0.6
30	NRF-3.0P-20CS	60.67±2.3

A.3 Effect of DI Water on Flexural Strength of Foam

Table A.3.1 Flexural strength data of polystyrene foam

	Maximum	Minimum	Mean	Median	Coefficient of Variance	Standard Deviation	TRUE
Sample Passed							100.00%
Speed	10.000 mm/min	10.000 mm/min	10.000 mm/min	10.000 mm/min	0.00%	0.00000 mm/min	
Height	5.0000 mm	5.0000 mm	5.0000 mm	5.0000 mm	0.00%	0.00000 mm	
Width	20.000 mm	20.000 mm	20.000 mm	20.000 mm	0.00%	0.00000 mm	
Span	40.000 mm	40.000 mm	40.000 mm	40.000 mm	0.00%	0.00000 mm	
Maximum Load	3.434 N	3.133 N	3.274 N	3.255 N	3.78%	0.1239 N	
Maximum Deflection	7.0044 mm	7.0028 mm	7.0038 mm	7.0041 mm	0.01%	0.00070084 mm	
Maximum Bending Stress at Maximum Load	0.41211 MPa	0.37592 MPa	0.39287 MPa	0.39058 MPa	3.78%	0.014862 MPa	
Maximum Bending Strain at Maximum Load	0.13133	0.13107	0.1312	0.1312	0.08%	0.0001073	
Maximum Bending Stress at Maximum Deflection	0.39668 MPa	0.35187 MPa	0.37963 MPa	0.39032 MPa	5.21%	0.019797 MPa	
Maximum Bending Strain at Maximum Deflection	0.13133	0.1313	0.13132	0.13133	0.01%	0.000013141	
Young's Modulus of Bending	13.535 MPa	10.589 MPa	11.834 MPa	11.378 MPa	10.52%	1.2449 MPa	
Flexural Rigidity	0.0028197 Nm²	0.0022061 Nm²	0.0024654 Nm²	0.0023705 Nm²	10.52%	0.00025936 Nm²	
Elastic Strength	0.29953 MPa	0.28320 MPa	0.29318 MPa	0.29682 MPa	2.44%	0.0071436 MPa	
Resilience	0.0040224 J	0.0036454 J	0.0037889 J	0.0036989 J	4.40%	0.00016655 J	
Secant Modulus	6.0053 MPa	5.6965 MPa	5.8496 MPa	5.8468 MPa	2.16%	0.12608 MPa	
Chord Modulus	10.183 MPa	8.4121 MPa	9.1675 MPa	8.9075 MPa	8.14%	0.74597 MPa	
Number of Rows that Passed	3						
Number of Rows that Failed	0						

Table A.3.2 Flexural strength data of rubber foam with 20 phr chitosan using potassium oleate as a foaming agent

