Agriculture and Natural Resources 50 (2016) 220–226

Contents lists available at ScienceDirect

Agriculture and Natural Resources

journal homepage: http://www.journals.elsevier.com/agriculture-and-natural-resources/

Original article

Evaluation of benzenesulfonyl hydrazide concentration on mechanical properties, swelling and thermal conductivity of thermal insulation from natural rubber

Rungtawee Padakan,* Surachai Radagan

Department of Mechanical Engineering, Faculty of Engineering, Kasetsart University, Bangkok 10900, Thailand

ARTICLE INFO

Article history:
Received 19 June 2015
Accepted 4 January 2016
Available online 25 June 2016

Keywords:
Benzenesulfonyl hydrazide
Mechanical properties
Natural rubber
Thermal conductivity
Thermal insulation

ABSTRACT

An experiment was carried out to obtain the optimum natural rubber thermal insulation for a refrigeration and air conditioning system. Thermal insulation not only adds value to the rubber, but also develops an improved new product from natural rubber. Concentrations of benzenesulfonyl hydrazide (BSH) blowing agent at 2, 4, 6, 8 and 10 parts per hundred of rubber (phr) were used to study the effect of the BSH concentration on the mechanical properties, swelling and thermal conductivity of thermal insulation which were evaluated using the American Society for Testing and Materials (ASTM) standards (ASTM D412, ASTM D471 and ASTM C518, respectively). The rubber compound was prepared using a two-roll mill and expanding in a hot mould at 150 °C. The results showed that both the average values of the tensile modulus and tensile strength were reduced by 25%. The average value of elongation at break not only increased by 33% before thermal aging, but also reduced by 33% after thermal aging. The maximum value of swelling was 324%. Moreover, the lowest value of thermal conductivity was 0.040 W/m/K. Therefore, the optimum concentration of the BSH was 6 phr which had optimum properties for thermal insulation.

Introduction

In general, the thermal insulation materials used in a refrigeration system or an air conditioning system can be made from metals, polymers and composites such as aluminum foil, polyethylene foam and fiberglass according to Al-Homoud (2005). He discussed other desirable features and noted that materials should possess the ability to limit heat gain or loss from surfaces operating at temperatures above or below ambient temperature. He defined thermal conductivity as a measure of the effectiveness of a material in conducting heat. Therefore, knowledge of the thermal conductivity values allows a quantitative comparison to be made between the effectiveness of different thermal insulation materials. For example, the thermal conductivity values of rock wool, fiberglass and polyethylene are 0.037 W/m/K, 0.040 W/m/K and 0.041 W/m/K, respectively (Al-Homoud, 2005). In particular, an important role of thermal insulation is to maintain the temperature and to increase the energy efficiency of refrigeration systems or air conditioning systems (Leon and Ellann, 2012). At present, developing and improving new products from natural rubber is an important alternative not only for adding value to natural rubber but also for increasing the efficiency of new products, such as a natural rubber nanocomposite of multi-walled carbon nanotubes (Takeuchi et al., 2015), the application of natural and synthetic rubber/waste in the footwear industry (Diana et al., 2015), natural rubber Ca/P blends for biomedical uses (Nascimento et al., 2014), and especially natural rubber for thermal insulation (Abdel-Kader et al., 2012). In polymer-based thermal insulation, chemical blowing agents are required to produce rubber foam with low thermal conductivity and the decomposition rate of the blowing agent is the critical parameter for selecting the optimum blowing agent and furthermore, the amount of blowing agent, the heating time and the processing temperature play important roles in determining the cell morphology (Guobin et al., 1998). The chemical blowing agent influenced the structure and mechanical properties of ethylene propylene diene monomer (EPDM) foam by increasing the number of cell structures, increasing the porosity, lowering the thermal conductivity and increasing the concentration of the blowing agent for optimum interfacial adhesion (Yamsaengsung and Sombatsompop, 2009). An investigation of the

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* Corresponding author.
E-mail address: rungtawee.padakan@gmail.com (R. Padakan).

http://dx.doi.org/10.1016/j.anres.2016.01.004

mechanical response and stability of closed-cell foams found that the presence of internal pore pressure significantly stiffens and stabilizes the response of elastomeric foams (Oscar et al., 2012). Nabil et al. (2014) reported the effect of the accelerators and vulcanizing system on the thermal stability of natural rubber/ recycled EPDM blends with four types of accelerators: n-tert-butyl-2-benzothiazylsulphonamide (TBBS), n-cyclohexylbenzothiazylsulphenamide (CBS), disulphide tetramethylthiuram (TMTD) and mercaptobenzothiazol (MBT). They found that CBS-vulcanized blends exhibited satisfactory overall mechanical and thermal stability compared to the other accelerators used. Moreover, the optimal vulcanizing system involved semi-efficient vulcanization which had the highest tensile strength compared with the other vulcanizing systems.

