

Polyurethane and Natural Rubber Latex Blend Foam Rubber

LIM, H.M.^{*#} AND AMIR-HASHIM, M.Y.^{*}

Latex blending is a common technique employed to obtain a combination of properties inherent in the individual polymers and to enhance the properties of the final product. In this present investigation, the natural rubber latex was blended with polyurethane dispersion. The blended latex was compounded and processed into a latex foam rubber at a laboratory scale using the Dunlop process. A comparative study between the natural rubber latex foam and blend foam with different densities was carried out. The mechanical properties of the foam were evaluated and the surface morphology was visualised with SEM. The results showed that the blend foam has satisfactory tensile strength and hardness value, but with a higher volume of shrinkage, compression set and age hardening. The elongation at break value was comparable to that of normal NR latex foam. Both types of foam showed similar foam cell structure whereby the cells were interconnected with each other and were of open cell structure.

Keywords: natural rubber; polyurethane dispersion; foam rubber; Dunlop process

The production of moulded latex foam began in 1930 following the discovery of combined whipping and controlled gelling process by the Dunlop Rubber Company¹. The process involves the whipping of a latex compound which has been de-ammoniated and matured, followed by the addition of a gelling agent. The delayed action gelling agent, sodium silicofluoride, is able to set the foam in a few minutes at room temperature². The foamed latex is then transferred to the mould and vulcanised in a steam oven.

Latex foam is a suitable base material for cushioning in comfort products, such as mattresses, pillows, furniture cushions, toppings over springs in automobile seats and rug paddings³. The exceptional high resilience and

low creep in compression characteristics suit its application in these soft comfort products.

Initially the latex foam industry developed using only natural rubber latex (NRL). However, due to the substantial improvement and the price of the synthetic latex, blends of styrene butadiene rubber (SBR) with NRL foams were later produced by foam manufacturers using the Talalay process^{4,5}. Amid improved manufacturing technology, convenient flexible polyurethane (PU) foam is a popular alternative to the NRL foam for similar applications. The PU foam, a viscoelastic material produced by the interaction of active hydrogen compounds, water and isocyanates⁶ is used extensively as foam cushioning material in home furnishings⁷.

^{*}Rubber Research Institute of Malaysia, Malaysian Rubber Board, P.O. Box 10150, 50908 Kuala Lumpur, Malaysia

[#] Corresponding author (e-mail: evelyn@lgm.gov.my)

There have been previous attempts using blending as a technique to obtain a combination of properties inherent in the individual polymers in fabricating foam rubber. Nakason *et. al*⁸ prepared latex foam rubber from a graft copolymer of deproteinised natural rubber and methyl methacrylate then blended them with high ammonia concentrated latex to give a product with improved indentation hardness but inferior compression set. A study by Angove *et. al*⁹ concluded that foam rubber made from acrylonitrile isoprene rubber latex had good ageing and oil resistance, high tensile strength and elongation properties but lower resilience. However, blending with NRL, the foam failed to retain the values of both tensile strength and elongation in direct proportion to the values for the foams made from each material independently.

In this investigation, NRL was blended with water borne polyurethane dispersion (PUD) to produce latex foam rubber with different densities. NRL is green and sustainable, while the anionic PUD is produced by the formation of a polyurethane polymer followed by incorporation of anionic groups dispersed in an aqueous medium without the aid of surface active substances¹⁰. PUD is an established material that has undergone development in the past few years to widen its product range.

It has been used to make gloves, condoms, adhesives and coatings^{11,12}. The objectives of this study are to demonstrate the feasibility of developing a natural rubber latex and polyurethane dispersion blend foam rubber and to evaluate the mechanical properties of the blend foam.

MATERIALS AND METHODS

Commercial high ammonia (HA) latex concentrate was obtained from a Malaysian supplier. The waterborne polyurethane dispersion (*Envithane 9000*) was supplied by Dongsung Chemical Co. Ltd, Korea. The composition and specification of the PUD is as shown in *Table 1*.