	Maximum	Minimum	Mean	Median	Coefficient of Variance	Standard Deviation	TRUE
SamplePassed							100.00%
Speed	10.000 mm/min	10.000 mm/min	10.000 mm/min	10.000 mm/min	0.00%	0.00000 mm/min	
Height	6.0000 mm	5.0000 mm	5.6667 mm	6.0000 mm	8.32%	0.47140 mm	
Width	20.000 mm	20.000 mm	20.000 mm	20.000 mm	0.00%	0.00000 mm	
Span	40.000 mm	40.000 mm	40.000 mm	40.000 mm	0.00%	0.00000 mm	
Maximum Load	0.5316 N	0.4026 N	0.4522 N	0.4226 N	12.54%	0.05670 N	
Maximum Deflection	7.0079 mm	7.0009 mm	7.0038 mm	7.0027 mm	0.04%	0.0029501 mm	
Maximum Bending Stress at Maximum Load	0.048308 MPa	0.035214 MPa	0.042607 MPa	0.044300 MPa	12.86%	0.0054780 MPa	
Maximum Bending Strain at Maximum Load	0.15752	0.12267	0.14471	0.15392	10.81%	0.015648	
Maximum Bending Stress at Maximum Deflection	0.046883 MPa	0.034220 MPa	0.041801 MPa	0.044300 MPa	13.07%	0.0054631 MPa	
Maximum Bending Strain at Maximum Deflection	0.15768	0.1313	0.14883	0.15752	8.33%	0.012398	
Young's Modulus of Bending	121.21 MPa	2.6507 MPa	74.089 MPa	98.407 MPa	69.33%	51.365 MPa	
Flexural Rigidity	0.035426 Nm²	0.00095425 Nm²	0.020544 Nm²	0.025252 Nm²	70.39%	0.014462 Nm²	
Elastic Strength	0.024956 MPa	0.019419 MPa	0.022187 MPa	0.022187 MPa	12.48%	0.0027686 MPa	
Resilience	0.0012218 J	0.00055105 J	0.00088643 J	0.00088643 J	37.83%	0.00033537 J	
Secant Modulus	0.38828 MPa	0.26618 MPa	0.32358 MPa	0.31627 MPa	15.49%	0.050116 MPa	
Chord Modulus	0.33926 MPa	0.081676 MPa	0.18229 MPa	0.12593 MPa	61.69%	0.11246 MPa	
Number of Rows that Passed	3						
Number of Rows that Failed	0						

Table A.3.3 Flexural strength data of rubber foam with 20 phr chitosan and 10% DI water using potassium oleate as a foaming agent

	Maximum	Minimum	Mean	Median	Coefficient of Variance	Standard Deviation	TRUE
Sample Passed							100.00%
Speed	10.000 mm/min	10.000 mm/min	10.000 mm/min	10.000 mm/min	0.00%	0.00000 mm/min	
Height	5.0000 mm	5.0000 mm	5.0000 mm	5.0000 mm	0.00%	0.00000 mm	
Width	20.000 mm	20.000 mm	20.000 mm	20.000 mm	0.00%	0.00000 mm	
Span	40.000 mm	40.000 mm	40.000 mm	40.000 mm	0.00%	0.00000 mm	
Maximum Load	0.5736 N	0.5148 N	0.5428 N	0.5398 N	4.44%	0.02408 N	
Maximum Deflection	7.0040 mm	7.0019 mm	7.0032 mm	7.0037 mm	0.01%	0.00092141 mm	
Maximum Bending Stress at Maximum Load	0.068832 MPa	0.061782 MPa	0.065131 MPa	0.064780 MPa	4.44%	0.0028891 MPa	
Maximum Bending Strain at Maximum Load	0.13094	0.11494	0.12135	0.11816	5.70%	0.0069113	
Maximum Bending Stress at Maximum Deflection	0.063796 MPa	0.052757 MPa	0.056721 MPa	0.053611 MPa	8.84%	0.0050148 MPa	
Maximum Bending Strain at Maximum Deflection	0.13132	0.13129	0.13131	0.13132	0.01%	0.000017276	
Young's Modulus of Bending	121.65 MPa	6.1395 MPa	80.373 MPa	113.33 MPa	65.45%	52.600 MPa	
Flexural Rigidity	0.025343 Nm^2	0.0012791 Nm^2	0.016744 Nm^2	0.023611 Nm^2	65.45%	0.010958 Nm^2	
Elastic Strength	0.057007 MPa	0.018229 MPa	0.032944 MPa	0.023596 MPa	52.08%	0.017156 MPa	
Resilience	0.0012165 J	0.00016205 J	0.00058478 J	0.00037582 J	77.83%	0.00045511 J	
Secant Modulus	0.53699 MPa	0.42351 MPa	0.49497 MPa	0.52440 MPa	10.26%	0.050786 MPa	
Chord Modulus	0.62891 MPa	-0.37096 MPa	0.24104 MPa	0.46516 MPa	181.67%	0.43788 MPa	
Number of Rows that Passed	3						
Number of Rows that Failed	0						