This article considers part of the development of a thermal insulation system using natural rubber air-dried sheet (ADS) by focusing on improvement of the thermal insulation properties of the natural rubber foam. The natural rubber compounds were cured using a conventional vulcanization system. Natural rubber foam was processed into thermal insulation using the BSH. The effects were investigated of the BSH blowing agent and its content on the tensile modulus, tensile strength, elongation at break, compression set and swelling of the natural rubber foam. Moreover, the thermal conductivity of the natural rubber foam was also studied.

Materials and methods

Raw materials additives for the natural rubber

The materials used for the preparation of the compounds were natural rubber and chemical agents. Natural rubber air dried sheets (ADS) were supplied from plantations. The characteristics of the natural rubber ADS were investigated by the Rubber Research Institute (Bangkok, Thailand). The physical properties of the ADS (dirt content, volatile matter, ash content, nitrogen content, initial plasticity, plasticity retention index and Mooney viscosity) were determined using Standard Malaysian Rubber (1992) as shown in Table 1.

The additive essential for the natural rubber foam was the benzenesulfonyl hydrazide (BSH) blowing agent. The molecular formula of the BSH blowing agent is $C_6H_8N_2O_2S$. It was used to change the cell structure of natural rubber in this work. The decomposition temperature of the BSH blowing agent was 105 °C at 120 cm^3/g gas evolutions. The loading of BSH was varied from 2 parts per hundred of rubber (phr) to 10 phr as shown in Table 2. The BSH blowing agent and flame retardant (antimony trioxide) were supplied by KiJ Paiboon Chemical Limited Partnership (Bangkok, Thailand). The other additives consisted of stearic acid, zinc oxide, TMTD, TBBS, sulfur, polydicyclopentadiene-co-p-cresol (wingstay L) and paraffin oil and were supplied by the Rubber Research Institute (Bangkok, Thailand). The chemical structure of the natural rubber and the BSH blowing agent are shown in Fig. 1.

Table 1
Characteristics of air dry sheet natural rubber.

Parameter	Value
Dirt content (%weight basis)	0.027
Volatile matter (%weight basis)	0.830
Ash content (%weight basis)	0.160
Nitrogen content (%weight basis)	0.350
Initial plasticity	46.200
Plasticity retention index	66.500
Mooney viscosity	78.000

Table 2
Compound formulation of natural rubber used in this study.

Ingredient	Contents (parts per hundred of rubber)				
Natural rubber	100	100	100	100	100
Zinc oxide	5	5	5	5	5
Stearic acid	2	2	2	2	2
Wingstay L	4	4	4	4	4
Paraffin oil	10	10	10	10	10
Antimony trioxide	20	20	20	20	20
BSH	2	4	6	8	10
TMTD	0.2	0.2	0.2	0.2	0.2
TBBS	1	1	1	1	1
Sulfur	2	2	2	2	2

Compounding and vulcanization process

The mechanical mixture was prepared to attain a homogeneous mixture of the rubber compound in three stages. In the first stage, the natural rubber ADS and plasticizer were masticated in a two-roll-mill mixer (Model R11-3FF; Kodaira Seisakusho; Bunkyo-Ku, Japan) at a temperature of 30 °C for 30 min (Somjate et al., 2014). The Mooney viscosity of the rubber compounds was determined using a Mooney viscometer in compliance with Spanish Association for Standardization and Certification (AENOR, 2007). In the second stage, the rubber compound obtained in the first stage was mixed with various chemicals at 70 °C for about 15 min to attain a homogeneous mixture of the rubber compound, according to the formulations for mixing shown in Table 2. In the final stage, the rubber compounds were then left 24 hr prior to testing for curing characteristics. Each batch of rubber compound was rolled to produce a sheet of approximately 5 mm thickness. Cure characteristics were analyzed using a moving die rheometer for 30 min at 150 °C according to ASTM International (2007). In the vulcanization process, all rubber compounds were expanded in a hot mould at 150 °C according to their respective cure time (t_{90}) which was the time for the completion of cure determined with a moving die rheometer (Arayapranee and Rempel, 2007).

