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PRODUCTION OF MOULDED PALM-BASED FLEXIBLE POLYURETHANE FOAMS

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ABSTRACT

In our previous study, incorporation of phthalates in slab stock flexible foam formulation improved the properties of the foams. This paper describes the properties of moulded flexible foams which incorporated phthalate alone, and with two other additives. Flexible foam from blended polyols (50:50 ratio palm-based to polyether polyols) was also produced, by the best formulation selected from the above. The properties evaluated were density, tear strength, compressive stress and hysteresis. The results were compared to those from the commercial seating cushions. The flexible foams from total palm-based polyol had tear strength of 140-150 N m^{-1}, and, therefore can only be used in automotive parts such as carpet underlay and thermal insulator. Better foams were produced from blended polyols (50:50 palm-based to petrochemical polyether polyols) with the tear strength approaching those of commercial foams and improved resilience. More improvements to the properties are expected when a high dispensing machine is used in the manufacturing.

Keywords: moulded flexible foams, phthalates, FH-300, potassium acetate, blended polyol.

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INTRODUCTION

The use of natural and renewable resources to substitute petrochemicals has gained considerable importance due to supply and cost considerations. The plastics industry, especially for polyurethane has shown great interest in using renewable resources because of their lower cost and abundant supply. Many attempts have been made to substitute some of the raw petrochemicals, especially polyols, with those derived from soyabean, rapeseed, castor and fish oil. In Malaysia, the abundant supply of palm oil has prompted Malaysian Palm Oil Board (MPOB) to investigate the production of palm oil-based polyol. The process has been patented in Singapore (55223), Malaysia (MY-114189-A) and Indonesia (patent application: P962884) (Salmiah *et al.*, 1995). The production of polyol has been upgraded to pilot plant scale with a capacity of 800 kg batch^{-1}.

The market for flexible polyurethane foams continues to grow at a rapid pace throughout the world because of their comfort features. In Malaysia, the domestic polyurethane consumption reached about 80 000 t in 2002 with polyols constituting 40 000 t (data by Ooi of Akashi). The bulk of this is in flexible foams as shown in *Figure 1*.

Previously, the production of flexible foams used chlorofluorocarbon (CFC) as the blowing agent for low-density products. However, because of environmental awareness, more companies are moving towards a more environmental-friendly process with water used instead (Lin *et al.*, 1996).

In our previous study, incorporation of phthalates in slab stock flexible foam was found to improve its properties, especially tear strength (Norin *et al.*, 2003). This paper describes the properties of moulded flexible foams produced with phthalates alone with two additives (FH-300 and potassium acetate). FH-300 as foam hardener is expected to improve the tear strength, tensile strength and elongation of the foams. Potassium acetate as a trimerization catalyst is normally used in the moulding of foams to ensure a uniform mixture between isocyanate and polyols for smoother flow of the mixture into the mould. With a combination of catalyst and suitable amine catalyst, foam degradation (friability) can be prevented. A commercial cushion with modified MDI in its formulation was used as the control.

It was anticipated that blending palm-based polyol with petrochemical polyether polyol can