Table A.3.4 Flexural strength data of rubber foam with 20 phr chitosan and 20% DI water using potassium oleate as a foaming agent

	Maximum	Minimum	Mean	Median	Coefficient of Variance	Standard Deviation	TRUE
Sample Passed							100.00%
Speed	10.000 mm/min	10.000 mm/min	10.000 mm/min	10.000 mm/min	0.00%	0.00000 mm/min	
Height	5.0000 mm	5.0000 mm	5.0000 mm	5.0000 mm	0.00%	0.00000 mm	
Width	20.000 mm	20.000 mm	20.000 mm	20.000 mm	0.00%	0.00000 mm	
Span	40.000 mm	40.000 mm	40.000 mm	40.000 mm	0.00%	0.00000 mm	
Maximum Load	0.6234 N	0.4714 N	0.5371 N	0.5164 N	11.87%	0.06375 N	
Maximum Deflection	7.0042 mm	7.0026 mm	7.0033 mm	7.0031 mm	0.01%	0.00066987 mm	
Maximum Bending Stress at Maximum Load	0.074807 MPa	0.056566 MPa	0.064447 MPa	0.061969 MPa	11.87%	0.0076505 MPa	
Maximum Bending Strain at Maximum Load	0.1313	0.094726	0.11435	0.11704	13.16%	0.01505	
Maximum Bending Stress at Maximum Deflection	0.073439 MPa	0.044670 MPa	0.056606 MPa	0.051709 MPa	21.63%	0.012245 MPa	
Maximum Bending Strain at Maximum Deflection	0.13133	0.1313	0.13131	0.13131	0.01%	0.00001256	
Young's Modulus of Bending	229.54 MPa	46.432 MPa	143.52 MPa	154.57 MPa	52.37%	75.161 MPa	
Flexural Rigidity	0.047821 Nm^2	0.0096734 Nm^2	0.029899 Nm^2	0.032203 Nm^2	52.37%	0.015659 Nm^2	
Elastic Strength	0.050280 MPa	0.020952 MPa	0.032901 MPa	0.027470 MPa	38.22%	0.012574 MPa	
Resilience	0.0018165 J	0.00011292 J	0.00069774 J	0.00016383 J	113.41%	0.00079133 J	
Secant Modulus	0.60626 MPa	0.35452 MPa	0.46444 MPa	0.43255 MPa	22.65%	0.10522 MPa	
Chord Modulus	0.92081 MPa	-0.012143 MPa	0.41649 MPa	0.34081 MPa	92.35%	0.38462 MPa	
Number of Rows that Passed	3						
Number of Rows that Failed	0						

Table A.3.5 Flexural strength data of rubber foam with 20 phr chitosan and 30% DI water using potassium oleate as a foaming agent