Measurement of mechanical properties

In this work, the mechanical properties, consisting of the tensile modulus, tensile strength and elongation at break, were measured following the standard test methods for vulcanized rubber and thermoplastic elastomers—tension (ASTM International, 2013). Dumbbell samples were prepared with dimensions 115 mm × 25 mm × 2 mm. The testing speed used was 500 mm/ min at room temperature. The average value of five tests for each sample was reported. Therefore, in total, 50 specimens were tested for their mechanical properties (tensile modulus, tensile strength and elongation at break). The testing of compression under a constant deflection in air followed ASTM International (2014). The sample was in the form of a cylindrical disk with a diameter of 30 mm and thickness of 13 mm. The thickness of the space bar was 9.5 mm. The temperature and testing time were conditioned in an oven at 100 °C for 22 hr and then removed from the fixture and

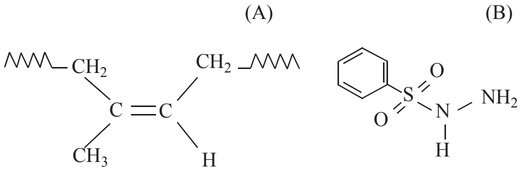

Fig. 1. Chemical structure: (A) natural rubber; (B) benzenesulfonyl hydrazide.

cooled at room temperature for 30 min before measuring the new dimensions. The average value of three tests for each sample was reported. Therefore, in total, 15 specimens were tested for compressed properties. The calculation of the compression set in terms of the percentage of the original deflection can be expressed using Eq. (1):

$$C_B = \frac{t_o - t_i}{t_o - t_n} \times 100 \tag{1}$$

where C_B is the compression set, t_O is the original thickness of specimen, t_i is the final thickness of specimen and t_n is the thickness of the space bars.

The influence of elevated temperature on the physical properties of vulcanized rubber was studied by aging at 100 °C for 22 hr according to ASTM International (2010a). The tensile modulus, tensile strength and elongation at break of the natural rubber foam were determined before and after thermal aging testing. The results of the aging test as a percentage of the change in tensile modulus, tensile strength and elongation at break were calculated using Eq. (2):

$$P_a = \frac{A_a}{O_a} \times 100 \tag{2}$$

where P_a is the percentage change in property, A_a is the value after aging and O_a is the original value.

The cell morphology of the expanded natural rubber foam was determined using a scanning electron microscope (SEM; JSM-5600LV; JEOL Ltd.; Tokyo, Japan) at 10 kV accelerating voltage and 35× magnification on the SEM. The effect of the compression on the cell structure of the natural rubber foam was observed. The razor-cut surfaces and the fractured surfaces of the compressive specimens were investigated using the SEM. Furthermore, all samples were gold coated before observation (Lin et al., 2004).

Swelling properties measurement

Swelling properties measurements were determined according to ASTM International (2010b). The specimens were prepared in rectangular shapes having dimensions of 25 mm × 50 mm × 2 mm. The rectangular test specimens were die-cut from molded slabs. These samples were weighed accurately in air and water before immersing into solvents kept at 25 °C for all tests. After that, the specimens were weighed in a weighing bottle which was covered with heavy hydro-treated naphthenic distillates (IRM 903) for 24 hr so that the state of equilibrium swelling could be reached. The IRM 903 was supplied by Chemical Innovation Co (Bangkok, Thailand). Then, the swollen specimens were weighed and dried in an oven until the specimens had constant weight. The last weight was taken as the correct weight of the specimens free from dissolved matter and the average value of three tests for each specimen was reported. In total, 15 specimens were tested for swelling properties. The percentage change in volume (%Swelling) can be expressed using Eq. (3):

$$\Delta V = \frac{(M_3 - M_4) - (M_1 - M_2)}{(M_1 - M_2)} \times 100 \tag{3}$$

where ΔV is the change in volume, M_1 is the initial mass of specimen in air, M_2 is the initial mass of specimen in water, M_3 is the mass of specimen in air after immersion and M_4 is the mass of specimen in water after immersion.

The interactions of solvents with cross-linked network structures occurring in the vulcanized rubber (molar mass of vulcanized rubber) were measured by applying the Flory and Rehner Equation (Flory and Rehner, 1943) as given in Eq. (4):

$$M_c = \frac{-\rho_p \times V_s \times \left(V_r^{\frac{1}{3}}\right)}{\mathrm{In}(1 - V_r) + V_r + \chi V_r^2} \tag{4}$$

where M_c is the molar mass, ρ_P is the density of polymer, V_s is the molar volume of solvent, V_r is the volume fraction of swollen rubber and χ is the interaction parameter of the natural rubber.