Aqueous dispersions of sulphur, ZDEC, ZMBT, Wingstay L[®], Diphenylguanidine, zinc oxide and sodium silicofluoride were prepared by ball milling under standard conditions. The potassium oleate solution was prepared by adding oleic acid to the hot potassium hydroxide solution.

Preparation of latex compound. The high ammonia latex concentrate was first compounded with stabilising and compounding ingredients according to the formulation in *Table 2*.

TABLE 1. COMPOSITION AND SPECIFICATION OF THE WATERBORNE POLYURETHANE DISPERSION

Chemical description	Polyurethane dispersion
Composition specification	
Active substance (%)	40.0 – 42.0
pH (25°C)	8.5
Viscosity (mPa.s)	40
Specific gravity (g/cm ³)	1.0
Particle size range, µm	0.20 – 0.24
Average molecular weight, MW (Daltons)	6.25 × 104
Appearance	White liquid

Preparation of latex foam rubber. The Dunlop process was used to prepare the latex foam rubber. Two types of foam of different densities were prepared, namely natural rubber latex foam and blends of NRL and PUD foam of 70:30 ratio.

About 500 grams of NRL or blend compound was mixed with a frothing aid – potassium oleate to reduce the surface tension of the latex mix and poured into a whisk and bowl type mixer to commence whipping. During the foaming operation, an increasing amount of air is included and the viscosity of the foam rises continually. After the desired froth height has been achieved, the secondary gelling agent – diphenylguanidine was added to sharpen up the gelling. This was followed by addition of zinc oxide. Zinc oxide plays a role in the destabilisation or gelling of the latex through formation of zinc soaps^{13,14}. Finally the gelling agent sodium silicofluoride

is added. The compounding ingredients were added according to the formulation in *Table 3*.

The viscous foaming liquid was then poured into a mould and vulcanised in a steam oven. After vulcanisation, the foam was stripped from the mould and the process was completed by washing and drying. Foam rubber samples of 1 inch thickness were produced.

Determination of foam density. Density of uncured foam was determined by calculation from the mass and volume of the specimen. A representative specimen with skins on the top and bottom surface measuring at least 0.01 m² in area by full-part thickness was cut from an area free of voids. The density was calculated in grams per cubic centimeter as follows:

$$\text{Density} = M/V$$

Where M = mass of specimen, g ... 1
 V = volume of specimen, cm³

TABLE 2. NRL COMPOUND FORMULATION

Ingredients	Amount	
	Dry (p.p.h.r.)	Actual (grams)
60% Latex	100	167
18% Potassium oleate	1	5.6
60% Sulphur	2.5	4.2
50% ZDEC	1	2
50% ZMBT	1	2
50% Wingstay L [®]	1	2

TABLE 3. FOAM BOWL ADDITION FORMULATION

Ingredients	Dry weight (p.h.r.)	
	NRL	NRL/PUD blend* (70:30)
18% Potassium oleate	2.5	2.5
40% Diphenylguanidine	0.75	1
50% Zinc oxide	5	5
25% Sodium silicofluoride	1.5	2

* Wet weight

The density of the foam was controlled by the amount of air introduced into the latex through mechanical agitation. The dry density of the final product was then determined. The foams were produced with a range of densities to compare their physical properties. Different densities of foam were fabricated to study their properties for different applications such as cushions, pillows, mattresses and others. The densities of the foams produced in this study were within the range of 0.06 – 0.07 g/cm³ for the soft foams and between 0.09 – 0.10 g/cm³ for the firm foams.

Determination of gelling pH. After the addition of sodium silicofluoride to the latex foam mix, a glass electrode was placed into the latex foam. A pH meter accurately measured the pH change in the latex during gelation.

Determination of volume of shrinkage. The dimension of the mould and finished foam rubber sample was measured. The difference in dimension between the mould and the foam sample was calculated as a percentage of volume shrinkage.

Mechanical properties of latex foam rubber. The tensile strength and elongation at break values of the foam samples were determined using an Instron 5565 Testing Machine with a crosshead speed of 500 mm/min. The test was conducted at room temperature ($25 \pm 1^\circ\text{C}$) and parallel sided test pieces were cut.