	Maximum	Minimum	Mean	Median	Coefficient of Variance	Standard Deviation	TRUE
Sample Passed							100.00%
Speed	10.000 mm/min	10.000 mm/min	10.000 mm/min	10.000 mm/min	0.00%	0.00000 mm/min	
Height	6.0000 mm	5.0000 mm	5.3333 mm	5.0000 mm	8.84%	0.47140 mm	
Width	20.000 mm	20.000 mm	20.000 mm	20.000 mm	0.00%	0.00000 mm	
Span	40.000 mm	40.000 mm	40.000 mm	40.000 mm	0.00%	0.00000 mm	
Maximum Load	0.5266 N	0.4824 N	0.5011 N	0.4942 N	3.73%	0.01869 N	
Maximum Deflection	7.0093 mm	7.0050 mm	7.0068 mm	7.0061 mm	0.03%	0.0018314 mm	
Maximum Bending Stress at Maximum Load	0.063193 MPa	0.040198 MPa	0.054233 MPa	0.059309 MPa	18.53%	0.010050 MPa	
Maximum Bending Strain at Maximum Load	0.14115	0.10955	0.12734	0.13134	10.37%	0.013207	
Maximum Bending Stress at Maximum Deflection	0.054295 MPa	0.037918 MPa	0.048257 MPa	0.052558 MPa	15.22%	0.0073452 MPa	
Maximum Bending Strain at Maximum Deflection	0.15771	0.13134	0.14014	0.13136	8.87%	0.012424	
Young's Modulus of Bending	115.65 MPa	2.8853 MPa	42.563 MPa	9.1578 MPa	121.56%	51.741 MPa	
Flexural Rigidity	0.041632 Nm²	0.00060110 Nm²	0.014714 Nm²	0.0019079 Nm²	129.41%	0.019042 Nm²	
Elastic Strength	0.056173 MPa	0.017545 MPa	0.031607 MPa	0.021103 MPa	55.15%	0.017431 MPa	
Resilience	0.0017954 J	0.00013135 J	0.00070756 J	0.00019596 J	108.78%	0.00076965 J	
Secant Modulus	0.55473 MPa	0.39738 MPa	0.47445 MPa	0.47123 MPa	13.55%	0.064279 MPa	
Chord Modulus	0.63343 MPa	0.12867 MPa	0.41003 MPa	0.46798 MPa	51.24%	0.21010 MPa	
Number of Rows that Passed	3						
Number of Rows that Failed	0						

Table A.3.6 Flexural strength data of rubber foam with 20 phr chitosan using sodium bicarbonate as a foaming agent

	Maximum	Minimum	Mean	Median	Coefficient of Variance	Standard Deviation	TRUE
Sample Passed							100.00%
Speed	10.000 mm/min	10.000 mm/min	10.000 mm/min	10.000 mm/min	0.00%	0.00000 mm/min	
Height	4.0000 mm	4.0000 mm	4.0000 mm	4.0000 mm	0.00%	0.00000 mm	
Width	20.000 mm	20.000 mm	20.000 mm	20.000 mm	0.00%	0.00000 mm	
Span	40.000 mm	40.000 mm	40.000 mm	40.000 mm	0.00%	0.00000 mm	
Maximum Load	0.3407 N	0.3044 N	0.3195 N	0.3134 N	4.83%	0.01543 N	
Maximum Deflection	7.0092 mm	7.0061 mm	7.0074 mm	7.0069 mm	0.02%	0.0013132 mm	
Maximum Bending Stress at Maximum Load	0.063880 MPa	0.057077 MPa	0.059906 MPa	0.058761 MPa	4.83%	0.0028930 MPa	
Maximum Bending Strain at Maximum Load	0.10514	0.10309	0.10444	0.1051	0.92%	0.00095664	
Maximum Bending Stress at Maximum Deflection	0.058666 MPa	0.048980 MPa	0.054905 MPa	0.057069 MPa	7.72%	0.0042403 MPa	
Maximum Bending Strain at Maximum Deflection	0.10514	0.10509	0.10511	0.1051	0.02%	0.000019698	
Young's Modulus of Bending	230.11 MPa	5.4703 MPa	121.79 MPa	129.78 MPa	75.45%	91.884 MPa	
Flexural Rigidity	0.024545 Nm²	0.00058350 Nm²	0.012991 Nm²	0.013844 Nm²	75.45%	0.0098009 Nm²	
Elastic Strength	0.033608 MPa	0.014915 MPa	0.023886 MPa	0.023137 MPa	32.03%	0.0076498 MPa	
Resilience	0.00026909 J	0.00010652 J	0.00018509 J	0.00017966 J	35.92%	0.000066482 J	
Secant Modulus	0.83059 MPa	0.55351 MPa	0.70261 MPa	0.72373 MPa	16.24%	0.11410 MPa	
Chord Modulus	-0.30388 MPa	-0.54144 MPa	-0.43000 MPa	-0.44468 MPa	22.68%	0.097538 MPa	
Number of Rows that Passed	3						
Number of Rows that Failed	0						