In this work, the density of natural rubber, the molar volume of the IRM 903 oil (Semyon and Zinoviy, 2001) and the interaction parameter of natural rubber (Abdel-Kader et al., 2012) were 0.91 g/cm^3, 356.55 cm^3/mol and 0.39, respectively. The relationship between the swollen weight and the dried weight of the specimen is shown in Eq. (5) and the volume fraction of swollen rubber can be obtained from Eq. (6):

$$Q_m = \frac{M_s - M_d}{M_d} \tag{5}$$

$$V_r = \frac{1}{(1 + Q_m)} \tag{6}$$

where Q_m is the swelling mass of nature rubber in the solvent, M_s is the swollen weight and M_d is the dried weight.

The crosslink density is defined for a perfect network as the number of elastically active network chains per unit volume; it can be obtained from the density of natural rubber and the molar mass of vulcanized rubber (Gwaily et al., 2003) as shown in Eq. (7):

$$v_e = \frac{\rho_p \times N_A}{M_c} \tag{7}$$

where v_e is the crosslink density and N_A is the Avogadro number.

Measurement of thermal conductivity properties

The ability to insulate the heat flow of the natural rubber foam was evaluated using thermal conductivity. The thermal conductivity test followed ASTM International (2010c). In total, 5 specimens were tested for thermal conductivity properties. The Nepzsch test apparatus was used to measure the thermal conductivity of the natural rubber foam and the thermal conductivity was determined using the principles of heat transfer and using the fundamental theory of the apparatus according to the relation as shown in Eq. (8) (Modesti et al., 2004; Barrios and Van-Sciver, 2013):

$$k = \frac{Q \times s}{A \times \Delta T} \tag{8}$$

where k is the thermal conductivity, Q is the sample heat flow, s is the sample thickness, A is the sample area and ΔT is the temperature difference across the plates.

Thickness and expansion ratio of the natural rubber foam

The mould was prepared with dimensions 160 mm × 160 mm × 25 mm for testing the properties of thermal conductivity of natural rubber foam. The thickness of mould was as thick as the thermal insulation used in industrial applications. Moreover, a small vent was designed around the mould to release the pressure within the mould in the vulcanization. The density of the natural rubber foam was controlled using the relationship between the volume of the sample and the weight of the sample or the expansion ratio (Uejyukkoku and Nakatsu, 1998) as shown in Eq. (9):

$$\text{Expansion ratio} = \frac{10 \times 10 \times t_1}{W_2} \tag{9}$$

where t_1 is the sample thickness and W_2 is the weight of sample.

Moreover, the expansion ratio of the natural rubber foam depended on the amount of blowing agent in the compound rubber. In each experiment, if the value of the expansion ratio is known in each content of the blowing agent, then the amount of compound rubber can be determined in order to produce a completed sample (The natural rubber was expanded fully until the mould was filled.). A 10 cm × 10 cm sample was cut out of the natural rubber foam.

Results and discussion

Effect of blowing agent contents on mechanical properties of natural rubber foam

The tensile modulus results of natural rubber foam with the BSH blowing agent loading before and after thermal aging testing are shown in Fig. 2. The average value of the tensile modulus was reduced by 25%. The stiffness of the natural rubber foam was assessed by the tensile modulus results which indicated that the tensile modulus both before and after thermal aging testing decreased with an increase in the BSH blowing agent. This could be explained by the reduction of the load bearing area in solid natural rubber foam by the formation of a gas phase. Moreover, the tensile modulus of the natural rubber foam after thermal aging testing was greater than for before thermal aging testing. This was caused by heating the samples under the specified conditions, which consequently made stiffer natural rubber foam. The heat caused crosslinking and degradation of the natural rubber foam after thermal aging. The considerable degradation resulted in aging which led to deterioration in the physical and mechanical properties of the vulcanized rubber (Komethi et al., 2012). On the other hand, the crosslinking of natural rubber foam increased due to the heating on aging process bringing about more stiffness of the natural foam. Therefore, the stiffness of the natural foam after thermal aging testing was higher than for before thermal aging testing.