Hardness of the latex foam rubber was determined using the indentation test. The indenter foot was first brought into contact with the test specimen, the test sample was then indented until 25% of its initial thickness was reached. The force necessary to produce a 25% indentation in the latex foam was observed.

The compression set value was determined using a compression device consisting of two

or more flat steel plates between which the foam specimens were compressed. The test specimens were compressed to 50% of their original thickness and the compression device was placed in the oven at 70°C for 72 h. At the end of the test period, the specimens were removed, and the thickness was measured after 30 min rest at room temperature. The compression set percentage was then calculated.

The foam samples that underwent the indentation test were then placed in a heated air oven and aged for 22 h at 100°C. After the exposure period, the oven was opened and the samples were removed immediately. The samples were allowed to cool to room temperature for not less than 16 h before the final indentation hardness value was determined. The age hardening percentage was then calculated.

SEM micrograph. Morphology of the latex foam was observed using scanning electron microscopy (SEM). The test portion of sample was cut and placed onto the specimen stub with carbon double sided tape. The specimen was then prepared for examination by evaporative coating with an ultra-thin layer of platinum under high vacuum. The JOEL SEM 5300 was operated at 2 kV and the images were captured.

RESULTS AND DISCUSSION

One critical aspect of making latex foam is the alkalinity change in the latex after adding the sodium silicofluoride (SSF) dispersion. The gelling pH is an important characteristic because it will determine the physical strength of the gel. *Figure 1* shows the pH change of the NRL latex mix and blend mix after the addition of SSF.

There was a gradual drop in the pH values after the addition of gelling agent. Both the

latex and blend gelled at a pH of approximately 8.5. The gelling times for the NRL latex mix and the blend mix were at 5 min and 2.5 min respectively. The faster rate of gelling in the blend is due to the higher loading of SSF in the blend.

It is common for foam to shrink during washing and drying due to the removal of water. The shrinkage of the foam samples in this study is shown in *Figure 2*. It is noted that shrinkage is an important characteristic in latex foam technology as it determines the size of the finished foam product.

In estimating the magnitude of shrinkage, it is important that diverse variables such as the water content of the latex compound and the speed of gelation are adequately controlled. The higher volume of shrinkage of the blend foam seen in this study can be attributed to the greater initial proportion of water in the blend

latex, as the TSC of the PUD is 40% while that of the NRL is 60%. Furthermore, the gelation time of the blend foam was relatively shorter than the NRL foam and this may have contributed to the shrinkage in some manner.

Although the strength of the blend foam was not as high as the NRL foam, the physical properties of the blend foam were good enough for the foam to make a reasonable product as it holds its shape and strength under normal deformation conditions. *Figure 3* indicates the tensile strength of the NRL foam and the blend foam of different densities. The tensile strength of the blend foam decreased by half compared to the NR foam for both densities. The elongations at break value of the soft foams were similar, while the firm blend foam showed a slightly lower value (*Figure 4*). This indicates that tensile strength was affected by the density of the foam while the elongation at break value did not depend on it.