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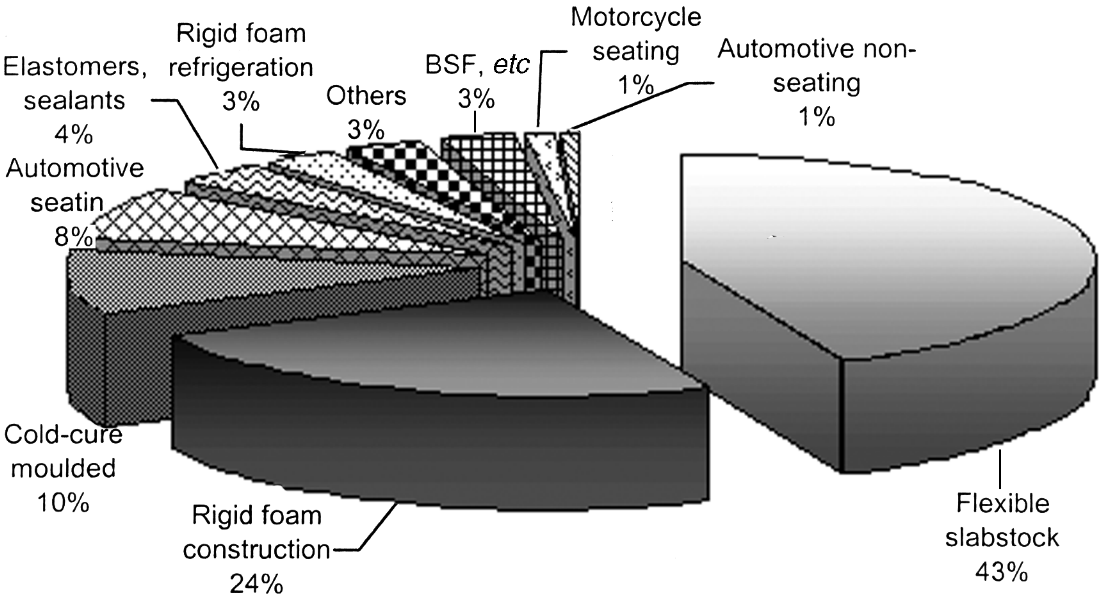

Source: David (2004).

Figure 1. Polyol consumption in Malaysia.

further improve the strength of foams. Moreover, some polyurethane products' manufacturers prefer blended polyols to ameliorate the recent rising cost of polyether polyol. Realizing this trend, blending of palm-based polyol with polyether polyol (molecular weight: 3031) was done at 50:50 ratio.

EXPERIMENTAL

Materials

The ingredients used to prepare the flexible foams included palm-based polyols (MPOB/InterMed Sdn Bhd), polyether polyol, Excenol 3031K (Soon Yang Sdn Bhd), dimethyl phthalate (Merck Sdn Bhd), Niax A33, surfactant (L603) and stannous octoate (Witco Corporation), FH-300 and potassium acetate (Crompton, Osi Specialties), modified MDI (Cosmonate MC-73, Cosmo Polyurethane), modified MDI (Suprasec 2412, Huntsman Polyurethane) and distilled water as the blowing agent.

Foam Preparation

The formulations were divided into four groups:

- besides other common additives, dimethyl phthalate (DMP) was incorporated into the formulation at 0.5 and 1.0 pphp (parts per hundred polyols). The tin catalyst concentration was varied from 0.2 to 0.5 pphp, a range based on the previous formulation. Above 0.5 pphp, the foam had shrunk;
- with DMP fixed at 0.5 pphp, FH-300 (an additive to improve tear strength and tensile strengths) was incorporated in the formulation at 1 to 4 pphp with the tin catalyst concentrations fixed at 0.2 and 0.5 pphp;
- with DMP fixed at 0.5 pphp and the tin catalyst at 0.2 or 0.5 pphp, potassium acetate (trimerization catalyst to ensure a uniform mixture between isocyanate and polyols) was incorporated into the formulation at 1.0 pphp and 2.0 pphp; and
- by choosing the best formulation from (a) and using modified MDI, Suprasec 2412 foam was produced from blended polyols (50:50 ratio of palm-based to polyether polyols).

The foams were prepared by adding modified MDI to the polyols, surfactant, Niax A33, DMP, FH-300/potassium acetate, stannous octoate and distilled water in the polyethylene jug followed with vigorous mixing (2000 rpm). At the creaming stage, the mixture was poured into a mild steel mould of 35 cm x 35 cm x 5 cm which was then closed. Once the foam was tack free, it was removed from the mould and left to cure for one day before cutting into the test specimens.

PROPERTIES OF THE POLYURETHANE FOAMS

Tack Free Time

The time between pouring the isocyanate into the polyol blend and the point when the outer skin of the foam mass no longer stuck to one's finger on gentle touching was taken.

Density

The test specimens (100 mm x 100 mm x 50 mm) were weighed to determine the density in kg m^{-3}. For each formulation, three samples were determined and the mean derived.