The effect of the BSH blowing agent on the tensile strength of natural rubber foam is shown in Fig. 3. The average value of the tensile strength was reduced by 25%. This indicates that the tensile strength of natural rubber foam both before and after thermal aging testing decreased with increasing blowing agent content, which was the same as the result for the tensile modulus. The increased volume of nitrogen gas which increased the amount of BSH blowing agent increased the porosity of the natural rubber foam resulting in reduced surface per unit of area and reduced the tensile strength in the natural foam. Moreover, the effect of heat from the aging process on the physical properties resulted in more stiffness in the natural rubber foam and thus a higher tensile strength in the natural rubber foam after thermal aging compared to before thermal aging. Fig. 4 shows the loading effect of the BSH blowing agent on the elongation at break of the natural rubber foam. The average value of elongation at break increased 33% before thermal aging and it reduced 33% after thermal aging. It was found that the elongation at break both before and after thermal aging testing increased slightly with increasing blowing agent content and produced the opposite trend to that of the tensile modulus and tensile strength in the natural rubber foam. Moreover, the elongation at the break of the natural rubber foam after thermal aging testing was lower than for before thermal aging testing due to the heat production that was absorbed during loading resulting in entropic behavior of the natural rubber foam (Samaca-Martinez et al., 2013).

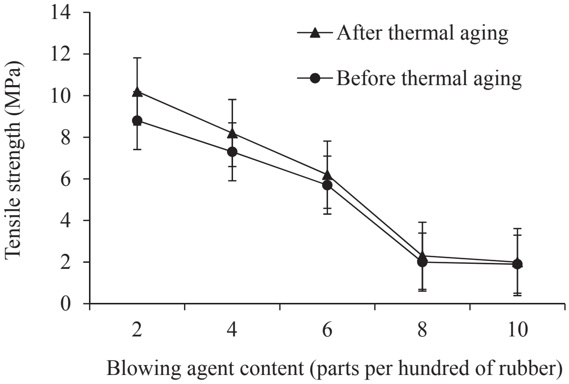

Fig. 3. Tensile strength of natural rubber foam for different contents of benzenesulfonyl hydrazide blowing agent contents before and after thermal aging testing (error bars = ±SE).

Most mechanical properties increased with thermal aging. Fig. 5 shows the loading effect of the blowing agent content on the percentage change in the tensile modulus, tensile strength and elongation at break. The experimental results showed that the mechanical properties did not differ with increasing blowing agent

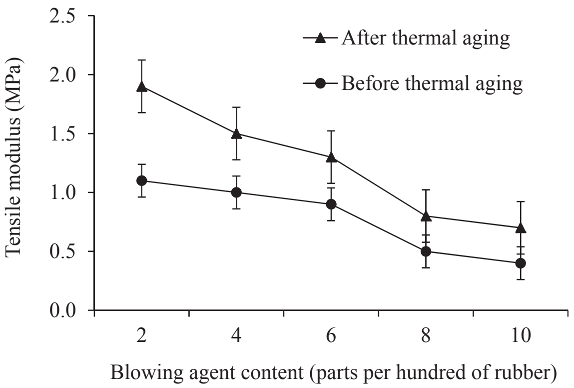

Fig. 2. Tensile modulus of natural rubber foam for different contents of benzenesulfonyl hydrazide blowing agent contents before and after thermal aging testing (error bars = ±SE).

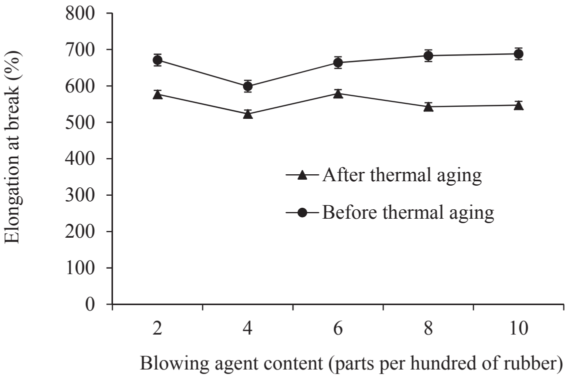

Fig. 4. Elongation at break of natural rubber foam for different contents of benzenesulfonyl hydrazide blowing agent contents before and after thermal aging testing (error bars = ±SE).