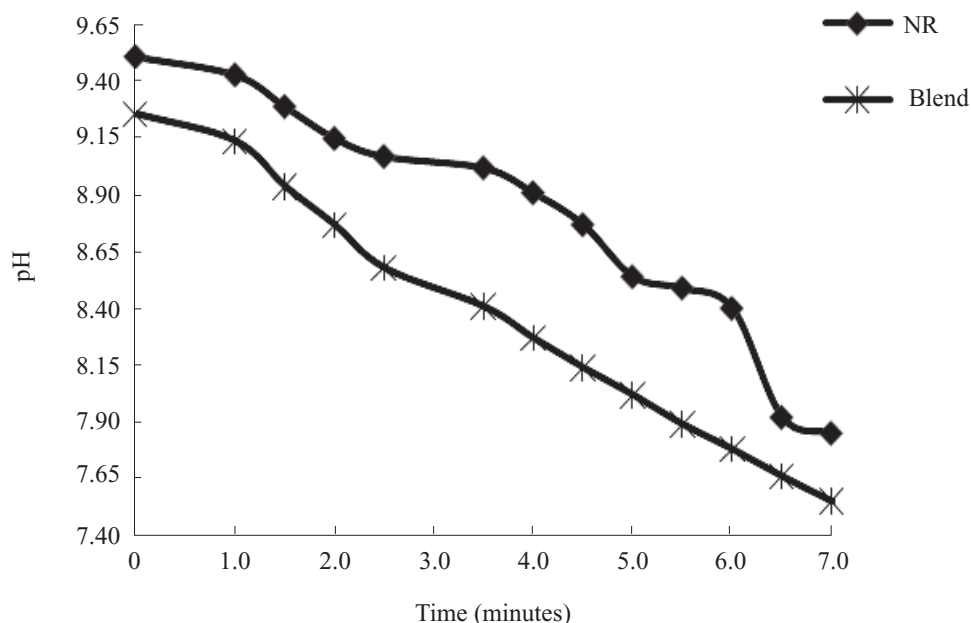


Figure 1. pH versus time of latex mix gelling curve.

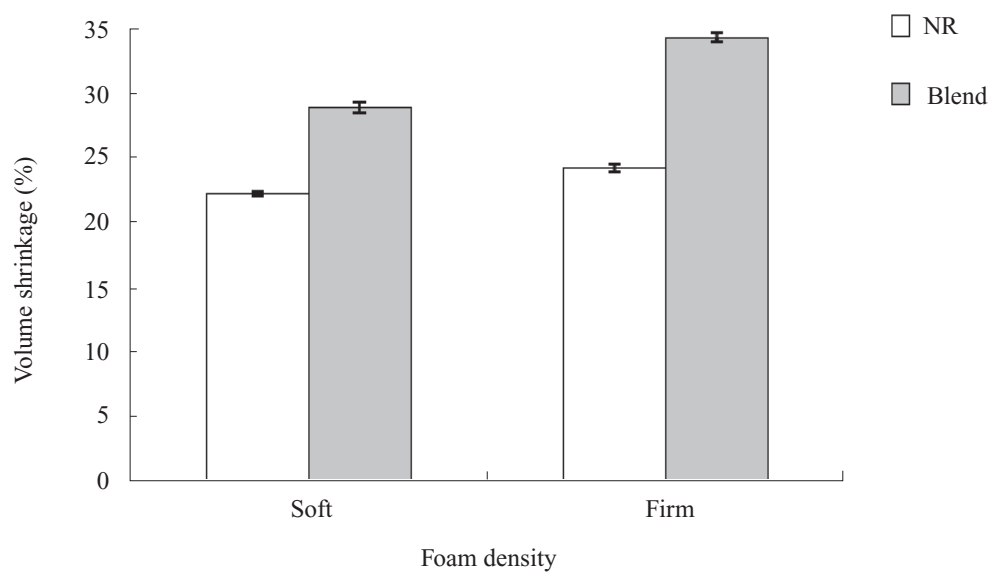


Figure 2. Volume of shrinkage percentage of NRL and blend foam.