Compressive Stress

This was the hardness at 40% strain from the compression hardness test. The test was conducted according to DIN 53 577. A piece of foam (60 mm x 60 mm x 30 mm) was compressed between two flat plates at a rate of 100 mm min^{-1} until 70% of its original thickness. The stress at 40% strain was recorded. Three samples were tested and the mean derived.

Hysteresis

Hysteresis measures the area between loading and unloading curves plotted on the stress *vs.* strain curve during the compression hardness test. A piece of foam (60 mm x 60 mm x 30 mm) was compressed between two flat plates at a rate of 100 mm min^{-1}. Then, the foam was decompressed at the same rate until the separation between the compression plate and the base plate was equal to the initial test piece thickness. The procedure was repeated three times and hysteresis recorded. The mean from the three samples were derived.

Tear Strength

The test was conducted according to ASTM 3574 – Method F using the Hounsfield Testing Machine. The samples used were 15 mm (thickness, T) x 25 mm in cross-section and 152 mm long. Each sample was cut in the middle along its length to a depth of 40 mm. At the cut, the specimen was pulled apart at a rate of 50 mm min^{-1}. The maximum force (F) registered on the testing machine was recorded. The tear strength was calculated from the maximum force and the average thickness of the sample (T),

$$\text{Tear strength (N m}^{-1}\text{)} = F/T$$

Three specimens per sample were tested and the mean derived.

DISCUSSION

From *Figures 2* and *3*, at the same concentration of tin catalyst, the higher concentration of dimethyl phthalate improved the strength and also increased the compressive stress of the foams. This was due to the rapid cross-linking reaction within the polymer with phthalate (Norin *et al.*, 2003). From *Figure 2*, with 0.2 pphp tin catalyst, 0.5 pphp DMP increased the tear strength of the foam to 88 N m^{-1} compared to the one without DMP which tear strength was only 79 N m^{-1} (based on previous data). However, compressive stress and hysteresis were almost the same with the one without DMP. Besides that, at a fixed amount of DMP, increasing the concentration of tin catalyst improved the tear strength as well as increased the hysteresis. A higher hysteresis indicated that the foams had lower rebound resilience. This resulted from the slightly lower percentage of open cells in the foams due to the rapid polymerization by the tin catalyst (Norin *et al.*, 2001).

Combining DMP and FH-300 did not improve the strength of the foams much. Although there was a slight improvement on the strength with 0.2 pphp tin catalyst (*Figure 4*), the effect was not observed at the higher concentrations of catalyst (*Figure 5*). Furthermore, the tear strength did not exceed 140-150 N m^{-1}, which was obtained by incorporating DMP alone in the formulation. Although it was claimed that FH-300 can yield polyurethane foam with better strength and elongation, the effects were not found here. In terms of the compressive stress, incorporation of 3-4 pphp FH-300 resulted in softer foams compared to the foam produced with lower FH-300. Besides that, the incorporation of FH-300 also improved the resilience of the foam, especially at 0.5 pphp tin catalyst.

From *Table 1*, there was a slight improvement on the tear strength by incorporating 1 to 2 pphp potassium acetate and 0.2 pphp tin catalyst as compared to the one without potassium acetate. However, at the same concentration of potassium acetate, there was no significant effect from increasing the concentration of tin catalyst (0.5 pphp) in the formulation. In fact, the potassium acetate decreased the tear strength. These results showed that the combination of DMP and potassium acetate did not significantly improve the properties of the palm-based foams.

From *Table 2*, by blending palm-based polyol with polyether polyol in 50:50 ratio, the properties of the foams particularly of resilience and tear strength, were improved from those of total palm-based polyol.

For comparison, the properties of foam from total palm-based polyols and foam from blended polyols *vs.* commercial foams are shown in *Table 3*.

In *Table 3*, the tear strength and resilience of foam from total palm-based polyol were lower than those of the commercial foam. With that tear strength (140-150 N m^{-1}), the palm-based foams can only be used in applications where the tear strength and resilience are not too stringent, *e.g.*, as carpet underlay and thermal insulator.