Table A.3.7 Flexural strength data of rubber foam with 20 phr chitosan and 10% DI water using sodium bicarbonate as a foaming agent

	Maximum	Minimum	Mean	Median	Coefficient of Variance	Standard Deviation	TRUE
SamplePassed							100.00%
Speed	10.000 mm/min	10.000 mm/min	10.000 mm/min	10.000 mm/min	0.00%	0.00000 mm/min	
Height	5.0000 mm	5.0000 mm	5.0000 mm	5.0000 mm	0.00%	0.00000 mm	
Width	20.000 mm	20.000 mm	20.000 mm	20.000 mm	0.00%	0.00000 mm	
Span	40.000 mm	40.000 mm	40.000 mm	40.000 mm	0.00%	0.00000 mm	
Maximum Load	0.7373 N	0.6264 N	0.6973 N	0.7282 N	7.21%	0.05024 N	
Maximum Deflection	7.0065 mm	7.0045 mm	7.0058 mm	7.0063 mm	0.01%	0.00088922 mm	
Maximum Bending Stress at Maximum Load	0.088470 MPa	0.075173 MPa	0.083675 MPa	0.087383 MPa	7.21%	0.0060288 MPa	
Maximum Bending Strain at Maximum Load	0.1299	0.12537	0.12795	0.12859	1.49%	0.0019007	
Maximum Bending Stress at Maximum Deflection	0.075588 MPa	0.063830 MPa	0.068590 MPa	0.066352 MPa	7.37%	0.0050542 MPa	
Maximum Bending Strain at Maximum Deflection	0.13137	0.13134	0.13136	0.13137	0.01%	0.000016673	
Young's Modulus of Bending	162.92 MPa	2.9203 MPa	59.385 MPa	12.315 MPa	123.45%	73.311 MPa	
Flexural Rigidity	0.033942 Nm²	0.00060839 Nm²	0.012372 Nm²	0.0025655 Nm²	123.45%	0.015273 Nm²	
Elastic Strength	0.083438 MPa	0.025962 MPa	0.057161 MPa	0.062082 MPa	41.50%	0.023721 MPa	
Resilience	0.0022787 J	0.00045626 J	0.0014444 J	0.0015981 J	52.06%	0.00075192 J	
Secant Modulus	0.75942 MPa	0.63453 MPa	0.68757 MPa	0.66874 MPa	7.66%	0.052695 MPa	
Chord Modulus	0.87548 MPa	0.19356 MPa	0.52676 MPa	0.51125 MPa	52.89%	0.27861 MPa	
Number of Rows that Passed	3						
Number of Rows that Failed	0						

Table A.3.8 Flexural strength data of rubber foam with 20 phr chitosan and 20% DI water using sodium bicarbonate as a foaming agent