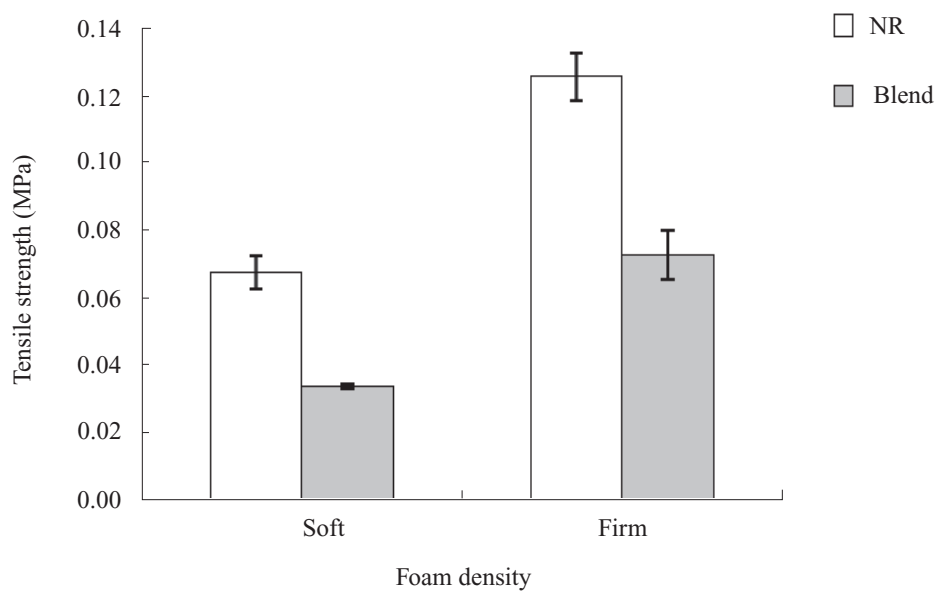


Figure 3. Tensile strength of NRL and blend foam.

The indentation hardness measurement indicated that the addition of PUD into NRL softens the latex foam. The texture of these blend foam materials is relatively soft, compared to the NRL foam of similar density (*Figure 5*). However, the hardness of the blend foam may be further modified with fillers⁹.

The compression set value of the blend foam shows a substantial increase compared to the NRL foam. The blend foam indicated a lower ability to recover from deformation as shown in *Figure 6*. This may be attributed to the overall structure of the foam which can be observed in the SEM micrograph.

Figure 7 shows the age hardening percentage of NRL and blend foam. The blend foam indicated a higher percentage of age hardening compared to the NRL foam, which suggested that the NRL foam's property performed better under humid conditions.

Figure 8 shows the morphology of the foam cell structure. Both types of foam showed similar foam cell structure. The cells were generally interconnecting with each other and were of open cell structure. The NRL foam micrographs showed good interconnected foam structure and the cells were well-knitted and strong. The SEM micrographs for the blend foam appeared to have weaker foam structure and not well knitted as compared to the NRL foam. This may be due to the lower solids content of the polyurethane dispersion. A good foam structure can be obtained using maximum solids content not diluted with water.

The NRL foam showed higher tensile strength and hardness value with lower compression set and these properties may be attributed to its good foam structure. The blend foam showed inferior mechanical properties and this may be due to its weak foam structure.