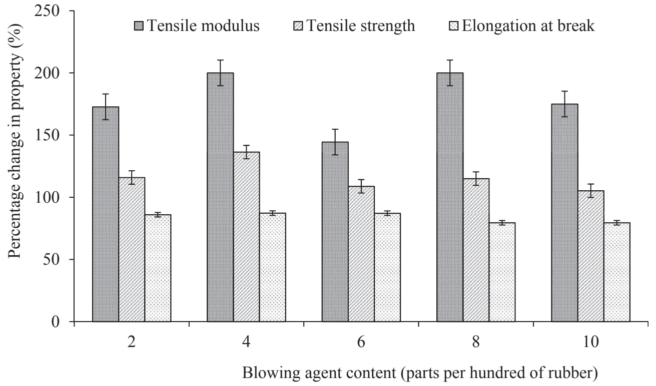

Fig. 5. Effect of the benzenesulfonyl hydrazide blowing agent contents on the percentage change in different properties (error bars = ±SE).

content. However, the percentage change in the tensile modulus was lowest with 6 phr of the BSH agent content.

The effect of the BSH content on the compression set of natural rubber foam at 100 °C for 22 hr is shown in Fig. 6. It was found that the compression set for the natural rubber foam with the BSH blowing agent decreased with increasing blowing agent content. This indicated that the recoverability of the natural rubber foam had increased with an increased amount of BSH blowing agent. The compression set results correspond to the ability to recover after compression loading of the natural rubber foam; a low compression set value indicates high recoverability of the natural rubber foam after unloading (Shamala et al., 2013). Furthermore, this result could be explained by considering the morphology of the natural rubber foam before and after compression loading during the test as shown in Fig. 7A–D. The results showed that the cell structure of the natural rubber foam was clearly different (Fig. 7A and C). Fig. 7A shows the morphology of the natural rubber foam at 2 phr of BSH concentration. It can be seen that the cell structure has a good distribution and small size. The diameter of cell ranged from 0.42 mm to 0.92 mm at 2 phr of BSH concentration. On the other hand, Fig. 7C shows an intermittent distribution of cells and their large size and here the diameter of cell ranges from about 1.50 mm to 1.71 mm at 10 phr of BSH concentration. Fig. 7B shows the morphology of the natural rubber foam at 2 phr of BSH concentration after compression and it is clear that the cell structure is deformed on surface and is intergranular. Moreover, the deformation of the cell structure at 10 phr of BSH concentration was less than the deformation of the cell structure at 2 phr of BSH concentration (Fig. 7D). In particular, deformation of the cell structure was observed at both 2 phr and 10 phr of blowing agent after compression as shown in Fig. 7B and D. Furthermore, all samples had deformation of the cell structure after compression. This could be explained by the increased blowing agent content that led to decreased density in the natural rubber foam because the volume of nitrogen gas increased and increased the foaming pressure within the natural rubber foam. Therefore, these results led to losses in the elastic recovery properties of the gas phase. Moreover, the specimen type was more significant than the percentage compression and the results may vary depending on the polymer type, cure system and recipe formulation or combinations (Chris and David, 2014)

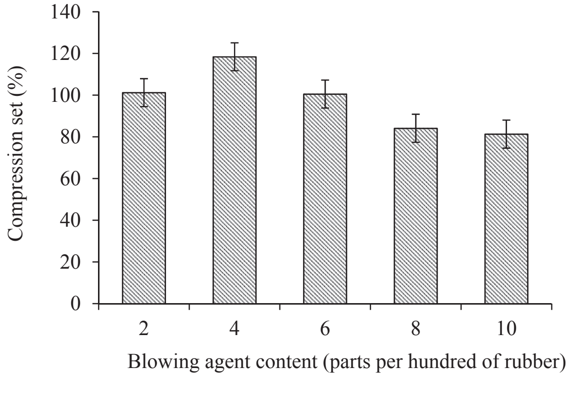

Fig. 6. Compression set results of natural rubber foam with varying contents of benzene-sulfonyl hydrazide blowing agent (error bars = ±SE).

Effect of blowing agent contents on swelling properties

The effect of the blowing agent contents on the swelling of natural rubber foam is shown in Fig. 8. It can be observed that the swelling increased with increasing BSH agent content up to 6 phr and then decreased for higher loadings from 8 phr to 10 phr. The changes in the swelling were monitored as a function of the blowing agent loading; the increase in the swelling for lower loadings from 2 phr to 4 phr was probably affected by the expansion level of the natural rubber foam. Moreover, the experimental results showed that the maximum value of swelling was 324% at 6 phr of the BSH blowing agent content and the swelling decreased for higher loadings from 8 phr to 10 phr. It was thought that the decrease in the swelling was associated with an increase in molecular compactions at the interface between the mould and rubber layers. This would result in high density at the grain boundary of samples. This explanation is in line with Kwang et al. (2008), who stated that the apparent density and cell structure of the sponge were extremely sensitive which again influenced the swelling of the natural rubber sponge and this was important to control properly the two reactions of decomposition of the blowing agent and of the natural rubber in the mould to obtain rapid swelling of the natural rubber sponge.