	Maximum	Minimum	Mean	Median	Coefficient of Variance	Standard Deviation	TRUE
SamplePassed							100.00%
Speed	10.000 mm/min	10.000 mm/min	10.000 mm/min	10.000 mm/min	0.00%	0.00000 mm/min	
Height	5.0000 mm	5.0000 mm	5.0000 mm	5.0000 mm	0.00%	0.00000 mm	
Width	20.000 mm	20.000 mm	20.000 mm	20.000 mm	0.00%	0.00000 mm	
Span	40.000 mm	40.000 mm	40.000 mm	40.000 mm	0.00%	0.00000 mm	
Maximum Load	0.5821 N	0.5368 N	0.5653 N	0.5770 N	3.59%	0.02030 N	
Maximum Deflection	7.0064 mm	7.0041 mm	7.0055 mm	7.0060 mm	0.01%	0.00098380 mm	
Maximum Bending Stress at Maximum Load	0.069858 MPa	0.064410 MPa	0.067837 MPa	0.069243 MPa	3.59%	0.0024360 MPa	
Maximum Bending Strain at Maximum Load	0.12467	0.11804	0.12205	0.12343	2.36%	0.0028772	
Maximum Bending Stress at Maximum Deflection	0.060607 MPa	0.052785 MPa	0.055951 MPa	0.054460 MPa	6.01%	0.0033627 MPa	
Maximum Bending Strain at Maximum Deflection	0.13137	0.13133	0.13135	0.13136	0.01%	0.000018446	
Young's Modulus of Bending	33.439 MPa	18.827 MPa	25.441 MPa	24.057 MPa	23.76%	6.0451 MPa	
Flexural Rigidity	0.0069665 Nm^2	0.0039223 Nm^2	0.0053002 Nm^2	0.0050119 Nm^2	23.76%	0.0012594 Nm^2	
Secant Modulus	0.49313 MPa	0.46108 MPa	0.47354 MPa	0.46642 MPa	2.96%	0.014017 MPa	
Chord Modulus	0.89223 MPa	0.55367 MPa	0.69590 MPa	0.64179 MPa	20.61%	0.14341 MPa	
Elastic Strength	0.063747 MPa	0.062003 MPa	0.062875 MPa	0.062875 MPa	1.39%	0.00087228 MPa	
Resilience	0.0015002 J	0.0014811 J	0.0014906 J	0.0014906 J	0.64%	0.0000095567 J	
Number of Rows that Passed	3						
Number of Rows that Failed	0						

Table A.3.9 Flexural strength data of rubber foam with 20 phr chitosan and 30% DI water using sodium bicarbonate as a foaming agent

	Maximum	Minimum	Mean	Median	Coefficient of Variance	Standard Deviation	TRUE
SamplePassed							100.00%
Speed	10.000 mm/min	10.000 mm/min	10.000 mm/min	10.000 mm/min	0.00%	0.00000 mm/min	
Height	5.0000 mm	5.0000 mm	5.0000 mm	5.0000 mm	0.00%	0.00000 mm	
Width	20.000 mm	20.000 mm	20.000 mm	20.000 mm	0.00%	0.00000 mm	
Span	40.000 mm	40.000 mm	40.000 mm	40.000 mm	0.00%	0.00000 mm	
Maximum Load	0.5383 N	0.4747 N	0.5120 N	0.5231 N	5.29%	0.02710 N	
Maximum Deflection	7.0049 mm	4.6012 mm	6.2026 mm	7.0018 mm	18.26%	1.1324 mm	
Maximum Bending Stress at Maximum Load	0.064594 MPa	0.056968 MPa	0.061444 MPa	0.062771 MPa	5.29%	0.0032517 MPa	
Maximum Bending Strain at Maximum Load	0.12109	0.086272	0.10598	0.11058	13.76%	0.014581	
Maximum Bending Stress at Maximum Deflection	0.061234 MPa	0.051354 MPa	0.056518 MPa	0.056968 MPa	7.16%	0.0040459 MPa	
Maximum Bending Strain at Maximum Deflection	0.13134	0.086272	0.1163	0.13128	18.26%	0.021233	
Young's Modulus of Bending	159.43 MPa	60.720 MPa	99.832 MPa	79.350 MPa	42.89%	42.820 MPa	
Flexural Rigidity	0.033214 Nm^2	0.012650 Nm^2	0.020798 Nm^2	0.016531 Nm^2	42.89%	0.0089209 Nm^2	
Elastic Strength	0.059294 MPa	0.046641 MPa	0.052968 MPa	0.052967 MPa	9.75%	0.0051656 MPa	
Resilience	0.0015531 J	0.00087350 J	0.0012397 J	0.0012924 J	22.58%	0.00027996 J	
Secant Modulus	0.47179 MPa	0.35863 MPa	0.41587 MPa	0.41718 MPa	11.11%	0.046206 MPa	
Chord Modulus	0.71015 MPa	-0.28270 MPa	0.31276 MPa	0.51081 MPa	137.12%	0.42884 MPa	
Number of Rows that Passed	3						
Number of Rows that Failed	0						

APPENDIX B

EXPERIMENTAL CALCULATION

B.1 Total Solid Content (TSC)

The TSC of SPNRL is obtained by drying of NR latex sample, the result is the sum of dry rubber content and solid nonrubber content such as protein. It was determined according to ASTM D1076-15 using the following equation:

$$\%TSC = \frac{W}{W_t} \times 100$$

W is the weight of dry SPNRL (g) after drying at 70 °C.