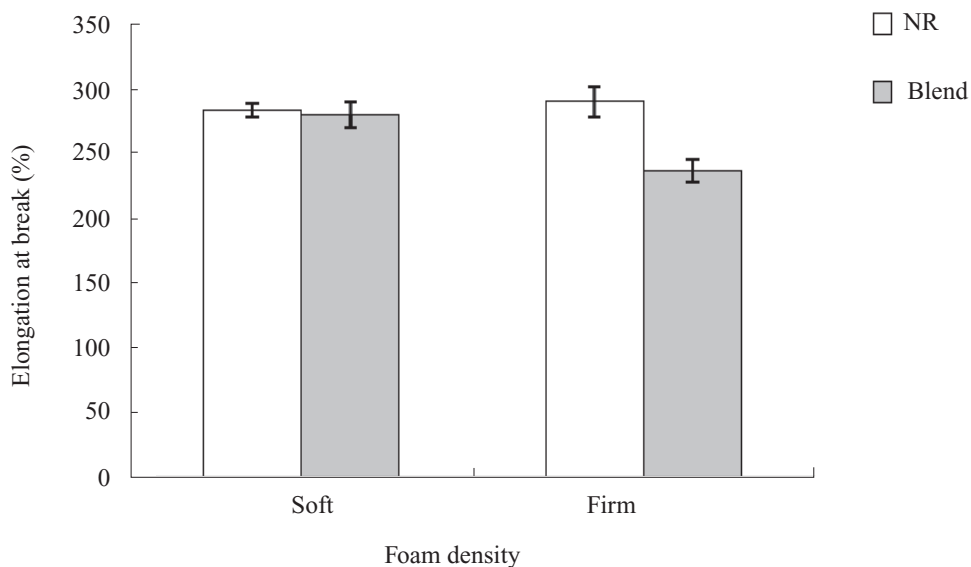


Figure 4. Elongation at break value of NRL and blend foam

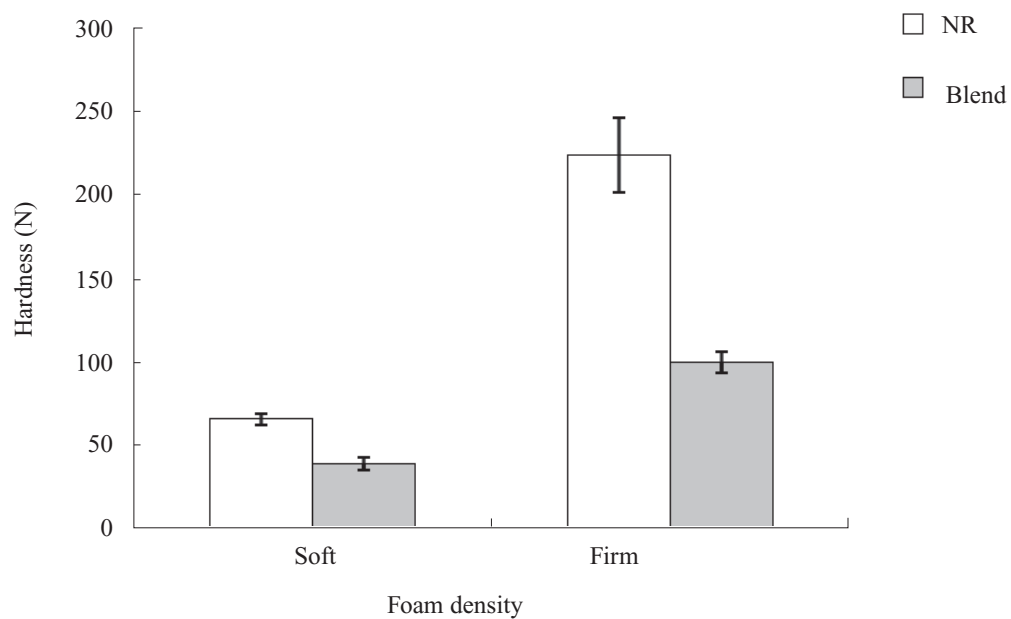


Figure 5. Hardness value of NRL and blend foam.

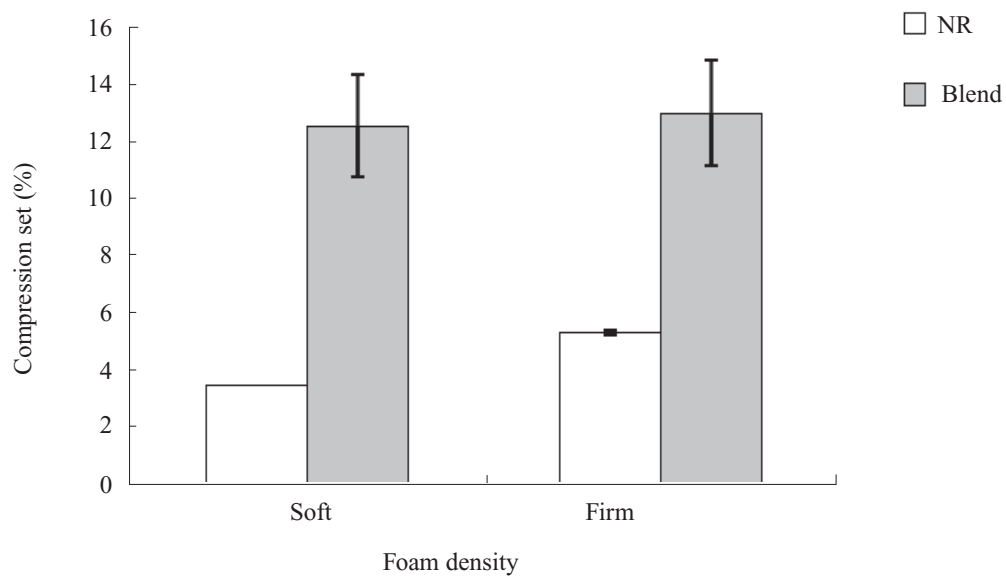


Figure 6. Compression set percentage of NRL and blend foam.