Better foams were produced from blended polyols (50:50 palm-based to petrochemical polyether polyol) with tear strength approaching that of commercial foam and improved resilience. In compressive stress, both the foams from total palm-based polyol and blended polyol were suitable as hard foam.

More improvements on these properties can be expected when a high dispensing machine is used in the manufacturing.

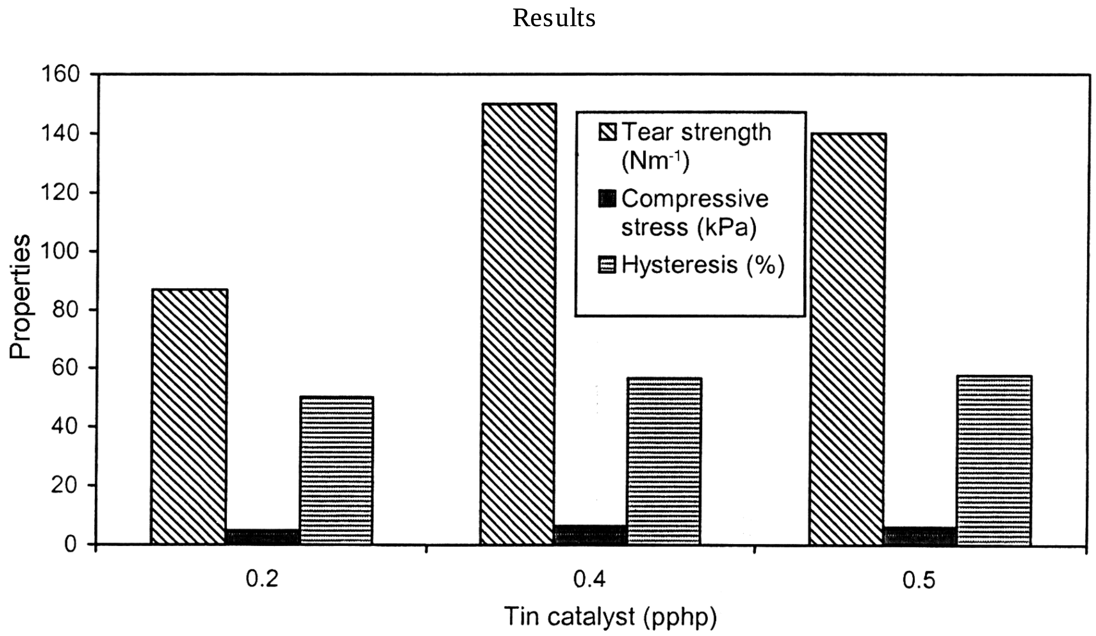

Figure 2. Effects of incorporating 0.5 pphp dimethyl phthalate on the properties of flexible foams with different concentrations of tin catalyst.