Fig. 9 shows the relationship between the crosslink density and the blowing agent content. The minimum value of the crosslink density was 16 Emol/cm^3 at 6 phr of BSH concentration. It can be seen that the crosslink density decreased with increasing BSH agent content up to 6 phr because the decomposition of the blowing agent increased which can result in a relatively low foam density in the natural rubber foam. In other words, the low crosslink density led to decreased foam density in the natural rubber foam because the volume of nitrogen gas increased with increasing concentration of the blowing agent. Moreover, the result increased for higher loadings from 8 phr to 10 phr due to an increase in the molecular compactions at the grain boundary, as discussed earlier.

Effect of blowing agent contents on thermal conductivity properties

Fig. 10 shows the thermal conductivity of the natural rubber foam by varying the content of BSH blowing agent. It can be observed that the thermal conductivity decreased with a range from 0.11 W/m/K to 0.04 W/m/K for an increase in the BSH blowing agent content up to 6 phr. The decrease in the thermal conductivity of the BSH blowing agent content was associated with the cell porosities (Yamsaengsung and Sombatsompop, 2009). After that, the thermal conductivity tended to increase slightly from 0.040 W/m/K to 0.054 W/m/K for higher loadings of the BSH blowing agent content, probably due to the effect of the gas containment limit on the reduction of cell porosity. The thermal conductivity of the natural rubber foam obtained in this work was relatively low compared with common building insulation materials such as cellulose, Perlite and Vermiculite which have thermal conductivity

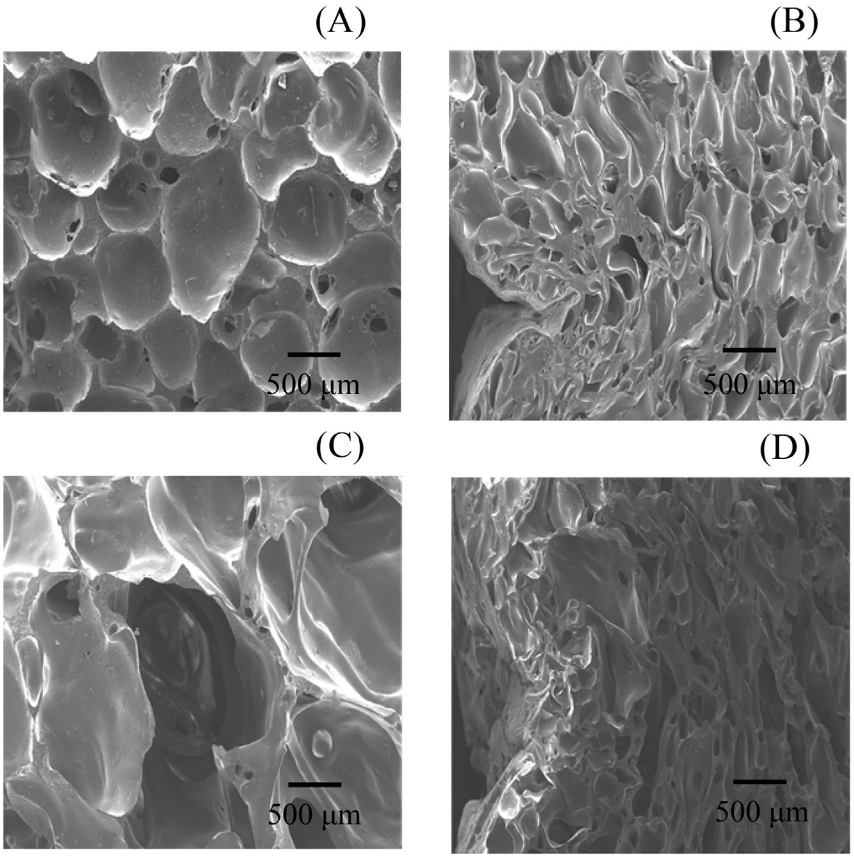

Fig. 7. Morphology images of natural rubber foam at 35× magnification: (A) before compression test at 2 parts per hundred of rubber (phr) of benzenesulfonyl hydrazide (BSH) concentration; (B) after compression test at 2 phr. of BSH concentration; (C) before compression test at 10 phr of BSH concentration; (D) after compression test at10 phr of BSH concentration; (Scale bar = 500 μm).

ranges of 0.050 W/m/K to 0.070 W/m/K, whereas, interestingly, the thermal conductivity of the natural rubber foam was 0.040 W/m/K at 6 phr of BSH blowing agent, being equal to fiberglass, polyethylene and rock wool which all have an open cell structure (Al-Homoud, 2005).