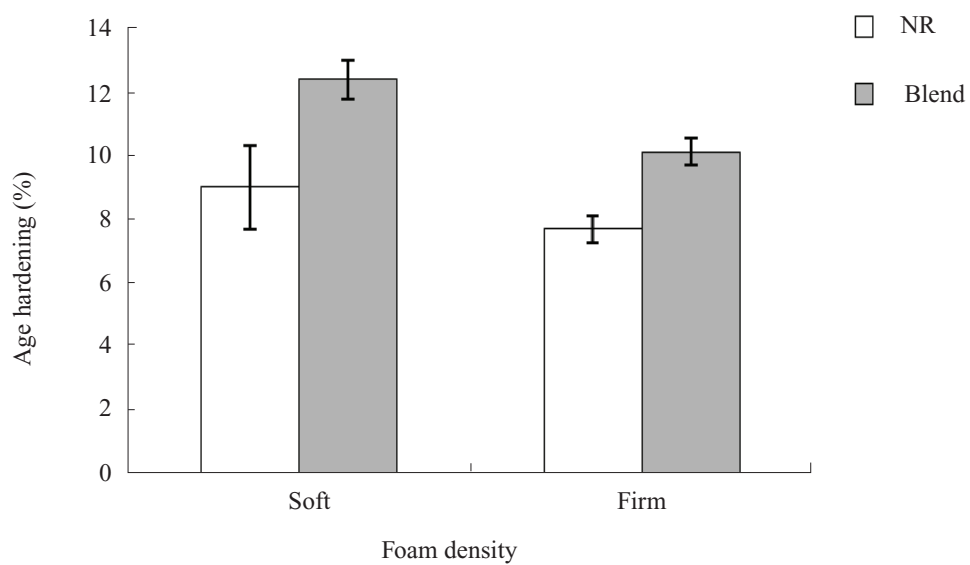
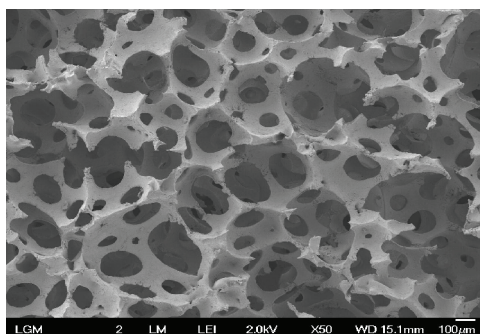
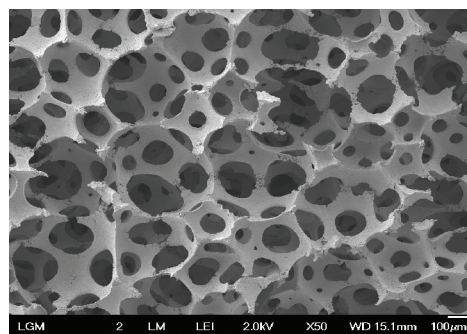


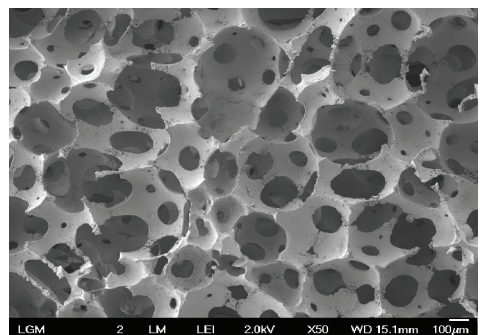
Figure 7. Age hardening percentage of NRL and blend foam.