W_t is the weight of SPNRL (g).

Sample no.	Petri dish (g)	NR latex (g)	Dry solid + Petri dish (g)	Dry solid (g)
1	17.977	1.053	18.615	0.638
2	17.752	1.006	18.353	0.601
3	18.162	1.124	18.836	0.674
Average		1.061		0.638

$$\%TSC = \frac{0.638}{1.061} \times 100 = 60.104\%$$

B.2 Dry Rubber Content (DRC)

The DRC of SPNRL is the percentage by weight of dry rubber, which is coagulated by 2% acetic acid. It was determined according to ASTM D1076-15 using the following equation:

$$\%DSC = \frac{\text{mass of dry coagulum}}{\text{mass of sample}}$$

Sample no.	NR latex (g)	Dry rubber (g)
1	1.156	0.676
2	1.067	0.622
3	1.010	0.590
Average	1.078	0.629

$$\%DRC = \frac{0.629}{1.078} \times 100 = 58.393\%$$

B.3 Chemicals

- SPNRL

60% TSC

$$100\,\text{g SPNRL} \rightarrow 60\,\text{g TSC}$$

$$50\,\text{g SPNRL} \rightarrow \frac{60\,\text{g TSC} \times 50\,\text{g SPNRL}}{100\,\text{g SPNRL}} = 30\,\text{g TSC}$$

- Foaming agent

1.5 phr

$$100\,\text{g TSC} \rightarrow 1.5\,\text{g foaming agent}$$

$$30\,\text{g TSC} \rightarrow \frac{1.5\,\text{g foaming agent} \times 30\,\text{g TSC}}{100\,\text{g TSC}} = 0.45\,\text{g foaming agent}$$

- SSF

2 phr

$$100\,\text{g TSC} \rightarrow 2\,\text{g SSF}$$

$$30\,\text{g TSC} \rightarrow \frac{2\,\text{g SSF} \times 30\,\text{g TSC}}{100\,\text{g TSC}} = 0.6\,\text{g SSF}$$

B.4 Water Absorption Test

The known-weight samples are immersed in deionized water at room temperature. Record the weight of samples at different time intervals until the weight is constant. Percent change in mass calculated as follows:

$$W_g = \frac{[W_e - W_0]}{W_e} \times 100$$

W_g is the weight gained.

W_e is the equilibrium weight.

W_0 is the oven weight samples.

$$W_g = \frac{0.113\text{-}0.101}{0.113} \times 100 = 10.619$$

Table B.4.1 Water absorption of rubber foam with 10% DI water using 1.5 phr sodium bicarbonate as a foaming agent