From the experimental results it can be concluded that both the average value of the tensile modulus and tensile strength were reduced by 25%, implying that the stiffness of the natural rubber foam decreased with an increase in the BSH blowing agent content. The average value of elongation at break not only increased 33% before thermal aging, but also reduced 33% after thermal aging. The natural rubber foam with a lower BSH blowing agent content had poorer elastic recovery compared to that with the higher BSH blowing agent content due to deformation of the cell structure after compression loading. Moreover, the swelling result showed the opposite trend to the crosslink density result of natural rubber. The maximum value of swelling was 324%, whereas the minimum value of the crosslink density was 16 Emol/cm^3 at 6 phr of BSH concentration. The result with the lowest value of thermal conductivity was 0.040 W/m/K at 6 phr of the BSH blowing agent content

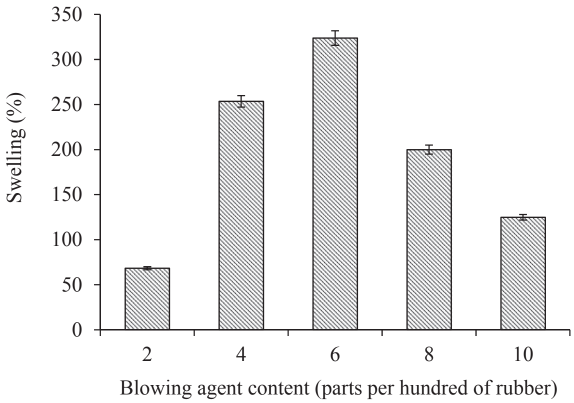

Fig. 8. Swelling of natural rubber foam with benzenesulfonyl hydrazide blowing agent contents (error bars = ±2.50%).

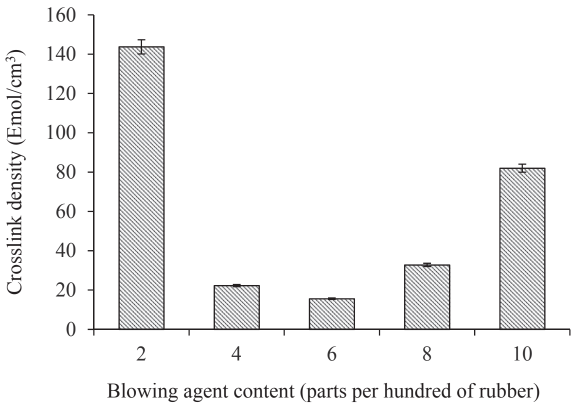

Fig. 9. Variation of the crosslink density with the benzenesulfonyl hydrazide blowing agents contents (error bars = ±2.50%).

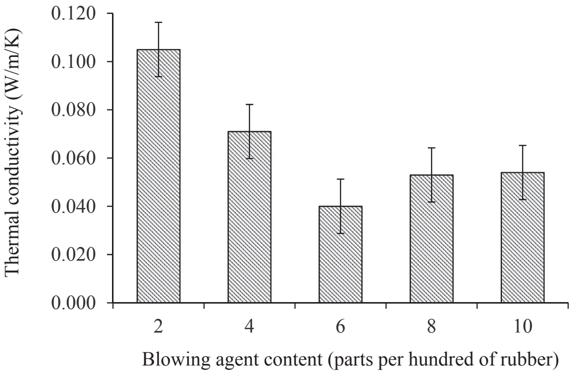

Fig. 10. Thermal conductivity results of natural rubber foam with varying contents of benzenesulfonyl hydrazide blowing agent contents (error bars = ±SE).

because the natural rubber foam in this condition can prevent heat gain and heat loss problems on the surface of equipment in a refrigeration system and an air conditioning system. Therefore, the optimum concentration of the BSH was 6 phr which had optimum thermal conductivity properties. The compound in this condition was suitable to produce the thermal insulation for these systems as discussed earlier.

Conflict of interest

The authors declare that there are no conflicts of interest.

Acknowledgements

The authors would like to thank the Rubber Research Institute of Thailand for research support and for providing facilities. The authors would like to thank Kasetsart University Chalermphrakiat campus, Sakon Nakhon province, Thailand for financial support.

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