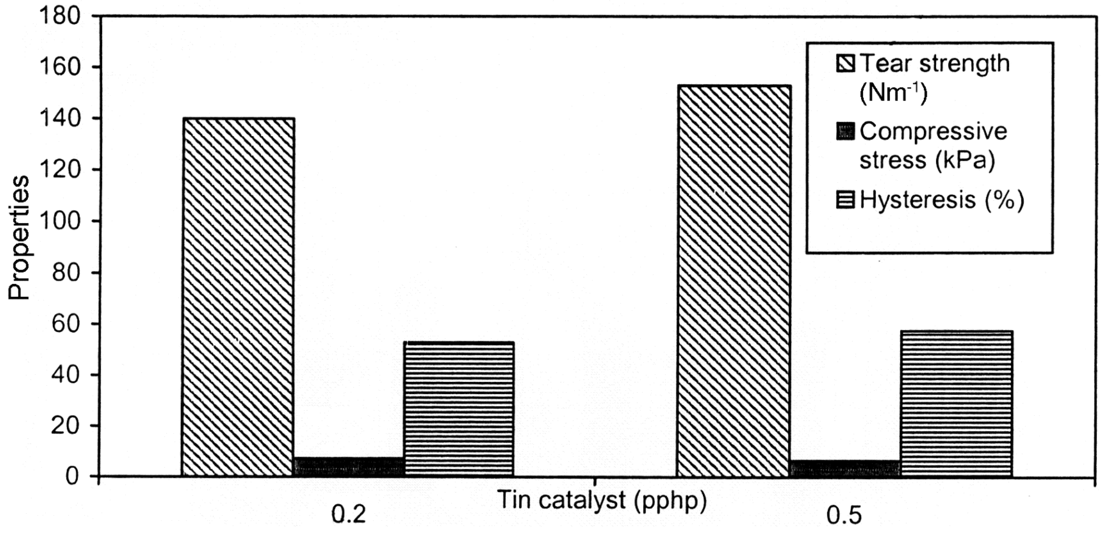

Figure 3. Effects of incorporating 1.0 pphp dimethyl phthalate on the properties of flexible foams with different concentrations of tin catalyst.

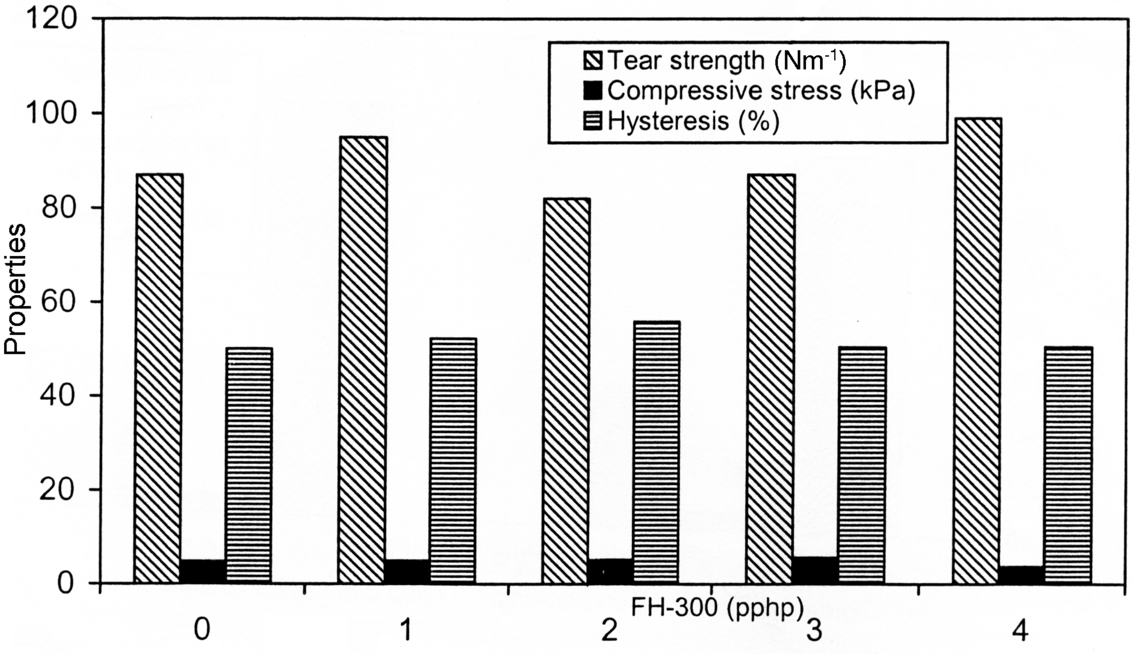

Figure 4. Effects of different concentrations of FH-300 on the properties of flexible foams with dimethyl phthalate at 0.5 pphp and tin catalyst at 0.2 pphp.