Time \ Samples name	NRF-1.5S-10DI									Average
	1			2			3			
	W_o (g)	W_e (g)	W_g (%)	W_o (g)	W_e (g)	W_g (%)	W_o (g)	W_e (g)	W_g (%)	
0 s	0.101	0.101	0	0.102	0.102	0	0.113	0.113	0	0
5 s	0.101	0.113	10.619	0.102	0.110	7.273	0.113	0.127	11.024	10±2.059
10 s	0.076	0.085	10.588	0.090	0.102	11.765	0.092	0.104	11.538	11±0.624
30 s	0.115	0.145	20.690	0.096	0.153	37.255	0.100	0.164	39.024	32±10.114
1 min	0.102	0.202	49.505	0.084	0.128	34.375	0.076	0.092	17.391	34±16.066
5 min	0.120	0.232	48.276	0.103	0.232	55.603	0.077	0.166	53.614	52±3.789
10 min	0.082	0.187	56.150	0.099	0.216	54.167	0.106	0.270	60.741	57±3.372
30 min	0.089	0.285	68.772	0.124	0.366	66.120	0.111	0.327	66.055	67±1.550
1 hr.	0.083	0.287	71.080	0.102	0.308	66.883	0.106	0.328	67.683	69±2.228
3 hr.	0.109	0.347	68.588	0.113	0.368	69.293	0.134	0.448	70.089	69±0.751
5 hr.	0.095	0.365	73.973	0.106	0.377	71.883	0.079	0.303	73.927	73±1.193
7 hr.	0.096	0.403	76.179	0.071	0.381	81.365	0.095	0.309	69.256	76±6.075
9 hr.	0.089	0.332	73.193	0.101	0.387	73.902	0.089	0.390	77.179	75±2.127
13 hr.	0.098	0.368	73.370	0.085	0.280	69.643	0.084	0.369	77.236	73±3.797
17 hr.	0.111	0.440	74.773	0.109	0.417	73.861	0.087	0.367	76.294	75±1.229
21 hr.	0.092	0.466	80.258	0.087	0.301	71.096	0.079	0.382	79.319	77±5.040
25 hr.	0.088	0.379	76.781	0.087	0.360	75.833	0.089	0.380	76.579	76±0.499

Table B.4.2 Water absorption of rubber foam with 20 phr chitosan and 10% Di water using 1.5 phr sodium bicarbonate as a foaming agent

Samples name / Time	NRF-1.5S-20CS-10DI									Average
	1			2			3			
	W_o (g)	W_e (g)	W_g (%)	W_o (g)	W_e (g)	W_g (%)	W_o (g)	W_e (g)	W_g (%)	
0 s	0.114	0.114	0	0.123	0.123	0	0.145	0.145	0	
5 s	0.114	0.130	12.308	0.123	0.140	12.143	0.145	0.162	10.494	0
10 s	0.134	0.146	8.219	0.110	0.137	19.708	0.108	0.129	16.279	12±1.003
30 s	0.131	0.150	12.667	0.096	0.114	15.789	0.097	0.117	17.094	15±5.898
1 min	0.106	0.128	17.188	0.146	0.179	18.436	0.132	0.163	19.018	15±2.275
5 min	0.126	0.167	24.551	0.122	0.185	34.054	0.120	0.164	26.829	18±0.935
10 min	0.102	0.147	30.612	0.100	0.185	45.946	0.108	0.177	38.983	28±4.961
30 min	0.108	0.226	52.212	0.101	0.240	57.917	0.103	0.285	63.860	39±7.678
1 hr.	0.089	0.233	61.803	0.118	0.320	63.125	0.119	0.264	54.924	58±5.824
3 hr.	0.108	0.335	67.761	0.126	0.381	66.929	0.132	0.373	64.611	60±4.403
5 hr.	0.107	0.387	72.351	0.101	0.383	73.629	0.128	0.375	65.867	66±1.632
7 hr.	0.108	0.335	67.761	0.126	0.381	66.929	0.132	0.373	64.611	71±4.162
9 hr.	0.139	0.462	69.913	0.099	0.330	70.000	0.170	0.533	68.105	66±1.632
13 hr.	0.115	0.384	70.052	0.105	0.350	70.000	0.106	0.353	69.972	69±1.070
17 hr.	0.111	0.314	64.650	0.101	0.229	55.895	0.103	0.270	61.852	70±0.041
21 hr.	0.095	0.293	67.577	0.112	0.384	70.833	0.138	0.476	71.008	61±4.471
25 hr.	0.096	0.338	71.598	0.114	0.405	71.852	0.099	0.319	68.966	70±1.933
										71±1.598

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