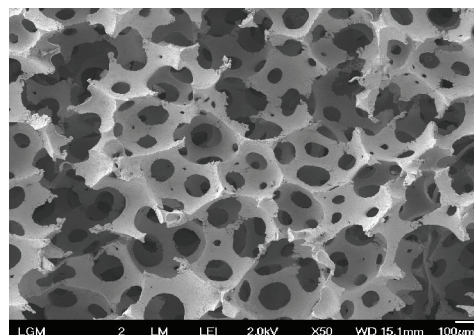
Soft NRL foam.



Firm NRL foam.



Soft Blend Foam.



Firm Blend Foam.

Figure 8. SEM micrograph of NRL and blend foam.

SUMMARY

The study concluded that water based polyurethane dispersion at 40% solids content can be blended into a compounded NR latex mix and can be made into a foam product using the conventional Dunlop foam process. The gelling pH at 8.5 was similar to the NRL foam gelling pH, but the blend required much more gelling agent. In solid foam properties, the PUD/NRL blend foam can be extended and deformed just like the NRL foam, but with a relatively higher volume shrinkage, compression set and age hardening. Both foams showed similar interconnected open cell structure. However, the PUD/NRL blend foam was always softer, thus creating a new product application for latex foam.

ACKNOWLEDGMENTS

The authors would like to thank the Director General of the Malaysian Rubber Board for her permission to publish this paper and Mr Augurio Pietro Tommaso for sharing his knowledge on the latex foam process. The authors are also grateful to Mr Suhaimi Mohamad for the SEM micrographs, Mrs Zaleha for the physical testing and Mr Syahril Zainul for the assistance rendered.

Date of receipt: July 2010

Date of acceptance: October 2010

REFERENCES

1. MADGE, E.W. (1962) Latex Foam Rubber. *London: Maclaren.*
2. CHAPMAN, W.H., POUNDER, D.W. AND MURPHY, E.A. (1929) BP 332525. Improvements in or Relating to the Manufacture of Goods of Rubber or Similar Material.
3. WINSPEAR, G.G. (ed.) (1954). The Vanderbilt Latex Handbook. 216–227 New York: R.T. Vanderbilt.
4. PENDLE, T.D. (1989) A Review of the Moulded Latex Foam Industry. *Cellular Polymers An International Journal.*
5. Latex foam–Talalay process (2004) *Malaysian Rubber Technology Developments*, Vol. 4. 6–10.
6. Flexible Polyurethane Foam. Dow Chemical Pacific Ltd., 1–28.
7. Polyurethane Foam Association (2000) IN TOUCH, **8(1)**.
8. NAKASON, C., KAESAMAN, A., YIMWAN, N., AND KETSARIN, K. (2001) Preliminary Study on the Preparation of Latex Foam Rubber from Graft Copolymer of Deproteinised Natural Rubber and Methyl Methacrylate, *J. Rub. Res.*, **4(3)**, 141–152.
9. ANGOVE, S.N., GRAHAM, E.S., HILDITCH, G., STEWART, R.A. AND WHITE, F.L. (1965) High Quality Foams from NIR Latex, Division of Rubber Chemistry ACS Inc.
10. BLACKLEY, D.C. (1997) *Application of Latices Polymer Latices: Science and Technology*, **2** (2nd Ed.), 434–435 London: Chapman & Hall.
11. HOWE, W.L. (2000) Medical Glove Market remains Tight. *Rubber Asia*, **14(1)** 117–119.
12. SHUSTER, F. (1998) Polyurethane Dispersion, A Review of the Materials and their Applications. International Latex Conference.
13. McKEAND, D.J. (1951) Influence of Soaps on Gelling Characteristics of *Hevea* Latices, *J. Ind. Eng. Chem.*, **43**, 416–420.
14. NEWNHAM, J.L.M. (1953) Zinc Soap Formation and the Gelling of Latex. *Transactions of the Institution of the Rubber Industry*, **29(3)**, 160–172.