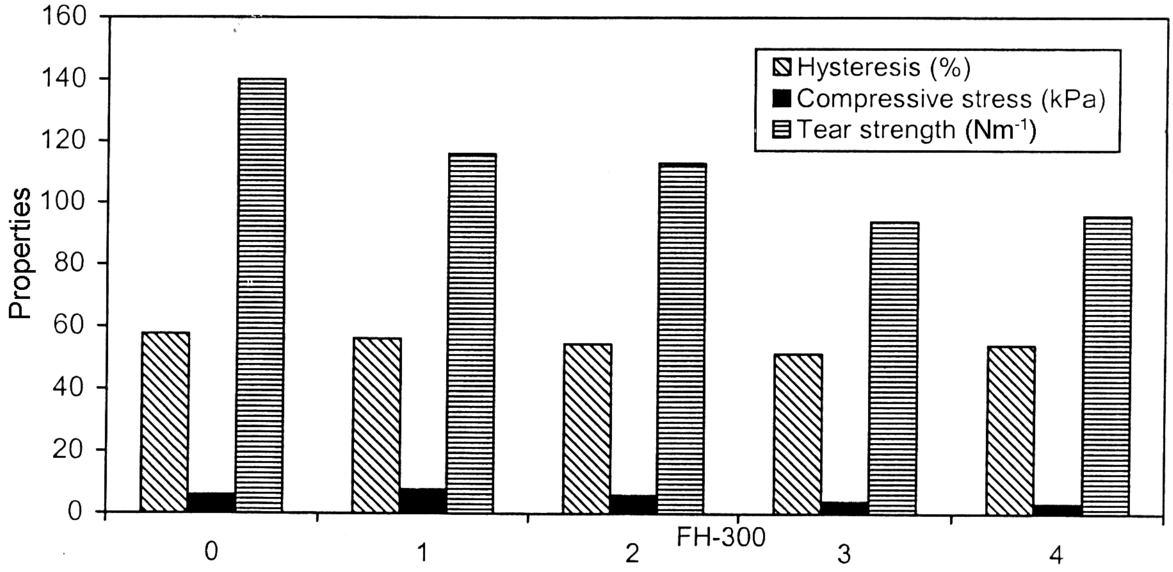

Figure 5. Effects of different concentrations of FH-300 on the properties of flexible foam with dimethyl phthalate at 0.5 pphp and tin catalyst at 0.5 pphp.

TABLE 1. EFFECTS OF INCORPORATING POTASSIUM ACETATE ON THE PROPERTIES OF FLEXIBLE FOAM (with dimethyl phthalate at 0.5 pphp)

Tin catalyst (pphp)	-	0.2	-	-	0.5	-
Potassium acetate (pphp)	0	1.0	2.0	0	1.0	2.0
Tear strength (N m^{-1})	87	94	100	140	88	103
Compressive stress (kPa)	4.9	4.0	3.0	6.1	4.0	6.0
Hysteresis (%)	50	52	52.2	57.7	57.4	57.3

TABLE 2. PROPERTIES OF THE FOAMS FROM BLENDED POLYOL

Tack free time/demoulding time (min)	4-5
Density (kg m^{-3})	50-55
Open-cell content (%)	96-99
Compressive stress (kPa)	5-12
Hysteresis (%)	35-50
Tear strength (N m^{-1})	150-180

TABLE 3. PROPERTIES OF FOAMS FROM PALM-BASED POLYOL AND BLENDED POLYOL IN COMPARISON TO COMMERCIAL FOAMS

	Foams from palm-based polyol	Foams from blended polyol	Commercial foam
Tack free time/demoulding time (min)	4-5	4-5	6
Density (kg m^{-3})	45-55	50-55	55-60
Open-cell content (%)	95-97	96-99	98-99
Compressive stress (kPa)	5-8	5-12	2-5 for soft cushion and 7-8 for hard cushion
Hysteresis (%)	50-55	35-50	20-30
Tear strength (N m^{-1})	140-150	150-180	>200

CONCLUSION

Flexible foams made from total palm-based polyol had tear strength of 140-150 N m^{-1}. They can be used in automotive parts, such as carpet underlay and thermal insulator. Better foams were produced from blended polyols (50:50 palm-based to petrochemical polyether polyol) with tear strength approaching that of commercial foam and improved resilience. More improvements in the formulation for applications in the automotive sector are being made.

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